COLLECTIVE FUTURES

ACTIENETWERK GasTerug

Gemeente Amsterdam

Application of Passive Cooling Techniques in Municipal Buildings

Reducing Urban and Indoor Heat Stress in Amsterdam

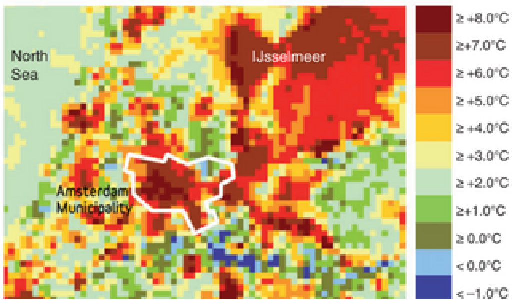
Eleni Anagnostopoulou, Anezka Bos & Chayenne Olumuyiwa

Executive Summary

In this report we aim to assist municipalities in choosing for passive cooling techniques by providing evidence of their usefulness as well as drawing up a concrete action plan for their implementation.

CONTEXT

Due to climate change, temperature is rising worldwide and extreme weather conditions have become more common. In the Netherlands, the number of days per year with a maximum temperature above 25 °C has increased from 9 to 26 in the last one hundred years. In 2050 this number is expected to grow to 29-36 [1]. Cities tend to warm up even more, with some studies showing that cities heat up an additional 8-10 °C compared to rural neighbourhoods. This phenomenon is called the Urban Heating Island (UHI) effect, and is caused by lack of vegetation and the inability of asphalt to transfer heat to the ground [2]. In short, cities warm up quicker and stay warm longer.



UHI effect in Amsterdam: night air temperature (2006) [2]

The government uses energy labels to indicate the climate adaptability of its buildings, with a higher label signifying a building with good insulation, modern heat pumps and LED lighting [3]. However, these factors do not necessarily ensure a comfortable indoor temperature during heat waves. Even with proper insulation, a building with large south-facing windows will heat up significantly if no measures are taken.

Air conditioning (AC) provides an immediate solution to discomfort caused by extreme temperatures. It is not surprising therefore that TNO expects a threefold increase of energy use caused by ACs in 2030 compared to 2022 [4]. This extra energy use causes more strain on the electricity grid, and indirectly increases global warming due to its CO2 emissions. ACs also contribute more directly to the UHI effect by transporting indoor heat to the outdoor. In Phoenix, USA, a study found that the use of AC caused a 1 °C increase within certain parts of the city [5].

PASSIVE COOLING

A sustainable and low-cost alternative to ACs is passive cooling, which requires minimal or no energy and is relatively easy to install. Not only do passive cooling techniques provide relief for people experiencing heat stress, they also lower energy costs and CO_2 emissions. The most cost-effective of these measures are:

- Solar Shading: Sheets, canopies or films that prevent sunlight from entering through the windows.
- Green Roofs: A layer of vegetation on the roof that absorbs and reflects sunlight, preventing heat from entering.
- White Roofs: A white paint layer that reflects sunlight and prevents the heat from entering the building through the roof.

- Night Ventilation: Opposite windows that are kept open at night to allow natural air flow and remove residual heat from the day.
- Vegetation: Plants and trees around the building can provide shade while also directly cool the surrounding area through evapotranspiration.

A building-adapted approach is needed, as not every technique is guaranteed to work for every building.

PILOT

To show the effectiveness of passive cooling and research practical barriers, we have created a pilot study on a building in collaboration with the municipality of Amsterdam. At the Witte Boei, a community centre in the centre of Amsterdam, solar shading will be installed in the main meeting area. While the effect of the techniques on the inside temperature is still to be measured, the pilot is accompanied by a simulation study, expert interviews and thorough literature research (chapter 2) to substantiate the effects of the passive cooling techniques. Chapter 3 describes the set-up of the pilot, and can be used as an example for the implementation on other buildings.

HANDOUT

We have designed a guide that municipalities can use to decide which passive cooling techniques to apply in a building. It can be found as a separate handout as well as in chapter 4 of this report.

Meet the Team

Chayenne Olumuyiwa
MSc student Computational Science
With a background in Global Sustainability Science and Mathematics, Chayenne is an expert in connecting research fields. She is currently following a masters in Computational Science, which provides the team with the opportunities to make extensive models and predictions.

Anezka Bos
MSc student Physics - Matter & Energy
Anezka has a bachelors in AI and is currently pursuing a masters in energy physics, providing her with a broad analytical background. She brings a knowledge of thermal physics to the team and an eagerness for applied research.

Eleni Anagnostopoulou
MSc student Chemistry - Energy & Sustainability
Eleni is a student at the masters Chemistry program at UvA and VU with a specialization on Energy and Sustainability. She also has a bachelor's in Chemistry from the University of Leeds and is eager to use her scientific and analytical skills to solve real-world challenges.

Jarik Guijt
Supervisor of Collective Futures Minor at UvA
Jarik is a former student at Collective Futures and also studied Brain and Cognitive sciences. He has experience in consulting and provided guidance and ideas to the team.

Dr. ir. Emiel van Loon
Associate Professor Statistical Ecology at UvA
Emiel is an associate professor dividing his time between teaching and research into estimation and modeling problems in the natural sciences. He is the academic supervisor of the team, providing them with feedback and scientific support when needed.

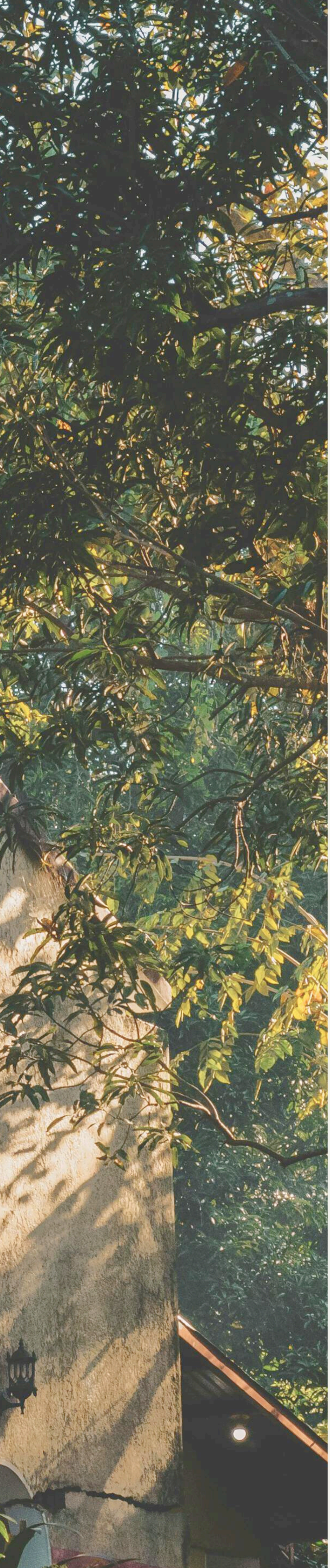
Renske van der Ploeg
Action Researcher Stichting Actienetwerk GasTerug
Renske is an action researcher at our partner GasTerug, and has a background in sustainability and transition management. Renske is an external supervisor of the group, overseeing the progress, assessing the work, and serving as the main person of contact.

Tessel Verschoor
Project manager Stichting Actienetwerk GasTerug
Tessel is a key contributor to Gas Terug, supporting projects that prioritize practical solutions with real-world impact. She brings strong skills in project management, planning, and strategic advice, helping to guide the team effectively throughout the process. She will lead the pilot at the Witte Boei after our project is finished.

Ieteke Schouten
Director Stichting Actienetwerk GasTerug
Ieteke is an advisor at our partner GasTerug, and has a diverse background in communications and circularity initiatives. Ieteke is an external supervisor of the project team.

Desirée Bernhardt
Senior sustainability advisor at City of Amsterdam
Desirée is a senior sustainability advisor in the municipal real estate department of Amsterdam. She has a background in circular economics and policy in Vienna, Melbourne and Amsterdam. She acts as an external supervisor for the group, providing the students with information and contacts from the municipality.

Eline Coolen
Policy advisor Climate Adaptation & Heat Plan Coordinator at City of Amsterdam
Eline Coolen is a Policy Advisor for the Municipality of Amsterdam, where she coordinates the city's heatwave response plan helping safeguard vulnerable residents. With her expertise in climate governance, sustainable development, environmental health and communications, she provided helpful insights to the project.



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Introduction

Due to global warming, the earth is facing higher temperatures [6]. While many communities will have to adapt to these new environmental conditions, urban areas tend to heat up faster then rural areas. This effect is called the Urban Heating Island (UHI) effect and is due to urban characteristics such as limited vegetation, concrete surfaces and high waste heat from buildings [2, 7]. For this reason, cities must urgently adapt to cope with rising temperatures.

The city of Amsterdam, like other metropolitan regions, will also need to address these challenges to ensure its resilience in the face of a warming climate. The increased temperatures will expose the population of Amsterdam to increased amounts of heat stress. In 2024, the Public Health Service (GGD) of Amsterdam developed a heat plan to address heat stress symptoms such as fatigue, excessive sweating, and nausea. While educating the public is crucial, it is equally important to explore efficient and effective cooling solutions for buildings: especially those used by individuals who are more vulnerable to heat stress.

Traditional air conditioners are effective at cooling buildings; however, they contribute to the UHI effect by releasing warm air, consuming large amounts of energy, and emitting greenhouse gases into the atmosphere [5].

In light of these issues, the municipality of Amsterdam and Actienetwerk GasTerug are exploring sustainable alternatives to protect public health while minimizing environmental impact.

ACTIENETWERK GasTerug

Gemeente Amsterdam

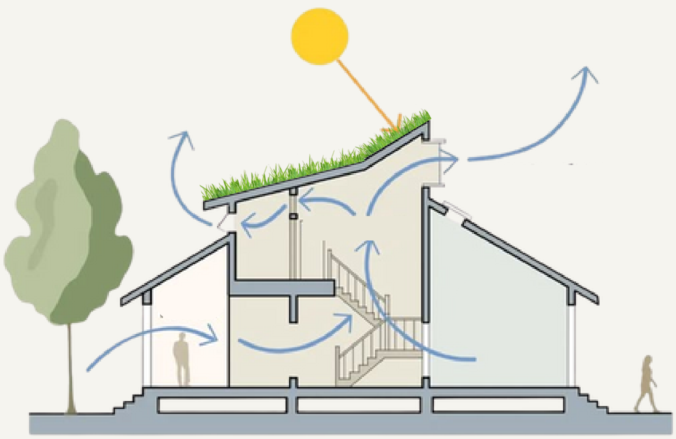
Municipality of Amsterdam
The municipality of Amsterdam is responsible for ensuring a safe and healthy living environment for its inhabitants. It is working towards creating a sustainable urban environment that can adapt to a changing climate, with a focus on issues of extreme heat, drought, extreme precipitation, and potential flooding [8]. This project focuses on adapting to higher temperatures and more frequently occurring heat waves.

GasTerug
Action network GasTerug (LessGas) is a non-profit organization supported by the central government, province of Noord-Holland and the municipality of Amsterdam to reduce the amount of natural gas used in the Amsterdam Metropolitan Region (MRA). It has the mission of decreasing gas usage by applying energy-saving techniques. This project, which focuses on optimizing cooling technologies with minimal environmental impact and improving energy efficiency, can serve as a key component in GasTerug's broader mission to reduce energy consumption in Amsterdam.

In this project, we will explore passive cooling methods to implement sustainable cooling strategies, with a specific focus on buildings in Amsterdam. We evaluate the social, environmental, and practical considerations and challenges that come with implementing specific cooling methods.

The main focus of the project is to contribute to both the climate adaptability as well as the public health of Amsterdam by designing an actionable plan to cool community buildings. This plan aims to maximize cooling efficiency and reduce environmental stress, considering social and behavioral barriers.

This project begins with a review of the most promising cooling methods to investigate their implementability and effectiveness. The key characteristics of buildings relevant to applying these cooling techniques, such as physical layout and stakeholder attitude, will then be analyzed. These findings will be applied to a set of buildings in Amsterdam, and finally a specific cooling strategy and implementation plan for community center the Witte Boei will be outlined.



This report gives a description of passive cooling methods, with the application to buildings in Amsterdam. We evaluate the social, environmental, and practical considerations and challenges that come with implementing specific passive cooling methods, and describe a set of general guidelines to consider when implementing cooling methods in buildings. These steps were performed to formulate an answer to our research question:

"Based on an analysis of different passive cooling strategies, how can these techniques be effectively implemented in buildings to reduce indoor heat stress without contributing to the Urban Heat Island (UHI) effect?"

Accompanied by the subquestions:

- *What are the key characteristics of buildings and their use that influence the choice and effectiveness of passive cooling methods?*
- *How can passive cooling methods be applied to a building, taking into account cost-effectiveness energy-efficiency and behavioural aspects?*
- *What implementation barriers (technical, social, organizational) can decrease the succes rate of these cooling strategies?*
- *What is the expected effectiveness of the selected cooling strategies?*

1. COOLING METHODS

COOLING METHODS

Over time, several cooling methods have been discovered and developed to maintain thermal comfort inside buildings, despite the external temperature increasing. The effectiveness and efficiency of these methods are heavily dependent on building usage, architecture, orientation, environment and human behaviour.

For cooling buildings, there is a distinction between passive and active methods. Passive cooling methods refer to methods of cooling that require little to no energy, whereas active cooling methods are measures that need energy. The active cooling methods can vary from low to high energy cooling techniques. Passive cooling methods are the most interesting focus from an energy perspective [1]. They work by both preventing outdoor heat from entering a building, as well as transferring indoor heat to the outdoor. There are several passive cooling categories: radiative cooling, evaporative cooling, heat avoidance, earth coupling, and ventilative cooling [2].

The most effective passive cooling strategies are those of the category heat avoidance: techniques that prevent heat from entering the building in the first place [1,2,3,19]. Heat primarily enters buildings through the windows. The second largest source of heat is the roof, which is the most exposed surface to solar radiation. A study on the impact of the building envelope found that increasing the window-to-wall ratio (WWR) by 10% led to an approximate 5.67% increase in cooling energy demand, and buildings that have a WWR of over 20% failed to ever reach comfort temperature [3]. In efficient building design, decisions on window orientation, material choice and ventilation routes can improve indoor thermal regulation [5]. However, since we are working with already existing buildings, these measures are not taken into consideration in the report.

INDIRECT EMISSIONS

In the context of climate action, emissions are commonly categorized into three scopes as defined by the Greenhouse Gas Protocol [9].

Scope 1	Direct emissions from owned/controlled sources
Scope 2	Indirect emissions from purchased energy
Scope 3	All other indirect emissions

Currently the municipality's emissions are 99% scope 3, so their priority has been targeting and reducing this type of indirect emissions. By investing in passive cooling, the municipality would decrease the scope 2 emissions (AC uses more electricity therefore more CO_2 is emitted) and scope 3 emissions (LCA emissions of AC are higher compared to passive cooling methods).

In our analysis we aim to investigate the scope 3 emissions of traditional AC and how they compare to those of passive cooling techniques. We aspire to provide a conceptual or comparative analysis, not an official carbon audit, which can then be used by the City of Amsterdam to promote passive cooling.

In the following sections we will present information and data based on previous research and expert interviews for the following methods: solar shading, reflective roofs, natural ventilation, vegetation and insulation. In addition we will explore the indirect emissions of solar shading and green roofs to show how they compare with those of traditional AC based on LCA data.

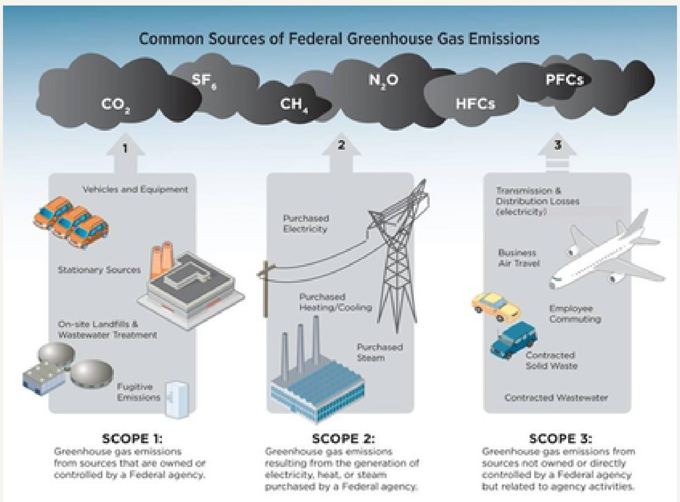


Figure 1: GHG emissions derived from [10]

1.1 Traditional AC

LITERATURE

Air conditioning is used to deal with rising temperatures and heat waves globally since it can lower indoor temperatures efficiently and quickly. For that reason demand for AC is expected to rise by 244% by 2050 according to the Intergovernmental Energy Association, shown in figure 2. However, AC requires electricity and thus it is projected that by 2050 it will be one of the biggest contributors to building electricity energy demand [11]. Since most electricity comes from burning fossil fuels, AC use results in high carbon emissions and presents a significant environmental concern [12]. In addition refrigerants have high Global Warming Potential, which means that leakages can increase global warming [13].

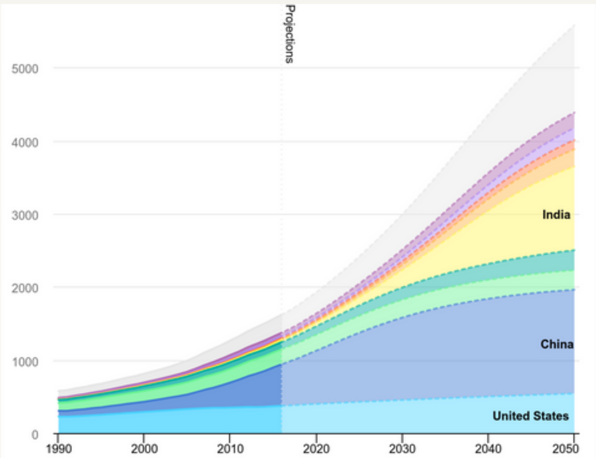


Figure 2: AC usage trends derived from [11]

LCA

In order to estimate and compare the scope 3 emissions of a traditional AC unit with passive cooling methods, we used an Environmental Product Declaration (EPD) published by Daikin [14], a leading manufacturer of HVAC (Heating, Ventilation and Air Conditioning) systems. The EPD provides a standardized, third-party verified life cycle assessment (LCA) of the Daikin SkyAir Alpha Series split AC system in accordance with the PEP Ecopassport program and EN 15804 standards. This product can provide cooling and heating, it includes both the outdoor and the indoor unit and has an assumed lifetime of 22 years.

An EPD outlines the environmental impact of a functional unit throughout its life cycle and it can be used to derive specific CO_2 equivalent emissions for each stage in the upstream production (A), usage (B) and downstream disposal (C). For this analysis and in order to align with scope 3 emissions as defined by the Greenhouse Gas Protocol we will focus on the following stages:

- **Stage A** (A1–A5): Product manufacturing, transport, and installation
- **Stage B** (B1–B7): Use phase, focusing on refrigerant leakage and maintenance
- **Stage C** (C1–C4): End-of-life processing and disposal

The emission related to usage (in B) will be excluded, as they are scope 2 emissions.

Stage	**$kgCO_2e$**
Manufacturing (A1-3)	504
Transport (A4)	7.27
Installation (A5)	12.8
Refrigerant leakage (B1)	87.1
Maintenance (B2)	6.99
End of life (C1-C4)	62.5
Total	**681**

Table 1: Emissions of a DAIKIN air-condition for cooling/heating. Derived from (11)

It is important to mention that previous studies have shown that HVAC systems including AC, insulation and ventilation may account for up to 36% of the building's total embodied carbon [15]. The embodied carbon of the materials is part of the scope 3 emissions since it refers to the stages of extraction, transport and manufacturing [16]. This supports our argument that by choosing passive cooling methods, as well as bio-based insulation with lower GWP, the building's overall carbon footprint and scope 3 emissions could be reduced significantly.

Research papers investigating the life cycle assessment of traditional AC units lack consistency on the methodology and region explored although most focus on the different GWP values [17]. As a result it was difficult to identify specific emission values for each stage of the product's life. Still, this review [17] concludes that most emissions from air conditioners arise during the use phase of air conditioners which accounts for around 80–90% of their global warming potential (GWP). This percentage is not only caused by electricity consumption, but also by refrigerant leakages during operation. In addition, the embodied carbon (scope 3 emissions) associated with the manufacturing and transporting of AC units adds to the total emissions. Though this is a smaller contribution than operational emissions, it is still significant, especially for shorter product lifespans.

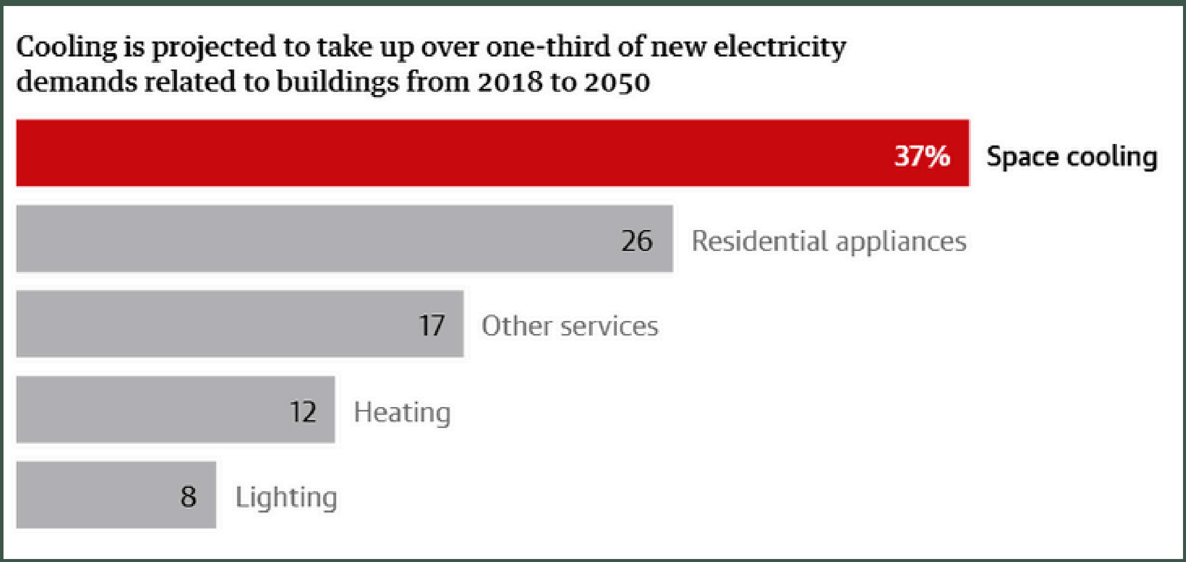


Figure 3: AC projected electricity demand derived from (9)

1.2 Solar Shading

LITERATURE

Solar shading is one of the most effective, efficient and cost effective measures of heat avoidance [1] (Appendix A.1). By blocking the sun from entering the building in the first place, heat associated with solar radiation is avoided. Solar radiation through windows can account for 50 to 80% of heat gain during hot days, depending on the building orientation and the window to wall ratio. With efficient shading devices, window heat gain can be decreased by 50 - 90%, leading to large temperature decreases [5,18].

There are several shading devices, and based on building orientation and purpose the most appropriate and effective shading device varies. It is difficult to objectively compare different solar shading methods due to its sensitivity to the building. Bellia et al. (2014) [19] has attempted to structure the different shading methods. They can be classified in fixed or movable solar shadings, and as external, intermediate or internal, as seen in figure 4.

When evaluating the efficiency of shading strategies, it is essential to consider the seasonal implications of the installation. Fixed solar shading devices, while effective for cooling in summer, can increase heating demand during winter months since it then also prevents solar heat gain.

Internal shading devices range from blinds to internal shutters. These devices have a limited effect: only 10 to 40% of the solar gain is blocked since the heat still has the possibility to hit the window and then finds a way into the building [1] (section 2.2.4). External solar shading is far more effective. There are possibilities for movable vertical shading such as screens, fixed vertical shading such as solar foil, as well as fixed horizontal shadings such as awnings. The most effective measure is placing the shading on the south side of the building, since generally these windows receive the most sun hours [16]. While these measures are highly effective, placing external shading devices can significantly impact indoor light distribution. Especially in buildings with a social purpose, such as community centers, it is important to have access to natural light, make sure visitors have views to the outside, and convey an open, welcoming image rather than a closed-off appearance. Choosing darker screens with a higher light transmittance or openness percentage finds a balance between visitors' visual experience and heat regulation (Appendix A.1, A.4).

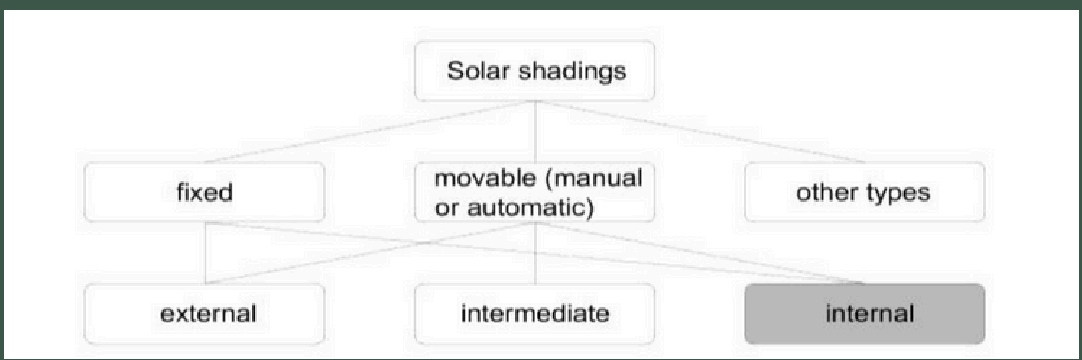


Figure 4: Solar Shading systems for buildings: a possible classification [19]

LCA

Modelling and LCA studies [21, 22] have revealed that solar shades can reduce and save energy by lowering the need for AC or mechanical cooling. However, it has been emphasized that the benefits and energy savings depend on specific climates and regions. This is why later in our report we will include a simulation on energy savings from solar shading in a community centre in Amsterdam. Interestingly, a study by Babaizadeh et al. [22] concluded that wood shades have the lowest environmental impact, followed by aluminium, and PVC exhibits the highest environmental burdens across most impact categories.

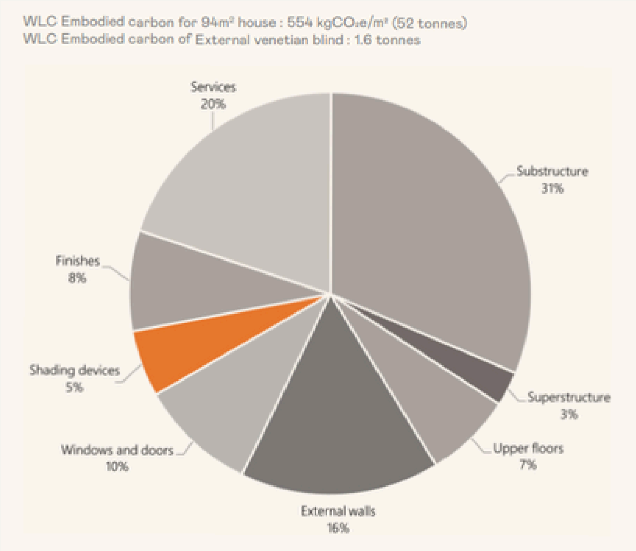


Figure 5: Embodied carbon in a new building [21]

A technical report [21] published by the Good Homes Alliance (GHA), a UK-based non-profit organization that promotes sustainable housing practices, shows a LCA of the embodied carbon of various shading products commonly used in residential buildings. The results outline the embodied carbon for the stages of production A1-3 but also for the whole life cycle including usage phases and the study period of 60 years, therefore including one replacement of the device. Some indicative values from the report are summarized in table 2, showing that for both sets of values the embodied carbon and thus the scope 3 emissions are much lower than those of ACs. In the previous section of traditional AC we did not include the usage phase carbon emission because for AC this would add a lot to the total amount as it needs electricity in order to operate, and these are scope 2 emissions. For solar shading, we assume that the usage emissions are not significant and therefore a comparison can be made. Moreover the AC measurements are derived from a shorter life time of 22 years, therefore the amount of carbon would be even higher for 60 years and if a replacement is assumed.

Moreover, the same study by GHA concluded that the embodied carbon of shading products is small compared to the total embodied carbon of a new building. Figure 5 shows their results for a two story building with 50% of the windows with solar shades. It supports that using solar shading can lead to a significant reduction of need for cooling and ventilation and therefore help lower these method's operational and embodied emissions.

Type of green roof	**Upfront embodied carbon A1-3/ $kgCO_2e/m^2$**	**Whole life cycle A1-C4/ $kgCO_2e/m^2$**
Overhang	117	350
Aluminium screens	85	92
External venetian blinds	41	120
External roller shutters	50	150

Table 2: embodied carbon for solar shading in 60 years life-time. Derived from (17)

1.3 Green Roofs

LITERATURE

A green roof is a vegetative layer grown on a rooftop [28]. Vegetation can provide cooling in two ways. First, plants use the sun's energy for photosynthesis, which prevents it from being transformed into heat. Second, plants get rid of water through evapotranspiration, a process where heat of the air is used to change water from its liquid to its vaporized form [36]. This process cools down the surrounding area. Studies show that green roofs can reduce the mechanical cooling needed by 70% and can also lower the indoor temperature of a building by ~3°C. However, green and white roofs have minimal effect on inside temperature if a building is already well-insulated. If there is a choice to make between renovating for insulation or for adding a green or white roof, the first option is more advantageous since it also helps keep the building warm in winter (Appendix A.1). Nevertheless, green roofs have gained a lot of attention due to the environmental benefits, cooling capacity and energy savings it could provide.

There are two types of green roofs: extensive and intensive [28]. Extensive green roofs are simpler and require less maintenance and structural support. There are very few plants and the growing medium depth is two to four inches. Intensive green roofs are more complex, require more maintenance and better structural support since they are heavier and can even consist of small trees and a lot of vegetation.

Blue/green roofs refer to green roofs with water storage medium that is also used for stormwater management. One study [29] investigated the potential benefits of blue/ green roofs in Amsterdam and compared them with typical green roofs. They found that blue/ green roofs result in higher evaporation rates and therefore more cooling efficiency than Sedum roofs, that have a thin layer of vegetation and very low evaporation. They also showed that some different plants and herbs showed greater evaporation than Sedum, therefore the type of vegetation should be carefully considered. Although more costly and higher required maintenance, the overall benefits to climate adaptation of the city have been proved to be higher from blue green roofs as they can tackle UHI effect and stormwater management.

Another study [30] investigated the innovative idea of adding a forecast system to the blue-green roof. This system checks the weather and adjusts how the roof stores or releases water based on the upcoming weather. The authors used the city of Amsterdam as a case study and concluded that this addition could increase the evaporation rates during hot days and therefore improve cooling and heat stress reduction. In addition these roofs could capture 70%-97% of extreme rainfall and therefore propose them as measure for flood-prone urban catchments in Amsterdam.

Extensive Green Roof

Intensive Green Roof

Figure 6: Types of green roofs derived from [28]

LCA

A recent review [31] on the LCA of green roofs revealed the potential net environmental benefits of green roofs. They looked at 44 LCA studies on green roofs to understand the environmental impact such as the embodied carbon emissions. Most studies focus on the Global Warming Potential at each stage of the life cycle. Most emissions related to the production stages A1-A3 are related to the embodied carbon of materials like concrete, waterproof membranes and substrate. However, it is important to mention that the phase B of usage involved negative values because green roofs may reduce the energy consumption for cooling during the hot weather.

Moreover, extensive green roofs (thin, lightweight, low maintenance) generally have lower embodied carbon than intensive green roofs (deeper soil, higher biodiversity). Table 3 below summarizes the total GWP for two green roofs derived from the companies' published EPDs. Phase B1 (Use) for the extensive sedum roof is -61.5 $kgCO_2$ whereas for the intensive roof it is 0.09 $kgCO_2$, which is still very low, but not negative [33, 34].

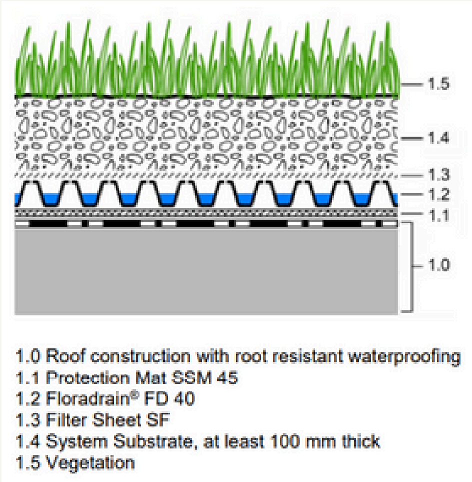


Figure 7: Intensive Green Roof graph (31)

Another important factor when considering carbon emissions from green roofs is their potential to sequester carbon [32]. This study looked into the sequestration potential of 12 sedum green roofs considering the above ground biomass, the belowground biomass and the substrate organic matter. The total sequerestation calculated was 375 g C/m². The embodied carbon of the materials used to construct a green roof was 6.6 kgC/m2. Lastly, the study referenced simulations indicating annual energy savings translating to 702 g C/m² in avoided carbon emissions. Based on these savings, the carbon payback period, the time it takes for the energy savings to offset the embodied carbon, is approximately 9 years.

Type of green roof	LCA carbon per m2 / stages A1-C4	EPD source
Rock Mineral Wool Urbanscape® Green Roof System - Extensive/Sedum	13.29 $kgCO_2$-Eq	(30)
"Heather with Lavender" Intensive Green Roof System ZinCo GmbH	17.24 $kgCO_2$-Eq	(31)

Table 3: calculated total GWP from EPD sources green roofs

1.3 White Roofs

LITERATURE

Since roofs are important heat exchange surfaces, another way to block heat from entering a building is targeting the roof reflectivity [23, 24]. By increasing the reflective capacity of the roof marked by the Solar Reflection Index (SRI), less sunlight is able to penetrate the building from above. A standard roof has an SRI of about 5 to 15%, which can be increased to 70% by introducing a white roof [1]. As a result, indoor temperatures can decrease by up to 2 degrees on peak summer days [27].

The effectiveness of white roofs is heavily dependent on the current existing state of the roof, particularly its insulation level (Appendix A.1). In buildings with poor roof insulation, white roofs have the greatest impact, since the minimal amount of heat is absorbed and surface reflectivity of the surface directly impacts inside temperatures. Raising a low-insulation roof's albedo from 0.05 (dark) to 0.75 (white) can give a benefit in the temperature equal to adding around 14 centimeters of insulation on a black roof [26].

White paint is a relatively low-cost (Appendix A.2) and simple solution to block sun from coming in, and its installation compared to other cooling strategies is minimal, requiring only basic roof preparation followed by applying the reflective coating. However, drawbacks include accumulation of dust and dirt, which decrease the performance of the roofs over time, and the potential for increased light pollution for surrounding buildings.

A big drawback is that in colder climates, white roofs often imply added energy cost in winter due to a lower amount of heat penetrating the roof, generating more heating costs. In the Netherlands, a detailed investigation needs to be done to establish whether the benefits of a white roof outweigh the costs [25, 27]. In choosing between white or green roofs, green roofs are preferred since these roofs also insulate the roof, minimizing the mentioned negative effects during winter (Appendix A.1).

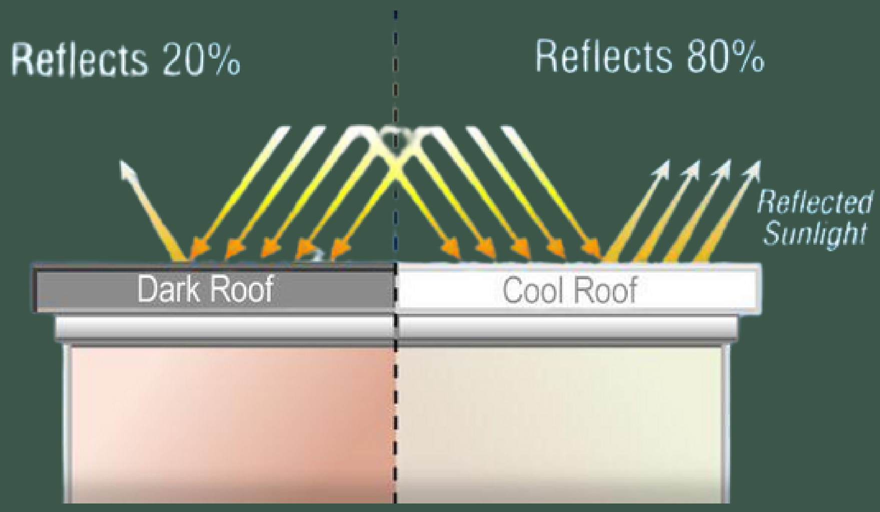
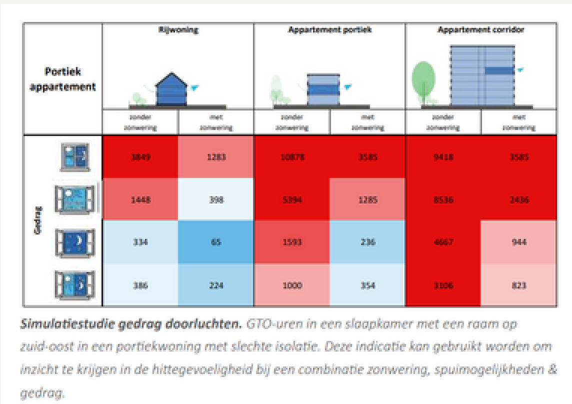


Figure 8: differences in reflectivity dark and white roof

1.4 Ventilation

LITERATURE

Once heat has already entered a building, the most effective way of passive cooling during a heat wave is by natural ventilation. This effect is especially prevalent in buildings that have the opportunity for airflow on opposite sides of the building as well as airflow throughout different floors of the same building [40]. Research in office buildings found that ventilation can lower indoor temperatures by 1.5 to 2 °C when the day–night temperature difference is around 8 °C [44]. It can be achieved by opening windows or installing ventilation ducts that can be opened or closed at specific times. The most effective form of natural ventilation is 'night ventilation', where windows are kept closed during the day and opened at night (figure 9). It is an attractive option for so-called 'mixed mode' cooling, where passive and mechanical cooling are combined, as it can use the existing airflow network with limited extra costs [44].



Portiek appartement	Rijwoning		Appartement portiek		Appartement corridor	
	zonder zonwering	met zonwering	zonder zonwering	met zonwering	zonder zonwering	met zonwering
Gedrag	3849	1283	10878	3585	9418	3585
	1448	398	5394	1285	8536	2436
	334	65	1593	236	4667	944
	386	224	1000	354	3106	823

Simulatiestudie gedrag doorluchten. *GTO-uren in een slaapkamer met een raam op zuid-oost in een portiekwoning met slechte isolatie. Deze indicatie kan gebruikt worden om inzicht te krijgen in de hittegevoeligheid bij een combinatie zonwering, spuimogelijkheden & gedrag.*

Figure 9: Hours of extreme heat in 3 different dwellings. Compared with and without solar blocking as well as with different ventilation behaviours [40].

A problem with ventilation, especially during the night, is the danger of break-ins, noise complaints and infestation of insects and rodents. Break-in safety can be prevented by using summer night ventilation shutters or transom windows. Insect or rodent repellent screens help prevent infestations but can diminish the speed of heat transfer through windows or shutters [39].

Figure 10: Inbreak-proof ventilation shutters and a transom window

In a location with an extreme UHI effect, the temperature at night does not decrease enough to provide proper cooling through ventilation (36). Then ventilation on its own does not suffice to cool a building. A heat exchange systems with the ground can provide a solution to this problem. Soil is better than air at maintaining cool temperatures throughout the summer due to its mass. A ground-coupled heat exchanger consists of a ventilation pipe running through the ground, causing outside air to be cooled down before entering the building. The system has an added advantage of preheating the air in winter, since the ground's temperature will be higher than that of the outside air [40]. However, these systems are usually quite expensive and work better as an integral approach for neighbourhoods (for instance, see the cold net at the Zuidas [42]). Measures also need to be taken to ensure the air does not become contaminated in the ground with mold or bacteria [40].

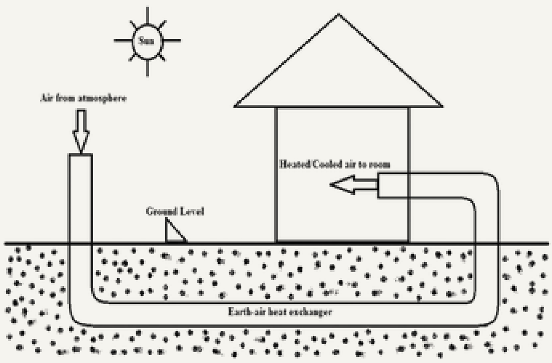


Figure 11: Design of a ground-coupled heat exchanger [41]

1.5 Insulation

Figure 12: Possible insulation layer structures

Another method of passive cooling is improved insulation. Insulation is slightly more complex, since it can have both a negative and positive effect on indoor heat stress. Insulation prevents heat from entering through the roofs and walls, but once heat has entered the building through the windows, insulation also causes that heat to stay trapped inside. In this way the temperature of a room can quickly rise.

However, if good insulation is combined with sun shading and efficient night ventilation, it can steeply increase a building's resistance to heat [1] (Appendix A.2). A well insulated building takes longer to heat up, and if heat has a way to escape the building at night, for example through opening windows at night, it will decrease the risk of exceeding a comfort temperature threshold [42]. Insulating a building can be done in various ways.

An environmentally friendly option is biobased insulation; using materials such as hemp, flex and cellulose [43]. Biobased insulation uses the phase changes of different materials, ensuring that solar radiation takes a longer time to permeate the building. The walls absorb heat and release it gradually as mentioned, preventing indoor peak heat spikes leading to heat related health risks [42]. Furthermore, the production and disposal of these materials result in a lower overall carbon footprint, contributing to more sustainable embedded carbon values.

A downside to improved insulation is that it requires large scale renovations, with a large price tag and the potential for stalling the building’s day-to-day activities for a period.

1.6 Vegetation

Vegetation can have a major effect on cooling down cities. On a hot day, the perceived temperature in forest areas is significantly lower than in urban areas [35]. Urban green infrastructure can play a large role in cooling down cities due to the multi-faceted cooling abilities of plants and trees. First of all, trees provide shade for buildings and large parts of ground; maintaining a lower surface temperature and preventing heat from entering buildings. Besides this, plants perform photosynthesis and evapotranspiration (see section 1.3), both of which cool down the surroundings. The intensity of the cooling effect of these measures is dependent on the age, coverage and density of the trees [36]. Also the water availability in plants is relevant. During a dry season vegetation has less water to evaporate, reducing the cooling effect [38].

There are multiple ways to introduce vegetation to urban spaces, varying from tree lanes to smaller green patches, placed on different orientations of the street. Research shows that the perceived temperature in urban areas can decrease by up to 19°C with the right implementation of vegetation [35].

The way trees are planted depends on the characteristics of the street. The most important factors are the available space for tree canopy development, if there is sufficient space for root growth, the access to groundwater, and the oxygen levels in the soil. From a cooling perspective, the orientation of the trees is important. The highest effectivity is achieved if the shade is located on sun-exposed sides like the south-west or south-east. An example of effective urban green infrastructure for narrow streets are espaliered trees, which are trained to grow flat. They provide substantial shade and evaporative cooling while needing little horizontal space [35].

While the cooling effects of vegetation are strong, and an increased amount of trees improves biodiversity and the amount of water infiltrating the soil, the costs of implementation can be high. Trees need regular maintenance and can have a considerable impact on the street layout. Apart from this, root systems may cause damage to building foundations and underground infrastructure if not planned correctly [37].

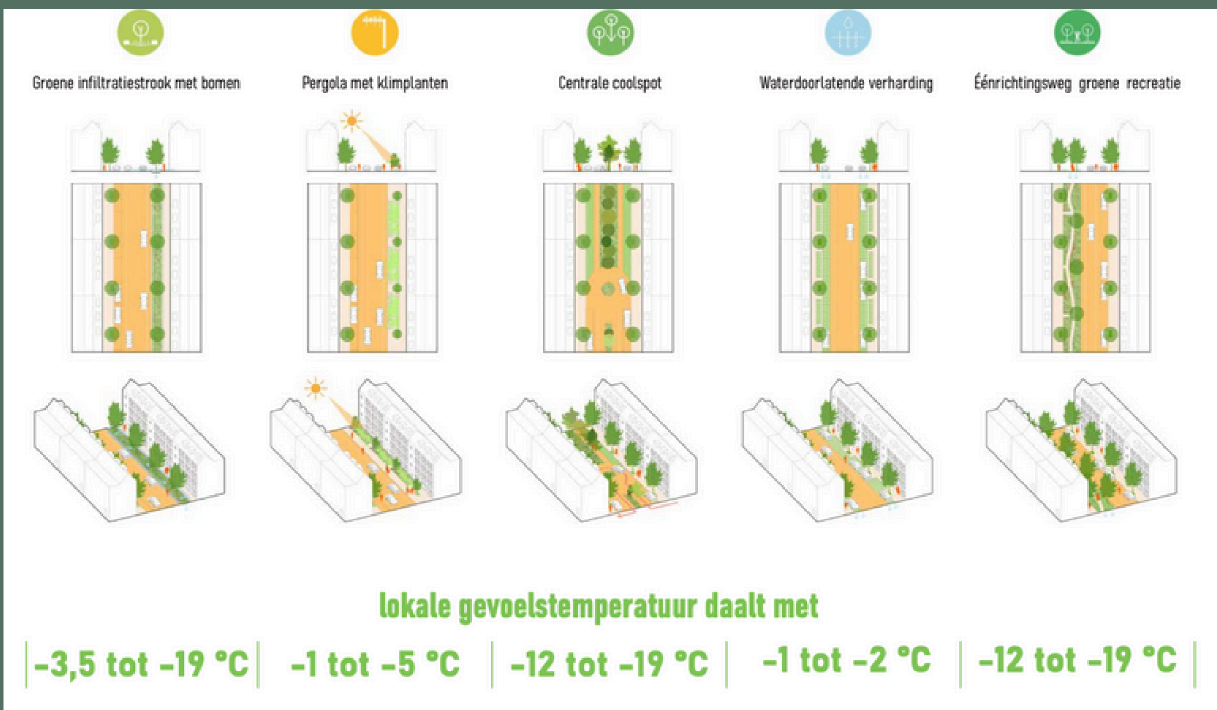


Figure 13 : Estimated decrease in perceived temperature for different vegetation planting strategies

1.7 Method Comparison

Comparing the efficiency and the costs of different passive cooling methods can be challenging. In terms of efficiency, the actual temperature reduction is heavily dependent on factors such as building architecture, orientation, and its surrounding environment. Similarly, the costs of implementing these methods vary significantly based on the scale of the project, the complexity of installation, and the expected lifespan and maintenance costs of each method.

A study conducted by the Lawrence Berkeley National Laboratory [46] attempted to quantify and compare the effectiveness of several passive cooling strategies. The analysis was based on simulations of buildings in various global climates and included both multi-story detached homes and single-story housing blocks, with houses from different building years.

The research showed that from all the passive measures investigated, the two most effective strategies in simulation were the installation of solar-control window films and the addition of roof insulation.

Figure 14 represents the amount of hours that the buildings remained outside of the desired comfort range (UDH) in a single-story family unit. Roof insulation and window film show significant decrease, especially for housing built in 2015. Adding roof insulation significantly lowers attic air temperature, which then reduces transfer of heat from the attic to the lower floors.

However, the paper did not explicitly cover green roofs. Another study was performed by Cubi et. al. (2015) [47] comparing white roofs, green roofs and PV panels in cold climates. From this study it appeared that in the geographical location of this study (Canada) the increase in heating demand for white roofs far outweighs the decrease in cooling demand. However, for green roofs the decrease in cooling demand outweighs the increase in heating demands.

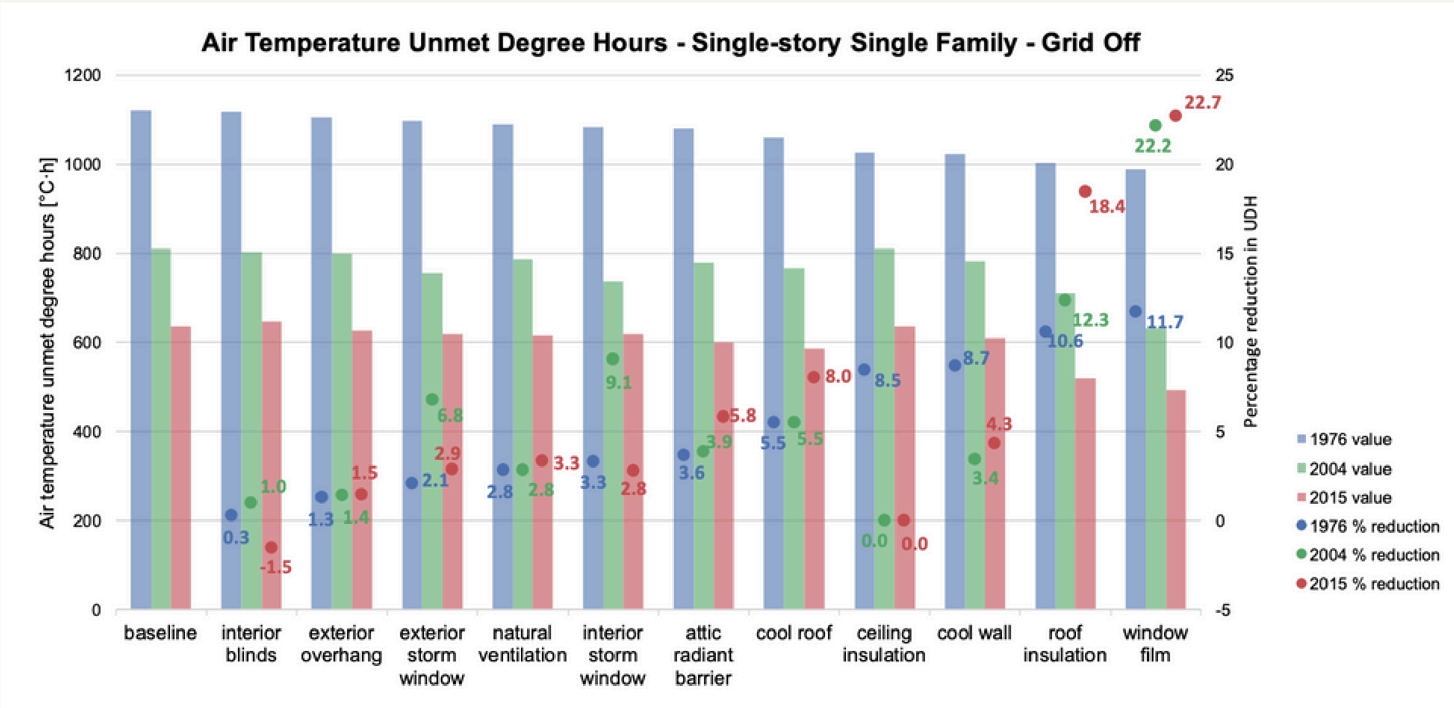


Figure 14: The differences of UDH for a Single-story family home for different passive cooling methods

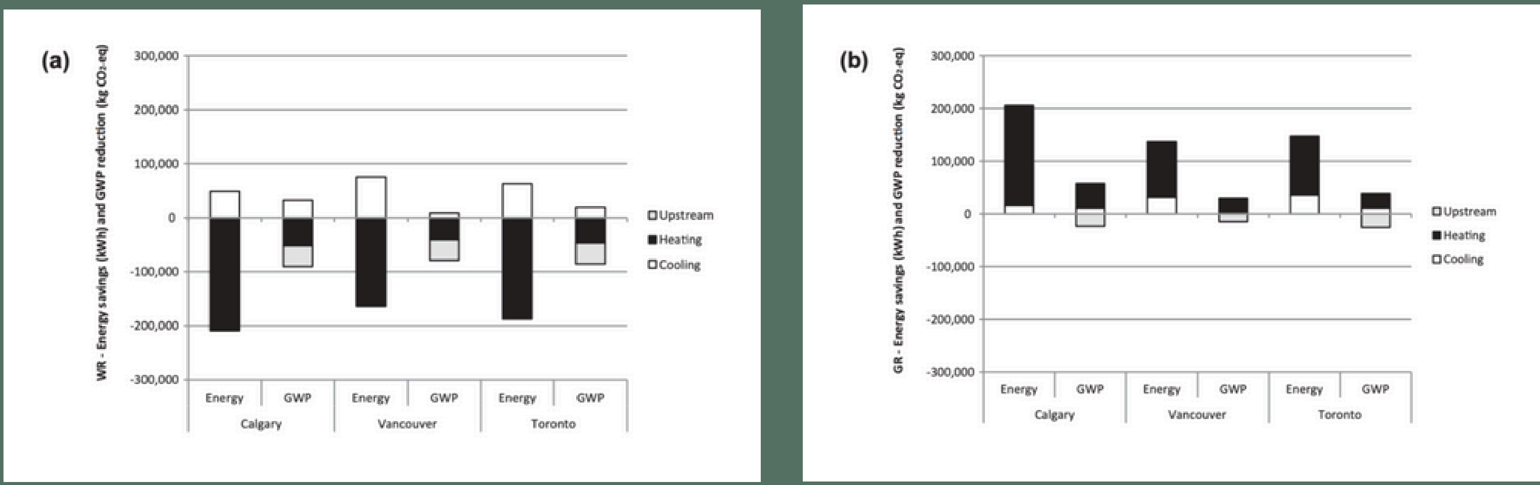


Figure 15: Energy savings of white roofs (a) and green roofs (b) [47]

Even though the comparison of costs is complicated, the Dutch Green Building Council has established a cost matrix and mapped the implementation complexity for the different cooling methods relative to each other [48]. This matrix highlights that active cooling methods or methods that imply large alterations to the building such as heat pumps or insulation are the highest cost and highest complexity options. Passive cooling methods score low on costs and also on implementation feasibility. Installing a green roof and installing solar shading are measures that are classified as relatively low ost and simple implementability compared to measures such as heat pumps or insulation adjustments.

The studies' findings do provide a comparison framework for different passive cooling methods, and help understand their relative effectiveness and cost-efficiency. However, an objective comparison remains challenging because of the building-specific factors like insulation quality, design, and climate. Results from comparison studies can vary with geographical location. For example, the Lawrence Berkeley study highlights how window film is the most effective measure on average, however in colder regions like for example Amsterdam such a static solution can increase heating demand in winter, resulting in increased net energy costs. A similar problem arises with white roofs, where in colder climates its effectivity in reflecting heat can have a negative effect in winter. These examples emphasize the importance of using strategies that fit the local context of the building.

While literature review heavily suggests that keeping the sun out of a building is the most effective and cost-efficient approach, the best passive cooling strategy is very building-specific, and usually involves a combination of different methods.

When considering Amsterdam's climate, where blocking solar gain in winter leads to higher heating costs, and considering the scale of this project, we weighed the cost-efficiency and seasonal dependence of the different cooling methods. While study [47] labels window films and insulation as highly effective, we have adapted this conclusion to suit the context of our project; adjusting permanent window films to movable exterior solar screens, and using green roofs for higher roof insulation. The flexibility of solar shading is essential in Amsterdam's climate, and green roofs are proven to be effective in insulating, come with multiple added benefits, and are more cost-effective than building insulation. Together, these solutions represent a strong passive cooling strategy for the considered building facing heat stress in Amsterdam.

2. RESEARCH FOR THE WITTE BOEI

2.1 Building Selection

In choosing a building to run a passive cooling method pilot, many aspects need to be taken into consideration. As the efficiency of cooling methods is highly dependent on building characteristics, an important step in deciding which building to cool with which method comes from mapping and describing the different buildings.

We started out with a list of 12 buildings. Some were suggested by the municipality, others were selected due to ongoing sustainability measures, and some were included spontaneously after exploring the locations ourselves. All these buildings have differences in energy labels, environment, usage, and also internal management structures. By visiting these buildings, looking up relevant information online, and interviewing staff and visitors, we formulated an initital selection of buildings of interest. For all the buildings we explored the most important aspects are listed below

Building focus areas

- Perceived heat stress (based on observation and staff/visitor input)
- Year of construction
- Building type (heritage listed or modern)
- Existing cooling systems
- Ownership and possible renovation plans
- Potential for cooling methods

A full overview of all building findings can be found in appendix C. After collecting the initial data, we started connecting with building owners and further assessing the impact of heat stress on the visitors of each location. Key considerations included whether visitors or staff perceived heat stress as a serious issue, how fit the building architecture appeared for cooling methods, and how accessible and cooperative the building owners or managers were during communication.

From the initial 12 buildings, a selection of 3 buildings was made. As an example, the reasons for not choosing buildings where the following:

- The AV23 building users did not experience much heat stress due to the nature of the building visits.
- Ouder en KindTeam Oud Oost indicated only limited problems with heat stress, and high limitations to building alterations due to an already installed AC.
- NoLimit appeared satisfied with a working AC system and not eager to switch to passive cooling methods.
- The Wildeman Theetuin seemed hesitant to work with new initiatives,
- The community center Havelaar and city farms Zimmerhoeve and Osdorp had already implemented methods to combat heat stress.
- At Studio Lely there were already large scale renovations planned in parts because of the heat, so there was no need for low-cost passive cooling solutions.

In the end, we narrowed the selection down to three possible buildings:

1) *De Meeuw*, due to its flat roof and the team's openness to collaboration

2) *Kwakoe*, because of the seemingly vulnerable nature of its visitors, highlighting the importance of thermal comfort

3) *Witte Boei*, as the building layout showed strong potential for cooling interventions and communication with the staff and representatives was clear and straightforward

From these three buildings, we continued with the plan to select one for the pilot. Buurthuis de Meeuw initially seemed like a good option, but further investigation (see section 3.2) showed that its visitors were not significantly affected by heat stress. For Kwakoe, we were unable to get in touch with the asset or building managers.

Eventually, the Witte Boei was selected because its visitors reported the highest level of heat stress (section 3.2), the building is located right outside of the section of Amsterdam where building alterations were prohibited (section 4.3), it features a relatively straightforward architecture layout with a flat roof and many windows, and had engaged and communicative stakeholders.

2.2 Questionnaires

In order to assess in which of the three buildings, people experience more heat stress we prepared and distributed a questionnaire (see Appendix B). The aim was to get an overview of how the people using the buildings feel during hot days and whether they view cooling methods as an urgent solution. All results were summarized in pie charts and can be found in Appendix B.2. People mentioned having experienced most heat stress at the Witte Boei, followed by De Meeuw. At Kwakoe the is no need for more cooling according to visitors

At De Meeuw and the Witte Boei, 18 people responded at each building and the average age was 71. Most of the respondents said they visit the building weekly or even daily. At the third building which was Kwakoe, the average age was 60 and there were 9 responses. Also, around 30% of people said they visit monthly.

For the question “On hot days, how uncomfortable does indoor temperature feel in this building?” , shown in figure 16, around half of the people from De Meeuw responded “Not at all”, whereas around 70% of people from the Witte Boei responded “very”, “moderately” and “slightly”. At Kwakoe almost everyone said “Not at all”.

Moreover, for the question “Do you feel like the current cooling options for this building are adequate?” everyone from Kwakoe and 60% of people from De Meuw said “Yes” but only 30% of people from the Witte Boei said “Yes”. Therefore, it was concluded that the Witte Boei is in more urgent need of passive cooling based on the users of the building.

This was a good initial indication of the comparative need of cooling methods. However, there exist some limitations to this qualitative research such as the fact that people may not remember how much heat stress they experienced if many months have passed. Results may be different if questionnaires like this one are distributed after very hot days.

It is very important to consider users of municipal buildings before deciding on implementations and changes as they are the ones affected by them in the end. We therefore suggest similar questionnaires to be used by municipalities that want to start applying passive cooling methods and to prioritize spaces where people need them the most.

a) Witte Boei b) De Meeuw c} Kwakoe

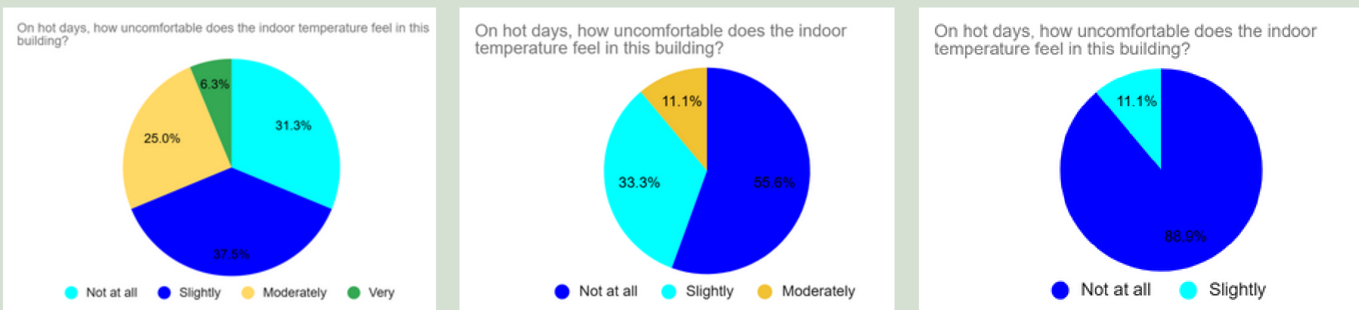


Figure 16: Results from Heat Stress Questionnaires

2.3 Simulation

Another important part of assessing the fitness of cooling methods is estimating the potential energy savings. This is a complex task, since measuring the success of passive cooling strategies depends on factors such as visitor perception, building orientation, and solar intensity. In practice, it is difficult to isolate the impact of one chosen strategy, and often there is no prior energy data available to compare against, making it hard to measure effectivity precisely. A good alternative to gain understanding of the possible impact is to use building simulations, allowing for easy and isolated alteration of building aspects. We've modelled and performed an analysis on the Witte Boei using the simulation tool EnergyPlus.

The process began by translating the floor plans of the Witte Boei into zones. EnergyPlus defines zones as relatively isolated parts of a building. For the building, two zones were defined: zone 1 as the ground floor, and zone 2 as the first floor. Air mixing between the two floors was enabled. due to an open stairwell connecting the two floors.

Combining detailed floor plans with a sustainability report created by Ecocert, we were able to gather data on building materials, insulation values, and other specifications for walls, windows, roofs and floors.

Material layers were created based on known construction data. External walls were for example designed by layer sequence Plaster-Insulation-Brick, with a thermal resistance value of 1.25 m^2K/W, as defined in the report.

In the model we have compared four different scenarios, described in figure 17.

Exact parameters for solar shades and green roofs can be found in Appendix E.

For these four models of the Witte Boei have calculated the total energy costs for a simplified heating, ventilation and air conditioning (HVAC) system on the building for the months July and August in Amsterdam in 2015. We have set a cooling setpoint of 23°C and a heating setpoint of 20°C. Cooling and heating energy demand is calculated for both zone one and two, and then summed to have the total energy costs for the scenario of temperatures in Amsterdam in July and August 2015.

1. The baseline model, representing the current situation of the building without any passive cooling methods. It is the reference case for comparison.

2. Full solar shading model, where the building has 95% reflective solar screens on all windows on both floors of the building, active daily between 09:00 and 17:00. This setup is used to investigate the impact of continuous external shading.

3. Full green roof model, where the building has green roofs on both major roof surfaces.

4. Implemented scenario, representing the planned implementation. It includes solar shading only on the ground floor on the south east and south west side of the building. It also includes a partial green roof, applied to the large roof area only

Figure 17: Overview of the four modelled scenarios

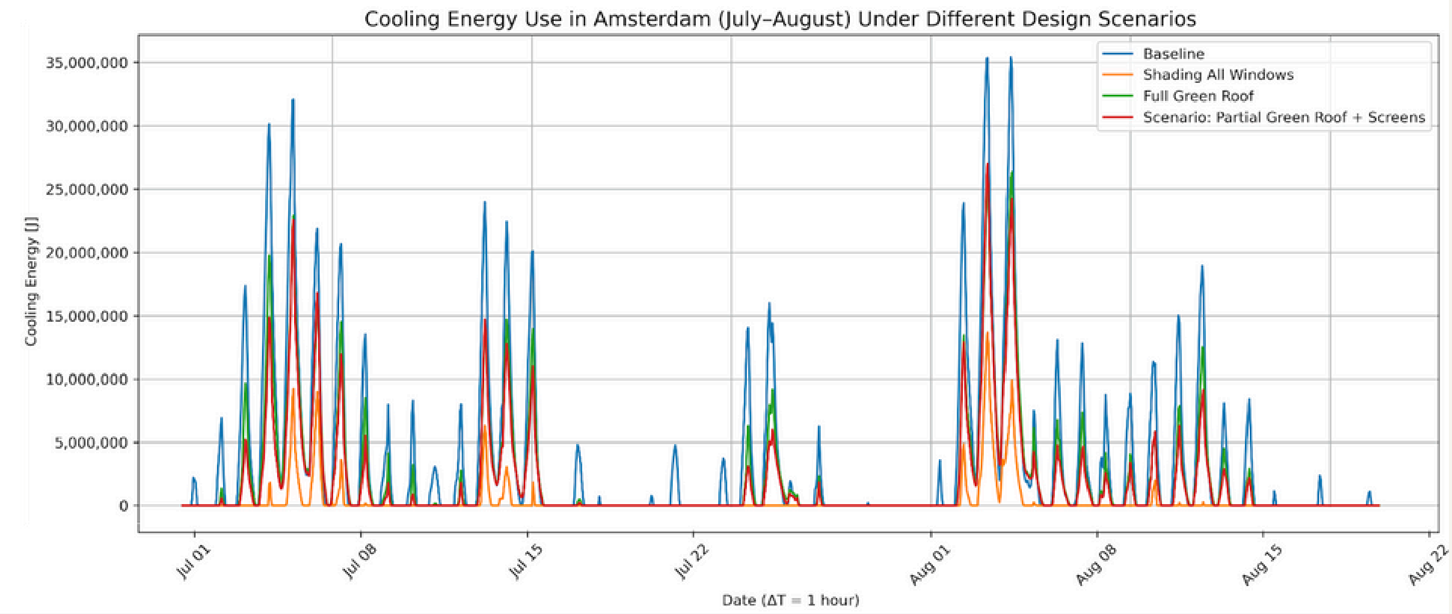


Figure 18: Cooling Energy Use for the Witte Boei for the different scenarios

Based on the simulations of the four different models, we find that the full shading of all windows leads to the lowest energy costs. This aligns with expectations set by the literature review (2.1.1). However, it is important to note that the model assumes a fixed shading schedule from 09:00 to 17:00 each day, which does not fully reflect real-world usage. The largest reductions in demand happen on days where the base model has the highest cooling demand. This makes sense, since these are the days when shading blocks the largest amount of incoming solar radiation.

Interestingly, the model with a full green roof usually results in higher energy costs compared to our planned scenario of a partial green roof with partial solar shades. There is a variation between the difference in effectiveness of the two models. For some days, it can be observed that the models are actually very close together. The variation in results can be explained by the fact that heat transfer happens through both direct solar radiation and also through thermal emittance. On cloudy days, there is less solar radiation to block, reducing the effect of shading elements: there the two scenarios behave more similarly. For sunny days however, the partial shading scenario shows a clear advantage.

Scenario	Energy Saved (kWh)	€ Savings (@ €0.35/kWh
Full shading	1027	359.45
Full green roofs	454	189.90
Implemented combination	565	197.75

Table 5: Overview of energy and cost savings for different scenarios

In table 5 we can observe the amount of energy saved for the different models over the entire 2-month period. The baseline scenario uses a total of 1146 kWh for cooling energy.

These results are based on the summer temperatures of 2015. However, with projected temperature increases in the coming years reaching an estimated 29–36°C by 2050 [1], the potential for energy savings is expected to rise accordingly.

Figure 19 shows the temperature profile of an entire day (august 1st) for the baseline and the implemented scenario if no HVAC system is activated. The implemented scenario results in a continuously lower indoor temperature, with the largest difference being around 13:00 to 15:00, when the temperature is highest and incoming solar radiation most intense.

While the results of the simulations are based on a few assumptions, such as individual rooms not being defined and shading by buildings and trees being estimated and simplified., the results do offer valuable insights and a clear picture on the effectiveness and impact of different measures relative to each other. The set up reveals that the cooling methods suggested can significantly lower indoor temperatures and cooling demand.

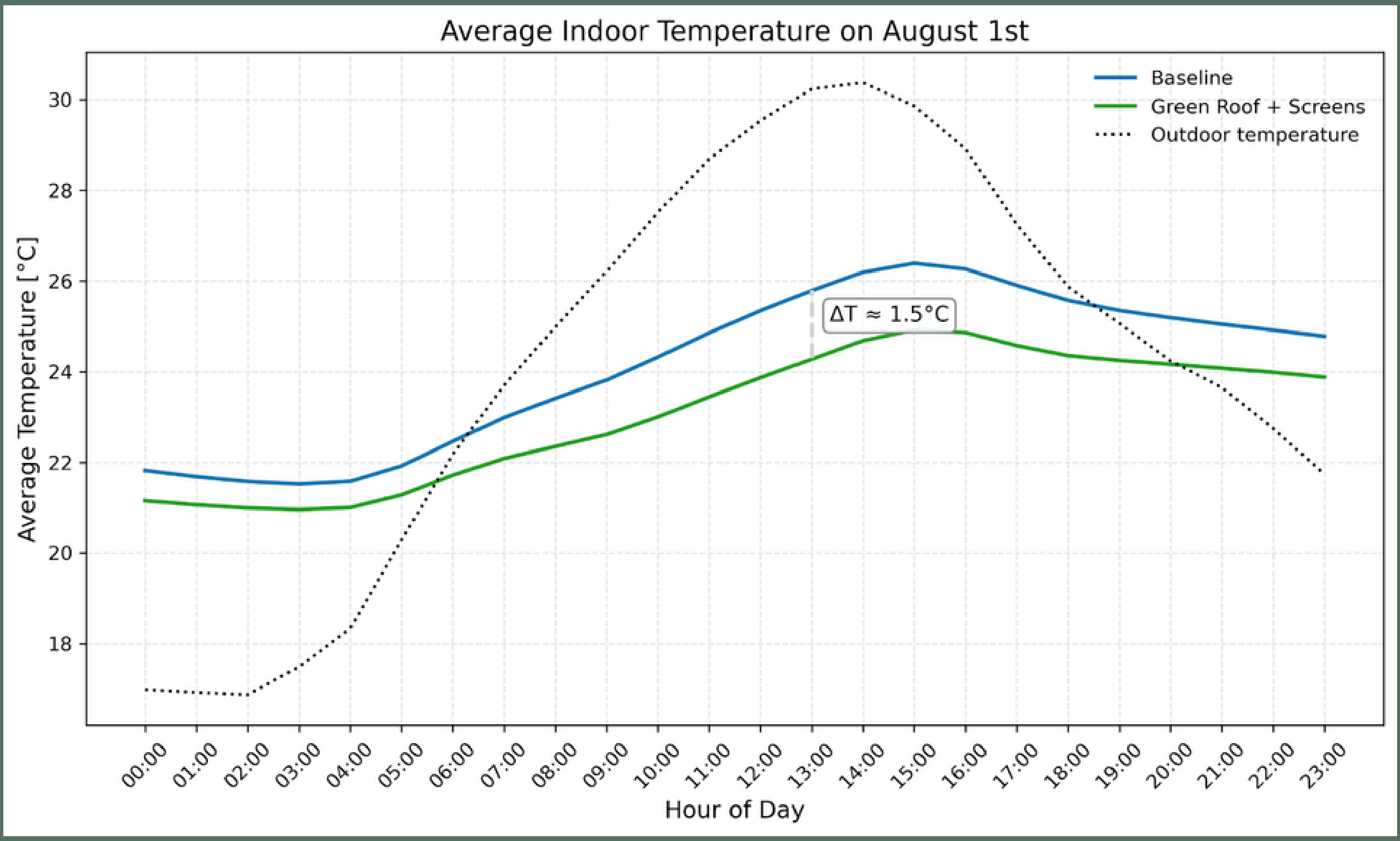


Figure 19: Cooling Energy Use for the Witte Boei for the different scenarios

3. RECOMMENDATIONS FOR THE WITTE BOEI

3.1 Cooling Method Selection

Based on literature review, expert interviews and simulations of the specific building, we have formulated recommendations for how to best decrease heat stress at the Witte Boei. These were made in collaboration with the project leader of the Witte Boei and with our partner GasTerug. It initially consists of the following improvements, ordered by how much of a difference they are expected to make in terms of heat stress. Dependent on the budget, one or more of these measures can be implemented:

- Adding solar shading to the south west and south east facing windows of the building.
- Adding a green roof on the larger roof
- Adding a white roof on the small roof

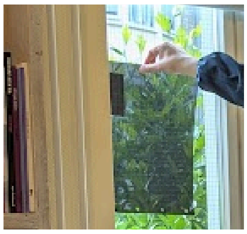
SOLAR SHADING

In summer, the south west and south east sides of the building are exposed to direct sunlight for a large part of the day. There is little shading from vegetation, trees and other buildings and there is currently only inside solar shading available, which has little effect on preventing heat from entering the room [40].

Figure 20: South east and south west side of the Witte Boei

We propose adding outside solar shading to these windows. The priority should be on the south east side, since the lack of shade on this side causes more direct sunlight to enter. Retractable awnings, solar screens or a combination of the two would be recommended, however the municipality has voiced their preference for solar screens over awnings. This is because on the ground floors awnings can obstruct the sidewalk for pedestrians, and they require more maintenance (Appendix A.4). We recommend prioritizing the ground floor, as this is where the community centre is located. The ground floor can then function as a 'cool hub', where visitors can seek comfort during extreme heat.

Due to the function of the building as a community centre, it is important that even when completely closed, the shades let through some light. The companies we approached provide shades with different levels of light transmittance. The downside of a higher percentage of light transmittance is that more heat is carried inside the building [40]. We recommend 5% light transmittance, a good balance between the two. In terms of colour, a darker shade is advised as it is easier to look through and doesn't appear dirty as quickly.



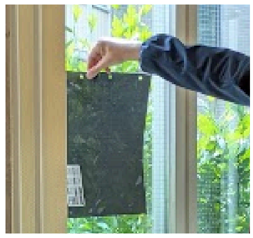


Figure 21: resp. 10% and 5% light transmittance shades

To prevent the shades from rattling in the wind and possibly breaking, the solar screens need to be held down on the sides of the window. For this, steel cables or rails are both sufficient. The companies we approached both use rails, as they are less prone to breaking.

The municipality prefers the screens to be installed on the facades (gevels). For the Witte Boei this is not possible on the bay window on the south east side. Therefore the screens can be installed on the window frame there. For the screen installations approval was gained from the project leader of the location.

GREEN ROOF

The Witte Boei has a large roof of two stories high as well as a one story high roof of a later addition to the building. A green roof is preferred on this roof over a white roof, due to the reasons given in section 1.3. The large roof is currently covered in gravel and is made out of concrete, which implies the roof can handle a large amount of weight. However before installation an expert would need to confirm what the exact weight carrying capacity is of the roof. The smaller roof is expected to not be able to carry the weight required for a green roof.

A schematic drawing based on the building papers of the large roof can be seen in the figure below. Part of the roof (light green in the drawing) is elevated roughly one meter above the rest of the building. The total area of the roof is 328.13 m^2. A significant part of the roof is however already covered in solar PV panels and outlets of ventilation and rainwater. We estimated that roughly 200 m2 could be made available for roof coverings.

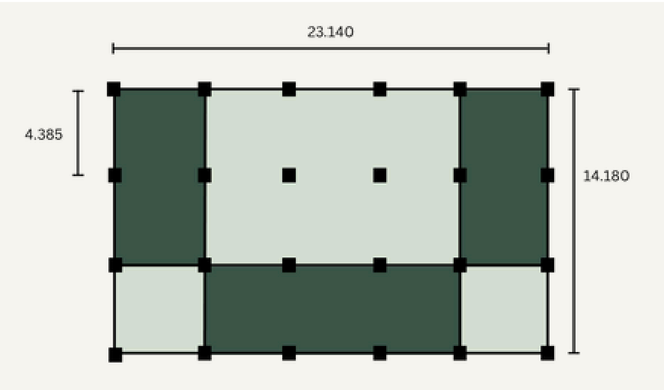


Figure 22: Schematic drawing of the Witte Boei based on building drawings

There are different types of green roofs that could be applicable for this building. Sedum roofs, a type of intensive roof, require the least maintenance and are usually the cheapest. However, their insulation and cooling capabilities are limited and they do not contribute significantly to biodiversity. Extensive roofs containing grasses, flowers and bushes are better at cooling and have a positive effect on biodiversity. For this reason the municipality provides subsidies only for green roofs consisting of less than 50% of sedum.

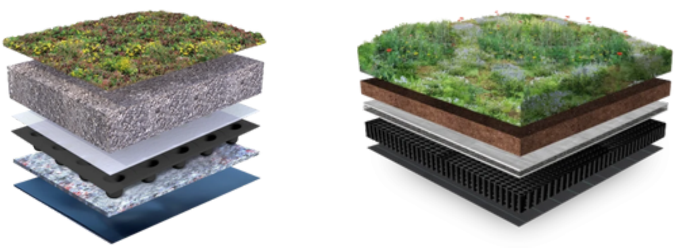


Figure 23: Sedum and Green roof structure, from GroenDakSpecialist [50]

Other variations on green roofs exist to make them more sustainable or weather proof. The blue green roof has a special layer of water retention which prevents plants from drying out in summer and manages flooding during a heavy rainfall with a smart drainage system. Cork green roofs are completely biobased roofs which do not require synthetic materials in the bottom layers of the roof. These variations add to the cooling capacity and circularity of the roof, but come with a larger price tag.

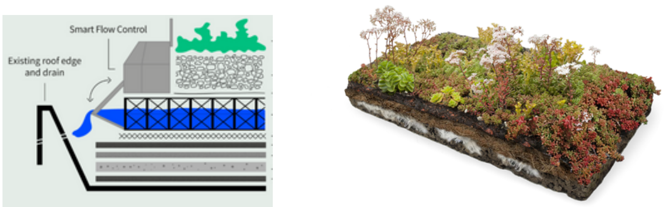


Figure 24a: Blue Green roof from RESILIO [51]. 24b: Cork Sedum roof from EarthKweek [52]

WHITE ROOF

The smaller roof of the Witte Boei covers an area of the community centre used as a meeting or activity room. Since the building here is only one story high and the roof is most likely not made out of concrete, the temperature of the roof is expected to make a large impact on the interior temperature. Adding a layer of white reflective paint could dramatically decrease the roof temperature, effectively also reducing the inside temperature on sunny days. On winter days the sun is unlikely to reach this roof at all, due to the lower position of the sun and shade provided by surrounding buildings. The adverse effects of white roofs in winter as discussed in 2.1.2 are thus not as pronounced in the Witte Boei.

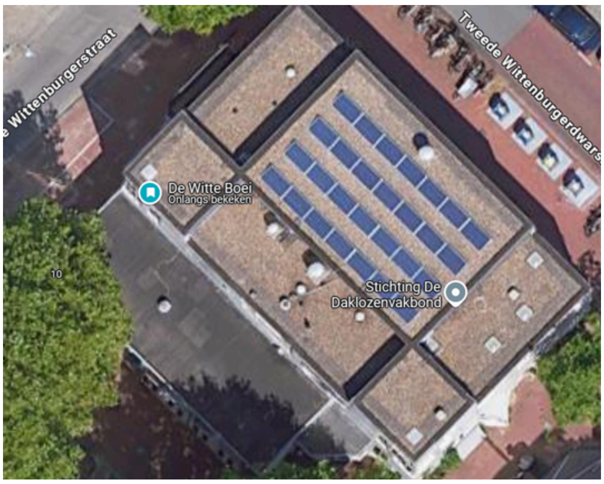


Figure 25: Satellite image of the Witte Boei [53]

Based on the building papers, the dimensions of the roof is roughly 6.0 by 16.7 meters, so a total area of 100.2 m2 needs to be covered. Either the roof can be painted or the current covering can be replaced by a white reflective covering. Painting is the cheaper option, but is also less durable.

3.2 Costs

To anticipate the costs of each building adaptation, we have reached out to several companies for inquiries on the methods. All prices are incl. BTW unless otherwise stated.

SOLAR SHADING

We reached out to two solar shading companies, who came to measure each window. They both advise the same 5% fibreglass solar shades in rail guards. They made an inquiry for solar shading on the ground floor for both the south east and south west sides of the building. The companies have been labelled Solar Shading Company (SSC) 1 and 2 for privacy. The prices they gave per window are displayed in the sketch at the bottom of this page.

The difference in price per window can be attributed to the fact that for SSC1 the cost of installment is added separately at the end. SSC1 also made the effort of combining some windows with just 1 shade, which lowers the total price. The total price of the inquiries including installment:

- SSC1: **€19.985,20**
- SSC2: **€24.571,20**

GREEN ROOF

We approached 3 companies for installing a green roof on the building. A subsidy exist for green roofs in Amsterdam, see the next page for the specifics.

GRC1:
We asked for an inquiry for both a 50/50 sedum/green roof, as well as a 100% green roof. They sent us the following inquiries for an area of 200 m2:

- Green: €19.000, **€9.500** with subsidy → €47.5/m^2
- Sedum: €18.000, **€12.000** with subsidy → €60/m^2

GRC2:
This company designs blue green roofs for companies. They made the inquiry for 298 m_2 due to some original confusion over the area of the roof. The rescaled amount may be inaccurate for this reason. The water storage capacity was unclear in the inquiry so no subsidy has been assumed in the price.

- Total: €23,972.10 → €80.4/m^2 (excl BTW)
- For 200 m^2, would be **€16.088**

GRC3:
This company specializes in green roofs with a cork bottom and using only biobased materials. They are interested in doing research into the effects of these roofs on the inside temperature, and we offered to collaborate on this research. In return they agreed to discuss a discount on the roof's total costs.

- Total: **€30.942,75** → €154.5/m^2

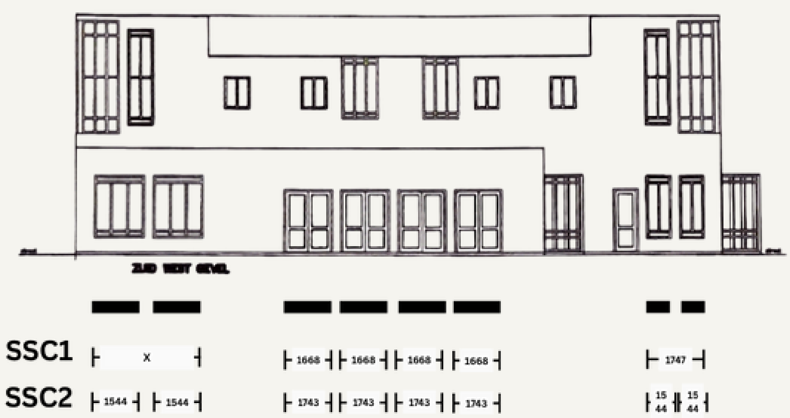


Figure 26a: Solar Shade Company price comparison per window, SW side

Figure 26b: Solar Shade Company price comparison per window, SE side

WHITE ROOF

We didn't reach out to any companies for white roof inquiries. However, a comparison online found the costs per m^2 as stated in the table below, with labour included [49]. For the small roof of the Witte Boei, painting is the cheapest option, at **€5600**.

Method	Per m2	100 m2 (WB)
Bitumen covering	€86,-	€8600
EPDM covering	€90,-	€9000
PVC covering	€95,-	€9500
TPO covering	€95,-	€9500
Paint	€56,-	€5600

Table 6: White Roof covering price comparisons [49]

GREEN ROOF SUBSIDY

The municipality of Amsterdam offers a subsidy for green roofs. The following terms and conditions apply for this subsidy:

- Green roofs are up to 50% eligible for subsidy, with a total maximum of €50.000. Per m^2 the maximum is
  - €30 per m^2 if the water storage capacity is between 30 and 50 L per m^2
  - €50 per m^2 if the water storage capacity is more than 50 L per m^2
- The full terms and conditions can be found here.
- Application to the subsidy needs to happen before starting the renovations
- Renovations need to happen within 1 year
- The green roof needs to have a water storage capacity of at least 30 L per m^2.
- If the green roof has a water storage capacity of more than 50 L per m^2, a higher subsidy is available.
- The roof has to consist of more than 50% other plants than sedum and moss.

DUMAVA SUBSIDY

There exists a governmental subsidy for making social real estate more sustainable, called DUMAVA. Companies and municipalities can apply to this subsidy to get partial funding for the renovation of a building. There are two separate funding streams within the subsidy:

1) Integral project subsidy: This is for a large multifaceted project on a building to increase its energy label. 30% of the costs will be subsidized by DUMAVA upfront. 40% will be subsidized if the renovations end up improving the building's energy label by 3 or more levels (so from D to A for instance).
2) Separate project subsidy: These projects do not require an improvement of energy label. It can be several projects on one building or just one project. 20% of the costs will be subsidized by DUMAVA

This subsidy initially seemed promising for our project, but since 2023 it is no longer intended for any of the methods we recommend. It is mostly meant now for improved insulation of buildings and installing heat pumps, as these are both expensive investments that have a long payback period. However, it is still good to know about the existence of this subsidy and its terms and conditions.

3.3 Policy

The Witte Boei is located in the centre of Amsterdam, where there are many restrictions on what is and is not allowed. Especially installing solar screens can change the outlook of the building, which would require a permit.

Two especially important aspects are whether the building is a monument and whether it is part of a protected cityscape. To find out whether this is the case for the Witte Boei, we looked at maps made by the municipality of Amsterdam. It can be seen here that the Witte Boei is neither a monument nor a protected cityscape.

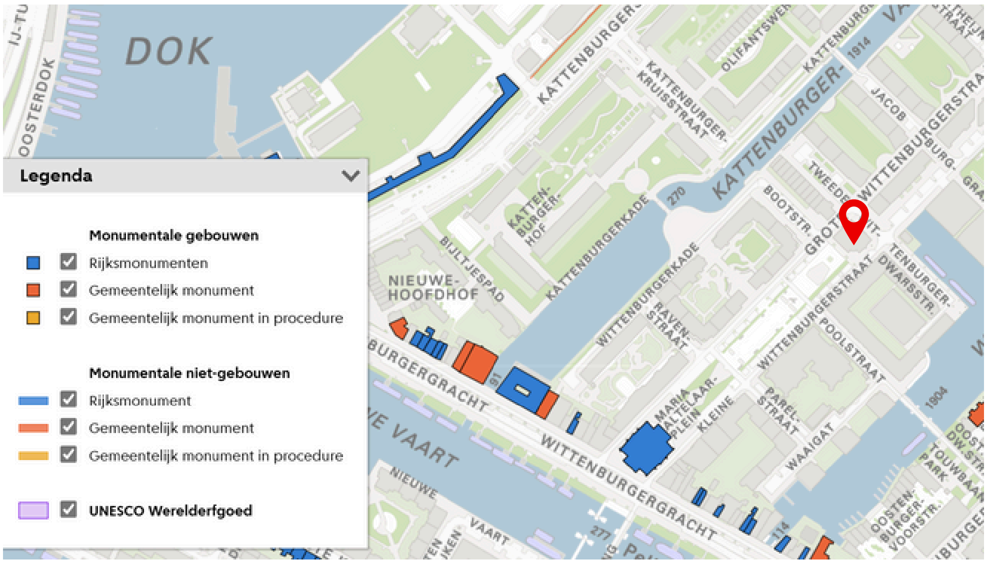


Figure 27: Monuments in Amsterdam, from maps.amsterdam.nl/monumenten

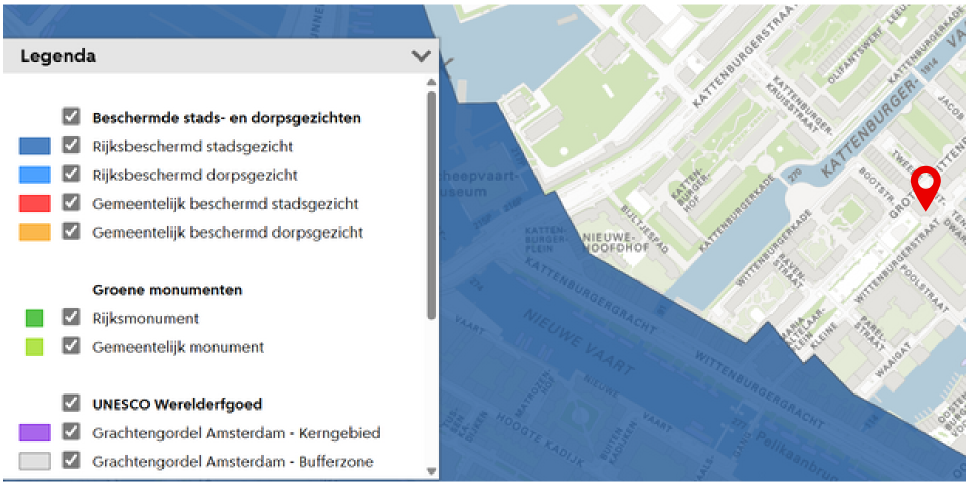


Figure 28: Protected cultural heritage in Amsterdam, from maps.amsterdam.nl/cultuurhistorie

However, some permits may still be needed to install solar shading, green or white roofs at the Witte Boei.

3.4 Network

Over the past several months, we've built an extensive network of contacts who have a stake in or are otherwise involved in the projects. We have made an overview of these contacts as well as their roles in the project. Municipal contacts were usually found through our supervisor at the municipality. Information from the building's renters (DOCK, PBAZO) and stakeholders (Regenboog groep, Prisma) was gained through community centre visits. We found involving the renters is very useful since they are the connection between the municipality and the users, and might have information that would otherwise be overlooked. We for instance found the building papers of the Witte Boei through DOCK, and found out about the subsidy for green roof through Diana from Prisma. They are also more aware of the heat stress at the buildings, as project leaders of the municipality often have limited time to visit their buildings often.

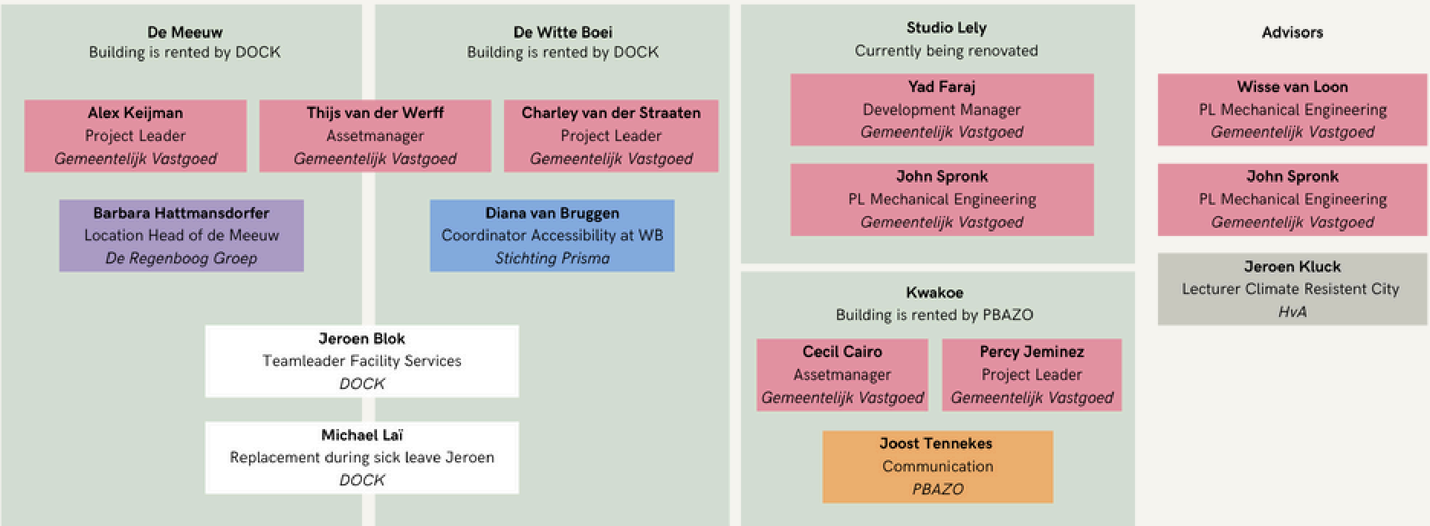


Figure 29: Network of people involved in our project. For each person their name, role and company is stated. PL stands for Project Leader

4. MUNICIPAL GUIDE: HANDOUT

Passive Cooling

A guide to installing low-cost and energy-saving cooling methods in municipal buildings

COLLECTIVE FUTURES

ACTIENETWERK GasTerug

Gemeente Amsterdam

This handout is meant as a guide for municipal building stakeholders on how to install passive cooling in their buildings. The methods described are extremely efficient at lowering indoor temperatures while having low emissions and costs. They are a sustainable solution to the increasing use of Air conditioning energy.

CONTEXT

Due to climate change, temperatures are rising worldwide and extreme weather conditions are becoming more common. Cities are experiencing an even stronger rise in temperatures, with studies finding that **cities heat up 8-10 °C more than rural neighbourhoods**. The government uses energy labels to indicate the climate adaptability of its buildings, with a higher label signifying a building with good insulation, modern heat pumps and LED lighting. However, the **energy labels do not ensure a comfortable indoor temperature during heat waves**. Additional cooling is therefore needed.

Air conditioning provides an immediate solution to discomfort caused by extreme temperatures. Due to global warming, it is expected that the **energy use in the Netherlands caused by ACs will triple by 2030**. This extra energy use causes more strain on the electricity grid, and indirectly contributes to global warming due to its CO2 emissions. ACs also contribute more directly to the UHI effect by transporting indoor heat to outside.

A sustainable and low-cost substitution for air conditioning is passive cooling, which includes **cooling techniques that require minimal or no energy.** After extensive research, this handout discusses the most energy-efficient and cost-effective of these methods:

- **White Roofs:** A white layer reflects sunlight to prevents heat from entering the building through the roof.
- **Green Roofs:** A layer of vegetation absorbs and reflects sunlight, preventing heat from entering through the roof.
- **Solar Shading:** Sheets, canopies or films prevent sunlight from entering through the windows.
- **Night Ventilation:** Opposite windows are kept open at night to allow natural airflow and remove residual heat.
- **Vegetation:** Trees, bushes and plants provide shade and lower the temperature of the building's surrounding through evapotranspiration.

On the other side of this handout, the methods are compared and their benefits and drawbacks are discussed. In practice, a combination of passive cooling methods is the best solution for most buildings, and **an integrated approach can eliminate the need for ACs entirely**.

GENERAL ADVICE

If a building already has Air Conditioning, changing to passive cooling techniques will most likely face resistance from building users. Therefore the priority should be on preventing more ACs from being installed over replacing the ACs that are already there.

Involve at least the building manager, building renter and building users in the passive cooling project to ensure everyone is on the same page and aware of the possible downsides of the cooling methods.

Check whether the building is a monument or protected city scape. If this is the case, some cooling methods most likely require a permit or are not possible at the location. For Amsterdam, check here.

There are several mechanical engineers at the municipality who play an advisory role in projects regarding the municipal buildings. It can be very helpful to include them in the project as they know a lot about passive cooling and can provide contacts.

Building papers can be found either through the building's owner, renter or architect.

Cooling methods that require large-scale renovation may interfere with the already planned activities of the building, especially when considering community centres. Therefore close contact with the buildings renter is needed to ensure this does not lead to miscommunication and strife along the way.

SOLAR SHADING

Cooling Efficiency: ❄❄❄
Costs: €€
Implementation difficulty: 🛠🛠

Use if a building has large, south facing windows that are exposed to sunlight for a large portion of the day.

Do not use if the building is a monument or a protected cityscape. Often outside shading is not allowed on these buildings.

Main Benefit: Extremely effective at lowering inside temperature

Drawbacks: The inside of the building will become darker, which can interfere with planned activities. Maintenance can also be a problem in windy areas or dependent on the chosen shading technique.

Variations:


Awnings: Allow light to come in, but require frequent maintenance and can obstruct street traffic


Shades: Clean and no street obstructions, but blocks a lot of light transmittance.


Solar Films: Allow visibility and light t. However, also cool down the building in winter.

NIGHT VENTILATION

Cooling Efficiency: ❄❄
Costs: €
Implementation difficulty: 🛠🛠

Use if building does not cool down properly at night and has opportunity for airflow throughout the building. Ideally, the building allows for airflow to opposite walls and to multiple floors.

Do not use if the building is used extensively at night or if airflow around the building is limited.

Main Benefit: Low-cost, often only requires behavioural change and optimization of existing structures. Can be easily combined with other passive cooling methods.

Drawbacks: Airflow at night can cause noise complaints as well as rodent and insect infestations. Opening windows at a ground level can also be unsafe from break-ins. Requires behavioural change.

Variations:


Timer switches can limit behavioural change required


Break-in proof window shutters provide a safe way to open windows at night


Fan-Assisted Ventilation: Uses minimal energy to enhance airflow

VEGETATION

Cooling Efficiency: ❄❄❄
Costs: €€€
Implementation difficulty: 🛠🛠🛠

Use if building has large, south facing windows that are exposed to sunlight for a large portion of the day. Or if area around building experiences strong UHI effect.

Do not use if the building is a monument or protected cityscape, or if there is limited budget or policy knowledge available.

Main Benefit: Extremely effective at lowering indoor and outdoor temperature by adding shade and because of the evapotranspiration effect. Improves biodiversity and quality of life of area.

Drawbacks: Expensive and requires permits for almost every location.

Variations:


Espalier trees add shade without obstructing the street


Vertical Gardens add vegetation without obstructing the street


Plant covered pergolas act as awnings in summer while letting through light and warmth in winter

GREEN ROOFS

Cooling Efficiency: ❄
Costs: €€
Implementation difficulty: 🛠🛠

Use if the building has insufficient insulation, and if it has a flat, concrete roof that is exposed to sun many hours of the day

Do not use if the building has a roof with minimal weight carrying capacity or if it has an inclined roof (see variations)

Benefits: Municipal subsidies exist for green roofs, often covering up to 50% of costs. They contributes to ecosystem diversity of neighbourhood and require no behavioural changes.

Drawbacks: Can be expensive (~€100 per m² without subsidy), can dry out in summer (see variations)

Variations


Blue Green Roof: Has an extra layer of water retention to prevent drying out and provide storm water retention


Sedum Roof: Roof covered with sedum, moss and other small plants that or more resillient to heat and can be built on an inclined roof

WHITE ROOFS

Cooling Efficiency: ❄❄
Costs: €
Implementation difficulty: 🛠

Use if building has insufficient insulation, has a flat roof and has a roof that is in the sun many hours of the day. Ideal for a roof that cannot carry a green roof.

Do not use if building is surrounded by buildings that are taller, as the white roof may reflect too much light into those buildings (see variations).

Benefits: Low-cost and

Drawbacks: The roof can accumulate dirt quickly. Frequent maintenance is therefore needed

Variations


Grey Roof: Still reflects a lot of the light without causing problems for high rise buildings

Conclusion

Air conditioning is not a sustainable solution to the UHI effect and heat stress. In contrast, a combined passive cooling approach has the potential to combat heat, while at the same time reducing energy consumption and emissions. Choosing the right cooling strategy is building-specific and takes some planning and coordination. However, this report shows that with good preparation and research, passive cooling is ultimately beneficial for buildings and contributes to a climate adaptive city.

COOLING METHODS

Keeping the sun out of buildings through **solar shading** or natural vegetation is the most cost-effective and impactful cooling strategy. This is supported by both literature and the simulation at the Witte Boei. **Vegetation** provides shading while also cooling down the neighbourhood, but it requires a specific neighbourhood setup and knowledge of city policy, making it difficult in already existing neighbourhoods. **Green roofs** offer promising benefits like improved insulation, biodiversity and water retention. However, their cooling effectivity is limited in well-insulated buildings. **White roofs** are a simple and effective solution, especially for poorly insulated roofs, though in colder climates increased winter heating demand can outweigh summer benefits. **Ventilation** can give relief to buildings where heat tends to stay for long periods, but requires some behavioural change. **Insulation** also proved to be highly effective in reducing indoor temperatures. However, it is a large-scale intervention and requires big renovation efforts.

IMPLEMENTATION

The implementation of passive cooling methods requires more than just identifying the most energy-efficient solution. Stakeholder needs, policy and costs all play a role in the execution. In this report we highlighted barriers we encountered and provide a detailed guide to support municipalities in implementing passive cooling methods in their buildings.

EFFECT MEASUREMENT

It is difficult to find the effect of passive cooling methods due to the complexity of measuring perceived temperature. Simulation modelling provides a solution, as we show with the simulation at the Witte Boei. In combination with literature research and Life Cycle Analyses, the impact of different methods is laid out more extensively than can be done with direct temperature measurements.

BROADER CONTEXT

The effects of climate change will continue to have an impact on human lifestyles, with heat waves becoming more and more frequent. The need for cities adapted to climate change, as well as sustainable and future-proof buildings is becoming increasingly urgent. Passive cooling illustrates how we can cool our urban areas in a way that is both environmentally responsible and accessible to different socio-economic groups. Reducing energy consumption, lowering emissions and offering cooling hubs for citizens are some of the main benefits regarding the broader societal context. With measures and strategies like this we can minimize negative environmental footprints and combat heat stress considering all social groups.

FUTURE RESEARCH AND STEPS

There is a lot of interesting future research to be done for the advancement of passive cooling techniques. Developing a clear framework to evaluate buildings for their vulnerability to heat stress or their suitability to passive cooling methods could help in streamlining the implementation process. Furthermore, introducing more regular surveys to map the lived experience of heat stress could be beneficial. Also an investigation into a larger range of passive cooling strategies, and the potential of increasing vegetation in the surrounding area could give insights into other effective interventions.

This project has showed the potential benefits and the increasing need of passive cooling. Apart from scientific research, it is essential for municipality of Amsterdam but also in other cities to add passive cooling in their climate adaptation strategies to reduce heat stress and prevent the rise in AC demand. Building owners, project leaders and sustainability advisors from the municipality need to collaborate in order to start implementation in community buildings. Amsterdam could then set the example for more cities and municipalities to follow and achieve significant impact by scaling up these project nationally and internationally.

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Appendix A:
Expert Interviews

Within the project we contacted multiple experts on the topic of passive and active cooling. These are the written out bullet points of these interviews

A.1 INTERVIEW WITH JEROEN KLUCK

Jeroen Kluck is a lecturer at the University of Applied Sciences of Amsterdam in the topic of climate adapted cities. His research is focussed on designing cities to ensure its livability in the future (https://www.hva.nl/medewerkers/k/kluck-jeroen). We contacted him in the early stages of our project to get a better sense of the most promising cooling methods to continue on.

The most important outcomes of the interview were the following:

- The most promising passive cooling methods are a combination of solar blocking and night ventilation. This is in line with the handout Hitte in de Stad which Jeroen Co-authored (36). The best way to prevent heat is to prevent light from coming into the room. Solar blocking is therefore an important measure to research:
  - Sunscreens: Very effective at blocking sunlight, but can block too much light such that the room becomes too dark for certain purposes.
  - Awnings: Provides a solution to this problem, indirect sunlight can still come in when using awnings or solar blocking. However in some parts of the city there are strict regulations for what is allowed to be put onto a building, which might create a problem for installing awnings.
  - Solar films: Can be effective at blocking sunlight dependent on how much light they let in.
- For night ventilation, it is important to find a way in which the building is still safe from break-ins and infestations without compromising the effectiveness.
- We discussed the Resilio research into the effect of blue-green roofs throughout the city, of which the results were disappointing. If large-scale implementation of green roofs were to happen in Amsterdam, the temperature of the city would only drop by an insignificant amount. The results of this study were never published.
- Green and white roofs have minimal effect on inside temperature if a building is already well-insulated. Then if there is a choice to make between renovating for insulation or for adding a green or white roof, the first option is more advantageous since it also helps keep the building warm in winter. Biobased insulation can provide a sustainable alternative to traditional insulation materials, but these materials usually have a lower heat storage capacity.

When considering which building to choose for a pilot, he advised us to take into account the following aspects:

- How much sunlight enters the building from through windows?
- Who uses the building?
- How complicated is it to improve the building's ventilation system?

He also provided us with the EnergyPlus computational tool to model the effect of certain measures for the building.

A.2 INTERVIEW WITH JOHN SPRONK AND WISSE VAN LOON

Spronk and van Loon are mechanical engineers at the municipality of Amsterdam, providing an advisory role to the building managers of the GV department. We contacted them in the early stages of the project to gain more insight into the specifics of active and passive cooling.

- Regarding the active cooling solution ICECUBE, the municipality is already running a pilot on its effectiveness. The system uses adiabatic/dew point cooling, an alternative to AC cooling. The drawback of this technique is that the maximum temperature difference that ICECUBE can accomplish is lower than that of AC. Therefore it may be insufficient on extremely hot days
- Passive cooling starts with good insulation and solar shading. Next night ventilation can be added. Usually in large buildings there is already a large scale climate control system. A low energy contribution can be made by using balanced ventilation, where hot air from outside is run next to cold air from inside to cool the incoming air.
- When insulation is not possible, white roofs can be a cheap solution to overheating.
- Costs: Automatic solar shading with sensors could cost up to 30-40 thousand euros per building. ICECUBE costs 30-40 thousand, heat pumps 40-50 thousand.

Advice:
- Don’t choose a monumental building
- Choose a small building
- Research the municipalities policies of the building
- Consider the users of the building
- Be mindful of the data used
- Compare three cooling methods we might use by weighing their impact against their cost

A.3 INTERVIEW WITH HEIJMANS

Heijmans is the company responsible for heating and cooling at Science Park. We asked them for an interview in the later stages of the project to learn more about the solar screens, ventilation and green roofs at the location.

- Solar Screens: Science park uses dark solar screens made of fibreglass wool. They are made windproof by being attached to steel cables on the sides. However since the winds are strong at science park, the screens still break down often. They warned us of the high maintenance cost of installing solar screens. They estimate a cost of €1500 per large window for shading. The screens they use are connected to the local weather station and work completely automatically based on this information and the inside temperature.
- Solar Foil: They advised us to also look into foil as it is much cheaper, roughly €150 per m2.
- Ventilation: Science park does not use any Air Conditioning, except for some labs that require strict climate control. It does have a large scale ventilation system that also runs through a cold water basin to cool down the inside air.

A.4 INTERVIEW WITH SOLAR SCREEN EXPERT

In the last month of the project we approached companies for inquiries of placing solar screens. We interviewed one of the salesmen for some questions regarding the screens they sell. It should be taken into account for this interview that his answers may be biased.

The solar sheets they install are made of glass fibre woven sheets. They advise the darker versions since they are easier to look through. When asked about the difference in reflectivity between dark and light materials, he mentioned this is not as much of a problem when the sheets are on the outside of the window, as the window blocks most of the heat absorbed and reemitted by the screen. Lighter screens also appear dirty quicker and are therefore not advised. They have no specific numbers on how successful the sheets are at keeping out warmth since this is very specific per building (depends on insulation, materials of wall, etc.). The sheets should last up to 20 years, require minimal maintenance and use negligible amounts of energy (only to retract and deploy the sheets).

Appendix B:
Heat Stress Questionnaires

B.1 Questionnaire

Age:

1. How often do you visit this building?
□ Daily
□ Weekly
□ Monthly

2. On hot days, how uncomfortable does the indoor temperature feel in this building?
□ Not at all
□ Slightly
□ Moderately
□ Very
□ Extremely

3. Have you ever experienced any of the following symptoms while in this building during hot weather? (Select all that apply)
□ Headaches
□ Fatigue or dizziness
□ Difficulty concentrating
□ Excessive sweating
□ Nausea
□ None

4. During hot days, how do you usually try to stay cool in this building?
□ Use fans or air conditioning (if available)
□ Move to cooler rooms
□ Drink water frequently
□ Reduce physical activity
□ Leave the building
□ Other: ___________

5. Do you feel that the current cooling options in this building are adequate?
□ Yes
□ No
□ Not sure

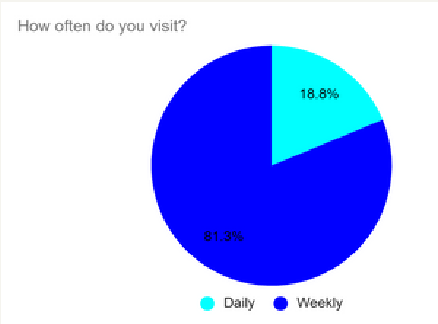
6. In your opinion, who is most affected by the heat in this building?
□ Elderly people
□ Children
□ People with medical conditions
□ Staff/volunteers
□ Everyone equally
□ Not sure

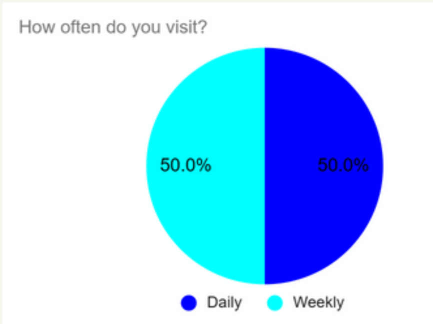
7. Is there anything you'd like to share about how the heat impacts your experience here?

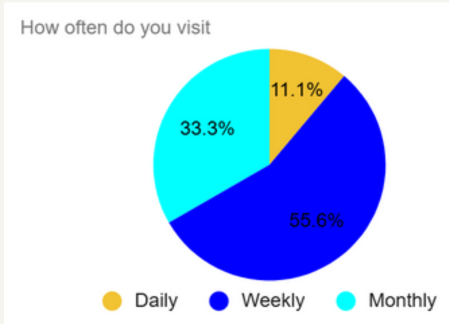
B.2 Questionnaire Results

	Witte Boei	De Meeuw	Kwakoe

Q 1







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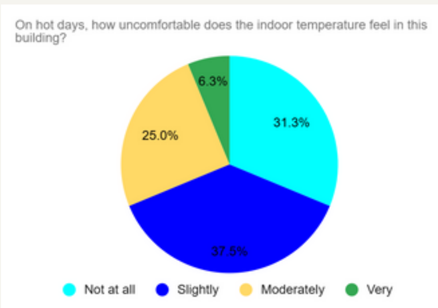

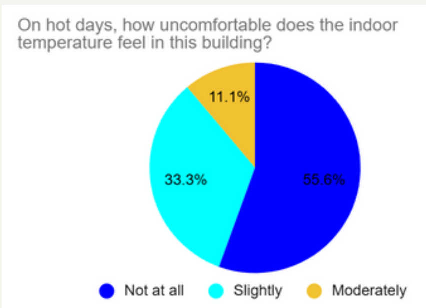

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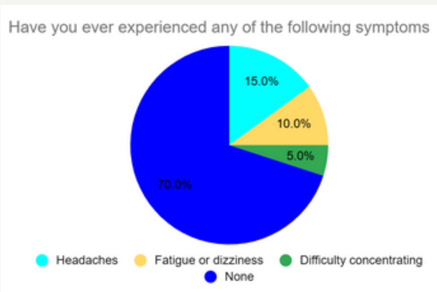

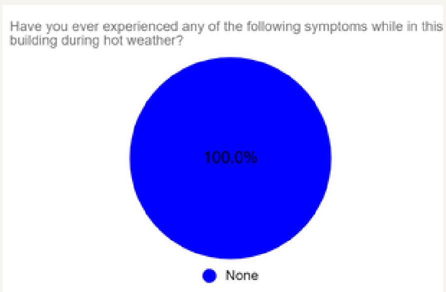

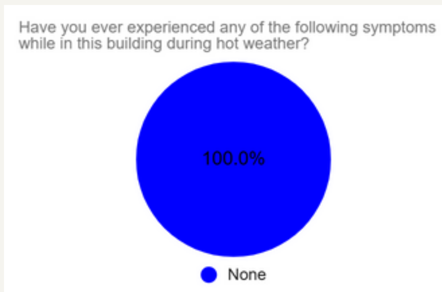

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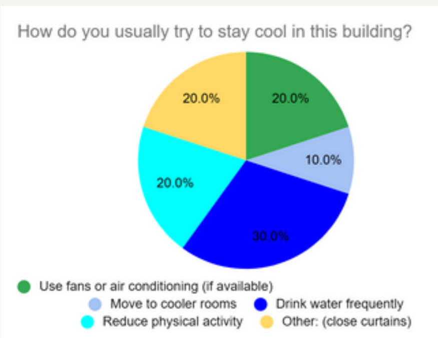
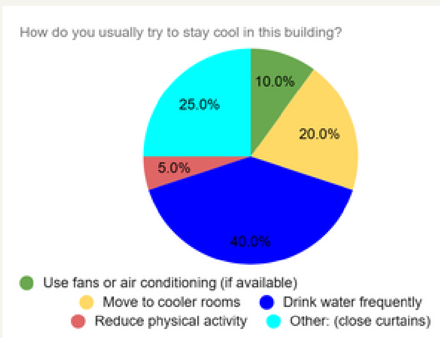
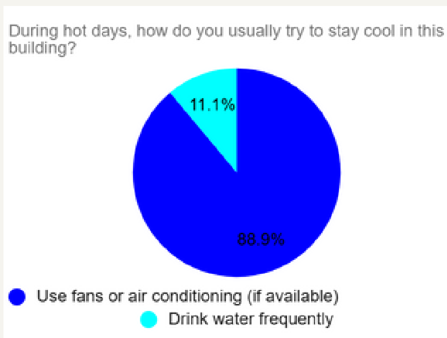
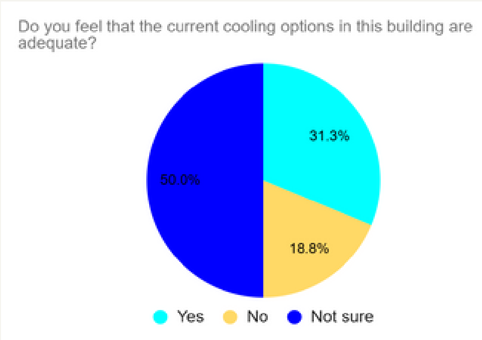


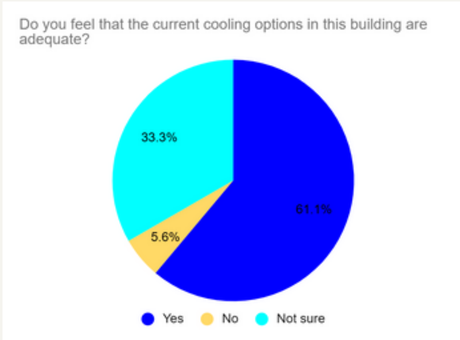


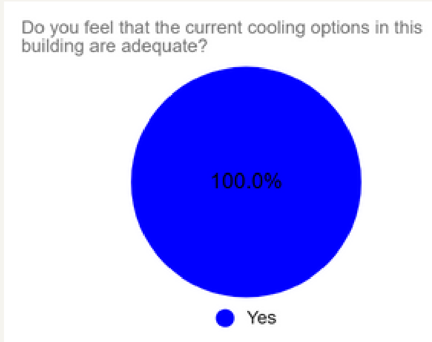


Witte Boei | De Meeuw | Kwakoe

Q 5







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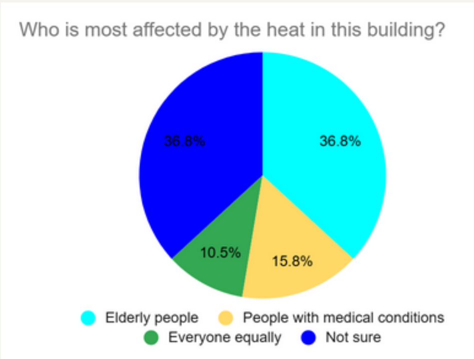

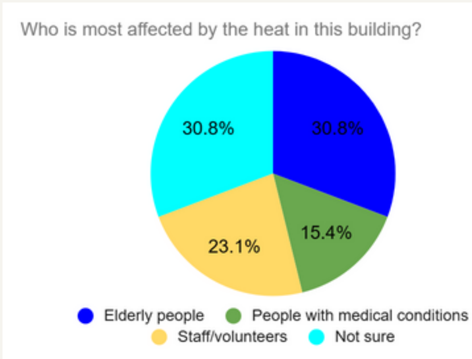

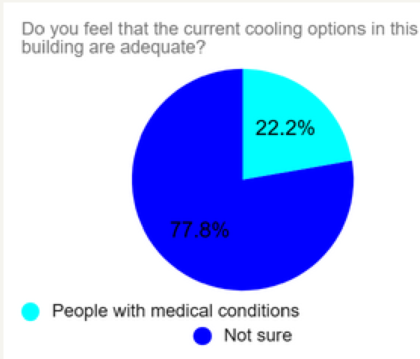

Appendix C:
Buildings Characteristics Summary

Building	Usage	Notes
De Meeuw	Community center	Energy label A. Has a kitchen that heats up but is overall not experiencing large amounts of heat stress. Interested in collaboration and also very excited about a green roof: but rather for sustainability purposes. High ceilings.
AV23	Sports center	Sports canteen does experience heat stress, but due to the nature of visits, visitors do not spend a large amount of time inside. Also, the demographics of people visiting these buildings are mainly older children and parents, so not the most vulnerable groups to experience heat stress.
Studio Lely	Sports Hall	Previously a school building, now used by a social circus association and a dance collective. Monumental building, so the established features need to remain in place. Renovation planned, and the plan is already established. Experience extreme heat stress in summer due to large WWR on the south side.
Ouder en KindTeam Oud Oost	Child (health) care	Building from 1900. Downstairs it remains very cold, it is old and monumental, during winter the heating is on high. They have a working air conditioner in the child care services on the first floor. Also already installed blinds.
NoLimit	Community center	Building from 2004. Do not experience heat stress due to a well integrated AC and ventilation system. Visitors we spoke to did not seem interested in behavioral change and very comfortable with the air conditioning. Also profit from shading of trees around the building.
Wildeman Theetuin	Social initiative hub	Wildeman is the owner of the building but also rents it to other interested parties. Two community rooms that are free to use for locals. They were recently renovated and used to be a school. Interested in outside shading mainly

Building	Usage	Notes
Cityfarm Zimmerhoeve	City farm	City farm that manages to stay cool even through very hot days. Large amount of vegetation shading the surface of the farm, and water in the close proximity, so a cool wind comes from the canal. Possibly increased ventilation due to the set up of the farm (circular structure). A ventilation system to cool down the animals, and have solar panels on the shed. Sometimes also use stones from the freezer and place these in the sheds.
Cityfarm Osdorp	City farm	Visitors experience heat stress but do not mind it all that much, since they do not tend to spend a lot of time inside. Green roof with moss on it, and large garden with parasols that can shade windows in summer. Black curtains on the inside of the building
Kwakoe/podium ZO	Community center	Building from 1992, with not many heat complaints downstairs due to the main hall being isolated through thick walls and little windows. Experiencing problems with lack of light. Upperfloor does get very hot, especially the music studio room. Renovations starting for accessibility in the near future. Vulnerable people dealing with psychiatric problems and addiction are regular visitors.
het Claverhuis	Community center	Monumental building, not many things are allowed. Windows do not open. Usual demography is people who are over 55. Top floor heats up on the street side. They close blinds to keep heat out on warm days. A lot of space and possibilities for ventilation.
Witte Boei	Community center	Building from 1989, with varying levels of heat stress across different parts of the building. Already implemented window films and inside blinds. Energy label A.
Buurthuis Havelaar	Community center	Stays cool during hot days related to effective solar shading all around the building. Ventilation system installed.

Appendix D:
Cooling Methods Applicability

Method	Specifications methods	Points of interest

Solar shading	Overhangs
	Awnings
	Shade sails
	Films
	Exterior shades/shutters
	Interior sunscreening
		• Permission to make adjustments to the outside of the building
		• Type of windows
		• Type of glass
		  ◦ Does the glass allow solar foil?
		• Availability of facade
		• Amount of floors
		• Usage of building
		  ◦ Can it be dark during the day?
		• WWR

Mechanical ventilation	Mechanical exhaust ventilation Mechanical ventilation with heat recovery Decentralized ventilation units	• Space for vents and ducts • Efficient airflow possibilities ◦ Where will air go in/out? • Room size and usage • Window arrangement • Height ceilings • Noise sensitivity

Night ventilation	Operable windows left open at night
	Louvered facades
	Fan-assisted night purify systems
		• Willingness behavioural change
		  ◦ Alternatively possibility for automatic time clock
		• Is the building in use at night
		  ◦ Noise pollution
		• Insect blocking
		• Amount of floors
		  ◦ Ideally 2 floors needed for night ventilation
		• Is there already a ventilation system in place that can be optimized
		• Is there enough opportunity for airflow

Reflective/Green roof	Sedum roof Green roof White roof	• Is there already proper insulation in place • Flatness of the roof • Are there buildings looking down on the roof • How much sunhours does the roof receive • Type of roof ◦ Material, color
Urban green infrastructure	Tree strips Flower pots Grass fields	• Permission to make adjustments to the outside of the building • Competitive species around the building • Available space to build • Underground structure of surrounding buildings • Sufficient ground water levels • Sufficient time for vegetation to establish

Appendix E:
Simulation Model Parameters

Solar shades

Parameter	**Value**
Solar transmittance	5%
Solar reflectance	5%
Visible transmittance	4%
Visible reflectance	5%
Infrared Hemispherical Emissivity	0.9
Infrared Hemispherical Emissivity	0.0001 m
Conductivity	0.05 W/m-K
Shade to glass distance	0.05 m

Green roofs

Parameter	**Value**
Height of Plants	0.5 m
Leaf Area Index	5
Leaf Reflectivity	2%
Leaf Emissivity	95%
Minimum Stomatal Resistance	180 s/m
Thickness	0.18 m
Conductivity of Dry Soil	0.4 W/m·K
Density of Dry Soil	641 kg/m^3
Specific Heat of Dry Soil	1100 J/kg·K
Thermal Absorptance	95%
Solar Absorptance	80%
Visible Absorptance	70%
Initial Volumetric Moisture Content	0.2