Dienst Justitiële Inrichtingen
Ministerie van Justitie en Veiligheid

Comparing heat stress reducing measures for implementation within penitentiary institutions

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Executive summary

Across the country, approximately 9,000 detainees are housed in cells within largely outdated penitentiary institutions (PIs), under the care of DJI (Dienst Justitiële Inrichtingen). These PIs are all scheduled for renovations, starting from 2030 onwards.

Increasingly warmer summers are putting penitentiary institutions under growing pressure by causing heat stress within cells, where detainees spend most hours locked up.
Heat stress in PIs significantly affects the physical and mental well-being of detainees, contributing to issues such as sleep deprivation, headaches, irritability, and a proven heightened risk of aggression and violence. These conditions compromise not only individual health but also the overall safety within the PI. This asks for heat stress reducing measures that can be implemented now, before renovations.

The causes of heat stress are both technical and behavioural. Poor ventilation, heat-retaining building materials, and high solar radiation contribute to excessive indoor temperatures. However, subjective experience also plays a critical role: the perceived temperature – or PET Index – is influenced by personal factors as well as environmental factors. Detainees are subject to strict regulations, providing limited autonomy within their sentence. Enhancing the autonomy of detainees leads to better wellbeing and behaviour regarding safety aspects.

This study utilises a detailed computer simulation to examine the heat flows in a standard cell at PI Zutphen. The simulation calculates key physical variables such as cell temperature, providing a reliable understanding of building-related heat dynamics.

Crucially, the model also incorporates human factors by estimating perceived temperature, allowing the influence of behavioural and psychological elements to be explored alongside technical ones. This dual approach strengthens the model's relevance for real-world decision-making.

Findings from the simulation show that limiting solar radiation is among the most effective measures for reducing heat accumulation.
In addition, the study highlights critical shortcomings in the current maintenance of ventilation systems in PI Zutphen. The simulation shows that the current state of the ventilation causes two to three times more heat stress, which is preventable with better maintenance. Bettering the ventilation implies offering knowledge to staff and detainees on heat, to make the link between their behaviour and the experienced temperature. This offers changes for bettering wellbeing and increasing autonomy among detainees, while reducing ventilation backlash and heat stress problems.

Beyond identifying effective technical measures for PI Zutphen, the simulation serves as a decision-support tool for DJI. It can guide short-term interventions prior to renovation and be adapted to evaluate other facilities across DJI.

In conclusion, this research provides DJI with actionable insights grounded in both physical and psychological analysis. It offers a road map for immediate implementations and renovation plan making, with the goal of enhancing detainee well-being while reducing heat stress in cells, in order to better the safety of the penitentiary institutions.

Roadmap

Problems

Detainees and PIWs suffer from heat stress

Problem statement DJI:
How can DJI reduce heat stress with a solution that is implementable now, before renovations?

What is really the problem?

Core of the problem:
DJI is focussed on exploring solutions in building technical aspects and renovations. The current problems leading to heat stress are not identified properly, causing preventable heat stress.

New Problem statement:
How can DJI reduce heat stress right now, ánd find the heat stress reducing measures, for now and renovations?

What factors show potential in reducing heat stress, now or for renovations?

1 **Ventilation**
The current ventilation is not functioning as desired, leading to preventable heat stress

2 **Heat stress education**
Knowledge on preventing and dealing with heat stress is lacking. causing preventable heat stress.

3 **implement measures to reduce heat stress**
In depth data on the effects of different measures on heat stress is not complete yet.

Solutions

Designing sun shading overhang. as this seems to have potential in reducing heat stress before renovations

Small noticeable effect of an overhang, data hard to validate
Other measures should be tested and compared

Setting up a Computer simulation
To quantify heat stress in cells for different variations

Using simulation data, the impact of ventilation flow and maintenance are shown

Current maintenance at the start of the summer, more maintenance moments and filter replacement

Implementing more structural maintenance on ventilation canals and filters

supervision on detainees actually cleaning cells and ventilation grilles

Assesing these effects, and measure remaining heat stress problems

Adressing knowledge and purpose for detainees and employees, so they can deal with heat stress and gain autonomy

Setting up and executing an effective heat protocol

Facilitate detainees with tools for heat prevention

Detainees should keep their own cells and ventilation grilles clean

Decision making on window films and white coating

Use Computer simulation
To quantify heat stress in cells for different variations

Compare different outcomes of measures in computer simulation to help decision making

Iterate simulation, and check winter situation of potential effects also

Implement the best further combination of measures
Additional measures during renovations.

Renovations

Abbreviations

PI	Penitentiary Institution, Prison
PIs	Multiple PI
DJI	Dienst Justitiële Inrichtingen
PIW	Penitentiary Institution Worker, personnel that works with detainees in the living department.
PIWs	Multiple PIW
RVB	Rijksvastgoedbedrijf Responsible stakeholder for all PIs and architectural aspects. Works closely together with DJI.
PET Index	Physiological Equivalent Temperature, the temperature how a person perceives the environment
PPD	Predicted Percentage Dissatisfied. Percentage of people that vote for heat stress (or cold stress)
PMV	Predicted Mean Vote, the value expressing the time (in hours) that people perceive heat stress
GTO	Grens Temperatuur Overschrijdend. A value expressing how severe the heat stress is perceived.

** All images are made for this study. Where images are adapted from Online found images, this is noted with a source. The full page images are sourced in the references in section 9

Dear reader,

You are now looking at a visual summary of this graduation project. It serves as a graphic overview of the process, and can be used as a tool to guide you through the content of this report.

Design Brief

1.1 Project Partners

This project is in collaboration with DJI

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1.2 Stakeholders

All stakeholders that are dealing with heat stress problems in cells are shown.

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1.3 Scope

Cells for one detainee are in scope.

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1.4 Design challenge

Comparing heat stress reducing measures for DJI, to implement before renovations, to increase wellbeing and safety in the PI.

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1.5 Research questions

This study focuses on answering three research questions that are answered in detail over the course of this report. In section 8, these are summarised.

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1. Who is experiencing heat stress and how is this causing problems for DJI?
2. What measures could be implemented and what impact do these measures have?
3. What steps are required for DJI to reduce heat stress before renovations?

Context

2.1 Penitentiary institution

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2.2 Cell

The important aspects of a cell are shown in this section.

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2.3 Daily schedule

The daily schedule is elaborated. This is later forms one of the solution spaces.

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2.4 Detainee population

Facts and figures on detainees in all PIs across the Netherlands.

p.34

2.5 Autonomy in a PI

Wellbeing plays an important role in this study. This is linked to autonomy in the PI. Opportunities lie in heat stress reducing measures that increase autonomy for detainees.

p.35

Problem

RQ1 is answered in these sections:
Who is experiencing heat stress and how is this causing problems for DJI?

This RQ is answered in three steps. The heat stress definition is given. The factors causing heat stress are explored. With that information, a SANKEY model is made. This leads to solution spaces for this study

3.1 Heat stress

Heat stress is the state of thermal discomfort, where one cannot dissipate body heat.

p.37

3.2 PET Index

Perceived temperature (PET Index) is the sum of six factors, and often lays higher than the actual air temperature. Reducing heat stress means reducing perceived temperature

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3.3 Effects of heat stress

Negative effects of heat stress on the physical, mental and psychological health show the need for measures. In total, these effects all create safety risks for the PI.

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3.4 Cell temperature regulation

The regulation of indoor temperature is elaborated. Detainees have only little autonomy. Automated mechanical ventilation is the main regulator. This system is elaborated in detail.

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3.5 Cell temperature

Available data shows the indoor temperature of cells. This data shows that the cells trap heat, and that ventilation cannot dissipate the heat enough.

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From combined studies and interviews, the experiences of heat stress all identify the stress of the problem.

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Potential measures that DJI is taking or considering are elaborated on. These are taken on board for this study.

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3.8 SANKEY model

A simple model is used to calculate the heat flows in and out of cells. This is done to work towards finding solution spaces.

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3.9 Solution spaces

From all gathers data and context information, five solution spaces are formulated that match the design challenge.

p.58

1	Reducing solar heat gain
2	Cooling down the detainee
3	Lowering electrical device heat gains
4	Increasing ventilation
5	Additional ideas and concepts

Ideation

4.1 Criteria

With clear solution spaces, ideation starts off in this section. All ideas are rated using criteria.

p.61

4.2 C-Box rating

A C-Box approach is chosen. With all ideas given a score on the criteria, finalist ideas are shared. An overview shows how these ideas are further explored.

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Computer Simulation

Simulation results

Different measures are modeled into the simulation. These sections are devoted to explaining the method and results of these simulations. Visualisations show this data, outcomes are discussed per measure

RQ2 is answered in this section:
What measures could be implemented and what impact do these measures have?

Measures explained

All measures that arised from ideation in section 4 are discussed on implementation. Feasibility, desirability and viability are key in this discussion. Per measure, a conclusion is reached on implementation for DJI.

Client advice

This section answers RQ3:
What steps are required for DJI to reduce heat stress before renovations?

Appendices

Design brief

1.1 Project Partners

This research is conducted in collaboration with the Dienst Justitiële Inrichtingen (hereinafter referred to as DJI).

DJI is responsible, on behalf of the Minister of Justice and Security, for the implementation of custodial sentences imposed on convicted individuals. Its primary mandate is to ensure the lawful detention of offenders, thereby upholding justice and contributing to a safer society. In addition, DJI oversees the daily care of detainees and facilitates their rehabilitation and reintegration into society (Inrichtingen, 2023). Consequently, DJI bears full responsibility for the living conditions within correctional institutions, including the state of individual cells.

At present, the quality of these living conditions is being compromised by heat stress, a problem DJI seeks to address.

The quality of life in detention is negatively affected by experienced heat stress in cells and other spaces inside PIs. This has potential negative effects on the safety in penitentiary institutions (PIs). Therefore, DJI is keen on finding the causes of heat stress to implement measures that reduce heat stress for detainees.

1.2 Stakeholders

Heat stress affects detainees and PIWs, staff working with detainees. Since detainees are locked up most of the day (14,5 hours minimally) in their cell, the main focus lies on reducing heat stress in cells. The scope is identified in figure 1.2.

Thus, the stakeholder that experiences heat stress most are the detainees. DJI provides housing to approximately 9,000 detainees, of which 94% are men (Inrichtingen, 2024). These men differ in origin, age and mental health. Almost half of the prisoners suffer from mild intellectual disability (Inrichtingen, 2024).

This project helps DJI in reducing heat stress by exploring the best measures to do so. This way, this project helps in bettering detainee wellbeing and quality of life in detention. Lastly, this contributes to maintaining, and possibly bettering safety in penitentiary institutions.

To clearly identify all stakeholders, a stakeholder map is presented in figure 1.1.

** Note
As DJI and RVB work closely together, on decision making and policy of the PIs, it is sometimes unknown who bears the final responsibility for what specific cases. In this report, DJI is often referred to, while DJI or RVB might be the one responsible.

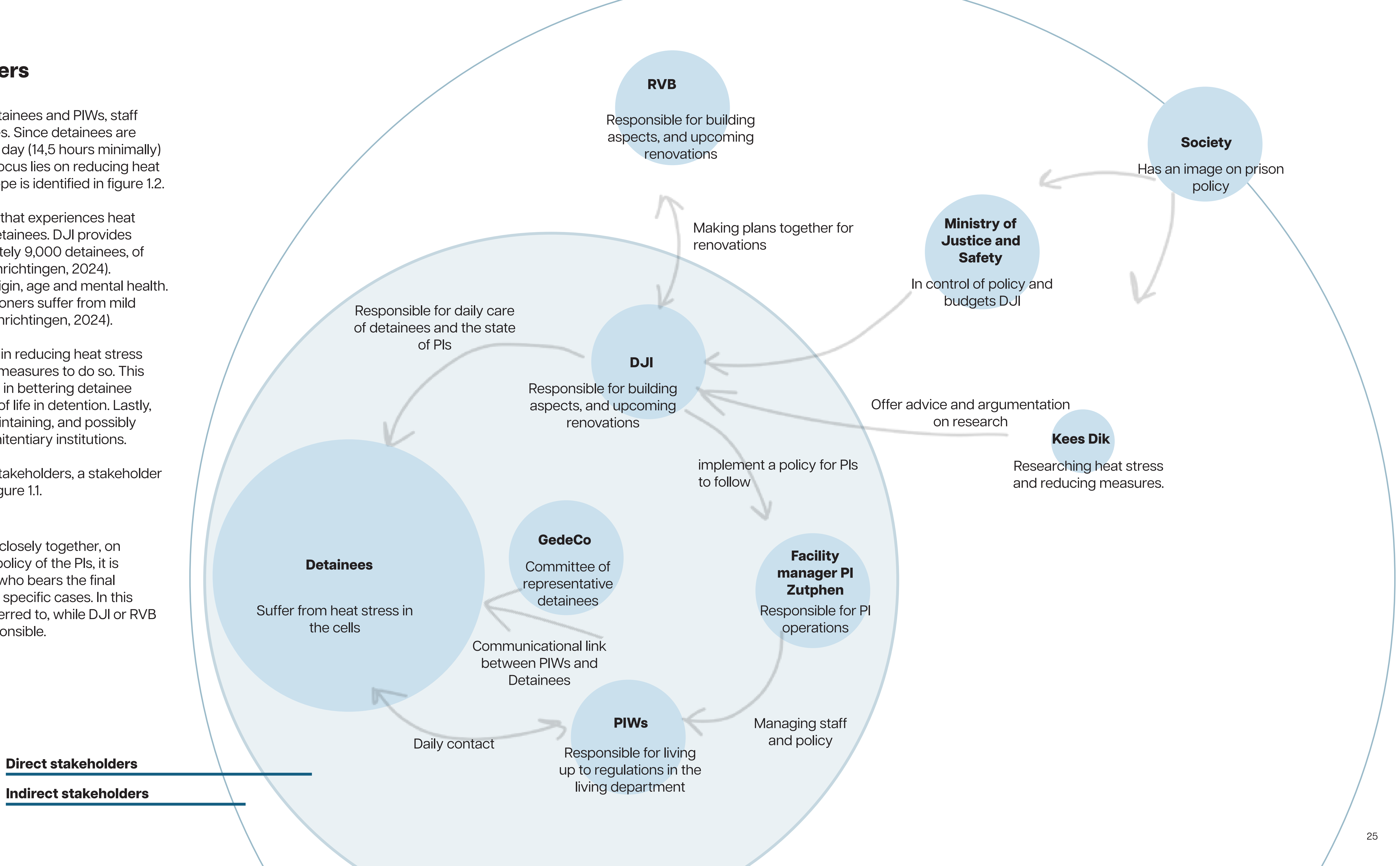
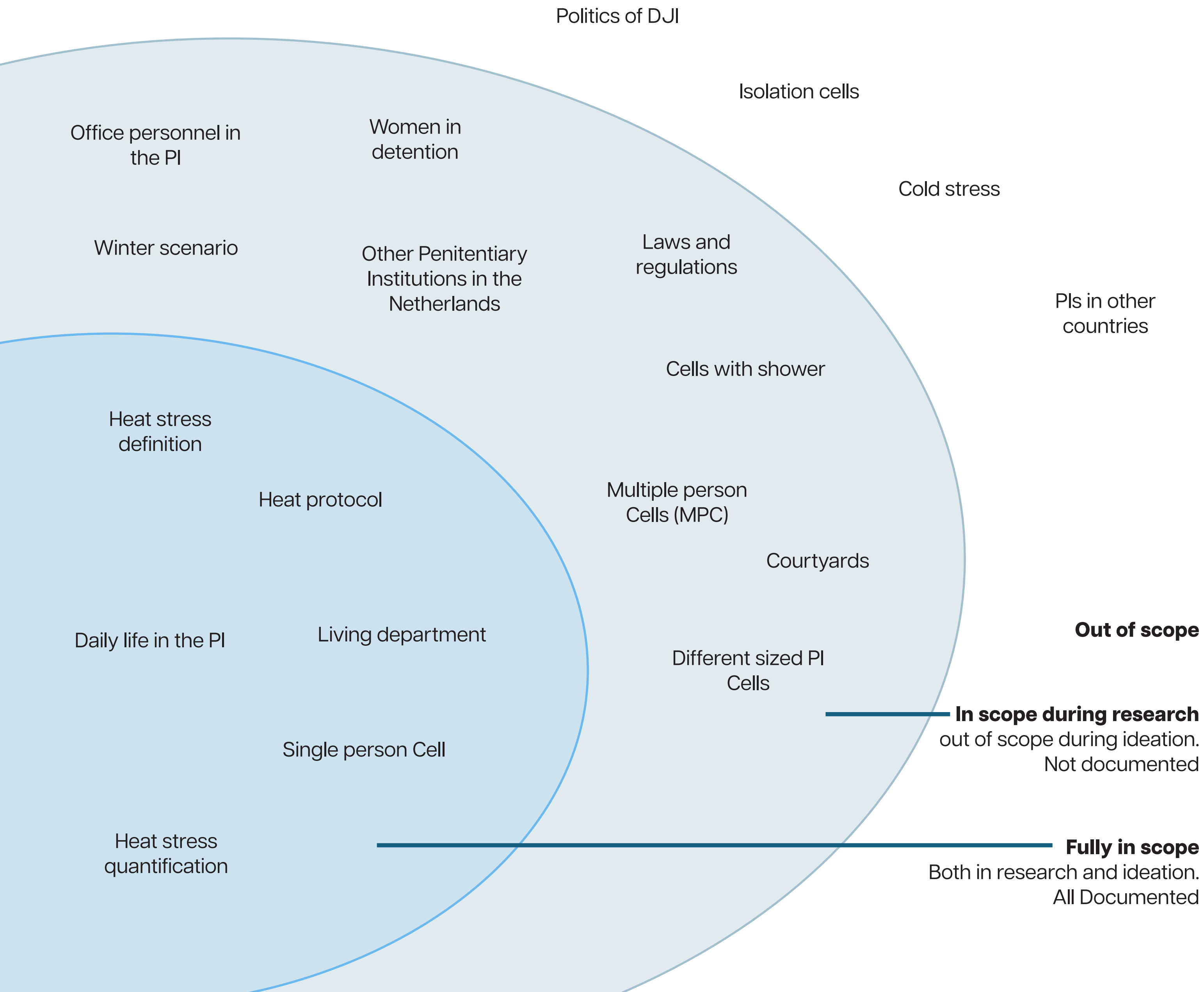


Figure 1.1
(In)direct stakeholders around heat stress

1.3 Scope

Figure 1.2
The scope of this study visualised

A visualisation of what is in scope for this research, is made below.



1.4 Design Challenge

Heat stress is explained as the state in which the human body cannot regulate its temperature enough, leading to health problems and complaints. These problems range from physical complaints such as sleep deprivation and dizziness, to psychological complaints such as frustration and more aggressive behaviour (GGD-richtlijn Medische Milieukunde: Hitte en Gezondheid, n.d.)

In current cells, the ventilation cannot prevent heat stress, which is problematic. Thus, DJI aims to find measures that can be implemented to reduce heat stress. With renovation plans for all PIs starting in 2030, large scale measures can and will be implemented to eliminate heat stress.

This research focuses on measures that could reduce heat stress now already. Where this research initially focussed on researching measures such as sun shading devices, a computer simulation indicated only very small potential. Thus, the design challenge changed during the project.

The course of this project and the outcoming advice and measures are visualised in the roadmap on p.X.

Design Goal

Comparing heat stress reducing measures for DJI, to implement before renovations, to increase wellbeing and safety in the PI

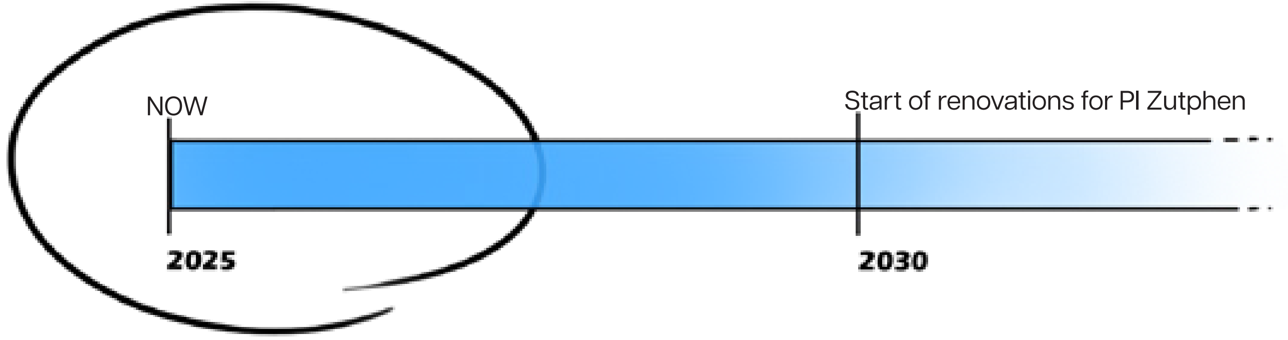


Figure 1.3
Timeline of PI Zutphen renovations

1.5 Research questions

With the aforementioned design goal in mind, three research questions are formulated to provide focus and clear study objectives. These questions are provided with subquestions, where answering these leads to take-aways that are needed for the main research questions. Thus, answering all these questions leads to the best outcomes for DJI.

Table 1.1
Research questions and sun questions that need to be answered

	Research Question		Supportive question	Section
1	**Who is experiencing heat stress and how is this causing problems for DJI?**	1.1	What is a PI, and what is a cell?	2.1
		1.2	What does daily life in a PI look like?	2.3
		1.3	How does autonomy influence wellbeing in detention?	2.3
		1.4	What is heat stress?	3.1
		1.5	What effects does heat stress have on physical and mental wellbeing in PI?	3.3
		1.6	How does heat stress affect PI safety?	3.3
2	**What measures could be implemented and what impact do these measures have?**	2.1	How and by who is cell temperature regulated?	3.4
		2.2	How, and by whom, is heat stress experienced?	3.6
		2.3	What measures are currently explored and taken by stakeholders?	3.7
		2.4	What are the factors leading to heat stress in cells?	3.8
		2.5	What solution spaces are there?	3.9
		2.6	Which measures fit the design challenge?	4.1
		2.7	How can the impact of measures be quantified?	5.1
3	**What steps are required for DJI to reduce heat stress before renovations?**	3.1	What next steps and measures should DJI take to reduce heat stress?	8.2
		3.2	What further research is needed for implementing these measures?	8.3
		3.3	How can DJI use this study for effective renovations?	8.3

Context

2.1 Penitentiary institution

RQ 1.1
What is a PI, and what is a cell?

Penitentiary institution always consists of a selection of elements, often in a symmetric plus- or H-shaped building. There are sections where no detainees are allowed, like office spaces and technical rooms.

The other part of the building, where detainees are allowed, consists of workspaces, visiting rooms and the living department, where detainees share a common space with living room, kitchen and recreation possibilities. Their cells are connected to the living department.

The staff that is present at the living compartments are called PIWs (Penitentiary Institution Workers). PIWs and detainees are the main stakeholders for this study. The cells are the main focus of the study.

For this study, PI Zutphen is taken as the baseline.

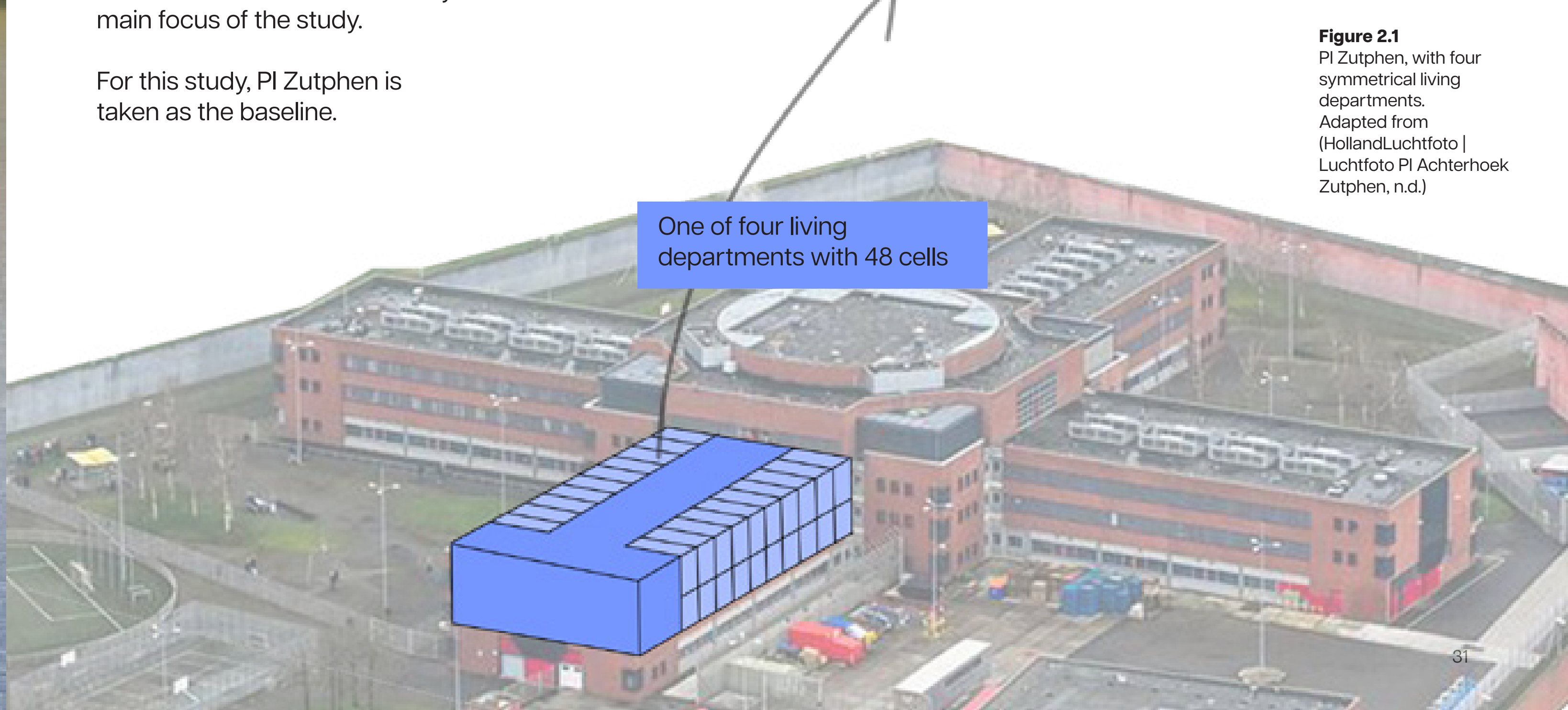


Figure 2.1
PI Zutphen, with four symmetrical living departments. Adapted from (HollandLuchtfoto | Luchtfoto PI Achterhoek Zutphen, n.d.)

2.2 Cell

Detainees are locked in their cell most of the time. The cell is their living space.

Window
The window of the cell is 1 m^2 minimally (Van Dongen & Rijken, n.d.)
Most cells in the Netherlands are equipped with window bars that are secured onto the exterior wall of the facade.
Above the window is a window grille, which allows detainees to let fresh air in.

Ventilation
All cells are equipped with mechanical ventilation for temperature regulation.

Furniture
Bed
Cabinets
Desk and chair
Toilet
Sink with facette

Appliances
Ceiling lamp
Sink lamp
Television
Fridge
Coffee machine
Sometimes a table fan

A more comprehensive overview of the mechanical ventilation and window grille is provided in section 3.4

Figure 2.2
Pictures of a standard cell (NOS Nieuws, 2025)

2.3 Daily schedule

RQ 1.2
What does daily life in the PI look like?

During the day, detainees can go to work and rehabilitation activities. Also, detainees have recreation time to play sports in the common area or to host visitors in the visitors section.

DJI provides detainees with standard meals, yet they are free to cook their own meals in the common kitchen during recreation time.
All meals are consumed in the cell, thus a fridge and microwave are necessary for detainees to preserve and prepare meals.
The lunch break is in the cell, from 12 to 13h.

This means that in total, detainees spend 15,5 hours in their cell per day.

Conclusion RQ 1.1
Detainees have their own cell, in the living department of the PI. In the living department, they have daily contact with PIWs.

Conclusion RQ 1.2
Detainees spend more than 15 hours a day locked up in their cell. They are not allowed to be elsewhere these hours.

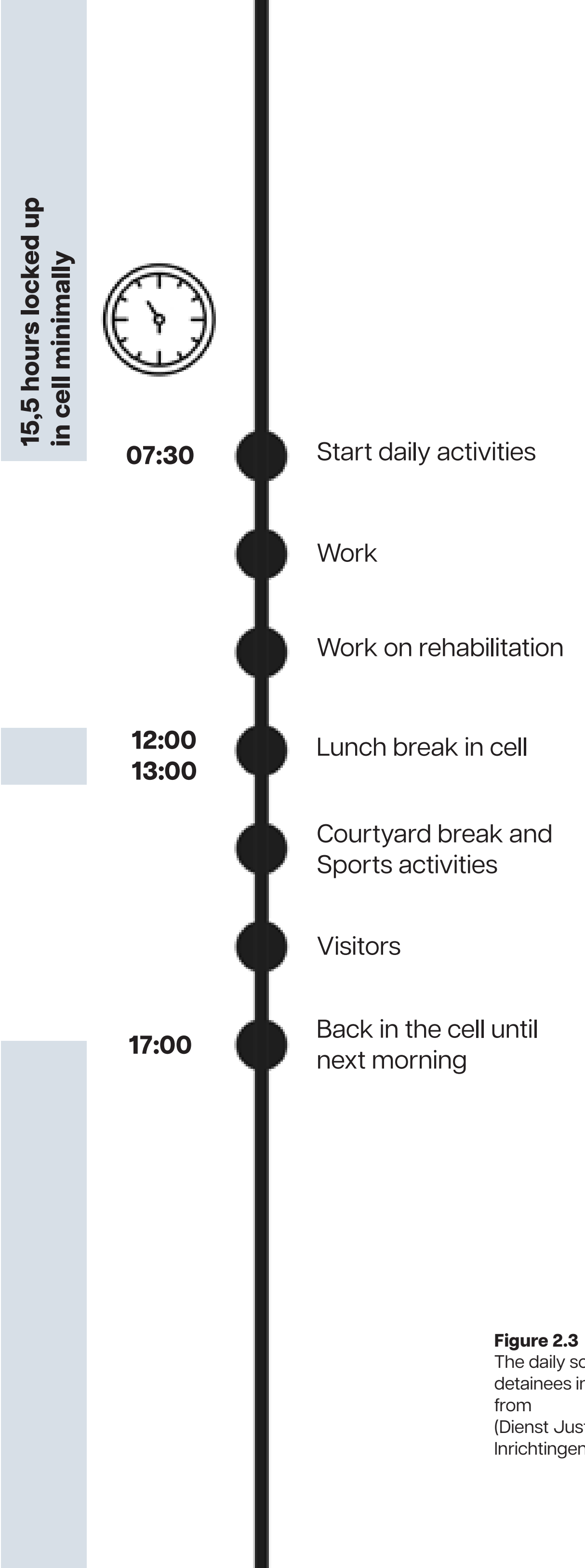
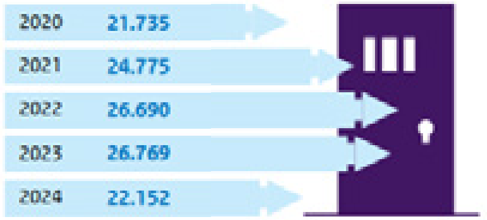


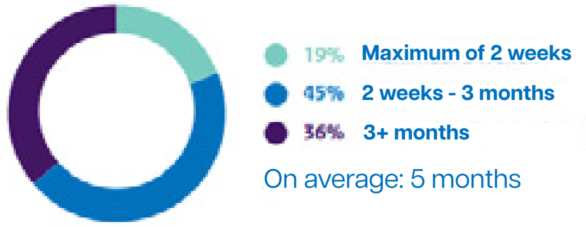
Figure 2.3
The daily schedule of detainees in a PI. Adapted from (Dienst Justitiële Inrichtingen, 2025)

Figure 2.4
Detainee statistics. Adapted from (Dienst Justitiële Inrichtingen, 2025)

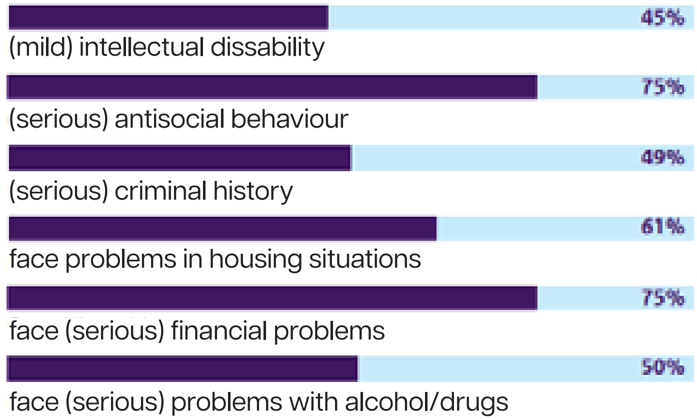
Total detainee intake
(2020-2024)



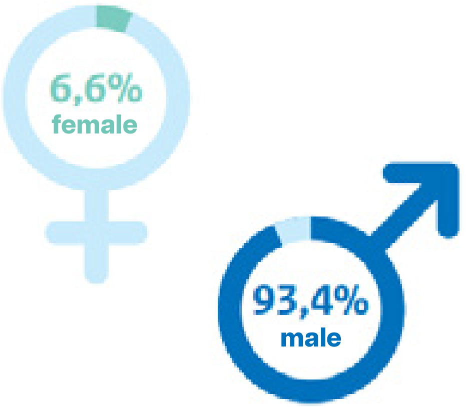
Total time of detention
At detainee release (2024)



Ploblems among detainees
adults



Male/Female ratio
Detainee intake 2024



2.4 Detainee population

Since detainees are the main stakeholder of this study, let's dive into the facts on this group. As mentioned before, DJI houses around 9.000 detainees in cells across the country. Who are these detainees, and how long are they held captive most times?

Detainees spend on average 5 months in detention. More than half of all detainees spend less time then this. Thus, not all detainees spend (more than) one summer in detention, facing heat stress.
Many detainees have serious problems, as is shown in the graphs below. This confirm that detainees need care and guidance, which is provided by PIWs in the PI.

2.5 Autonomy in a PI

RQ 1.3
How does autonomy influence wellbeing in detention?

Even though being locked up means losing most freedom and autonomy for an individual, the remaining autonomy is still a big factor for wellbeing in a PI. Autonomy is described as the freedom that detainees have to make their own choices. With the strict regime and daily schedule for detainees, most autonomy is taken away. This results in that a small increase of autonomy for detainees is experienced as a 'large improvement on quality of life' (Boone et al., 2016).

The fact that detainees are able to prepare their own meals in their recreation time in the common kitchen is important to them, shown by multiple results (Elbers et al., 2022). Interviews and case studies within DJI also suggest that more autonomy can lead to safer experiences of the institutions, and that it positively affects behaviour after prison sentence (Boone et al., 2016).

Since detainees spend most time alone in their cell, offering autonomy by making them in charge of matters such as temperature and light can have positive effects (Boone et al., 2016). With this knowledge, new measures or policy to reduce heat stress in cells might offer possibilities for detainees to gain more autonomy.

Conclusion RQ 1.3
Detainees have low autonomy in the current policy of the PI. Increase of autonomy leads to higher wellbeing. This creates opportunities for this study. Therefore, this is taken as an criteria later on, in the ideation phase.

Figure 12.5
Detainee and PIW during work inside the PI. (Dienst Justitiële Inrichtingen, n.d.)

Problem

3.1 Heat stress

RQ 1.4
What is heat stress?

Thermal comfort refers to the condition in which an individual perceives the ambient temperature as satisfactory, meaning there is no desire for it to be either warmer or cooler. This state provides comfort because the body does not need to physiologically compensate for differences in environmental temperature. In the case of heat stress, the body experiences thermal discomfort, and feels too hot.

This thermal discomfort is called heat stress. It occurs when the incoming heat load exceeds the body's capacity to dissipate heat to the environment, resulting in a build-up of internal heat (Cramer & Jay, 2016). The greater the imbalance, the more intensely the individual perceives the heat stress.

When experiencing high air temperatures, the body typically begins to sweat, a physiological response indicating the onset of thermal discomfort. Sweating facilitates heat loss through evaporation, serving as a cooling mechanism to restore thermal balance (Sayed et al., 2012).

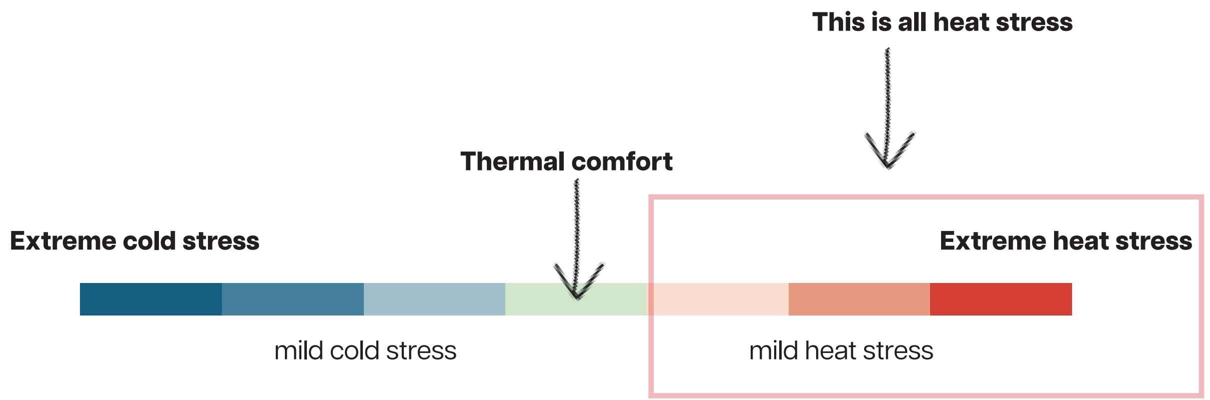


Figure 3.1
Perceived temperature scale.
Adapted from (Guenter, 2024)

** Connecting actual cell temperature with the perceived temperature scale is done later on in this study, in section 5.3.

3.2 PET Index

Not only air temperature is a factor that leads to heat stress. There are more environmental and personal variables that are important. These six factors are visualised in figure 3.2.

Heat stress is measured by looking into these factors that generate this unbalance in heat dissipation and heat gain. These factors interact so that the experienced temperature could be degrees higher than the actual air temperature.

These factors combined lead to how a person perceives an environment as if it is a number of degrees Celsius warm.

This is called the PET Index, which stands for Physiological Equivalent Temperature.

The PET Temperature is more important than the actual air temperature. Thus, reducing heat stress is not just reducing air temperature. The factors combined decide how people perceive temperature. Note that this might change per person also due to personal factors on top of weather factors.

These factors are key elements in further ideation and problem solving for DJI, and this project.

personal factor

Clothing isolation
The amount of coverage of clothing, and its insulation factors are important for how the body is isolated, and how well it can dissipate heat without being trapped by clothing.

personal factor

Metabolic heat
The more one moves, the higher the heat production. To be physically active in warm weather means more difficulty for your body to dissipate this heat.

Relative humidity
The air carries humidity. The more humid the air is, the less space the air offers for latent heat exchange such as sweating, and thus the hotter the environment is perceived by the human body.

Air movement
When air moves in contact with skin, this causes heat loss through convection. Although wind does not make the temperature cooler, people perceive it as such since it does actually cool down one's core temperature. This is called the wind-chill effect (NOAA's National Weather Service, n.d.).

Air temperature
The higher the air temperature, the hotter it feels for the human body.

Solar radiation
Solar radiation has a big effect on perceived temperature. Direct sunlight on human skin leads to higher perceived temperatures than for skin in shaded environments.

Figure 3.2
The six influences on perceived heat
Adapted from (Guenter, 2024).

Figure 3.3
Perceived temperatures (PET) on a 'tropical summer day' (Nationale Hittestresskaart, n.d.)

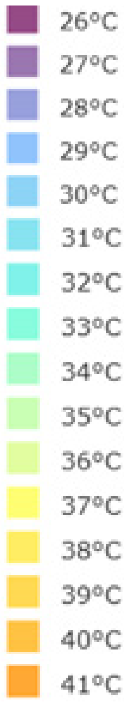
The PET index stresses the importance of how temperature is perceived, instead of the actual temperature. The importance of this difference can be seen in a PET Index map of PI Zutphen. A PET index map is made with weather data of a 'hot day'. This is a day where the air temperature lies between 25 and 30 degrees Celsius.

Even though this map shows outdoor spaces, it shows that the outdoor temperature at the PI is experienced as substantially higher than the actual temperature (25 to 30 ˚C, ranging up to 37 degrees Celsius.

This shows the importance of knowing and understanding the PET Index. The PET Index also works for indoor spaces.

This region has around 33 hot days per year. With current climate change, this number will most likely grow over the years (Goede, 2020).

Conclusion RQ 1.4
Heat stress is the state in which humans cannot dissipate heat to cool down. Heat stress is dependent on humidity and temperature, but also of other factors, that together predict the perceived temperature. The perceived temperature quantifies heat stress, and is used later on.



PET Index (*C)	Percepted as	Level of heat stress
18-23	Comfortable	No heat stress
23-29	Slightly warm	Slight heat stress
29-35	Warm	Mild heat stress
35-41	Hot	Severe heat stress
41+	Extremely hot	Extreme heat stress

Table 3.1
PET Index temperatures linked with perceived level of heat stress. Adapted from (De Nijs, 2019)

3.3 Effects of heat stress

Detainees are particularly vulnerable to heat stress due to their limited autonomy in taking mitigating actions, such as opening a window or seeking out a cooler space (“The Silent Killer,” 2022.) This vulnerability, combined with a warming climate and an increase in the number of hot days in the Netherlands (KNMI’23 Climate Scenarios – Climate Impact Atlas, n.d.), renders heat stress a growing concern within penitentiary institutions. The effects of heat stress give rise to multiple issues, affecting both detainees and PIWs.

As the PET Index can be higher than the actual air temperature, this perceived temperature is more important for identifying heat stress among people.

This insight is essential for the development of effective measures aimed to reduce heat stress.

Physical and mental health

RQ 1.5
What effects does heat stress have on physical and mental wellbeing in PI?

Studies show that exposure to high heat stress corresponds to health risks. Leading results for heat stress are sleep deprivation, stress, physical exhaustion, headaches, dizziness and in hectic scenario’s even death (kroese,2023; GGD-richtlijn Medische Milieukunde: Hitte En Gezondheid, 2023.).
Sleep deprivation and physical exhaustion lead to decrease in mental wellbeing (Noelke et al., 2016). Also, sleep deprivation and exhaustion is linked to higher perceived temperatures and PET Index (GGD-richtlijn Medische Milieukunde: Hitte En Gezondheid, n.d.).

Apart from this, heat stress leads to many mental problems. American studies show a big correlation between temperature increase and higher suicide rates. For one degree Celsius temperature rise, suicide rates went up with 0,7-1,0 percent (Burke et al., 2018).

Being locked up in a PI and cell has many effects wellbeing. These psychological effects are out of scope in this study.

Conclusion RQ 1.5
Heat stress causes high chance on physical and mental wellbeing risks. The severity of risks is in correlation with how long and severe heat stress is experiences. In total, lowering heat stress means increasing physical, psychological and mental wellbeing.

Safety risks

RQ 1.6
How does heat stress affect PI safety?

Health risks can also be potential risks for safety in the PI. Experiments show that heat stress provokes more violence and aggression in individuals (Miles-Novelo en Anderson, 2019). This can be explained looking into physiological and psychological aspects. During exposure to heat the adrenaline production increases, which in turn leads to higher sensitivity and aggressive thoughts and behaviour (GGD-richtlijn Medische Milieukunde: Hitte En Gezondheid, n.d.).

An American study that looks into aggressive behaviour among male detainees concludes that air temperatures of 26˚C and above increases the chances of aggressive behaviour by 20 percent (Mukherjee & J. Sanders, 2021).
Specific research showing numbers on violence and aggression within Dutch PIs is not very elaborate, yet a similar trend can be expected for the Dutch prison population.

Previously done interviews show that detainees and employees feel more unsafe during experienced heat in the PI (Uhlig et al., 2024; Kroese, 2023). On top of this, both detainees and employees state to feel unheard by DJI in stating their complaints (Kroese,2023). This leads to frustration.

These factors lead to higher ‘cumulative chances of violence’. This means that factors such as sleep deprivation, unheard complaints and higher perceived temperatures lead to frustration amongst detainees and employees. This increases the chances of aggressive behaviour and violence within the PI (Uhlig et al., 2024; Kamphuis et al., 2012).

Conclusion RQ 1.6
Health complaints and frustration may lead to cumulative frustration. This can potentially lead to dangerous situations.

Detainees and PIWs feel less safe due to the effects of heat stress.

Studies link increase of aggressive behaviour and aggressive thoughts to heat stress.
Cell temperatures of 26˚C already lead to 20 percent more aggressive behaviour.

3.4 Cell temperature regulation

RQ 2.1
How, and by who, is cell temperature regulated?

The indoor environment of the cell is the effect of multiple factors combined.

As elaborated before, there is six factors contributing to the perceived temperature. This section explains how the actual cell temperature is regulated, and what autonomy detainees have in regulating this themselves.

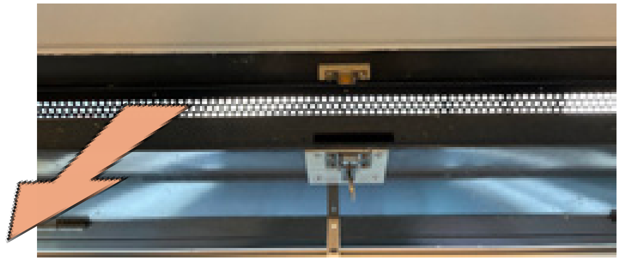
Detainees have autonomy over only a fraction of temperature regulation. This includes the table fan, curtains and window grille. Their function is explained in the figure.

Besides these, the PI has large automated systems that have large effects on cell temperature.

The cells are connected to a large radiator, heating up cells and other spaces in the PI in winter. This is not relevant for this study.

The main temperature regulator is the mechanical ventilation system. The principle is explained on the next page with photos and steps. Later in the report, it is made clear how important this system is for reducing heat stress.

Where detainees have autonomy over the use of the table fan, window grille and darkening curtains, they do not have any say on the mechanical ventilation. This is always operating on the same conditions.



Window grille
Allows fresh air into the cell if opened
The top picture shows the open holes in the grille. The hatch can be opened or closed by the detainee.

Darkening curtains
To stop solar radiation from entering the cell.

Table fan
For generating convection as cooling method

Radiator
Out of scope, only active in winter months

Mechanical ventilation
Automatically generated air flow, further explained on the next page

Stakeholder in control

Detainee
DJI

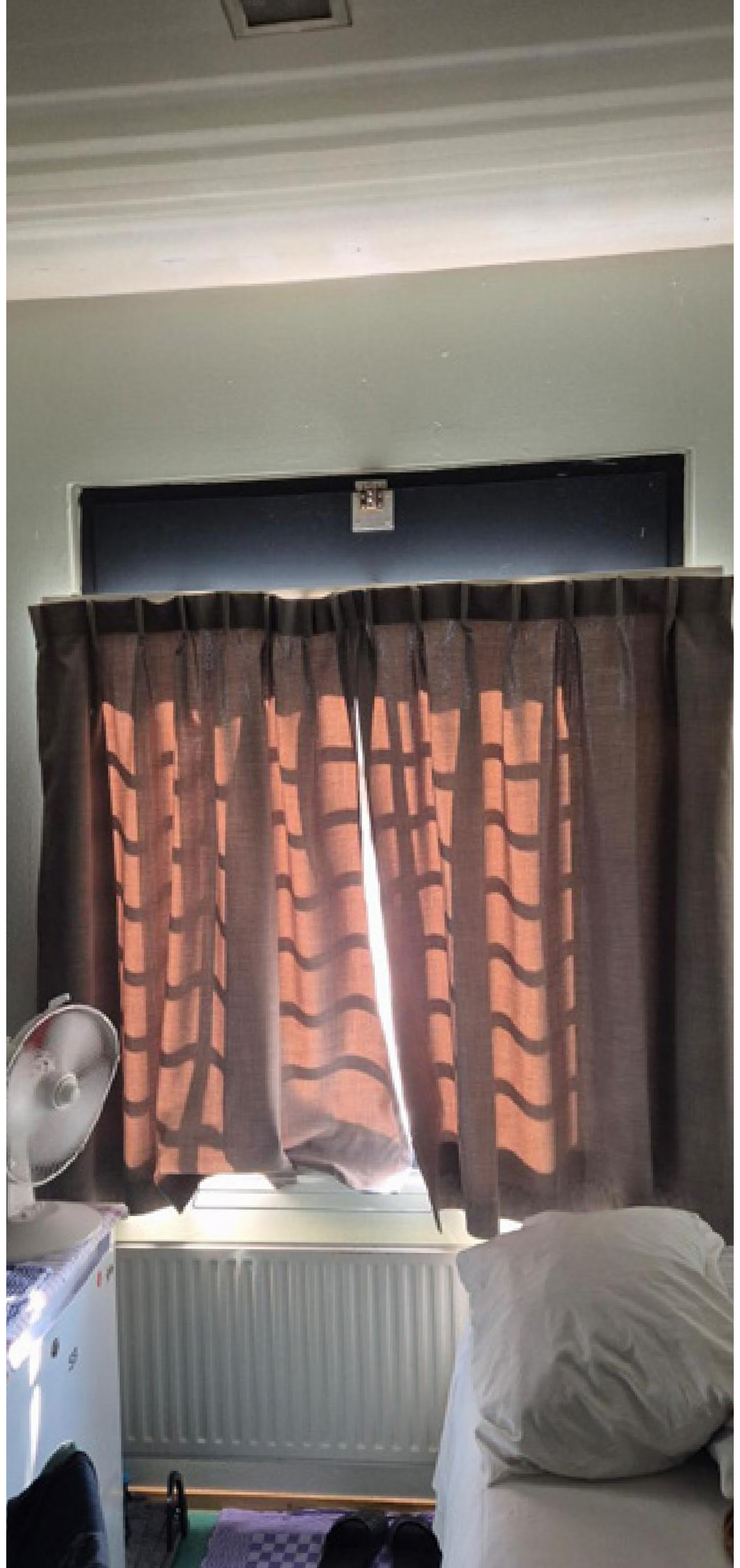
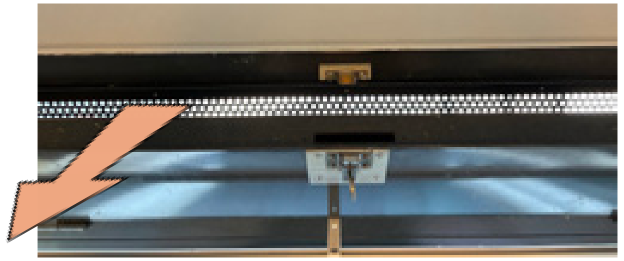


Figure 3.4
Cell temperature regulators, and the stakeholder in autonomy

1 Outdoor air is pumped into the living department which travels through the living department, and enters cells.

2 The air is sucked into the cell via small margins in the door frame. In the cell, this air circulates and is sucked out by the ventilation grille. 50 Cubic meters of air is sucked out per hour.



3 The window grille might be opened. In this case, the mechanical ventilation also pulls a small draft of outside air into the cell via the window grille.

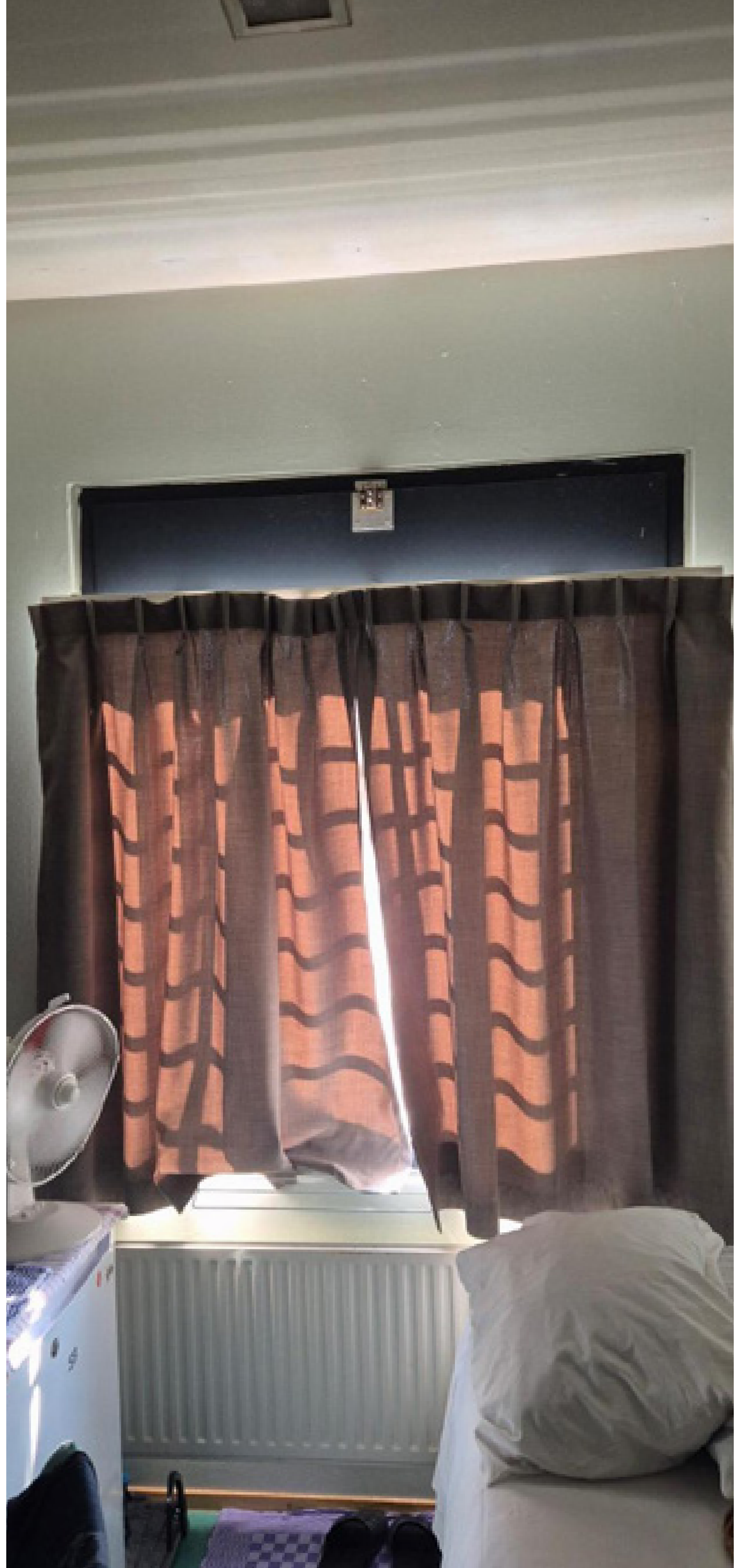
Figure 3.5
Temperature regulating inventory of a cell. Combined from previously shown and own pictures

Mechanical ventilation
The mechanical ventilation system installed in PI Zutphen circulates uncooled, outdoor air through the living department and cells. The circulating air can take away heat from the cell. The ventilation system is the main temperature regulator in summer.

The current ventilation cannot be increased to a higher flow. This would require implementation of a larger ventilation system, which can only be done during renovations. This is not in line with the design challenge.

Conclusion RQ 2.1
The autonomy detainees have in temperature regulation is rather small. The main regulator is the mechanical ventilation.

The mechanical ventilation circulates uncooled outdoor air through cells, taking away heat.
The ventilation flow is 50 cubic meters per hour per cell. This flow cannot be made higher with current systems installed.



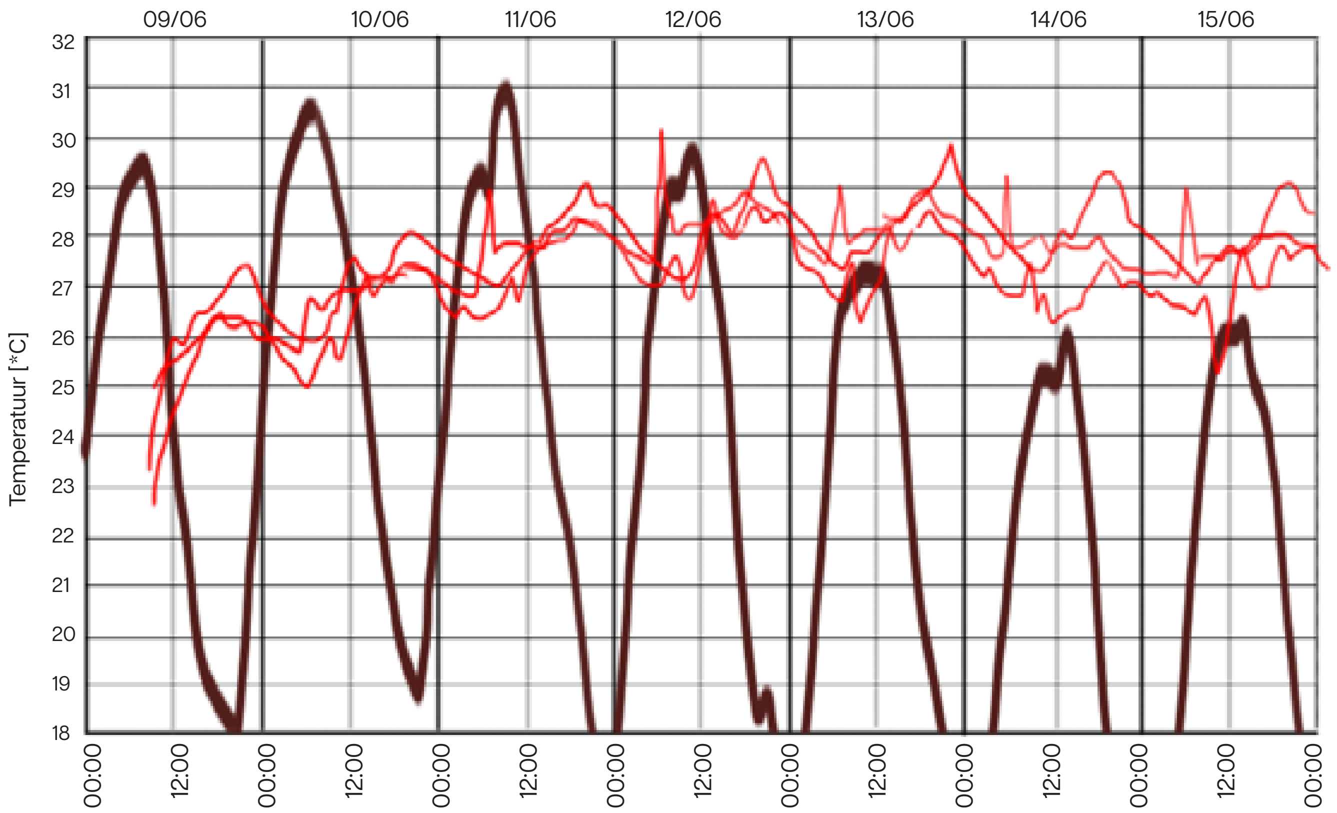
3.5 Cell temperature

Detainees complain about heat stress in cells, and high perceived temperatures. Cells are not monitored with thermometers in PI Zutphen. Thus, data telling the exact indoor temperatures is not available.

Data telling cell temperature is valuable to gain insights in temperature behavement.
A cell temperature study has been done on cells in PI Roermond. The differences between PI Roermond and PI Zutphen are unknown, but estimated as quite similar, as both PIs have cells with similar sized windows, and are inhabited by only one detainee.

The cell temperature is measured for a week in June 2023. With outdoor temperatures of 23 to 31 degrees during the days. The cell temperatures are shown with red lines in figure 3.6.

Figure 3.6
Cell and outdoor temperature, mid June 2023
Adapted from (Leenaerts, 2023)



The cell warms up to around 27 degrees Celsius at night, and up to 30 a day, while the night temperature outdoors is lower than 18 degrees Celsius around midnight.

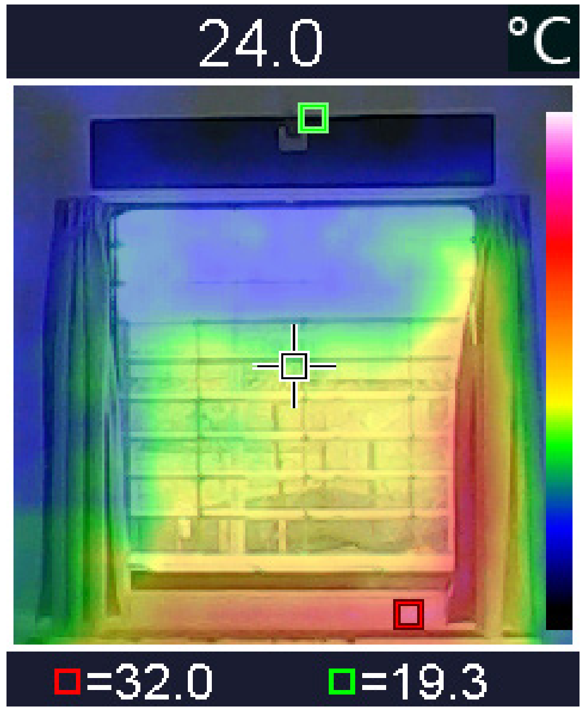
The graph shows that the cell temperature fluctuates a lot less than the outdoor temperature. Also, heat stays trapped in the cells, even if the outdoor temperature drops again after some days.

This can be linked to the heat stress complains of detainees.
Assuming PI Zutphen cells show similar behaviour, this data shows that heat is not effectively taken away out of the cell. This is a large downside, and needs attention in order to reduce heat stress.

Conclusion
The cell traps heat, causing a high temperature even at nighttime. When the outdoor temperature drops, the cell temperature stays constant for a time before also decreasing.

This data connects experienced heat stress with facts, making the problem more tangible.

The cell needs to be cooled down a lot more. The current ventilation cannot take away the heat, as this stays trapped. Thus, this creates opportunities for reducing heat stress.



Figuur 3.7
Cell picture taken during a visit in PI Zutphen

3.6 Experiences

RQ 2.2
How is the current heat stress experienced?

Quantitative data about heat stress is limited, due to the fact that no participatory interviews are performed on a large scale.

In a previous study, done by Roeland Kroese, 2 detainees in PI Nieuwegein were interviewed. Also, 2 PIWs in PI Nieuwegein, and 4 PIWs in PI Den Haag were interviewed. During this study, 2 detainees in PI Zutphen were interviewed, as well as the facility manager.

Interviews reveal that all detainees experience heat stress. In PI Nieuwegein, detainees report that cell temperatures are often excessively high and at times 'unbearable'. Curtains offer limited protection against the heat, prompting detainees to hang clothes or white bed linen in front of the windows, despite this being unallowed (Kroese, 2023).

Similar accounts were given by detainees in PI Zutphen, particularly those housed on the south and east facades, which receive significant solar radiation. They also find the curtains ineffective against the heat and resort to hanging white bed linen on hot days. Additionally, they note that the window grilles provide minimal fresh air unless the wind blows directly onto the facade.

During the interview in one of the cells in march, the detainee stated that it was already quite warm. PIWs confirmed that the radiator was turned off for weeks already, indicating that the high cell temperature is due to cumulative heat in the cells.

Detainees state to sweat more during these warm days where they experience heat stress. Their cells and living departments feel stuffy and hot, and they regularly suffer from headaches (Kroese, 2023), the detainees in PI Zutphen both confirm this.

The PIWs in PI Nieuwegein all indicate that heat stays trapped for a long time in the living departments, due to minimal ventilation (Kroese, 2023).
Also, they state to hand out more paracetamol in days of perceived heat stress, due to complaints of headaches among detainees and staff (Kroese, 2023).

They experience strong frustration among most detainees during hot periods, since they feel unable to do something about this. This indicated that detainees feel no autonomy over temperature regulation. All interviewed detainees in PI Den Haag, and in PI Zutphen confirm that they feel very low autonomy in dealing with heat stress (Kroese, 2023).

When visiting two cells, detainees said that the ventilation shafts do not provide much wind in the cell. They both use the ventilator 24/7 for a few months straight. With an outdoor temperature of 12 degrees and no clouds, the indoor temperature in the cell was already up to 24 degrees Celsius for the frame of the infrared camera. This is shown in the previous page in figure 3.7.

In times of hot weather and experienced heat stress, a heat protocol can be introduced. The heat protocols vary per institution. The heat protocol for PI Zutphen is not analysed. The heat protocol in PI Nieuwegein sometimes cancels activities (Kroese, 2023). This results in no sports activities where detainees can let go of their stress and energy. When detainees do go outside, the courtyard is experienced as hot because of the lack of shaded areas and green space (Kroese, 2023).

Data on severe health risks due to heat stress, like heath strokes and deaths, is not available for the Dutch prison population.

In July 2018, eight detainees in PI Roermond filed a complaint, stating cell temperatures of up to 40 degrees (Van Broekhoven, 2021).

Conclusion RQ 2.2
Detainees and PIWs state to experience heat stress. Although data is limited, DJI confirms that detainees are the main victim of heat stress. The limited data confirms this.
Key takeaways are taken on to ideation and recommendations later on.
- White curtains are desired
- Ventilation is not enough
- Window grilles get stuffed, stopping fresh air draft
- Table fans are desired in cells

3.7 Current action taken

RQ 2.3
What measures are currently explored and taken by stakeholders?

With the facts and figures presented, it is important to know what DJI is already doing, and how detainees cope with heat stress.
Here follows a short overview.

PI Zutphen

- New darkening curtains were installed in all cells, since detainees were complaining that they were not darkening enough. These new curtains stop solar radiation from coming into the cell.
- Table fans are handed out to all cells for detainees to cool down with.
- The facility manager states his interests in reflective window films, screens and possibly also a white roof.
These are measures that are discussed broader within DJI.
- Lastly, PI Zutphen has been exploring different sun shading ideas, such as louvres attached to the window bars. This is not implemented as the view of detainees was reduced too much, lowering wellbeing. The impact of this measure was never tested. This is further explained in Appendix 3.
- Detainees use their table fan for cooling effects.
- Detainees use white bed linnen as curtains, to reflect away solar radiation.

PI Den Haag

- In PI The Hague, 48 air-conditioning units were rented for immediate cooling effects. These are installed in the office spaces for PI Staff.

PI Nieuwegein

- A study done on heat stress reducing measures pitched measures for PI Nieuwegein to be taken to cool down the cells and living department. These measures are compared with an EnergyPlus simulation model. The outcomes are presented in Appendix 7.
- DJI (and Client Bas Kolkman with it) is looking into the effects of white coating and reflective window film for this institution.

PI Roermond

- W/E study done on cell temperature and cell ventilation flows. This led to valuable insights on heat stress problems.
- With an EnergyPlus simulation, different measures are explored and compared. This data can be used for this study.

Conclusion RQ 2.3
Detainees use white bed linen as reflective curtains, therefore, white curtains need to be considered as measure
White coating, window films, screens and window louvres are considered measures by DJI.
These measures are taken on to the ideation phase.

3.8 SANKEY model

RQ 2.4
What are the factors leading to heat stress in the PI?

Just like for the human body, a building also experiences heat gain and heat loss. These heat exchanges are important to dive into to know what factors lead to heat stress problems in cells.

By predicting these heat gains it becomes clear which part of heat gain is represented by which factors. This information is key to map out possibilities in reducing heat stress.

The heat flows are calculated using available data. These flows are visualised in a SANKEY model. The energy flows represent the total energy over a full day in Watt Hour (Wh). Because this model is based on assumptions, the outcomes have a factor of inaccuracy with it.

This method, calculations and assumptions made are further elaborated in Appendix 4.

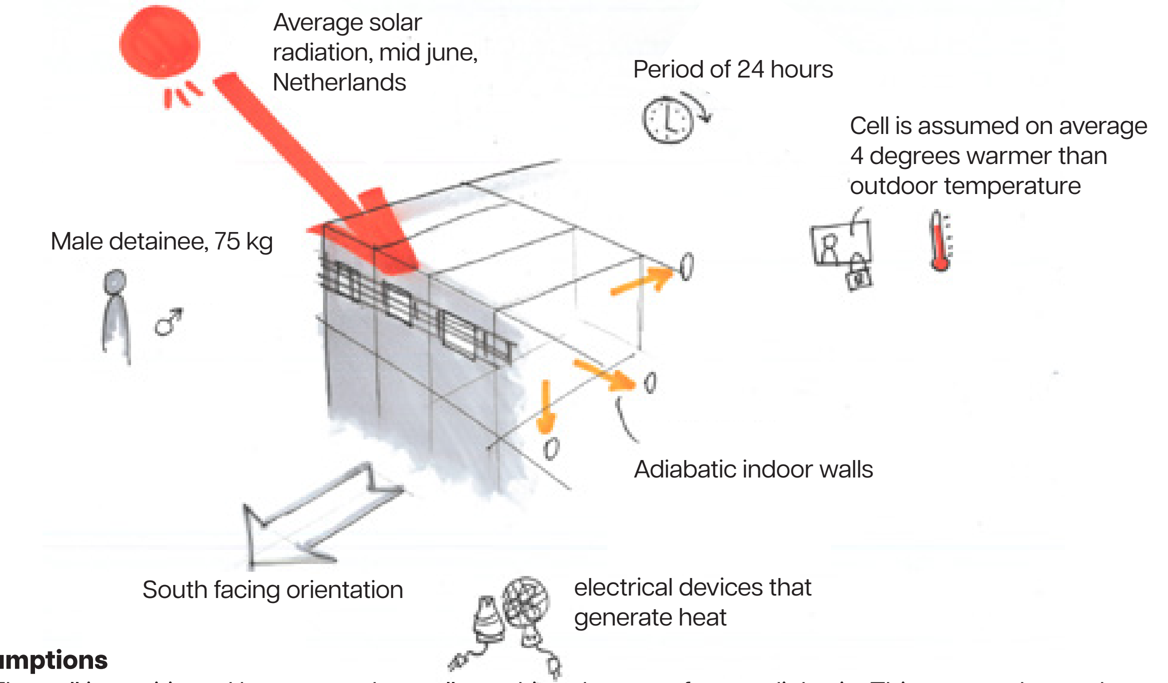


Figure 3.8
SANKEY assumptions and calculations

Assumptions

1. The cell is positioned between other cells, making these surfaces adiabatic. This means that no heat exchange happens over these walls.
2. We calculate heat flows for a cell with one detainee, over 24 hours. This detainee weighs 75 kg.
3. The weather data is data of 'typical sunny day' in July (Van der Linden, 2005)
4. Cell facade faces southwards, as the window is exposed to the most solar radiation this way (SunEarthTools, n.d.).

Incoming heat flows

External Load

Solar radiation
Solar radiation warms up buildings. The solar radiation that reaches the building is split up in two categories.
Direct solar radiation is the bright sunlight.
Indirect (diffuse) radiation is all other light that spreads around.

Solar radiation is a large influencer of indoor temperature on buildings. How radiation heats up the cell can be split up in two parts:

1. Solar radiation heats up the building fabric (walls and roof). These surfaces get heated up and over time give off heat to the surroundings and underlaying material. This way, heat is taken up by the walls and ceiling, and stored inside. With proper insulation, buildings can use this as in their advantage. This is called transmission through the building fabric. This heat flow can also be an outgoing heat flow!

2. Solar radiation enters windows and heats up the cell. Especially the direct solar radiation is responsible for a large fraction of the heat gain in the cell.
The properties of the window decide what fraction of solar radiation can enter the window with the so-called G-factor. The g-factor of the window in PI Zutphen cells is 0,64. Thus, 64% of solar radiation enters the cell.

Internal Load
Heat is also coming from inside the cell. This is split up into two categories:

Metabolic heat
The detainee in the cell gives off heat to the room. The amount of heat is dependent on the metabolic heat rate of the detainee. The more active one is, the higher this is.

Electrical devices
Besides the detainee, the electrical devices also give off heat to the cell. This is done during times that they are using electricity.

These heat gains are both dependent on the exact behaviour of the detainee. This is not researched, but assumed on logical assumptions. These assumptions and calculations are explained in appendix X.

Outgoing heat flows

Mechanical Ventilation
The mechanical ventilation takes away heat from the cell. The amount of heat that the mechanical ventilation takes away is dependent on the temperature difference of the cell compared to the outdoor environment. The higher this is, the more heat the circulating air can take up and take away.

Transmission
Heat can travel through the building fabric. This happens if the building fabric, a wall for instance, is standing in between different temperature environments.
As the cell can get warmer than the outdoor environment, heat travels out of the cell during night times. Here, a good insulation would stop this from happening.

Thermal mass
Lastly, the building fabric can store heat. This is called thermal mass. Materials in the building fabric are heated up over day and the heat is release to the surroundings later, when the temperature is cooler. This way, the building fabric of the cell gives off heat to the cell at night. The more this happens, the hotter the cell remains.

Disclaimers
As the heat flows on the cell are all dynamic, these are hard to predict or calculate. This sections elaborated their behaviour and calculates them using assumptions that simplify the calculations. As an effect, the outcomes are not realistic, but offer some insights in how they could behave in relation to each other.

The total calculations and assumptions are elaborated in more depth in Appendix 4.

In

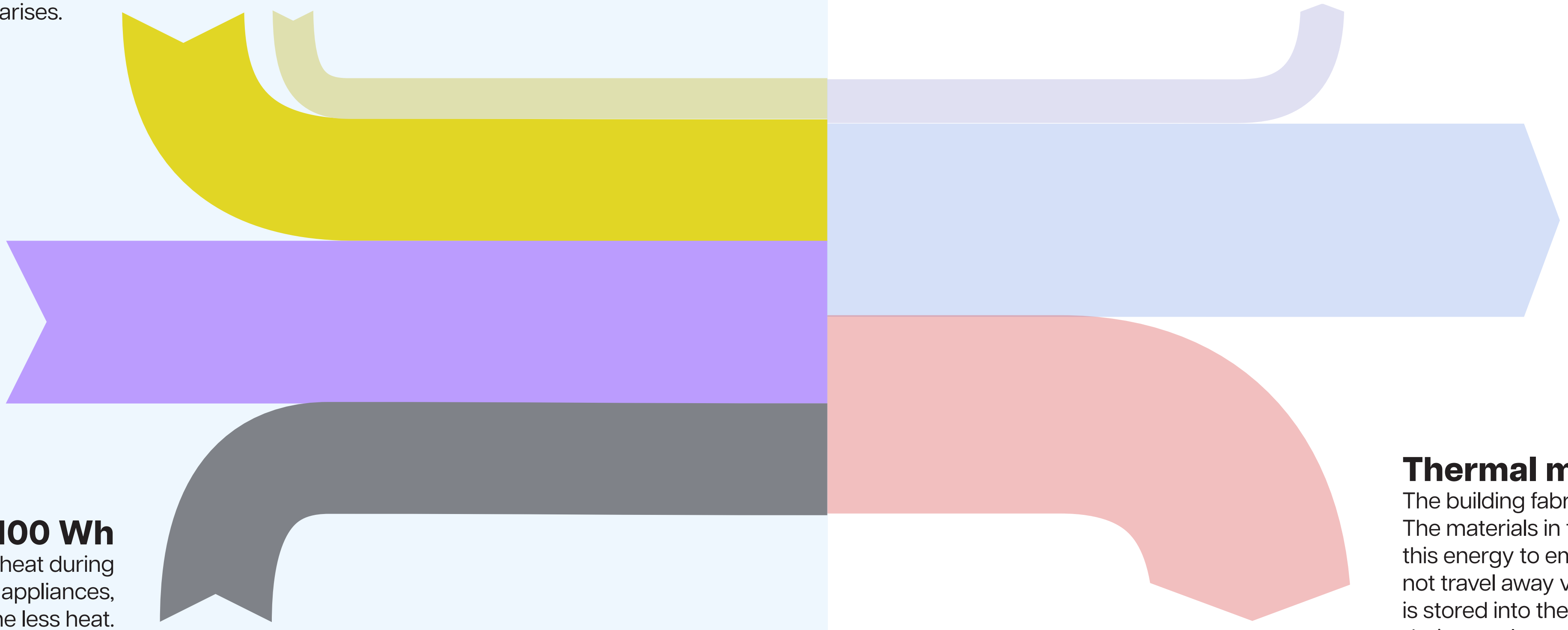
Solar radiation 1600 Wh
Solar radiation heats up the soil, building and surroundings. This is the heat source that is in essence so dominant, that heat stress arises.

1200 Wh
Direct solar radiation

400 Wh
Indirect solar radiation

Detainee 1600 Wh
The metabolic heat rate also leads to heat in the cell. The more active the detainee, the more heating of the cell. In times the detainee is not in the cell, no heat flow is summed up.

Electrical devices 1100 Wh
The electrical devices in the cell emit heat during operation. The more efficient these appliances, the less heat.



As these heat flows are the total sum over a full day. Their dynamics tough to visualise precise As during day, heat flows are behaving different than during the night, these effects need to be taken into account for understanding them fully.

More elaboration is given in Appendix 4.

Out

Transmission 500 Wh
The temperature difference over a wall or ceiling generates heat flow through the building fabric.

Ventilation 1600 Wh
Mechanical ventilation generates airflow through the cells. This moving air takes heat away from the cell. The ventilation is more effective if the incoming air is cooled down, this is not the case.

Thermal mass 2200 Wh
The building fabric heats up during the day. The materials in the walls and ceiling can store this energy to emit later on. All heat that does not travel away via transmission or ventilation is stored into the building. This heat is release during cooler periods, like at night.

Figure 3.9
SANKEY flows following calculations

Conclusion RQ 2.4
There is different factors leading to heat stress. The external heat flow is solar radiation. The internal heat gains are metabolic heat rate and electrical device heat gains.
Heat is taken out with ventilation. The state of the building determines the transmission and thermal mass.

3.9 Solution spaces

RQ 2.5
What solution spaces are there? And how are these explored?

DJI wishes to find solutions to reduce heat stress in cells to eliminate possible safety risks.

Now that the factors leading to heat stress are discussed and researched, possible solution spaces can be presented.
The SANKEY diagram demonstrates the heat flows through the cells.

Six heat flows are recognized. Four of these form a solution space, the other two do not fit in the scope.

They are discussed one by one.

1 Reducing solar heat gain
The first solution space is to block the sun from entering the cell, or heating up the building. The more this is done, the smaller the solar heat gain.

2 Cooling down the detainee
The second solution space is looking into methods to cool down the detainee. This solution space is important as this may create out of the box solutions, which are not connected to thinking on architectural implementations only.

3 Lowering the electrical device heat gains
The electrical devices are responsible for a part of the total heat gain. It should be investigated if this can be lowered effectively.

4 Increasing the ventilation
Increasing the mechanical ventilation seems like the straight forward solution, as this is meant for temperature regulation. The possibilities on changing and/or increasing this automated system should be closely analysed to find potential solutions.

The **two remaining heat flows** are transmission and thermal mass. These are both as important heat flows, yet do not create a solution space. Looking back at the design challenge, this project focuses on finding measures that can be implemented now before renovations. Affecting these heat flows is desired, yet challenging before renovations. As discussed earlier in this report, installation of measures is only possible if this can be done safely without creating potentially dangerous situations.

Changing the transmission and thermal mass heat flows would likely require operations that cannot be done in an operative PI, thus are kept for renovations.

These four solution space are explored to find measures that can be implemented before renovations.

5 A **fifth solution** space is also present. This solution space is made up from additional ideas, that are not directly placed in on e of these four tangible spaces. This solution space is elaborated more in the coming chapter, where ideation is presented. This solution space include looking into policy change within the PI.

Conclusion RQ 2.5
There is five solution spaces.
The next chapter discussed the important criteria on which measures are rated and selected. Then, the ideas that are rated best are taken back into these five solution spaces. A further plan on exploring these ideas is presented in section 4.2.

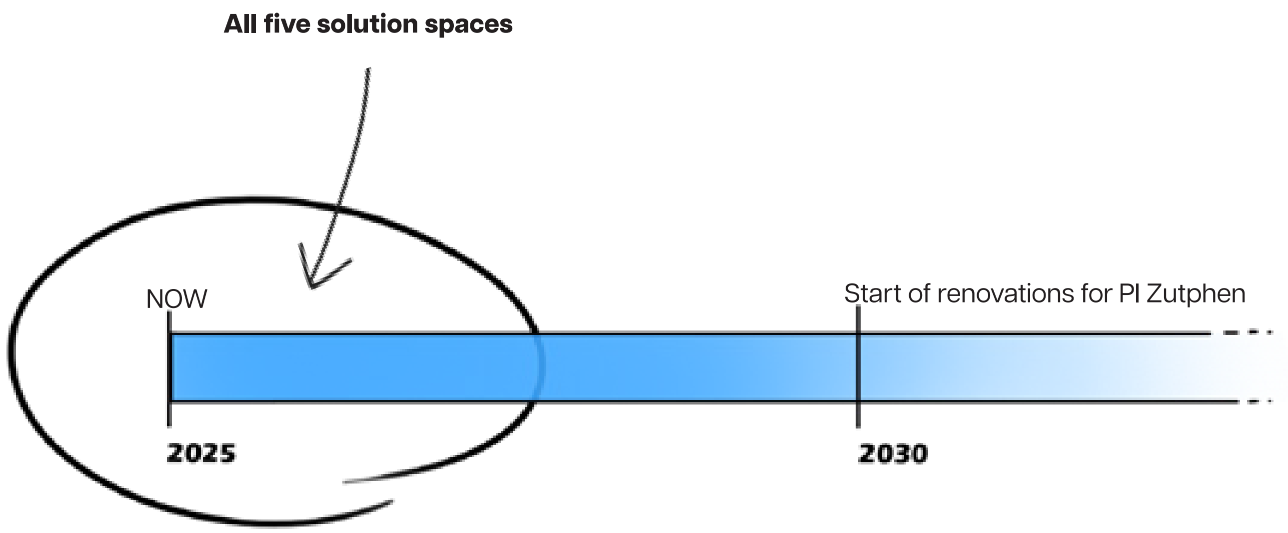


Figure 3.10
Solution spaces on timeline for DJI to tackle heat stress

Ideation

In this chapter, the ideation phase is elaborated on. An overview shows the final ideas and how these are explored further.

4.1 Criteria

RQ 2.6
Which measures fit the design challenge?

DJI aims to reduce heat stress by implementing effective measures during renovations, years from now. Up until that time, measures that are implementable now could also have a large effect on reducing heat stress in cells. With this in mind, all ideas that could potentially lead to less heat stress in the PI, are being explored.

First, all ideas are clustered together, categorised to the source of the brainstorm session or stakeholder interviews. These ideas are all given a code, corresponding to this cluster. The ideas are now explored by using three C-boxes to rate them on six criteria.

These six criteria result from stakeholder interviews with DJI. In these conversations, these six criteria were recognized as most important.

Since the six criteria are ordered in importance, they are placed in a C-box three consecutive times. In the end, this provides finalists. These are explored in depth. In Appendix 5, all clustered ideas can be found, with description and rating.

***** With these requirements in mind, not all ideas can be rated precisely in these criteria. Thus, the rating is to be interpreted as 'chance of'. This does not mark a veto on ideas that potentially lack one or more criteria, but aims for resilience in searching for the best potentials in all ideas.*

1. Low (extra) risks for safety
For a measure to be even considered, it needs to be proven safe in order to actually be implemented. Thus, risk on safety is the most important criteria.

2. Potential effect
The more potential effect the measure has, the more effective and thus important for DJI to further explore. This does not mean that ideas with little effect are permanently disqualified. These could, if they score high on all other criteria, still be important.

3. Quality of Life in detention // Wellbeing
Quality of life (leefbaarheid) is important to not be negatively impacted, since it is directly linked to detainee wellbeing and thus safety in the PI. This makes it an important criteria
Note: This is rated, apart from reducing heat stress.

4. Low energy / technology
DJI wishes for implementations that consume low energy on a daily basis, and preferably no technology involved. As this often goes hand in hand, this is made one criteria.

5. Implementability
Ideas score better if the implementation is easier. Measures that can be implemented in an operating PI score high, where measures that require a PI to be non operational score low.

6. Low maintenance and workload
Measures score higher if they require lesser workload and maintenance over the time of usage. The more time spent on this measure, the lower it scores.

4.2 C-Box rating

The ideas in the top-right quadrant are taken onto the next C-box. This way, all criteria are checked on their priority.

The ideas with minor safety risks and potential effects in reducing heat stress are now rated on energy use and technology, and their possible effect on wellbeing.

With those winners again rated on the last two criteria, a selection of finalists is chosen. These finalists are now further explored.

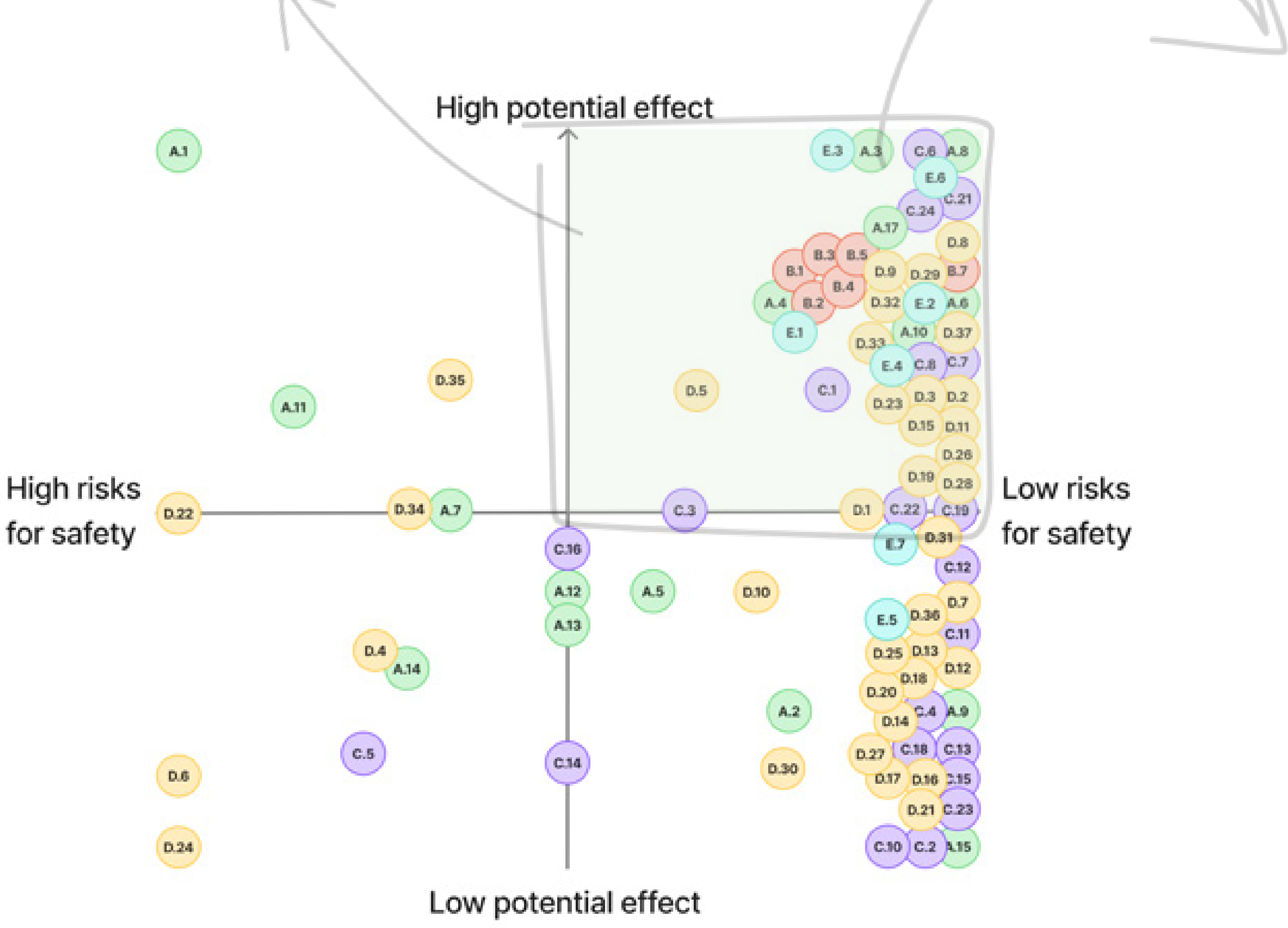


Figure 4.1
C-Boxes 1, 2 and 3

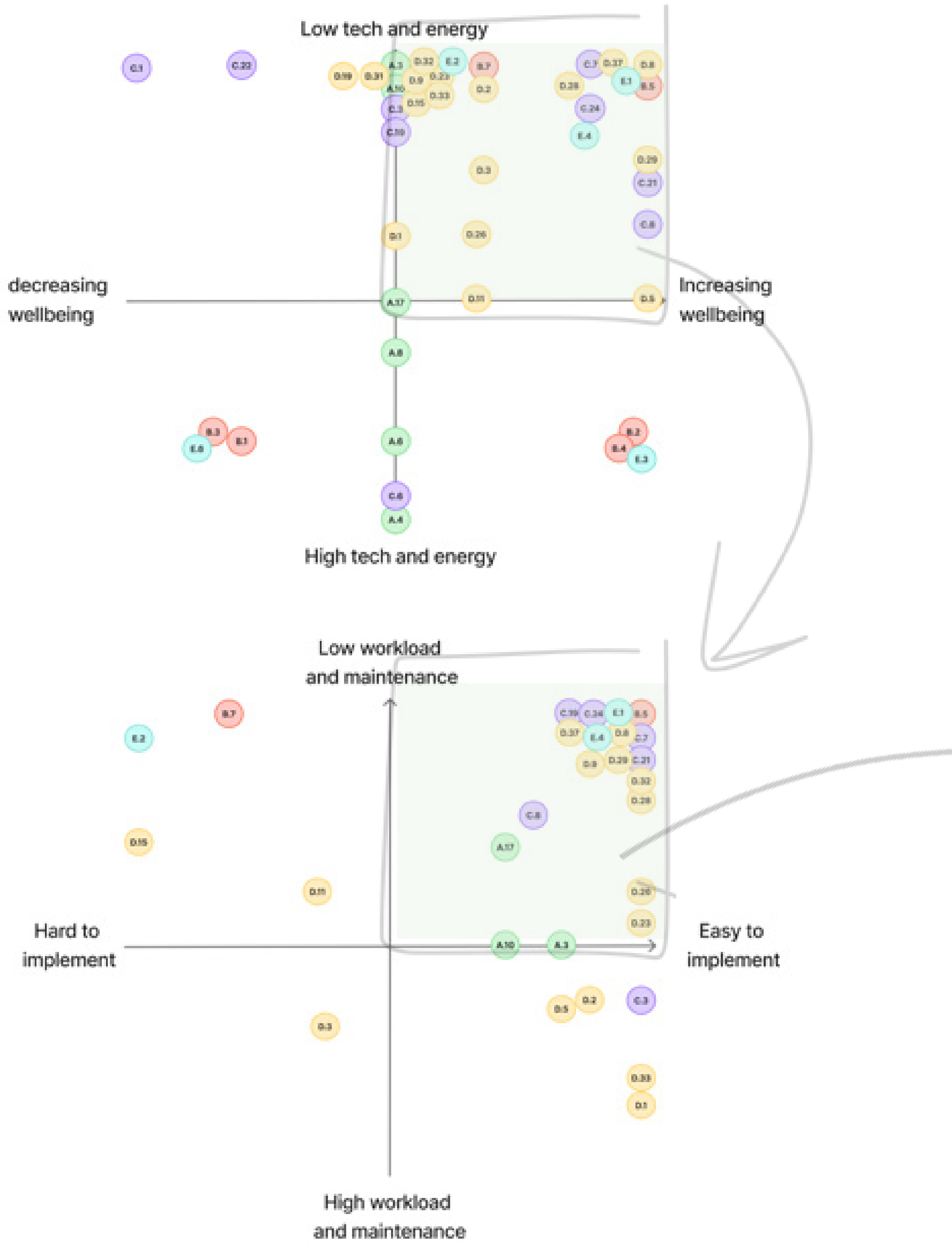
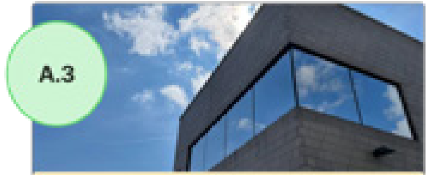


Figure 4.2
Next page:
Finalist Ideas and description

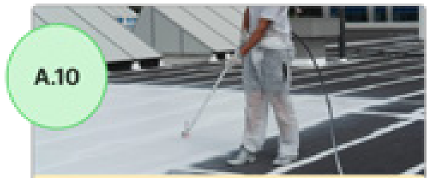


A.3

highly reflective window film on cell windows

Window Films, on the outside of the window, allow less solar radiation through the window.

1. Low risks for safety ●●●●●●
2. Potential effect ●●●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●
6. Low maintenance / workload ●●●●



A.10

Applying white coating on roof

Applying a white coating to the roof will reflect sunlight back to the sky, leading to less heating up of the building.

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●
6. Low maintenance / workload ●●●●

A.17

Higher ventilation rate on current canals

More ventilation means more heat taken away from the cells

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●
5. Ease of implementing ●●●●●
6. Low maintenance / workload ●●●●●

B.5

White reflective curtains in cells

White, reflective curtains in the cell that have the best specifications to reflect back solar radiation.

1. Low risks for safety ●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●●

C.7

wearing less isolating clothing

Wearing less isolating clothes resolves in lower PET Index since less heat is trapped

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●●

C.8

Ceiling fan in cells

Installing ceiling fans in cells to generate wind flow, cooling down PET Index

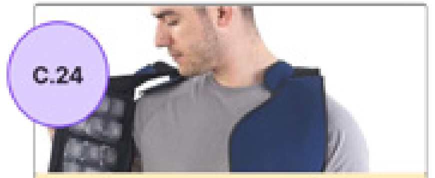
1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●
5. Ease of implementing ●●●●
6. Low maintenance / workload ●●●●

C.21

table fan in the cell

Providing detainees with a table fan, so that the perceived temperature drops

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●

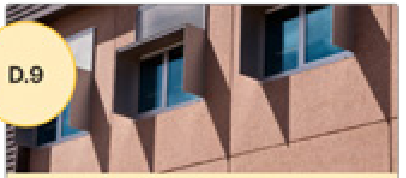


C.24

Cooling vests

Providing detainees and/or employees with cooling vests to stop overheating due to heat stress

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●●



D.9

mounting overhangs on cell windows

Overhangs will stop direct solar radiation from shining into the window in summer

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●
6. Low maintenance / workload ●●●●●

D.8

providing education on heat stress

Educating detainees and staff about heat stress, causes, and ways to deal with heat stress.

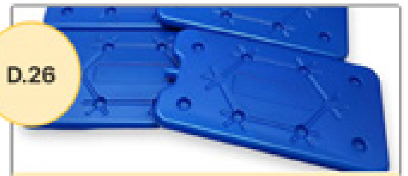
1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●

D.23

Different daily schedules for hot days

Shifting activities to less hot hours, and changing daily schedule for cooling effects

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●



D.26

Handing out icepacks

For detainees and staff to cool down with

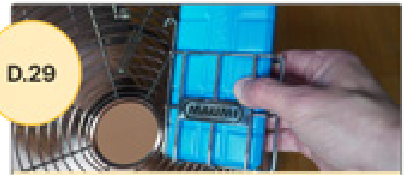
1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●
3. Wellbeing ●●●●●
4. Low technology / energy use ●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●

D.28

ice silk bed linnen / cloudpillo

This fabric makes one cool down easier, by better breathing abilities and more sweat take away

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●
3. Wellbeing ●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●

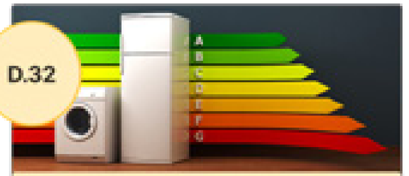


D.29

Attaching icepacks to the table fans

handing out icepacks so detainees can put them on the table fans to cool down with

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●



D.32

More energy efficient appliances

replacing appliances for more durable ones, leading to less heat production

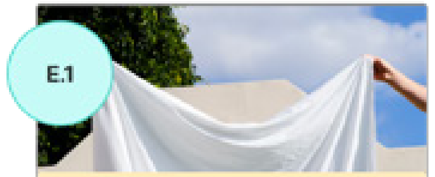
1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●

D.37

Cleaning supplies for ventilation grille cleaning

So that detainees have all tools to keep the ventilation grilles clean

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●



E.1

White cloth to hang in front of the window

Detainees can hang up with reflective cloths as curtains to reflect away radiation

1. Low risks for safety ●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●●●
4. Low technology / energy use ●●●●●●●
5. Ease of implementing ●●●●●●●
6. Low maintenance / workload ●●●●●●●

E.4

Mounting fans on the exterior wall grille

So that more fresh air is blown into the cell if detainees switch these on

1. Low risks for safety ●●●●●●●
2. Potential effect ●●●●●
3. Wellbeing ●●●●●
4. Low technology / energy use ●●●●●
5. Ease of implementing ●●●●●●
6. Low maintenance / workload ●●●●●●●

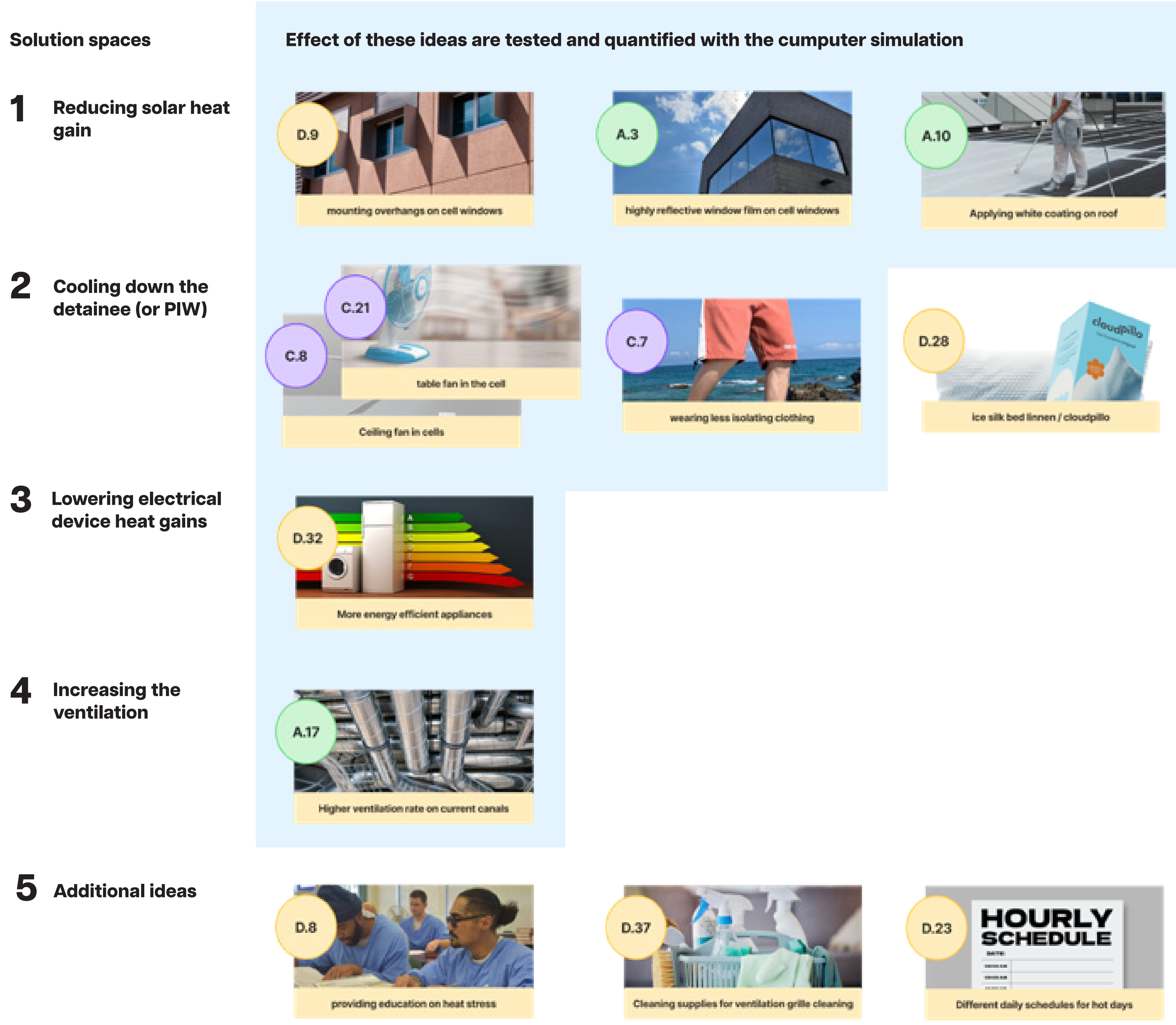


Figure 4.3
Finalists categorised on solution space and next steps of action

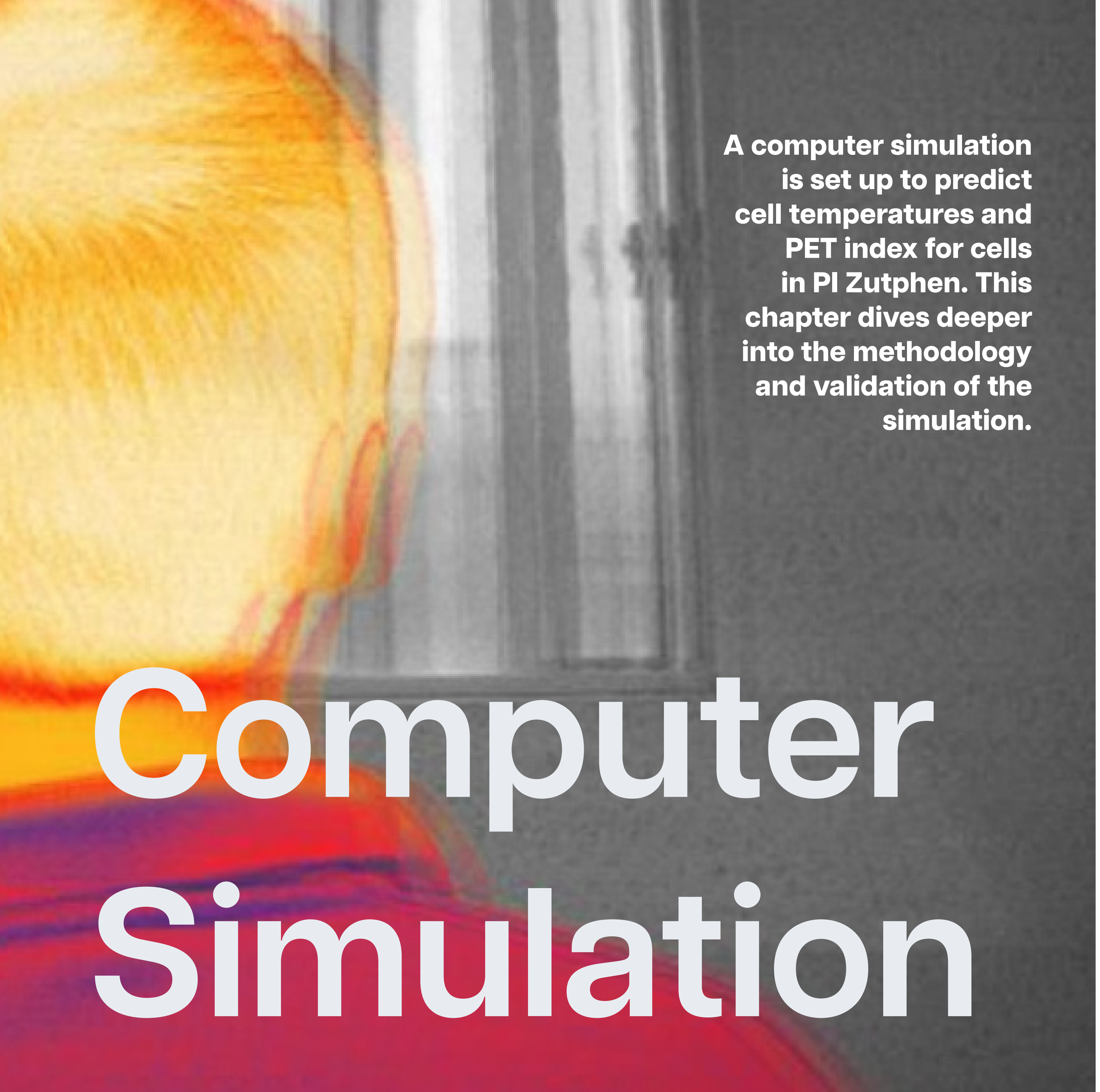
Conclusion RQ2.6
These measures are the finalists of a broad ideation. These ideas are rated best within the chosen criteria of the design challenge.

Next steps
Now that ideas are categorised into the five solution spaces. The next step is to explore their potential effects.

As the potential effect is important to know before effectively choosing the right measures, this has to be made clear some way.

A computer simulation is chosen as comparison tool to test the effects of half of these ideas. The rest of the ideas are explored via stakeholder interviews and additional desktop research.

In the next chapter, these ideas are explored and elaborated in depth. In conclusion, section 8 summarises the outcomes and scopes client advice and future vision.



Computer Simulation

A computer simulation is set up to predict cell temperatures and PET index for cells in PI Zutphen. This chapter dives deeper into the methodology and validation of the simulation.

5.1 Introduction

RQ 2.7
How can the impact of heat reducing measures be quantified?

Possibilities to test different measures in a penitentiary institution is tough on multiple levels. Different tests might be tough to perform in the PI environment from a safety perspective. Using a computer simulation, different measures could be compared on heat stress reducing capacity. Thus, a computer simulation is chosen as an effective comparing tool to gain insights on measures.

To gain valid insights, the software must be able to calculate PET Index for people if they were in cells.

EnergyPlus is an open-source software that is used for energy flows through buildings.

In EnergyPlus, a (part of a) building can be modeled, with the building fabric and thermal loads as realistic as possible. Together with environmental weather data, the software calculates indoor environmental conditions for dynamic time steps, such as per hour. EnergyPlus can calculate many insightful variables, including the six factors combining the PET Index.

Also, In EnergyPlus, heat stress can be calculated in the GTO and PMV values. These are explained later in section 5.2.

With a sparring session with assistant professor in building physics Eleonora Brembilla, of the Faculty of Architecture, TU Delft, EnergyPlus was confirmed as a good fit for this simulation. Altogether, this software is chosen.

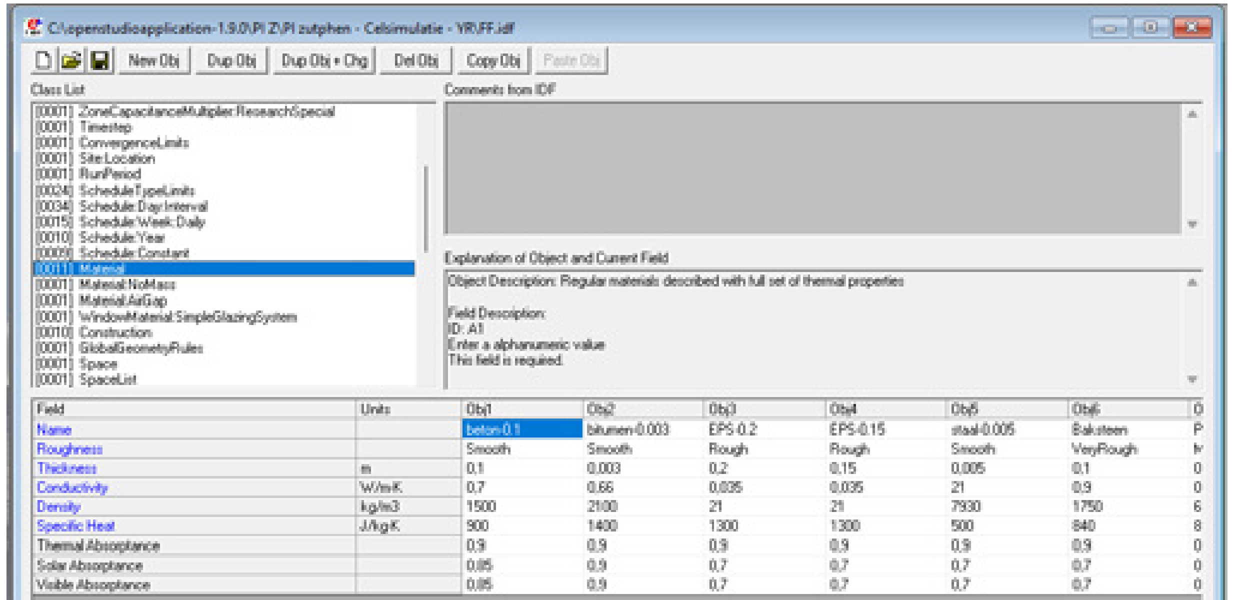


Figure 5.1
Screenshot of EnergyPlus software interface from the simulation

5.2 Method

In EnergyPlus, an indoor environment can be modeled by creating a thermal zone. This is done by creating a box. This box has the dimensions of a cell in PI Zutphen. Each surface of this box is linked with a construction consisting of a set of materials. The materials and thicknesses in the construction determine how much energy flows through. These materials and their properties represent the building fabric of PI Zutphen.

A complete overview is given in Appendix 6.
Of all surfaces, the facade and window, and the roof, are exposed to the outdoor environment. All other surfaces are indoor walls and a floor, these are modeled adiabatic.

Adiabatic means that no heat flows through these surfaces. This is chosen to be modeled adiabatic, since this cell is placed between other cells on both sides, and under this cell. These cells are assumed to have the same temperature and humidity. This way, the simulation calculates the effects from the outdoor environment via the facade and roof.

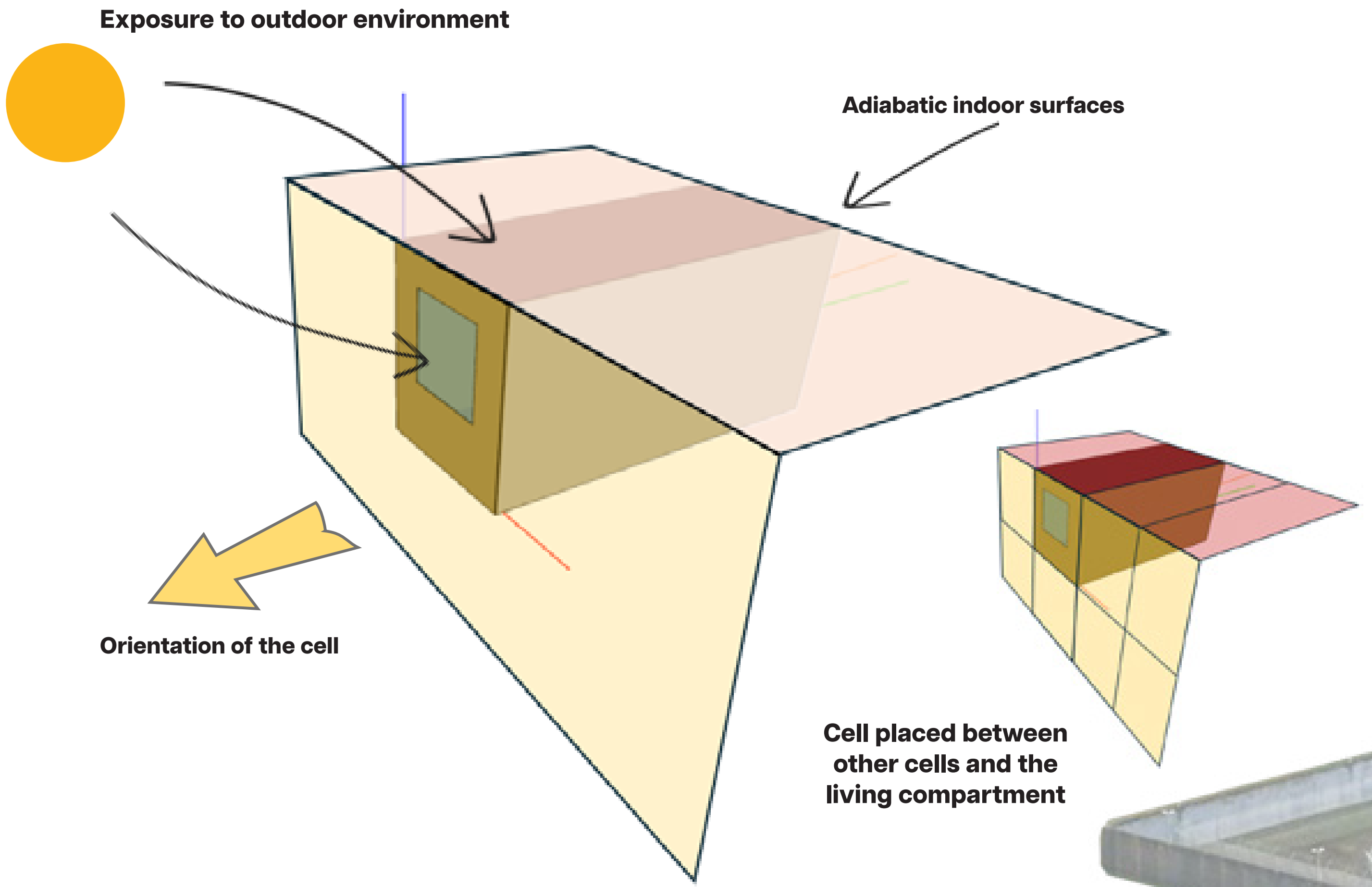


Figure 5.2
Visualisation of the modeled cell and orientation

The orientation of the cell can be easily changed, to calculate heat stress for cells on different facades. This is needed, since different facades have different heat flows. Where a south facing facade faces more solar radiation, a North facade has only a fraction of this.

To model heat stress as precise as possible, the cells in PI Zutphen on all four orientations are modeled.
These orientations are referred to as North, East South and West orientations.

Their true orientation differs from these directions, but is simulated correctly. This way, referring to cells with a certain orientation is done more easily.

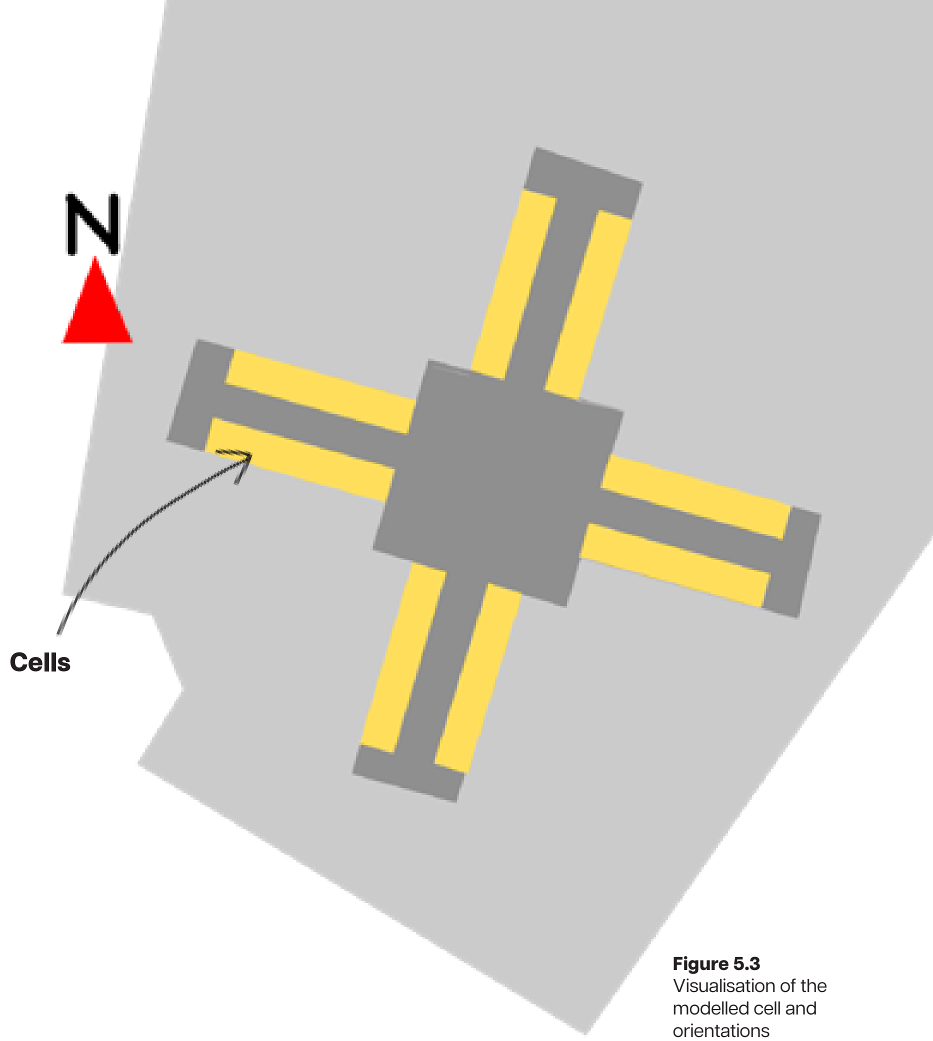


Figure 5.3
Visualisation of the modelled cell and orientations

Input variables

Outdoor environment
The cell gets exposed to environmental factors such as wind, outdoor temperature and humidity. These factors are all summed up in a large weather data file, containing numerous data for 'average weather' for a whole year. The data file that is used is that of average weather for Deelen, Netherlands, in the period of 2009-2023. With Zutphen 25 kilometers away from Deelen, this data is pretty accurate.

Now that the cell and the outdoor environment are modeled, the indoor environment is important to model as realistic as possible.
As explained before in the SANKEY diagram, there are internal loads that add heat to the cell. In EnergyPlus, this is modeled as follows:

Electrical devices
Different electrical equipment can be modeled. As there are many different appliances, this could be done exactly like any detainee might use it. Since this data is not present, an assumption on daily use is made.

The fridge is always turned on, and exposes 25 Watts of energy.
The television uses 35 Watts and is turned on from 17 - 22h. The ceiling lamp is turned on from 7.7:30 and from 17-23h. This lamp uses 40 W. These heat flows can be modeled in EnergyPlus using the Schedule feature.

Other devices, such as the microwave and coffee maker, are not modeled in. These operate only short times. Short usage would have effects on the perceived temperature. As it is unknown how detainees use these appliances, they are left out.

Detainee
The detainee in the cell is also giving off heat to the room. Since the detainee is not always in the cell, this should be zero during day activities. Now this is important, as this would pose problems for the heat stress calculations.
Heat stress is calculated with the use of the six factors that combine into PET.

The personal factors are metabolic heat rate and clothing factor. With realistic modeling of the detainees schedule, the metabolic heat rate IN the cell during daytime would be zero. This would mess up the heat stress calculations, as the PET Index cannot be calculated any more for these hours.
This is why the detainee is modeled inside the cell permanently. This way, the heat stress is also calculated during times the detainee would not actually be in the cell. Also, more heat is given off to the cell by the detainee. This is further discussed in section XX.

The metabolic heat rate and clothing factor of the detainee have a huge direct impact on the heat stress values. These values are best calculated for stable situations, in which the metabolic heat rate and clothing factor do not change (Zhao et al., 2020).

The clothing factor is chosen as 0,5. This is the value for 'light summer clothes, such as short pants and a t-shirt' (Van der Linden, 2005). This factor is chosen as this is estimated realistic for detainees in the summer period with potential heat stress, what the model will examine.
Later, other factors are chosen, to simulate the uniforms of PIWs

The metabolic heat rate is set on 100 W, as this is the average value over a day in the cell.

Ventilation and infiltration
The modeled cell should have 50 m^3/h of ventilation air flow. This is reached by modeling and air intake and outtake. An incoming flow of 50 m^3 per hour is modeled onto the cell. This is air with temperature and humidity like the outdoor air.

The air outtake is also 50 m^3/h. The air is taken from the cell and placed outside the model. This way, the real ventilation is modeled and simplified.

The effect of the window grille is modeled by adding infiltration. This means that, depending on wind speed and direction, outdoor air can be directly blown into the cell via the window. Since no available data is present on the true infiltration rate, the window grille is modeled open at all times, with a max infiltration of 0,05m^3 per hour. See appendix 6 for these calculations.

With the ventilation and infiltration modeled, the indoor environment can be calculated for the entire year. The inflow and outflow of air create a small draft through the cell. The wind speed that is perceived by the detainee is important for the perceived temperature. The wind speed in the cell needs to be modeled also. The indoor wind speed is 0,1 m/s for unventilated rooms. For rooms with mechanical ventilation, or an opened window, 0,2 m/s is often chosen. 0,15 m/s is often chosen for rooms with minor ventilation and no open windows. The cell fits that description best, thus 0,15m/s wind speed is modeled.

With the cell now modeled realistically, with some assumptions made, EnergyPlus can calculate heat stress in the cell. This is done hourly, for the whole year. Figure 5.5 shows how this is done.

Outcome data

Now, as mentioned before, heat stress is dependent on six factors, combined into the perceived temperature. These factors can be calculated with the simulation, and combined into the perceived heat stress by detainees. The software calculates all these values for each hour of the year, into a large excel file. The PMV and GTO values stress the severity and duration of heat stress via so-called 'Fanger calculations'.

The Fanger model is widely used to calculate the quantity of heat stress perceived by humans. Since this calculation is the norm widely used in the United States (ASHREA-55) and in Europe (ISO7730:2005), this is used to model heat stress, and quantifies heat stress with the PMV value. Another worldwide used norm is NEN 5060:2018 T5, which is also used by DJI. This norm measures heat stress with the GTO value. Thus, the computer simulation is used to calculate PMV and GTO values to be able to Compare these for different measures.

PPD [%]

First, the Percentage of People Dissatisfied is calculated. This number states the percentage of people that would vote perceived thermal discomfort, meaning a value lower than -0.5 or higher than 0,5 on the heat stress scale.

PMV

The PMV (Predicted Mean Vote) states the number that is voted most on this scale.

Together, these two values predict how many people would vote for thermal discomfort.

When at least 10 % votes (PPD ≥ 0,10) for heat stress (any PMV > 0,5), this is counted as heat stress. These values are chosen as a baseline in quantifying heat stress (W/E adviseurs, 2018).

Thus, The PMV value represents all hours that heat stress is present.

GTO

While PMV states the time duration that heat stress is perceived, the GTO (Grens Temperatuur Overschrijdend) value represents the severity of the heat stress.

This is done as follows. Hours where more people (high PPD) experience higher discomfort (High PMV) are weighed heavier.
When the PMV is higher, people experience extreme heat stress. This automatically means that the PPD value is higher, as more people would note this discomfort. Since these hours hold more risk, they are weighed heavier in the GTO calculation. GTO counts all hours above 27 degrees Celsius in the cell.

Thus, GTO counts the severity of heat stress. This number offers valuable insights in comparing measures later on.

The EnergyPlus simulation is runned for different situations, orientations and measures. The outcome data is put in an excel file, which is analysed.
Using a set of formula's, the GTO value is calculated from the PMV and PPD value. From these numbers, different plots are made.

An extensive overview of all Excel outcome data and graphs can be found in Appendix 8.

Conclusion RQ 2.7
The heat stress reducing impact of measures can be calculated using the EnergyPlus simulation. The simulation can predict the time heat stress is present in cells (PMV) and the severity of the heat stress (GTO).

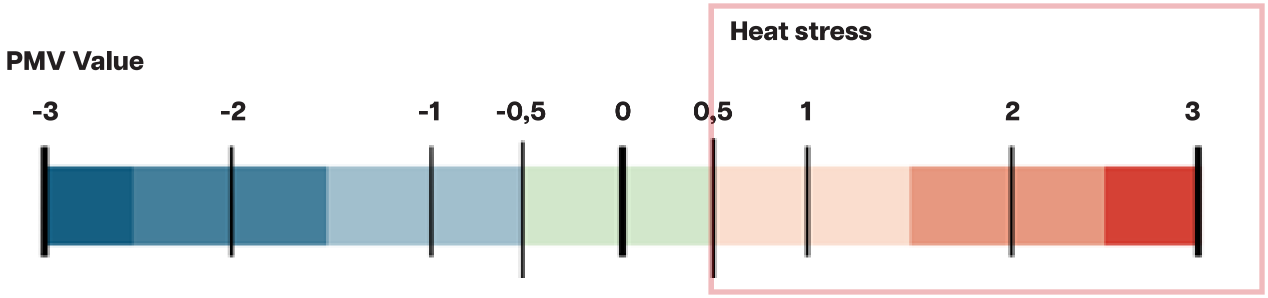
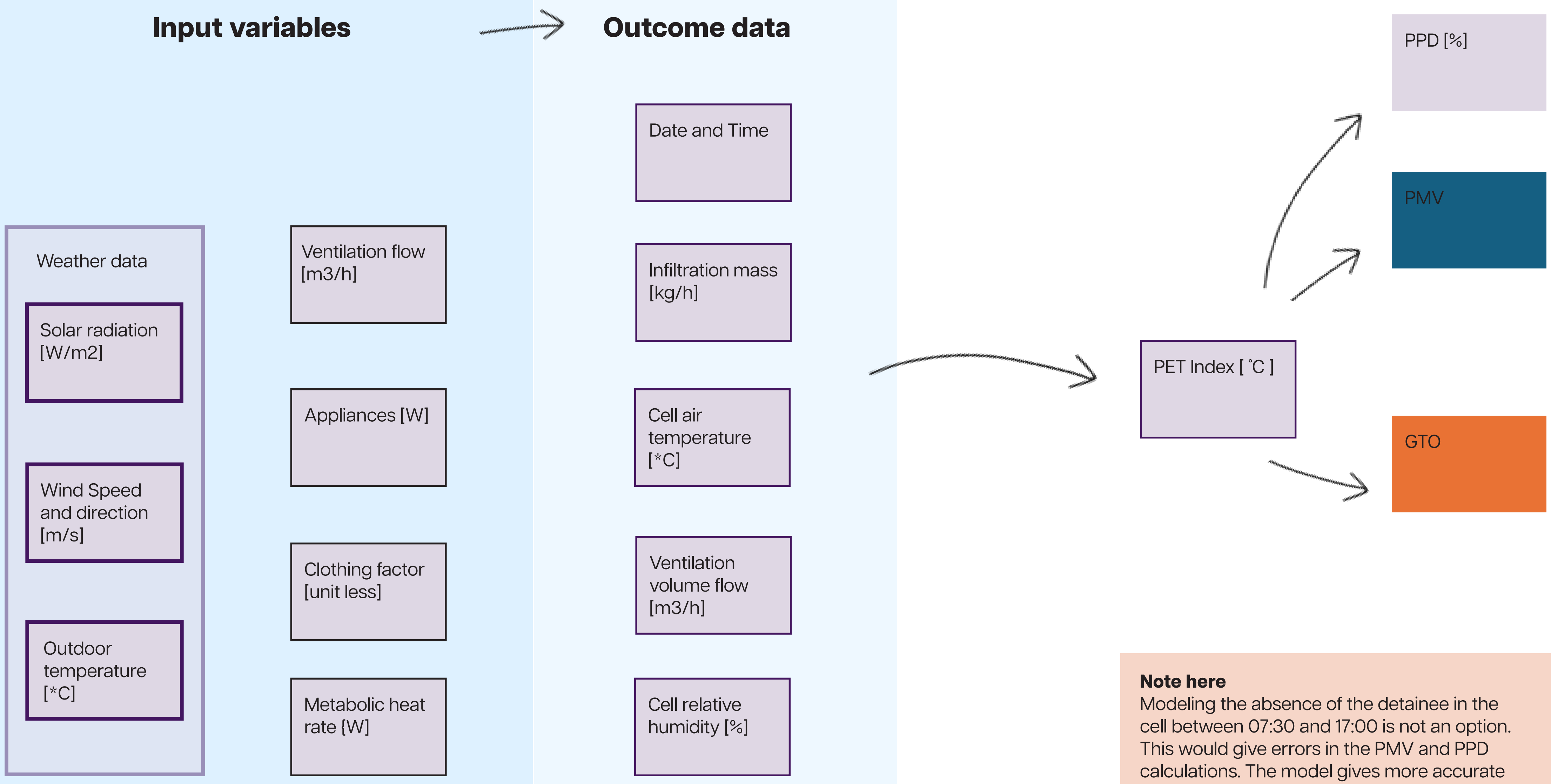


Figure 5.4
PMV linked to the perceived temperature scale



Predicted percentage dissatisfied (PPD) is the percentage of people that experiences any form of heat stress. (Slight heat stress to severe heat stress).

Predicted Mean Vote
The PMV value shows how many hours heat stress (PMV > 0,5) is experienced by at least 10 % of people (PPD ≥ 10%).

With PPD and PMV, the GTO value is calculated. The GTO value represents how heavy the heat stress is experienced.

The hours where more people (High PPD) experience higher heat stress (High PMV) are weighed in heavier than hours where some people (PPD is lower) experience any form of heat stress (PMV from 0,5 to 3,0).

Thus, The GTO value is always higher than the PMV value.

Note here
Modeling the absence of the detainee in the cell between 07:30 and 17:00 is not an option. This would give errors in the PMV and PPD calculations. The model gives more accurate insights if the detainee is always in the cell, with a constant metabolic heat rate.

The PMV and GTO values represent all experienced heat stress if a detainee would be in the cell 24/7. As this is not the case, the true experienced heat stress in cells is lower.

Figure 5.5
Schematic overview of simulation method

5.3 Validation

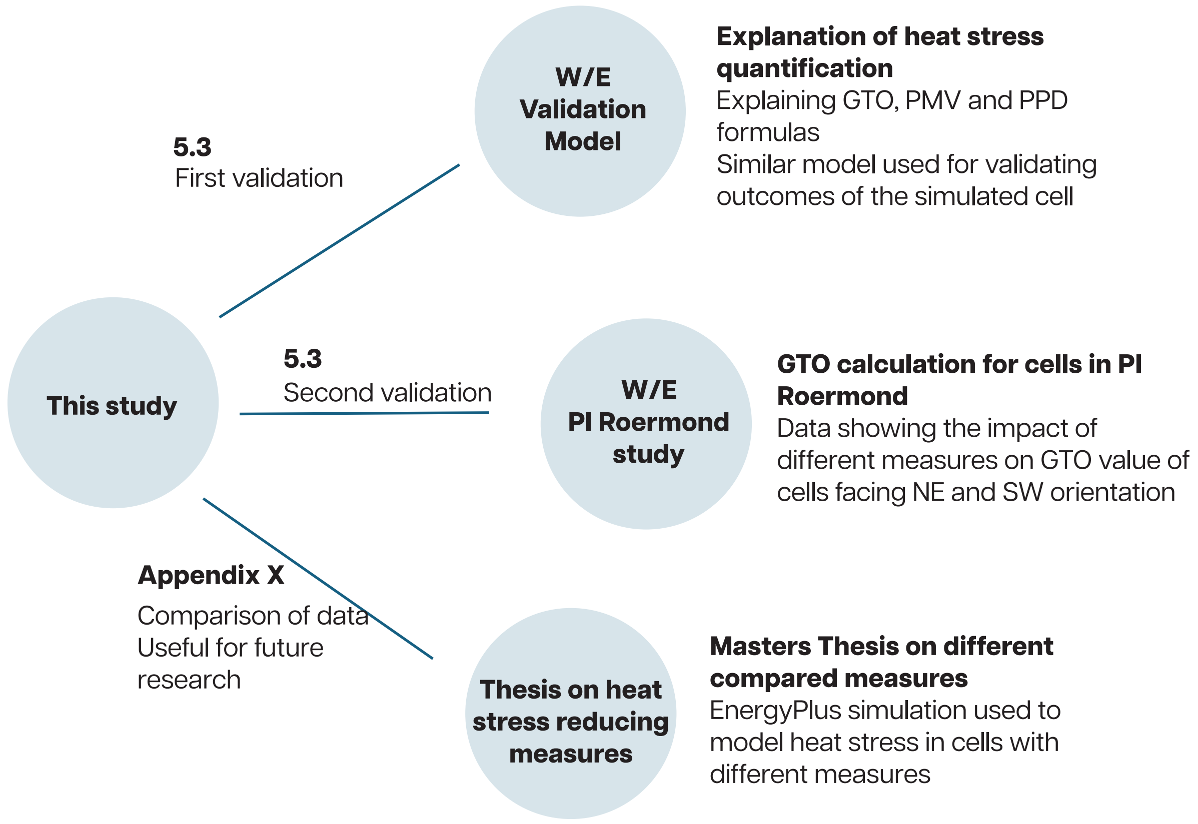
The outcome data of the model needs to be validated to see how realistic the values actually are. Two similar studies are found to compare to this studies simulation.

Both of these studies are performed by W/E. This is company that perform research into heat flows in buildings, for sustainability consults. W/E published a large bundle in which the GTO method is explained and demonstrated. In this bundle, the first validation model is found.

Also, this company is a partner of DJI that performed a heat stress calculations on cells in PI Roermond. These outcomes are used for validation.

Lastly, a masters thesis that compares different heat stress reducing measures is compared with this study. This thesis is not used to validate this simulation, but to compare the methods and results. This way, all results can be compared to gain valuable insights in all studies done.

Figure 5.6
Two similar simulations done by W/E, used for validation of this study



First Validation: W/E Validation Model
First, the relation between the outcome values needs to be validated.
The relation between indoor temperature, and PMV and PPD values can be checked with a validated model, which shows this relation in a graph. The validated model is built with similar chosen variables, and thus meaningful for validation. Since not all variables are chosen the same, some differences arise. This plot can be used to validate and discuss the results.

These variables are elaborated in the table below. The values of the table show that the model is actually quite similar in terms of the six factors controlling perceived temperature. This way, the PPD and PMV values should be comparable. With different variables between the models, and unknown aspects, there is also an offset between the two. This is analysed and discussed as validation.

First, The validation graph is presented. This is figure 5.7.

This graph links the indoor temperature to the perceived heat stress by showing the voted PPD and PMV values.

The relation of temperature and perceived temperature is thus made visible with the two trend lines.

The grey trend line links indoor temperature to the predicted percentage dissatisfied.
The orange line is the mean voted PMV value at that temperature.

The area of PMV values between -0,5 and 0,5 is the thermal comfort.

Figure 5.7
PMV and PPD correlation with indoor temperature (W/E adviseurs, 2018)

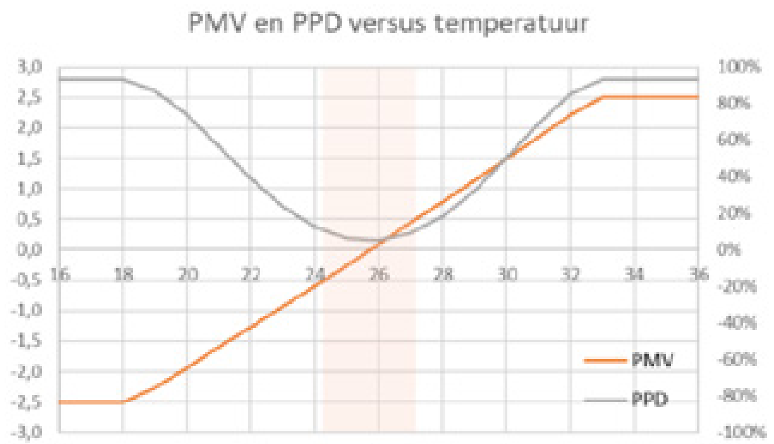


Table 5.1
Variable differences of the validation model

	This studies simulation	Validation model
Air speed	**0,15 m/s**	0,15 m/s
Clothing factor	**0,5**	0,5
Metabolic heat rate of person in the room	**100 W**	120 W (65W/m2)
Weather data	**Netherlands**	Netherlands
Ventilation	**50 m3/h**	None
Infiltration	**0,05 m3/h**	None

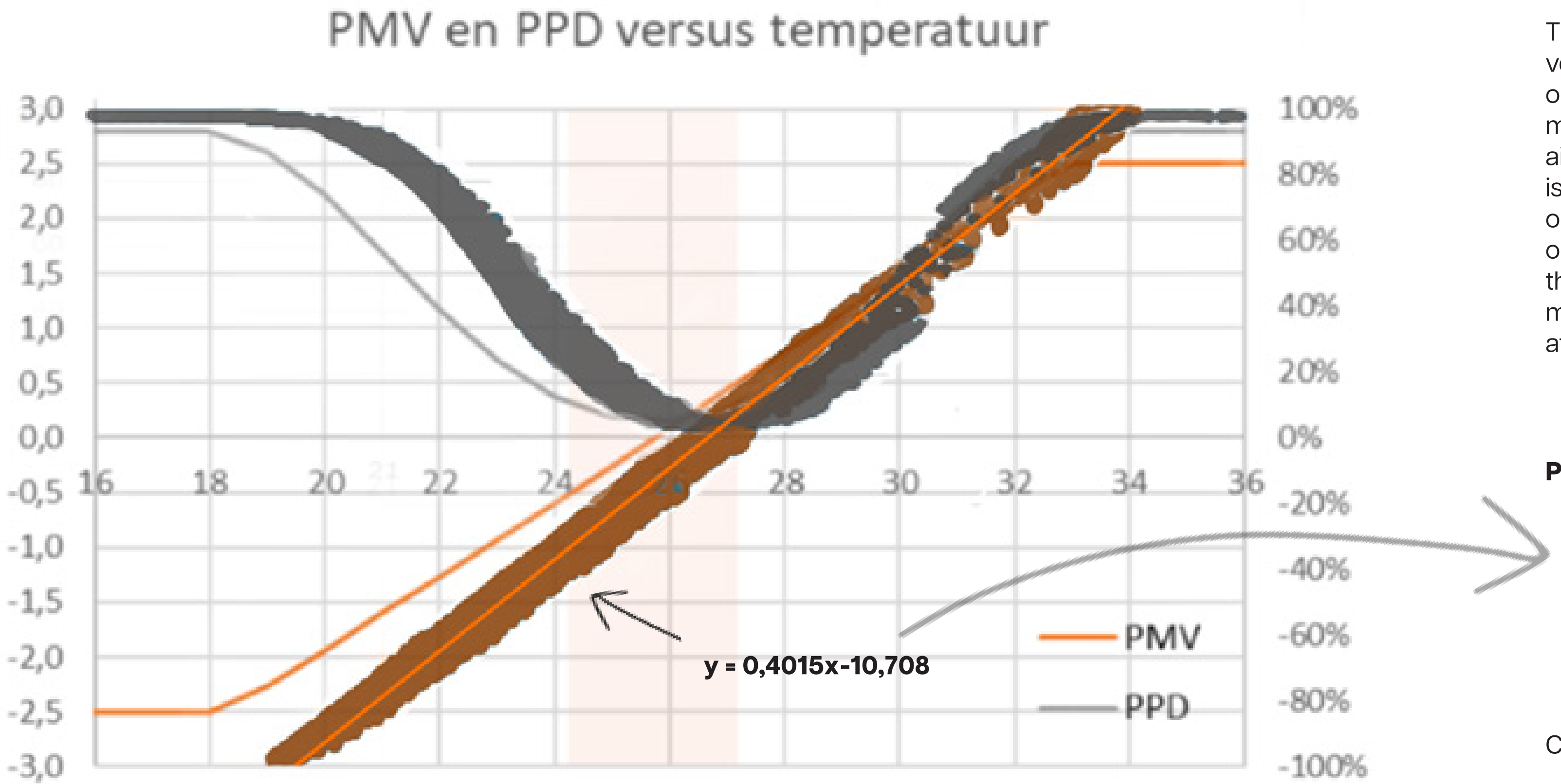
The PPD and PMV values of the PI Zutphen cell can be plotted as well. All values of the entire year are visualised, and form similar correlations. These lines are plotted onto the graph to analyse the differences. This is shown in the graph below.

The formula of the PMV trend line is shown also. This formula can be used to calculate the thermal comfort area for the PI Zutphen cell. This way, cell temperatures can be linked to the voted heat stress (PMV Values). The cell temperatures are shown on the PMV scale in figure 5.9.

The plotted lines show some differences with the validation plot. This is elaborated on:

1.
The PPD line has a similar shape, but is less broad. Near colder temperatures, of 26 degrees and under, the PPD lies higher. This means that more people are feeling discomfort at these temperatures. Similarly, the orange dotted line, representing the PMV relation of this simulation, has more offset around colder temperatures than for warmer ones. Thus, the colder the air temperature, the more people are dissatisfied and experience higher cold stress, compared to the validation model.

Figure 5.8
PMV and PPD correlation with indoor temperature of a PI Zutphen cell



This can be explained looking back to the table with input variables. The metabolic heat rate differs. In this study, an average value of 100W is modeled, while the validation model calculates 120 Watts. For colder temperatures, people in the simulated cell would feel colder more easily, since they are less active than they would be in the validation model.

2.
Secondly, the PMV relation of this study is steeper than that of the validation model. For temperatures in the cold stress region (PMV under -0,5), the PMV is estimated lower than for the validation model. The colder the cell temperature gets, the larger this difference.

This can be explained with the difference in ventilation. Where the validation model simulated only air speed in the indoor zone, this simulation models ventilation and infiltration also. These airflows are both outdoor air, and the colder it is in the cell, the colder it is outside. On these occasions, the people in the cell would feel cold outdoor air as means of ventilation. This makes this simulation feel colder than the validation model. Thus, The PMV line is steeper, and starts at lower indoor temperatures.

3.
Near warmer indoor temperatures, the difference between the validation model and this studies simulation is smaller. Thus, the differences play a smaller role in temperatures where heat stress arises. This is beneficial for heat stress calculation, as these only count temperatures above 27 *C and PMV 0,5.

For PI Zutphen cells, the thermal comfort temperature lies between 25,4 and 27,9 degrees Celsius. This region is fairly higher than that of the validation model. This can be explained with the lower metabolic heat rate in this study, as well as the ventilation.

In total, this validation proves a similar relation between cell temperature and perceived temperature.

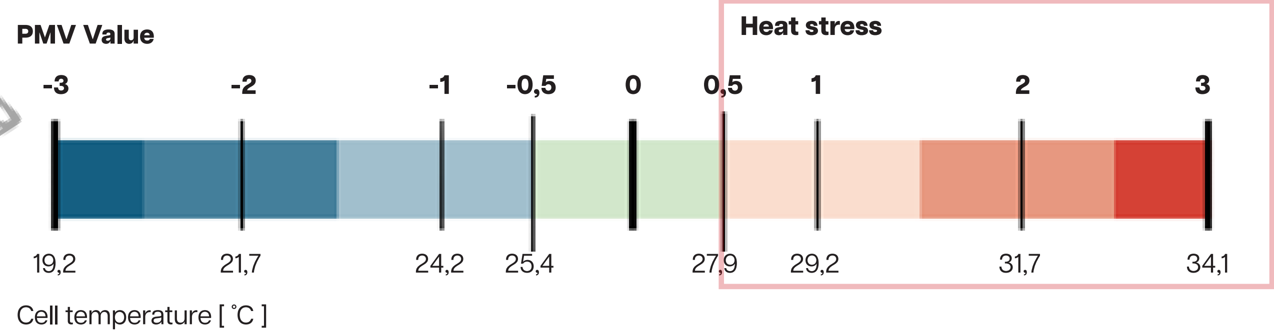


Figure 5.9
PMV linked to the perceived temperature scale and indoor cell temperatures

Second validation: W/E PI Roermond study
Secondly, The outcome data of this simulation can be compared with a GTO calculation of cells in PI Roermond, done in 2023. This GTO calculation is done by W/E as well.

In this validation study, cells of PI Roermond are modeled. Cells in PI Roermond are similar to cells in PI zutphen. They host one detainee, have no shower and are around 10 m². The differences of building fabric and window properties of PI Roermond cells are unknown.

The heat stress for cells in PI Roermond is calculated with the GTO value as well. The simulation software is not mentioned in the data from this simulation, but heat stress is quantified with the PPD, PMV and GTO values following the same method and formulas.

In the validation study, PI Roermond cells with a facade orienting Northeast and Southwest were modeled to calculate the GTO value.
To validate the results of this studies simulation, the same cell orientations are simulated.

The severity of heat stress (GTO) is described as maximum 210 for all cells (Leenaerts, 2023).

The outcome data of this study and that of the PI Roermond simulation differ quite a bit.

The GTO Value of both orientations is 24 % higher. Since the exact differences in building fabric and window size are not know, this could declare this difference. The fact that both GTO values for PI Zutphen are 24% higher than those of PI Roermond states that heat stress behaves the same regarding orientation of the window.

Still, variables of the validation study of PI Roermond are unknown. Where that study likely used similar weather data, the clothing factor, metabolic heat rate and air speed that are modeled are completely unknown. As this study is performed by W/E, it is assumed that this study is accurately modeled via the right variables. Since the model of this study is inspired and validated with that data, this provides sufficient validation.

The differences between the GTO value can be explained with the unknown differences in exact cell volume, window properties and building fabric.

This study also calculates GTO for the living department, which indicates that this simulation might be more refined in terms of true ventilation. In the simulation of this study, this has been made simple with the use of assumptions.
Since the differences in simulations are unknown, further discussion is not possible.

In section 6, results of heat stress reducing measures of this study are compared and elaborated.

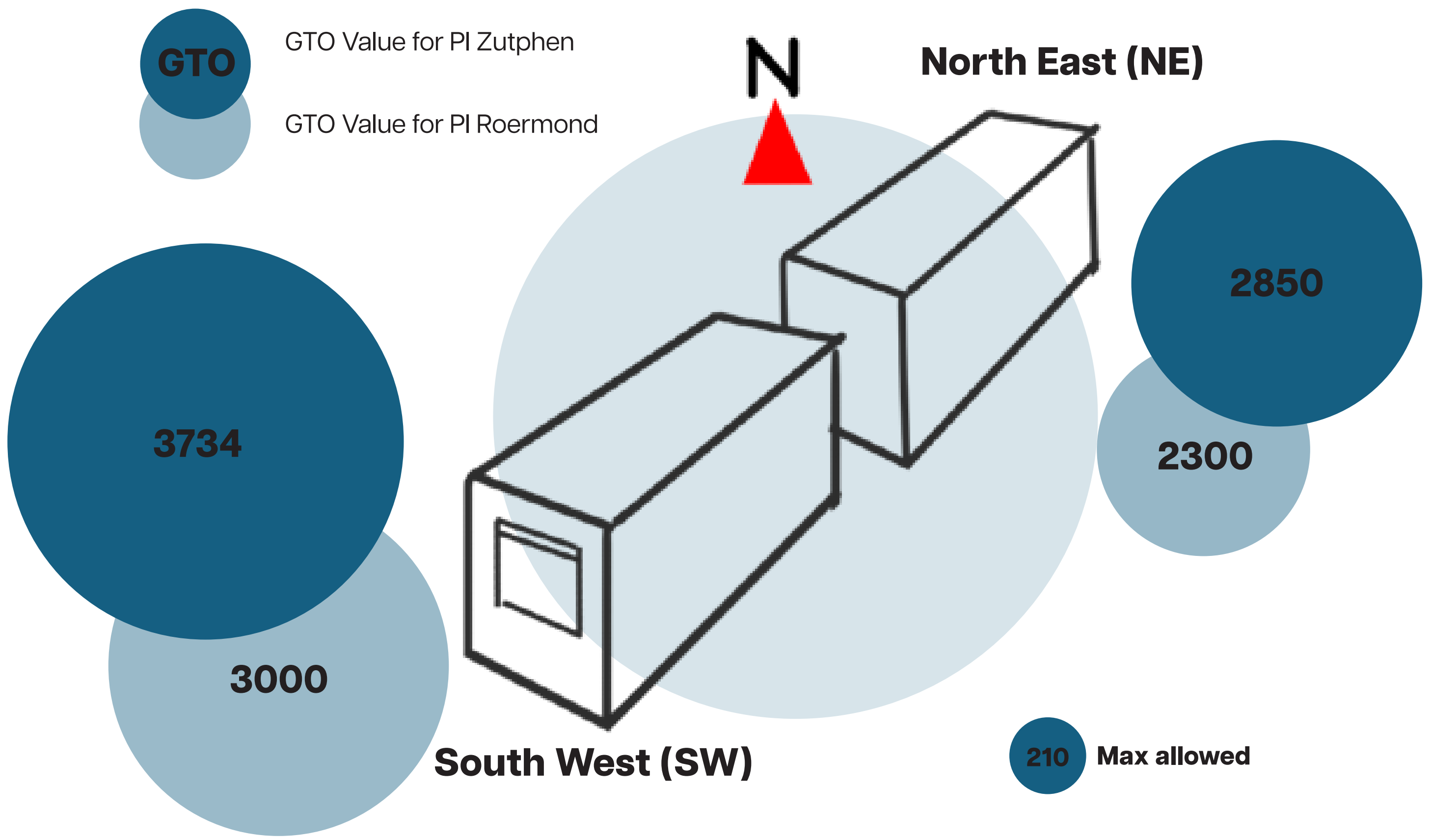


Figure 5.10
Visualisation of the heat stress outcomes of both simulations
Adapted from (Leenaerts, 2023)

5.4 Discussion

The validation section covers the differences between validated outcomes, and outcomes of this study. This indicates how precise the outcome data probably is. This section dives deeper and elaborates on what differences might be present, causing less reliable data.

Ventilation effect
The modeled ventilation is a simplified version of the true ventilation. While the ventilation flow is modeled accurately, the air comes straight from outdoors. In a PI, the air travels through ventilation canals, via the living department, to the cell. Before the air reaches the cells, it might heat up already. This could potentially be modeled, in a more sophisticated model. As for this study, these differences are not taken into account.

Adiabatic walls
The indoor walls and surfaces of the cell are modeled as adiabatic. In the real world, no wall is ever adiabatic. Thus, this simulation is in that sense not realistic. A cell placed in between other cells would likely have small heat flows, marking the use of adiabatic walls. Not all cells and indoor spaces can possibly host the same indoor environment. Warmer indoor spaces, or cells, give off heat to other indoor spaces.

Assumptions on variables
Input variables are chosen with the use of assumptions. Wind speed, clothing factor and metabolic heat rate are all chosen as realistic as possible. Yet, the difference between true values and chosen values might result in different GTO and PMV values.

The simulation shows heat stress, calculated as PMV and GTO values. These values count all heat stress, as if the detainee would always be in the cell, with the same metabolic heat rate. As detainees are not always in the cell, the true experienced heat stress (in cells) is lower!

Disclaimer
It is important to notify that the GTO and PMV values represent the whole summer period (15th April - 15th October) for all hours a day. As most detainees spend some daytime hours out of their cells, the actual perceived heat stress in cells is probably lower.

The actual heat stress is dependent on what activity detainees do during daytime, and the environment that that is in.

5.5 Conclusion

In total, the simulation shows logical results. The outcome data is validated in two ways, which both showed promising data. The input variables are carefully chosen and elaborated to make a simulation as realistic as possible. With outcome data showing resemblance with previous GTO calculations made for PI Roermond, this simulation shows to be valuable.

Differences in outcome data and true heat stress will always remain present. Therefore, this study is mainly used for comparing different measures on different orientations.

A more sophisticated simulation, of an entire PI, would be recommended to calculate the true heat stress. This would provide more realistic outcome data, as less assumptions need to be made.

Measuring the indoor temperature in cells across PI Zutphen over a period of at least a week will help in connecting the real life situation with this simulation. By collecting a large set of cell temperatures, and outdoor temperatures, these can be compared with what the simulation calculates. This fay, a final conclusion can be made on how realistic the simulation outcomes truly are.

5.6 Base values

With validation done and discussed, the value of the simulation is stated.

The simulation can be now used to compare different measures to one another.

To start off with this, the current heat stress and cell temperatures needs to be explored and discussed.

Results
The four different orientations have varying amounts of heat stress. The total PMV and GTO values are visualised in figure 5.11.

Let's run them down.
Cells on the North facade face the least heat stress. This can be explain logically as the effect of the sun is smallest on this orientation.

The most heat stress is experienced on the east facade.
The South and West facade face similar heat stress.

The average cell temperature is 24,7 ˚C.
By looking at average temperatures per orientation, the differences are made clear. This is visualised in table 5.2 also.

The South and West facing cells have the highest average temperature. The maximum temperature in these cells is also highest, with a top value of 36,2 ˚C. The North and East facing cells seem a few degrees colder.

More comprehensive data is shown in large outcome tables, in Appendix 8.

Table 5.2
Base values of heat stress for PI Zutphen cells

Orientation	North	East	South	West
GTO	1692	4707	3275	3027
PMV	398	1275	867	730
Average cell temperature [*C]	23,9	23,9	26,0	25,1
Max cell temperature [*C]	33,7	33,7	36,2	35,8

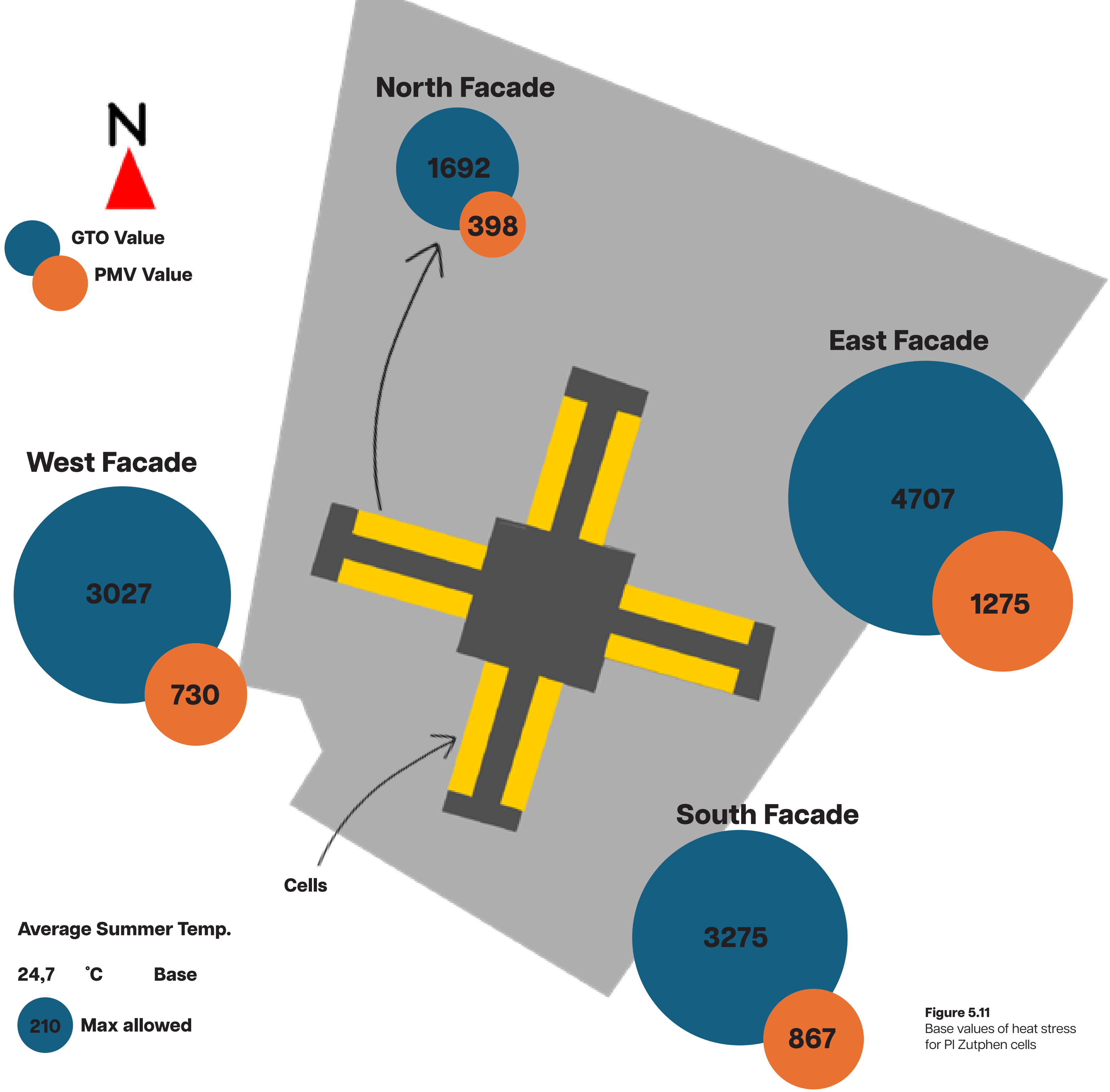
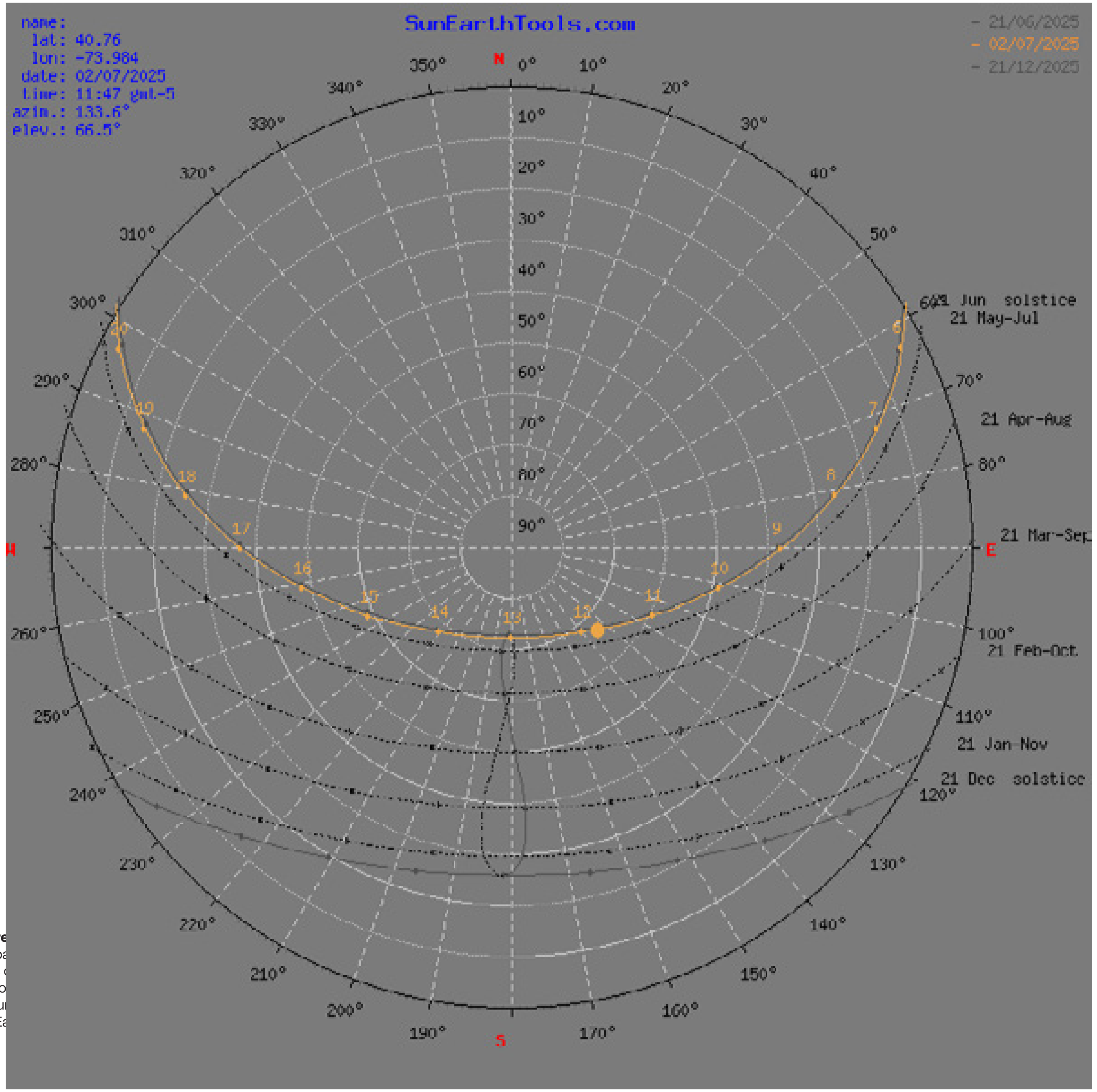


Figure 5.11
Base values of heat stress for PI Zutphen cells



Figure
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Validation

The four orientations all face the same internal loads: heat gain from electrical devices and from the detainee. The difference in heat gain between the orientations must be due to the solar heat gain.
Looking into the path of the sun during summer, it can be seen that the sun does not enter the window in the North facade for even half as long as the other three facades.

The South facade is exposed to the sun all day. The sun is highest around noon, showing the most heat with it alto. This is why the south facade faces the highest temperatures. The East and West facade both face a lot of radiation also. The East facade faces most radiation. With the sun being lower at these times, the solar radiation reached fan into the cell, causing higher perceived temperature.

As means of validation, a cell without a window is simulated as well. On a south facing cell with no window, only 520 GTO was counted (instead of 3275). This is shown in the data in appendix 8. Thus, the window lets in most heat gain. This is important for later, in solution space 2: Solar heat gain.

Discussion

A discussion on possible inaccuracies of the whole simulation is made in section 5.4.
This discussion discusses only these outcomes, to analyse the worth of the data.

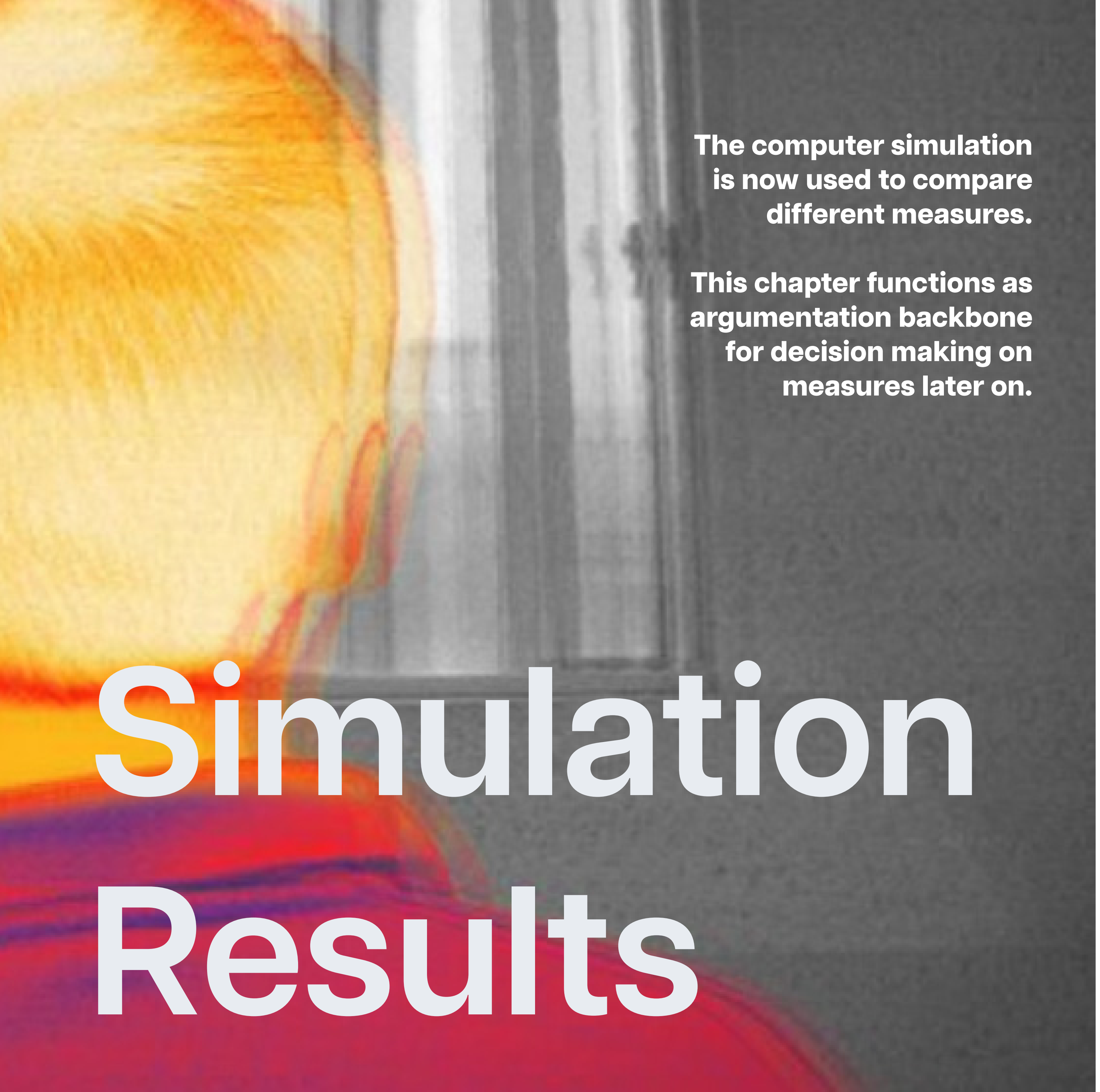
Interesting from these results is that the East facade faces the most heat stress. The GTO and PMV values are the highest here, while the average and maximum cell temperature are not.

Conclusion

The amount of heat stress differs a lot per orientation. This is due to the large effect of solar radiation on the facade and window of the cell. This shows that the impact of solar radiation is the most important heat gain. Reducing heat stress can be done most efficient by reducing this heat gain effectively. This is explored in the coming sections.

North facing cells are the coolest in PI Zutphen throughout summer period. Therefore, it would be best to fill these cells first.

With some cells used for two detainees, this is advised on the North facade. If some cells remain vacant during summer, these cells should be located on the east facade. This way, detainees face a lower amount of heat stress.



Simulation Results

The computer simulation is now used to compare different measures.

This chapter functions as argumentation backbone for decision making on measures later on.

Now that the simulation is carefully explained and elaborated. The simulation can be used to effectively test different measures.

This is done in the following format:

The current cell heat stress is compared to the new heat stress outcome data per measure
The method to simulate the measure is carefully explained.
After analysing and comparing the results, the method is discussed to state the possible inaccuracies or knowledge gaps.

As similar simulation data of measures is hard to find Online, a validation is made where possible, using similar studies. Where this is not done, the discussion section aims to validate the method used for testing the effects of the measure.

In total, this chapter compares each measure with the current situation. The conclusions of this chapter are taken onwards to the client advice chapter. Here, feasibility, viability and desirability of all measures are discussed.

Solution Space

1

2

3

4

5

6.1 Shading overhang

An overhang above the window is meant to stop direct solar radiation from entering the cell during peak hours in summer. In winter, when the sun stands lower, the solar radiation shines into the cell, under the overhang. Thus, an overhang could filter out radiation during the summer season on peak hours. Overhangs are widely used in modern architecture.

The actual effect of this measure depends on the total dynamics of the solar radiation in relation to other heat gain and losses.
In a study found Online, the heat stress (GTO value) of a south-facing apartment with poor insulation was reduced from 8300 to 4400 GTO ("Hitte in De Woning," 2024). This is a reduction of around 46 %.

Thus, this measure seems to be an ideal candidate for reducing heat stress by stopping direct solar radiation from entering the window. Therefore, the effects of an overhang are simulated.

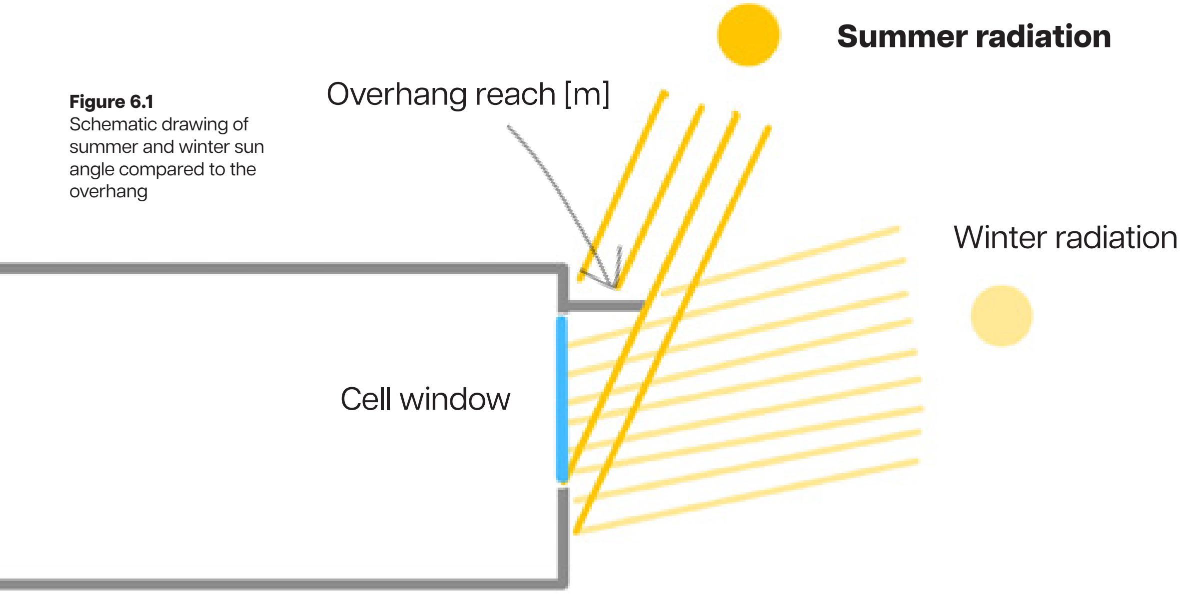


Figure 6.1
Schematic drawing of summer and winter sun angle compared to the overhang

Method
The overhang needs to be made in the right dimensions to only tackle summer radiation. The highest angle of the sun is 61,3 ° in summer (SunCalc Sun Position- Und Sun Phases Calculator, n.d.) With a window of 1,2 meter height, the overhang should reach 0,55 meters as this reach is required to stop all direct solar radiation around noon during summer. No solar radiation penetrates the overhang, thus creating shade.

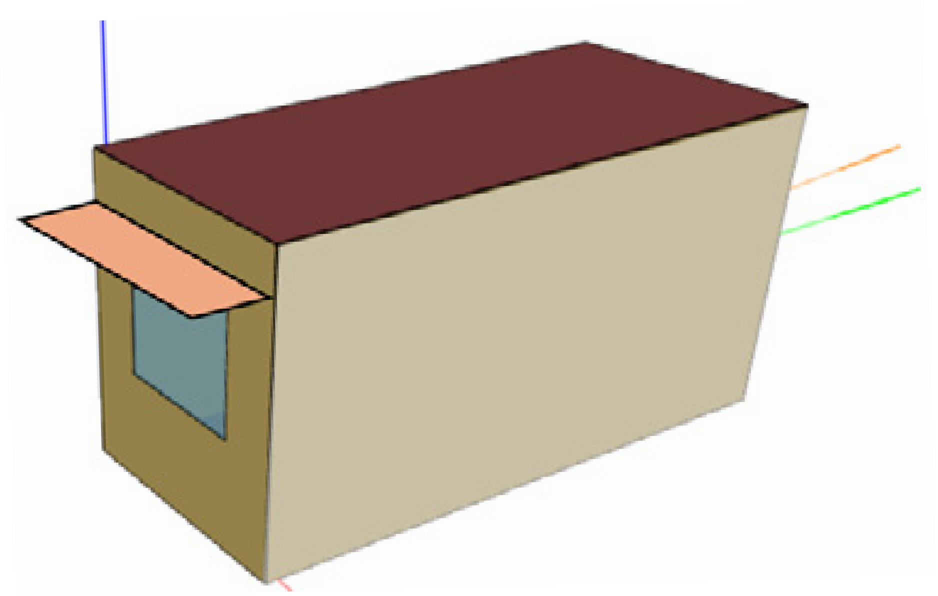
The material and thickness of the overhang have effects on temperature flow in and out of the cell. Wood is chosen as material, as this weighs less than steel or concrete, thus being more realistic to be installed on current facades.

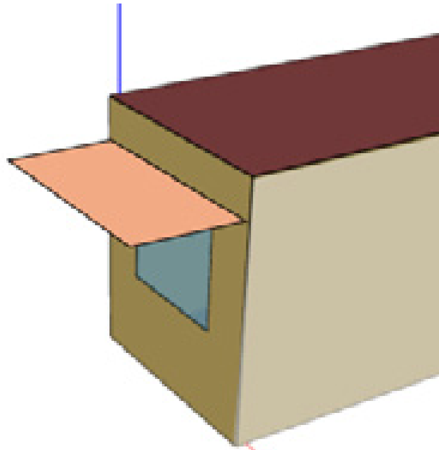
The design choices for the dimensions and material of this overhang are fully explained in Appendix 9.

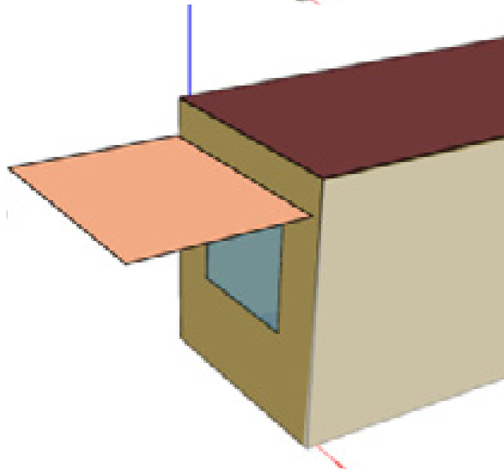
First, an overhang of 0,55 m reach is modeled over the full width of the cell. The overhang is modeled as an additional building surface, on top of the window. This is visualised in figure 6.2 below.

Then, a second test is performed.
To get insights on the correlation between overhang reach and heat stress reduction, different reaches are modeled. To stop more solar radiation, a larger overhang reach can be used. The outcomes can be used in decision making on the right overhang reach.

Figure 6.2
Schematic drawing of summar and winter sun angle compared to the overhang







Results
On this page, all results of the 0,55 m overhang are shown. Let's discuss these per orientation.

The North oriented cells are less exposed to direct solar radiation, thus having less heat stress problems in total. The effect of an overhang is smaller here for the same reason. In these cells, an average temperature reduction of 0,4 degrees Celsius is reached.

More heat stress reduction is present at the other facades.
In terms of time that heat stress is present (PMV), the East and South facing cells have the largest reduction, of 17,2 and 18,1 percent. Then, the West and North facades follow.

The severity of the heat stress (GTO) reduces most on the East and West facade with around 10-13 percent.

The average cell temperature of all cells reduces by 0,4-0,5 degrees Celsius.

The maximum temperature in cells increases in all orientations. This is unexpected and does not seem logical. Possible reasons for this are discussed in the discussion section later on.

Table 6.1
Overview of overhang heat stress compared to current situation

Orientation	North		East		South		West	
Measure	-	Overhang	-	Overhang	-	Overhang	-	Overhang
GTO	1692	1590	4707	4107	3275	2950	3027	2704
PMV	398	368	1275	1044	867	718	730	634
Average cell temperature [*C]	23,9	23,5	23,9	23,5	26,0	25,5	25,1	24,6
Max cell temperature [*C]	33,7	33,9	33,7	33,9	36,2	36,4	35,8	35,8

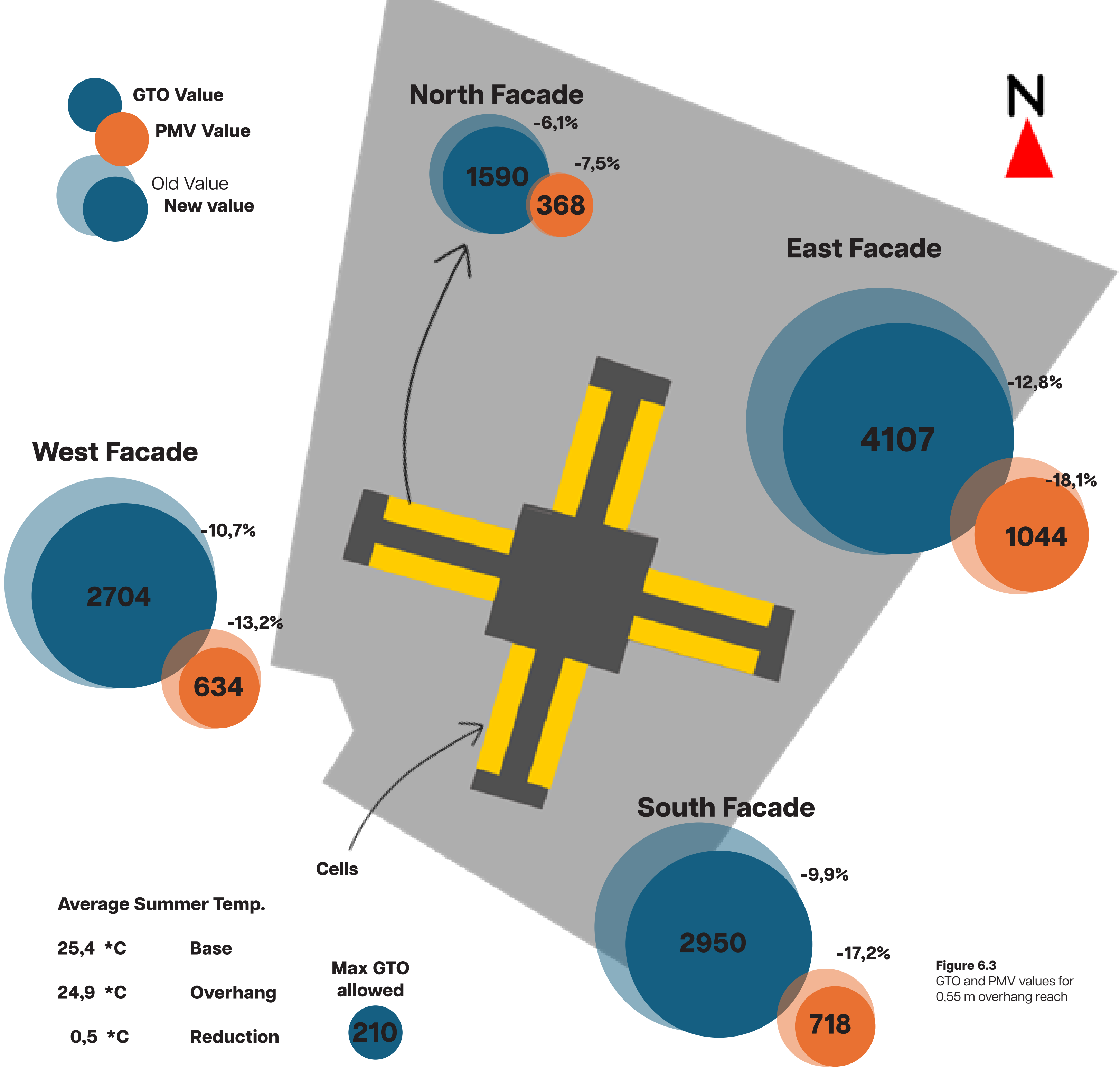


Figure 6.3
GTO and PMV values for 0,55 m overhang reach

Secondly, the results of different overhang lengths is shown. This is done by plotting the outcome GTO and PMV values in a graph, in figure xx.

The GTO line clearly shows that small differences in overhang reach weigh heavier the smaller the overhang is. Making the overhang reach further does help in reducing heat stress, but the effect gets smaller for higher reaches. An overhang of 5 meters would reduce the heat stress (GTO) by 30 %, while that of 0,55 meters only does around 10 %.

The table below shows the cell temperature for these different reaches.

Here it gets interesting.
The average cell temperature drops the further the overhang reaches. Yet, the maximum temperature rises. A possible explanation for this is discussed.

Table 6.2
Overhang reaches and matching outcomes

Orientation	**South**					
Overhang reach [m]	0	0,55	1	1,5	3	5
GTO	3275	2950	2816	2730	2440	2311
PMV	867	718	646	613	523	501
Average cell temperature [*C]	26,0	25,5	25,2	24,9	24,2	23,5
Max cell temperature [*C]	36,2	36,4	36,6	36,8	37,5	38,4

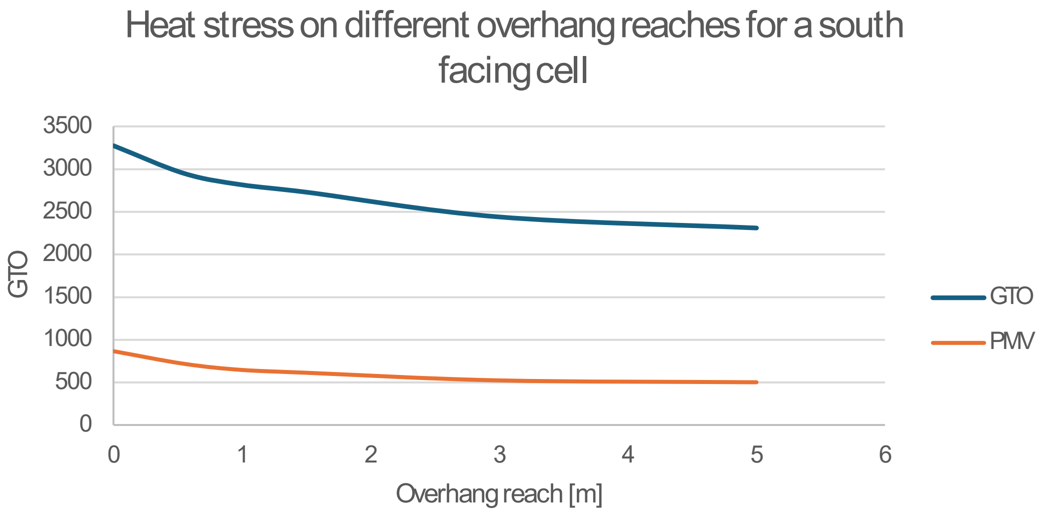


Figure 6.4
GTO and PMV values for a South facade cell for varying reaches

Discussion
The overhang has a different effect for all four orientations. In the Netherlands, The sun's highest angle is 61,33 ˚ in summer. Thus, the sun travels over PI Zutphen via the south facade. Thus, the percentage of solar radiation that is stopped from entering the cell is largest on the south facade.

EnergyPlus calculates heat stress as a sum of a complicated calculation. As demonstrated with the SANKEY diagram, the solar radiation is a large fraction of the heat gain into the cell.
The outcome results can be validated by comparing results with an Online calculation tool.

This tool calculates the percentage of solar radiation that is stopped from entering the window because of the overhang. By filling in the exact same dimensions, the following data is acquired:

North	**East**	**South**	**West**
10	**18**	**25**	**14**

Percentage of total solar radiation that is stopped by the overhang [calculator, appendix].

These percentages should correlate with the outcomes of this study. The relation between the total stopped solar radiation on the North East and West facade seems logical with these results. The south facade looks to be a bit of an outlier, showing only around 10 percent reduction in GTO.

The reduction in GTO is not exactly the same as reduction in total heat gain of course. As reduction in total heat gain is not plotted with the simulation, let's look into different data.

In total, the south facade should have the smallest amount of direct solar radiation entering the cell, due to the overhang. Although it feels logical, this does not automatically mean that the heat stress is reduced the most also. The GTO factor is a sum of difficult cocktail calculations, in which solar radiation plays just a part.

By looking at the PMV, the total amount of hours of heat stress shows a different behaviour.
Here, the South and East facades show the largest reduction in heat stress, which corresponds with the fact that most solar radiation is stopped from entering these cells.

The reason that the overhang creates a higher max temperature could be that the overhang traps heat from exiting the cell during night times.
The heat stravels through the window, and wants to rise up as warmer lighter air. The overhang stops this effect. The further the overhang reaches, the harder it is for this warm air to escape during night.

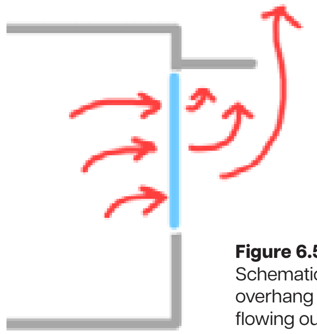


Figure 6.5
Schematic drawing of the overhang trapping heat flowing out of the cell

So far, the different reaches of the overhang provide logical results, which can be explain looking into the behaviour of the sun angle. Secondly, an analysation on the accuracy of the test results is made. Where some data may seem unlogical, efforts have been made to close the gap and explain the outcome differences. Since these differences are present and quite dominant, more validation is necessary.

Thus, The study found online is compared with this studies simulation, under as many similar variables as possible.

Simulation Validation
A computer simulation on heat stress in a 'small apartment' shows the effect of a 60cm overhang. The window of this apartment faces in a south direction. When the windows of the apartment are closed day and night, the GTO value is reduced from 8301 to 4493. This is a reduction of around 45 %. The details of that simulation are not shared in depth. Therefore, the properties and thicknesses of the building fabric are unknown in detail.

By running the simulation on a cell with a south facade, the outcome can be compared.
A southeast facing cell has a GTO value of 3270. This same cell with an overhang has a new value of 2936 GTO. This is a reduction of 10,2 %.

These numbers vary quite a bit, which can be explained by looking back at the SANKEY diagram. In the SANKEY diagram, it is demonstrated that the solar radiation is a fraction of the total heat gain. With the disclaimer that this exact fraction is hard to calculate, due to the dynamic behaviour of heat flows, the exact percentage of heat gain from radiation is unknown.

The simulation shows three large heat gains. Heat from the detainee, heat from appliances, and heat gain from solar radiation. With the overhang, only this last category is reduced. Thus, the percentage of heat gain reduction in total is a smaller percentage in the case of a PI Zutphen cell, compared to the 45 % of the apartment study where solar heat gain is the only heat gain.

Besides this, the simulated cell is equipped with ventilation, which takes away heat. This is not the case in the study found Online. These reasons explain how the GTO reduction is 10,2 % for a PI Zutphen cell, instead of 45%.

	Appartment with overhang	**PI Zutphen cell with overhang**
Location	Netherlands	**Netherlands, Zutphen**
Orientation	South	**South**
Overhang Reach	0,60 m	**0,55 m**
Overhang material and thickness	unknown	**Wood, 0,1m**
Weather data	Netherlands	**Netherlands**
Ventilation	-	**50 m3/h**
Infiltration	-	**0,05 m3/h**
Other heat gains	-	**Metabolic heat (detainee) Appliances**
GTO reduction because of overhang	45%	**10,2%**

Figure 6.3
Validation table with differences in simulations

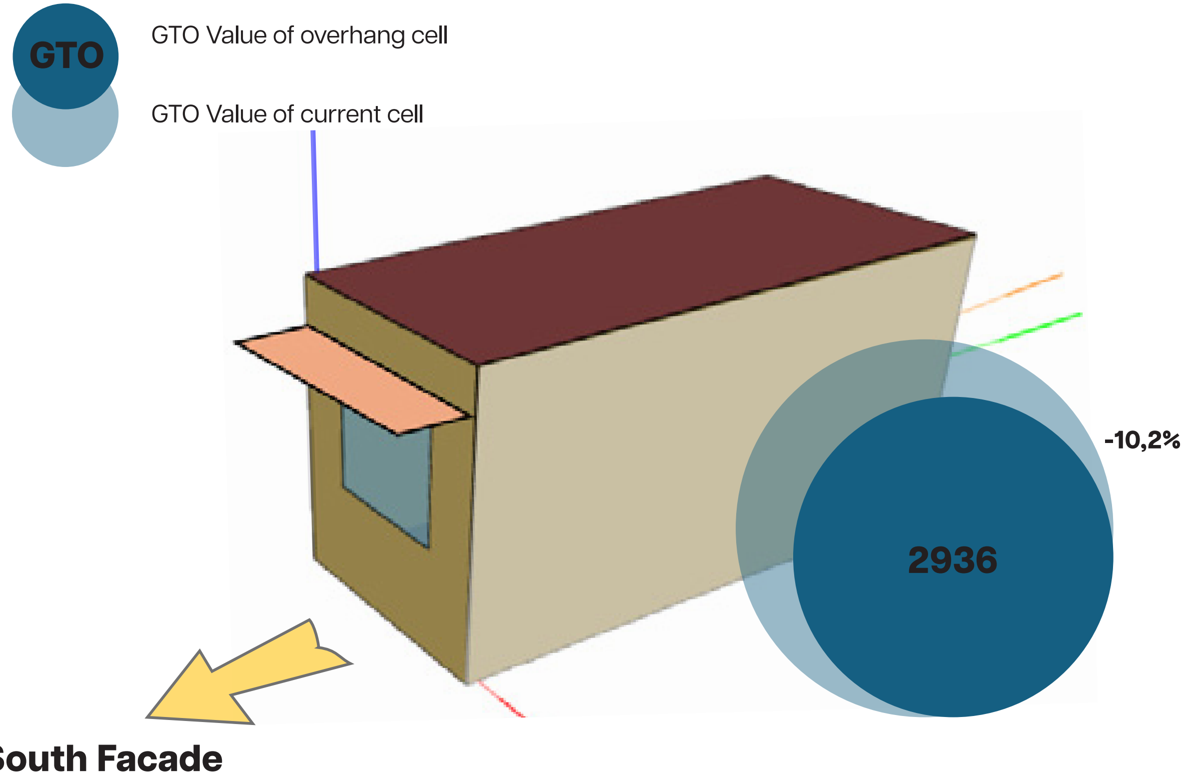


Figure 6.6
Schematic drawing of the validation cell

Conclusion
This simulation is used to test the effects an overhang would have on heat stress in cells. Modeling an overhang is relatively simple in EnergyPlus, and results are easy to compare to the output of cells without overhangs.

The exact behaviour of the overhang needs to be further analysed to explain how the cell faces higher maximum temperatures, even thought the heat stress is reduced.
Efforts have been made to validate the results as good as possible, yet the results remain hard to validate, as the validation model had different or unknown specifications.

Even thought the stopped solar radiation is easy to calculate and validate, the exact influence of the overhang should be researched better in order to make the right decisions in an overhang design.

For this study, this is not further analysed. Where an overhang reach larger than 0,55 meters would make the implementation challenging due to the weight of the overhang, the given heat stress reduction does not weigh in compared to other measures.
Thus, both on the difficulties on realising an overhang as well as simulation knowledge gap, other measures are further analysed and prioritised.

6.2 Reflective window films

A heat reducing measure that shows great potential is reflective window film. This film is placed on the outside of the windows and reflects more of the incoming solar radiation. A potential window film, that DJI already selected as a potential measure, is Alu-70xc.

In PI Zutphen, cells have thermopane windows, with a G-factor of 0.640. This means that 64% of radiation enters through the window, while the rest is reflected away.

ALU-70xc window foil has a g-factor of 0.36, which is almost half of the current g-value. Thus, halving the solar radiation that would enter the cell, leading to less heat stress.

Method
The window in the simulation is modeled as a building surface with properties assigned to it. The g-factor is one of these properties.

Thus, modeling in a window film comes down to changing the g-factor. The g-factor is changed from 0,64 to 0,36.

The simulation is runned for all four different facades to see the effect of this measure.

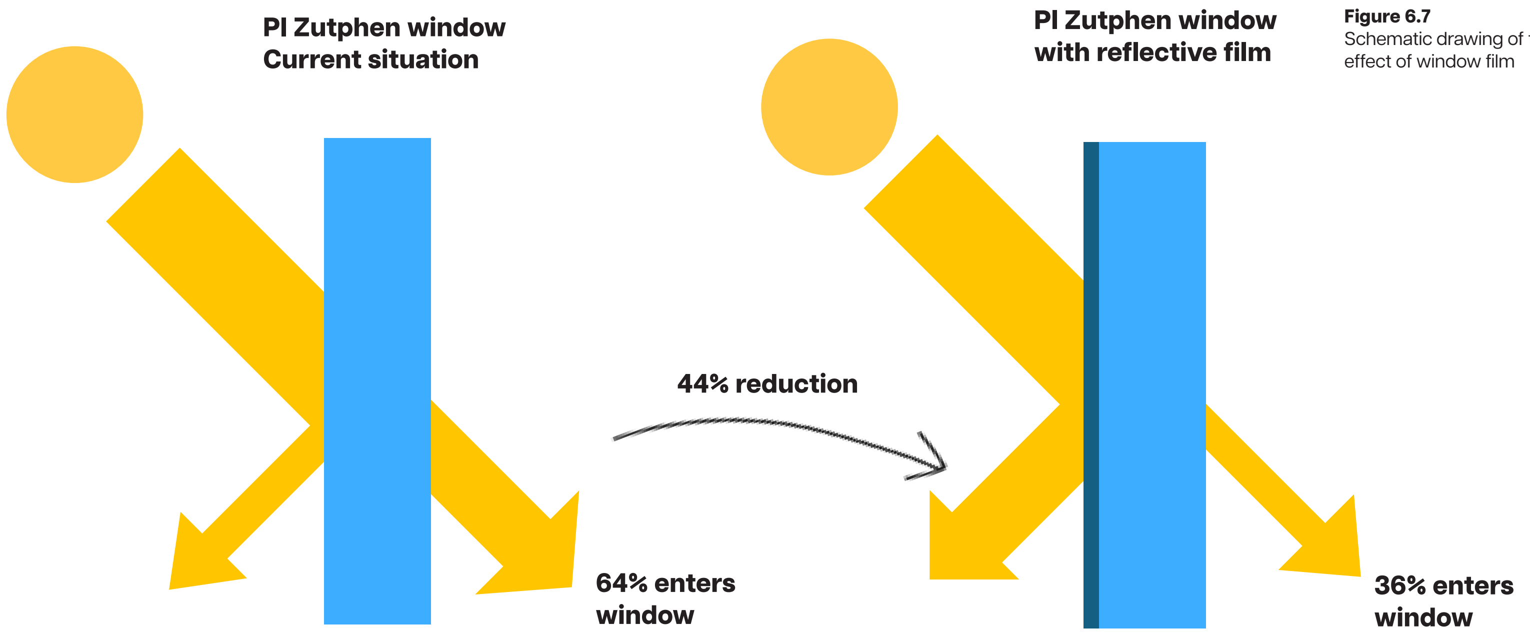


Figure 6.7
Schematic drawing of the effect of window film

Results

As shown in figure 6.7 on the previous page, the window film only lets through about half the solar radiation into the cell as apposed to the current window. The effect is a staggering reduction in heat stress.

The North facade faces the least reduction, when looking at the percentages. This is lower since this facade faces less solar radiation anyway. Therefore, the solar radiation fraction responsible for heat stress is likely smaller than for other facades.

The other facades face a reduction of 50% of the heat stress severity (GTO). For the South and East facades, the time heat stress is present (PMV) is reduced the most, around 60 percent.

The average temperature is reduced with 0,9 to 1,8 ˚C. The South and West facades face the highest temperature reduction in total, as these facades have the most solar exposure. Appendix 9.

The maximum temperature drops with around 1,2 degrees Celsius for the North facade. For the East facade, this is 1,2 ˚C. The South and West facade have a maximum temperature reduction of 2,3 and 2 degrees Celsius.

Discussion

This measure is simple to model into the simulation, as only one variable is changed. Thus, the results of this measure are just as valuable and realistic as the outcome results of the entire simulation.

Therefore, the outcome data is sufficiently validated this way.

Conclusion

This measure shows the highest reduction of heat stress on all facades compared to other measures. This makes this measure super interesting for DJI.

This measure is further analysed in section xx.x

Table 6.4
Outcome data of this measure for all cells

Orientation	**North**		**East**		**South**		**West**	
Measure	-	Window Film	-	Window Film	-	Window Film	-	Window Film
GTO	1692	1018	4707	2310	3275	1679	3027	1559
PMV	398	327	1275	482	867	367	730	375
Average cell temperature [˚C]	23,9	23,0	23,9	23,0	26,0	24,2	25,1	23,7
Max cell temperature [˚C]	33,7	32,5	33,7	32,5	36,2	33,9	35,8	33,7

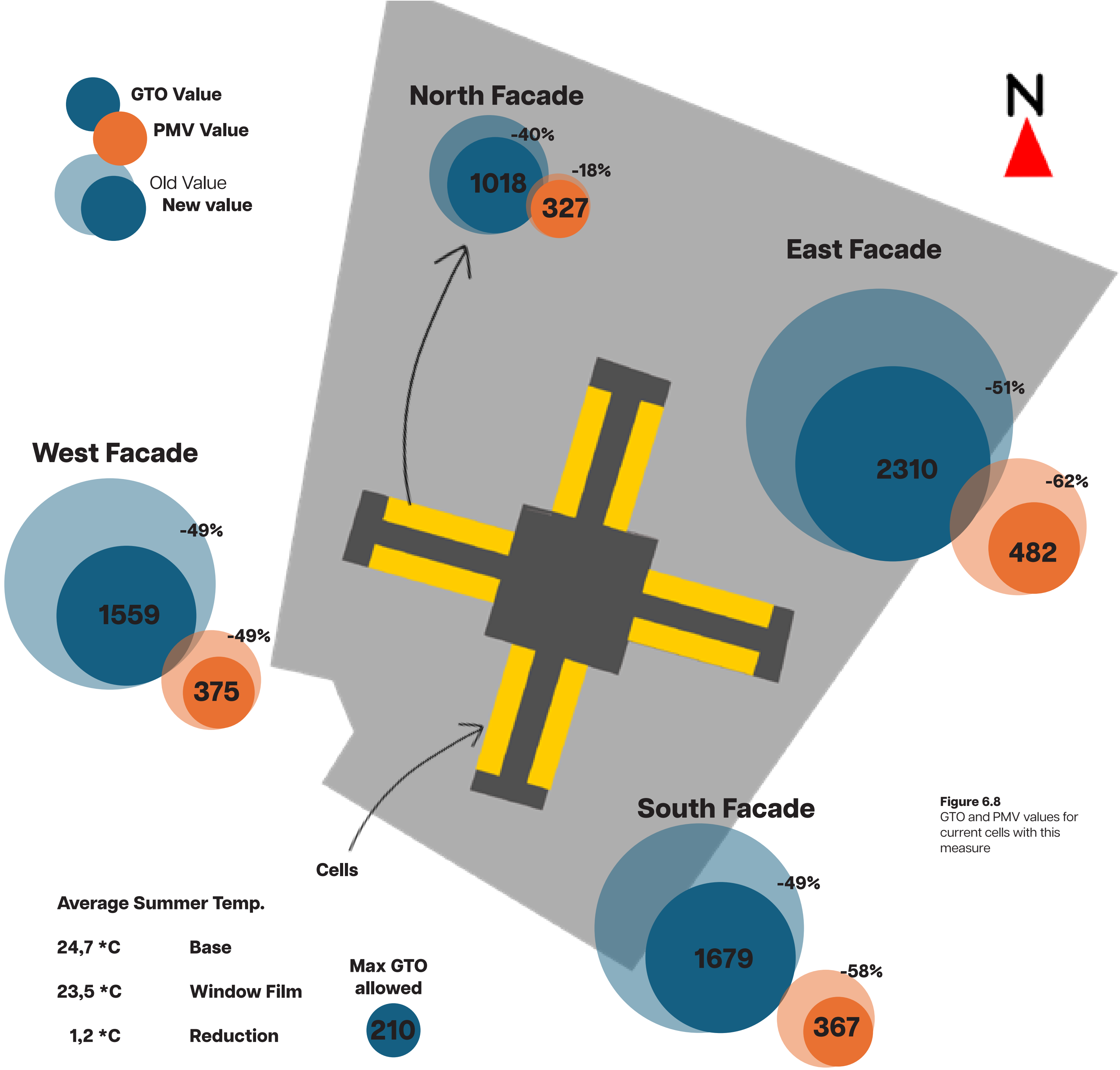


Figure 6.8
GTO and PMV values for current cells with this measure

6.3 White coating on the roof

The roof above the living departments and cells is flat, with a top layer of black bitumen.

Black bitumen has a low albedo, meaning that a small percentage of solar radiation is reflected back into the atmosphere. As an effect, the black bitumen absorbs most of the radiation, causing the building fabric to store heat. This heat is given to the cells via thermal mass and transmission.

Materials with a higher albedo reflect back more solar radiation, thus keeping the building fabric cooler. Studies show that the roof surface temperature can be reduced by up to 4 *C [18 GoF6].

Applying a white coating on the roof of the living departments would lower heat stress, as the majority of solar radiation is reflected away. The albedo of white coatings vary, but can be as high as around 0,85 (Sharma et al., 2016).

Method

The surfaces of the cell are linked with a construction set, made out of a pack of materials. These materials are all modeled as realistic as possible, with specific heat properties appointed to them.
The outside layer of the roof of the building is made from black bitumen. The solar absorptance of this material is modeled as 0,9. This means that 90% of all solar radiation is absorbed.

The exact albedo varies per white coating, therefore a value of 0,80 was chosen. This corresponds with a solar absorptance of 20%. Thus, the effect of a white coating can be modeled by changing the solar absorptance of bitumen from 0,9 to 0,2.

This way, the roof reflects more radiation, causing less heat gain into the cell and building fabric.

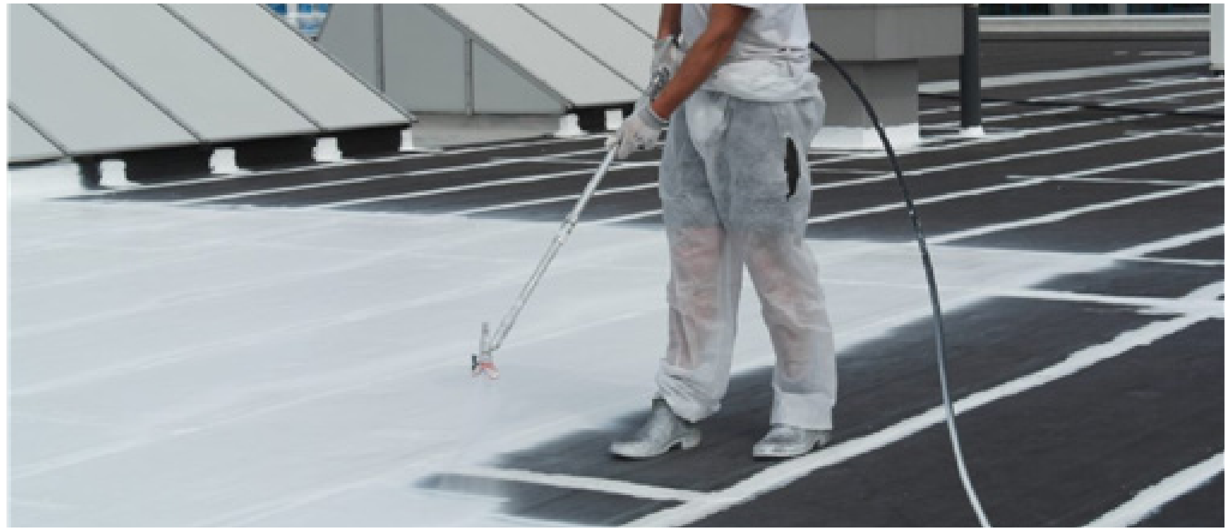


Figure 6.9
Picture of white coating being applied to a roof

Black roof
Low albedo
small fraction of radiation is reflected

Roof with white coating
High albedo
Large fraction of radiation is reflected

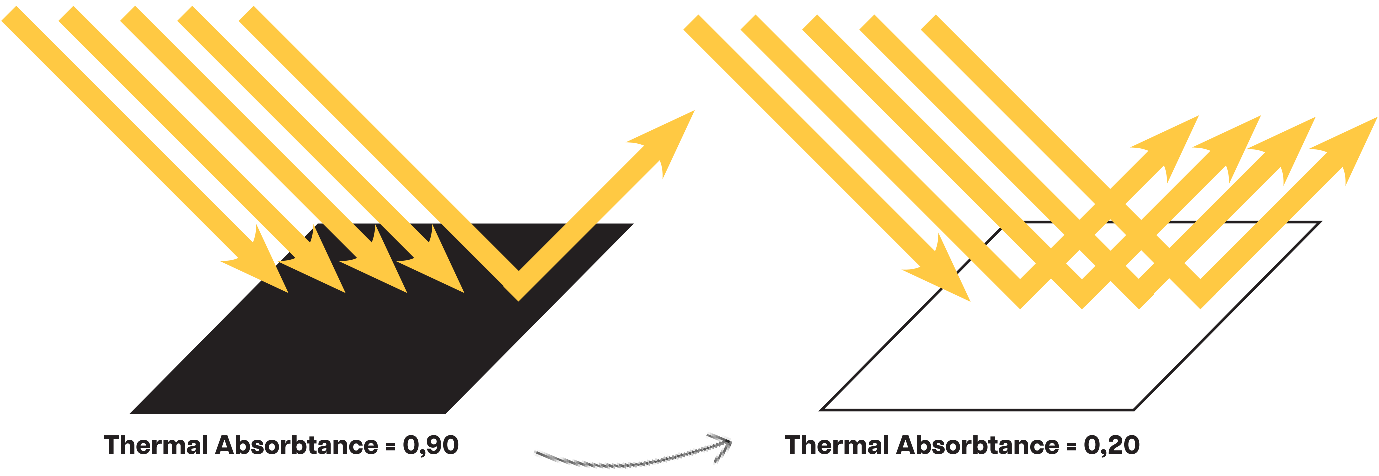
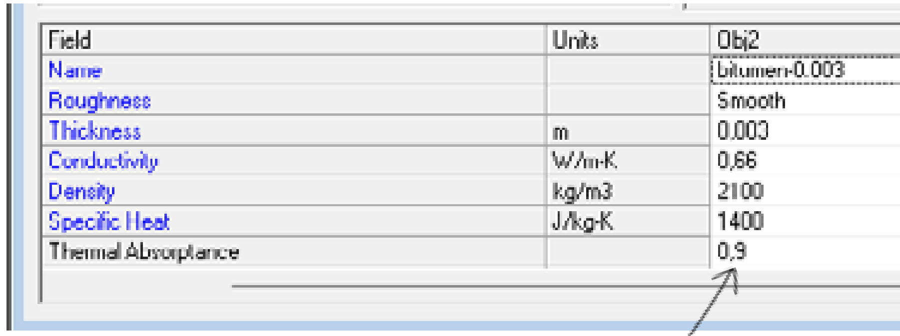


Figure 6.10
Visualisation of reflecting capacities of white coated roof

The simulation is runned for cells on all four orientations. The outcomes of cells with a black bitumen roof are compared to those with a white coated bitumen roof.

The results are shown on the next page.



Field	Units	Obj2
Name		bitumen-0.003
Roughness		Smooth
Thickness	m	0.003
Conductivity	W/m-K	0,66
Density	kg/m3	2100
Specific Heat	J/kg-K	1400
Thermal Absorptance		0,9

Figure 6.11
Image of EnergyPlus material properties

Results
The white coating on the roof is responsible for a decrease in heat stress hours (PMV) of 13 - 22 percent. The severity of the heat stress (GTO) is reduced by 14 - 24 %. The average cell temperature is reduced with 0,4 degrees Celsius. The North facade has a larger decrease in heat stress as opposed to the other three orientations, which show a GTO reduction of 14-16 percent.

The first thing that draws attention is the difference between the North facade and the other three. The North facade faces way less solar radiation onto the window and exterior wall then the other three orientations, which makes the solar heat gain of the roof a larger fraction of the total heat gain automatically. Now that this heat gain is affected by the white coating, the North facade has a higher percentage in GTO reduction because of this reason.

The maximum temperature in cells decreases by 0,6-0,7 degrees Celsius.

Discussion
This measure is simple to simulate in the software. The reflectivity of the roof is changed, causing the lower heat gain into the cells.
As the effect of this measure influences the top cells, and not the cells below this, the effects of this measure on these cells would be insightful to know also.

Thus, better would be to run this simulation for the entire PI.

Conclusion
Applying a white coating to the roof should definitely be considered by DJI for its effect.
A possible downside of this measure is the maintenance required to keep the roof white and clean. Costs and implementation are discussed in section X.x.

Table 6.5
Outcome data of this measure for all cells

Orientation	North		East		South		West	
Measure	-	White Coating	-	White Coating	-	White Coating	-	White Coating
GTO	1692	1292	4707	4043	3275	2753	3027	2560
PMV	398	345	1275	1065	867	680	730	617
Average cell temperature [*C]	23,9	23,5	23,9	23,5	26,0	25,6	25,1	24,7
Max cell temperature [*C]	33,7	33,1	33,7	33,1	36,2	35,5	35,8	35,1

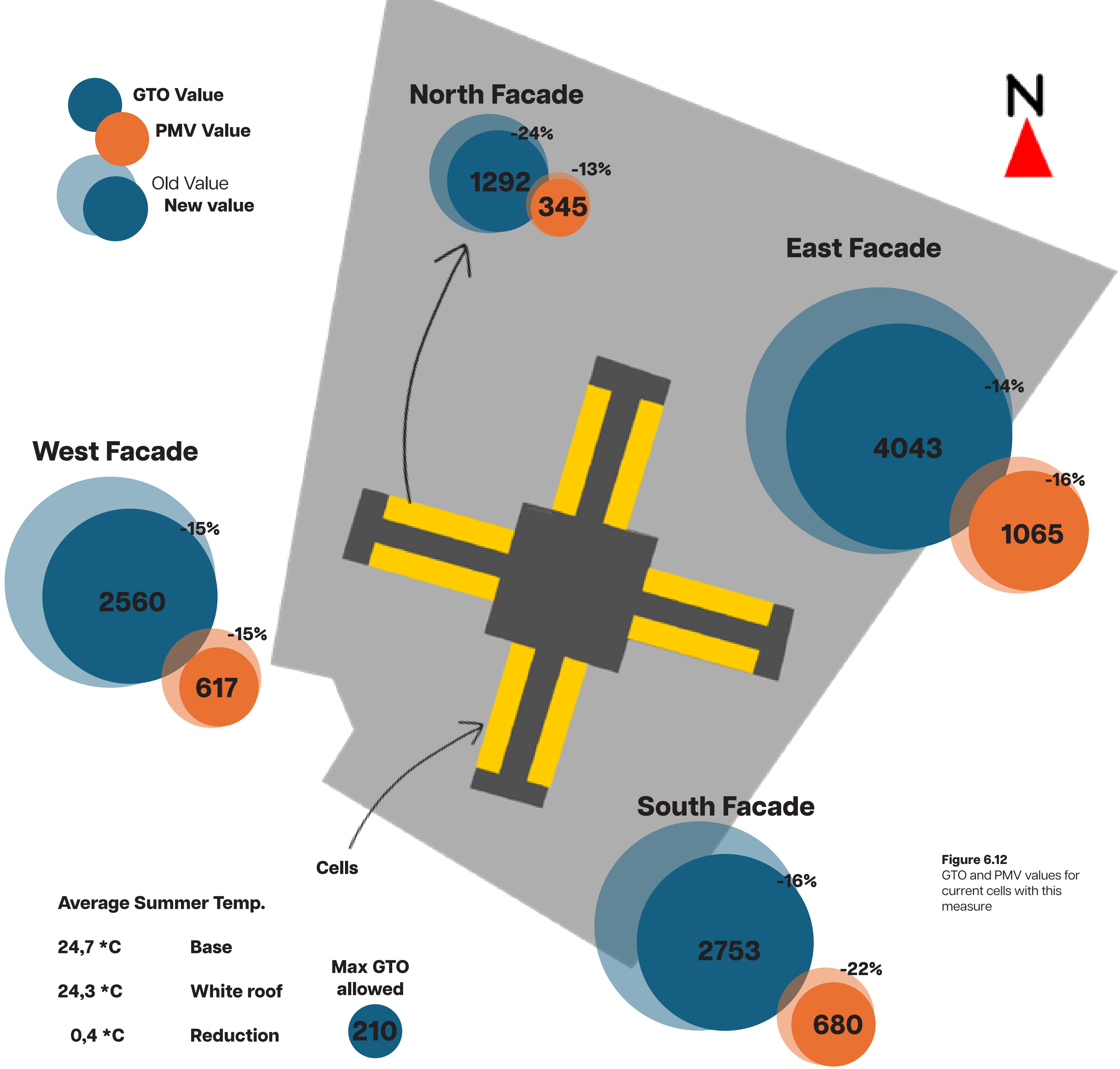


Figure 6.12
GTO and PMV values for current cells with this measure

6.4 White Roof and Window Film

As concluded, the window film and white coating seem promising. The combined effects reduce heat stress even more. Therefore, the simulation is done on both measures together, for all four orientations.

Conclusion
This combination of measures is showing great results. The heat stress is lowered enormously. These results are taken on to section 7 for decision making later on.

Results
The heat stress reduces with more than 50 percent. The temperatures of cells are decreased by 1-3 degrees Celsius. The PMV values all end up at around 310-390.

Discussion
These results are the measures combined. The discussion of these measures are elaborated on in sections 6.2 and 6.3. The inaccuracies of these modeled measures create a potential larger inaccuracy. Thus, the numbers are interpreted with a broader margin this time.

Table 6.6
Outcome data of combined measures for all cells

Orientation	North		East		South		West	
Measure	-	WR WF	-	WR WF	-	WR WF	-	WR WF
GTO	1692	727	4707	1866	3275	1315	3027	1169
PMV	398	314	1275	386	867	342	730	337
Average cell temperature [*C]	23,9	22,6	23,9	22,6	26,0	23,8	25,1	23,3
Max cell temperature [*C]	33,7	31,9	33,7	31,9	36,2	33,2	35,8	33,1

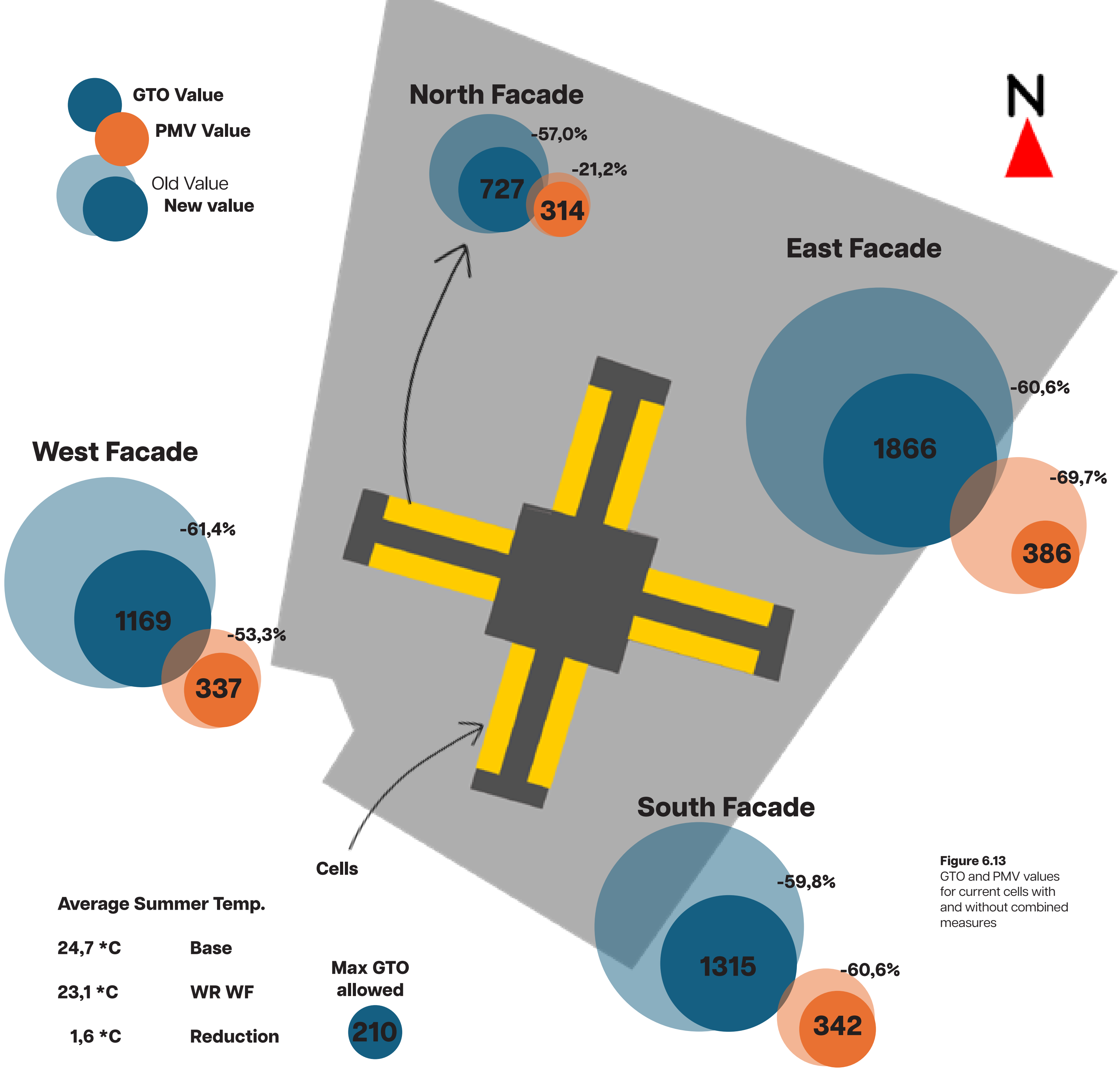


Figure 6.13
GTO and PMV values for current cells with and without combined measures

6.5 Clothing factor

The clothing factor is one of the six factors that determine the perceived temperature.
The effects of the clothing factor can be simulated, as this variable is taken into account in heat stress calculations.

Method
The clothing factor is initially chosen as 0,5 as this represents a summer outfit.
The heat stress calculations in all tests in this chapter are done for people who wear clothing representing this factor of 0,5.
By changing this factor, different outfits can be simulated to see the effect on perceived heat stress.

The factors of 1,0, 0,7 and 0,3 are chosen. These represent different outfits, as seen in table XX.

The effect of the clothing factor is tested on the measures PMV and GTO for a South facing cell.

Figure 6.14
Uniform VS own clotihing

Clothing	**Clothing factor**
Tropical clothing (shorts, t-shirt, thin underwear)	0,3
Light summer clothing (thin long pantalon, t-shirt, underwear)	0,5
Regular clothing (pantalon, shirt, underwear)	0,7
Regular work uniform (shirt with tie, pantalon, vest)	1,0

Table 6.7
Clothing factors and matching clothes
(Van der Linden, 2005)

Table 6.8
Clothing factor and matching heat stress

Orientation	**South**			
Clothing factor	0,3	0,5	0,7	1,0
GTO	2626	3275	4314	5347
PMV	536	867	1393	2345
Average cell temperature [*C]	26,0	26,0	26,0	26,0
Max cell temperature [*C]	36,2	36,2	36,2	36,2

Results
The clothing factor does not influence the cell temperature. Only the perceived temperature is affected, thus affecting heat stress.

The correlation between perceived heat stress is visible in the graph below. The relation between clothing factor and GTO and PMV values is linear.

Discussion
This measure is simple to model into the simulation, as only one variable is changed. Thus, the results od this measure are just as valuable and realistic as the outcome results of the entire simulation.

Therefore, the outcome data is sufficiently validated this way.

Conclusion
This information might seem intuitive, but the graph can be used as argumentation for DJI in reducing heat stress.
The way both detainees and PIWs dress in the PI affects the perceived heat stress.

Advice on how DJI can use this information into measures for lower heat stress among stakeholders is further discussed in section 7.

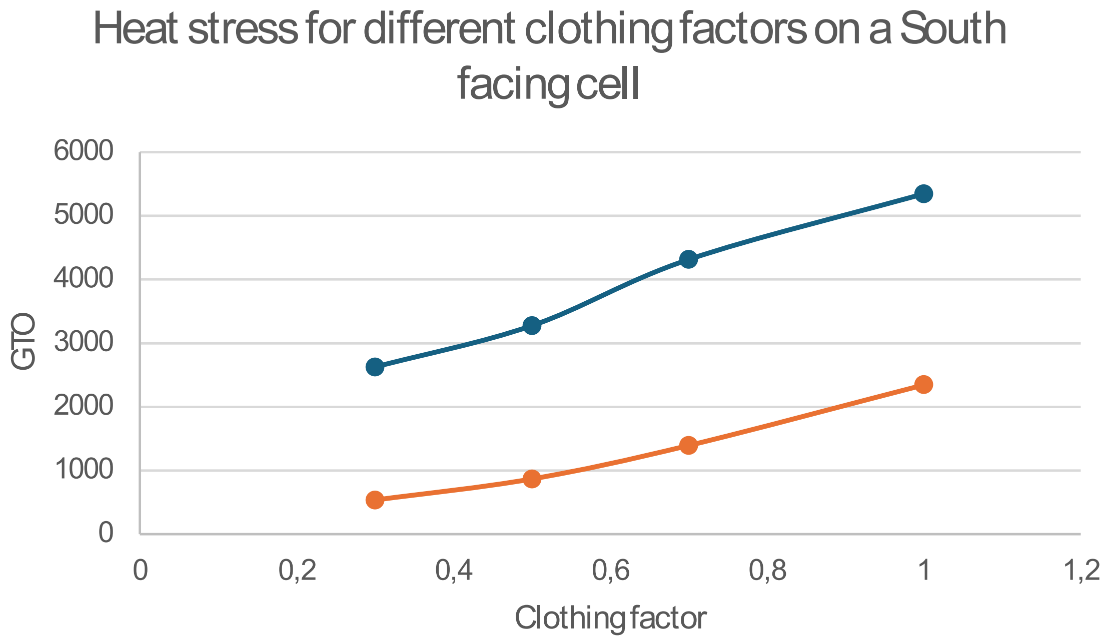


Figure 6.15
Trendline connecting heat stress and clothing factor

6.6 Table fan

The air speed is also one of the six factors that determine the perceived temperature.
As elaborated on in the explanation of the simulation, the air speed in the cell is modeled into the simulation. Thus, this can be changed to see the effect of air speed on the heat stress that detainees perceive.

Method
The air speed or draft that is active in the cell is modeled in with one variable. Thus, this variable is changed. An air speed of 1 m/s is chosen. The air speed that table fans can generate varies from 0,5 to 1,5 m/s.
The table fan uses energy to generate this air flow. Thus, an additional electrical device is modeled in, with 25 Watts of energy use, as heat gain into the cell.

Results
The higher air speed in the cell causes a draft, which is one of the factors determining perceived temperature.
The more air moves around our body, the more heat is given off as convection. This way, you cool down.

The GTO is reduced with 21 percent. The PMV value is even reduced with 44 percent. Thus, the table fan shows heat stress reducing effect.

The cell temperature rises due to the energy use of this measure.

Discussion
Important here is that the perceived temperature goes down, while the actual temperature rises due to the energy use of the table fan.

Conclusion
Handing out table fans to detainees causes a lower perceived temperature in cells, thus lower heat stress. The actual temperature rises quite a bit, which is not felt by detainees directly.

This measure is efficient to use just because detainees feel relieved and cooled down by it. Yet, a measure that lowers heat stress while creating additional heat may not be the best measure in total. This is further discussed in section 7.

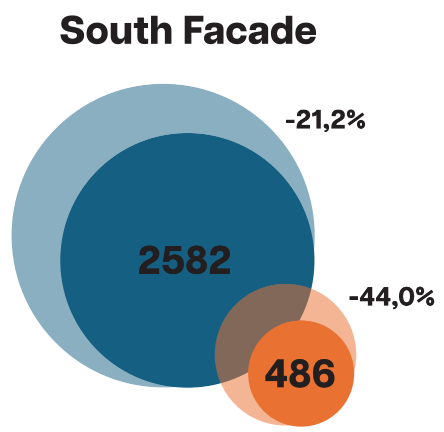


Table fan in cell to generate air speed of 1 m/s

Table 6.9
How air speed influences heat stress

Orientation	South	
Air speed in cell [m/s]	0,15	1
GTO	3275	2582
PMV	867	486
Average cell temperature [*C]	26,0	26,4
Max cell temperature [*C]	36,2	36,7

Figure 6.16
A table fan is shown in a PI Zutphen cell

6.7 Energy Saving equipment

The electrical devices in the cell are responsible for a part of the heat gain. By changing these to more energy efficient ones, this heat gain can be reduced, causing lower heat stress in cells.

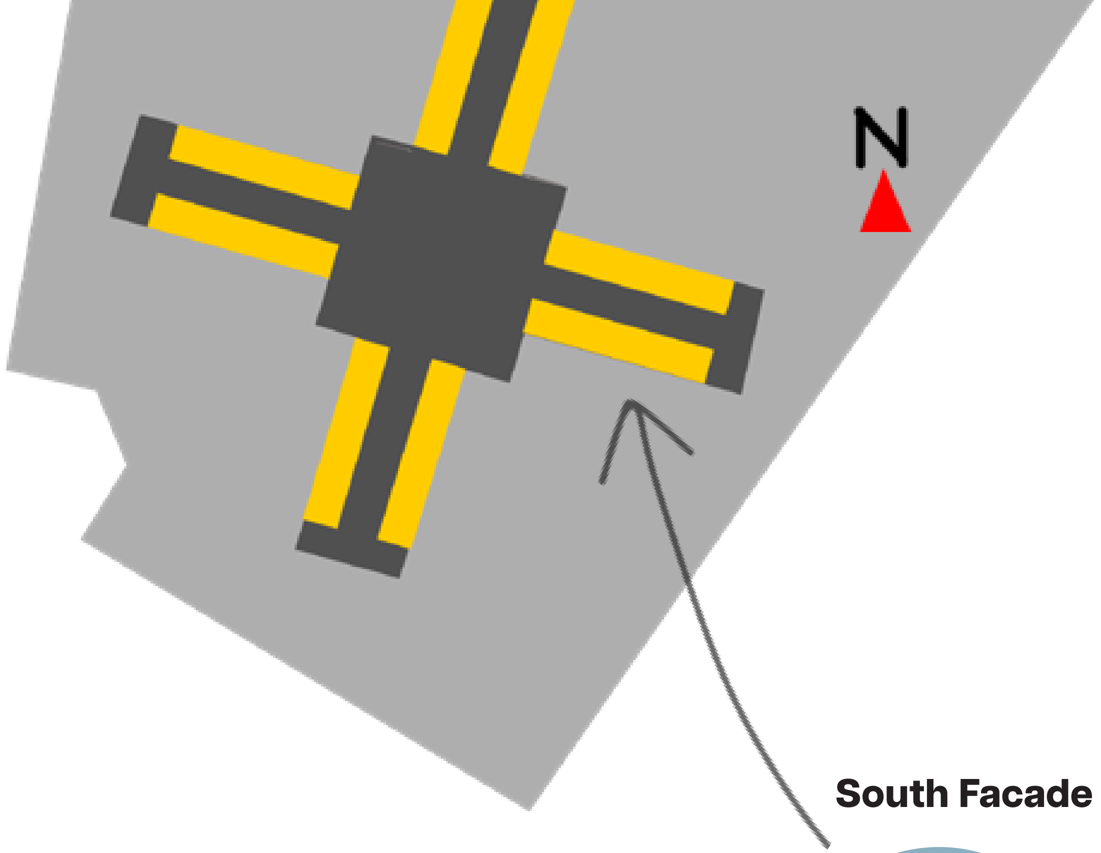
The exact possibilities of this measure depend hugely on what current devices are used, and whether or not these can be swapped for more efficient ones.

Without going in depth of this, the potential of this is measures by halving the electrical device heat gain in the simulation.

Method
The Wattages of all devices in the cell are halved in the simulation. The simulation is runned on a south facing facade only.

Table 6.10
Outcome data of energy saving equipment on the South facing cell

Orientation	South		Reduction
Measure	-	Energy Saving devices	
GTO	3275	2635	19,5 %
PMV	867	617	28,8 %
Average cell temperature [*C]	26,0	25,3	0,7 *C
Max cell temperature [*C]	36,2	35,5	0,7 *C



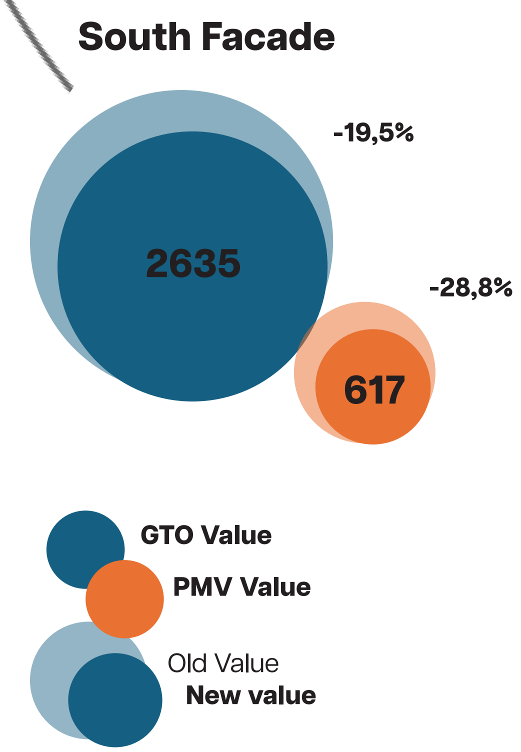


Figure 6.17
Visualisation of data from table 6.10

Results
As the table and graph show, the reducing effect of this measure is quite large.

Discussion
These results show what impact more efficient devices would have on the heat stress. Yet, this impact can only be reached if the current devices are replaceable by much more efficient ones.

Other electrical devices such as water cookers, coffee makers, and microwaves are not simulated in this model.

Conclusion
This test shows that energy saving devices are responsible for lower heat stress and cell temperatures. With specific Wattages of electrical devices, this simulation could precisely predict the heat stress reducing effect.
More on this measure is concluded in section 7.

6.8 Different ventilation flows

Since the ventilation is the biggest factor in taking heat out of the cell, the impact of ventilation is necessary to dive into.

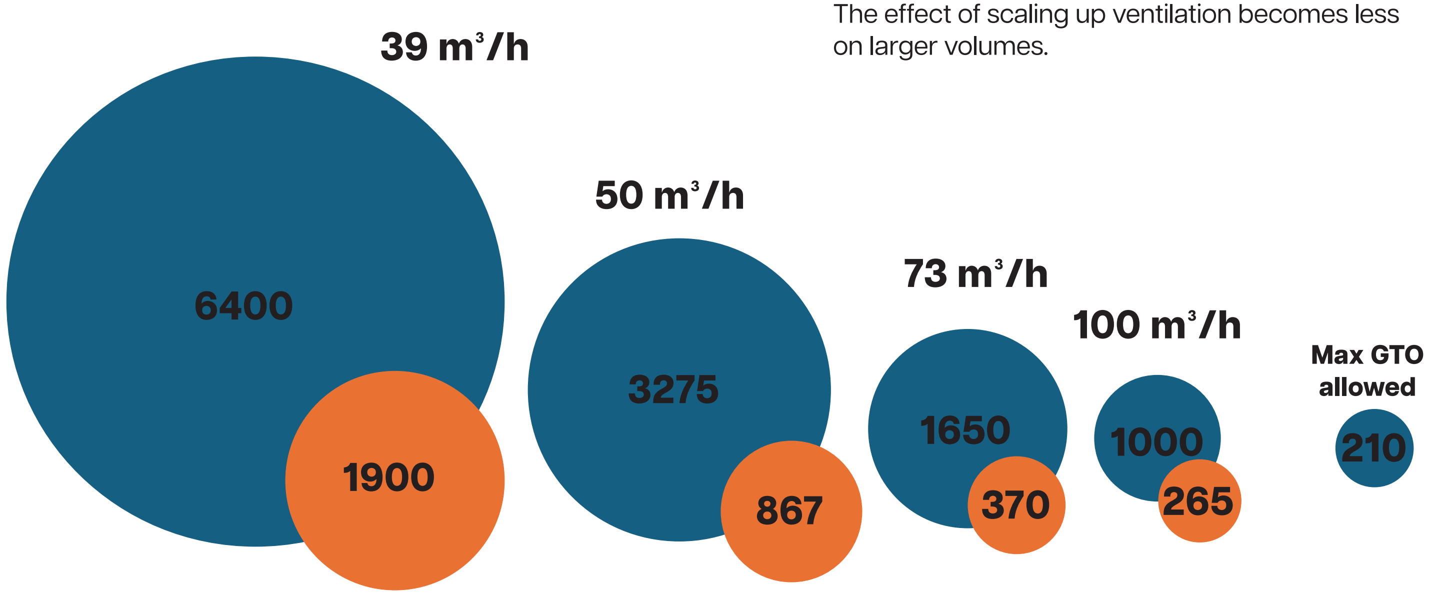
The cells have 50 m^3/h of air flow, theoretically. This value might differ from cell to cell, and is dependent on the true state of the ventilation canals, grilles, and operations.

As there were complaints about heat stress, and ventilation working badly, this is the first step to dive into.

Method
The ventilation rate of the simulated cell can be adjusted easily. To test the relation between ventilation flow and heat stress, this is done with 16 different ventilation flow rates. This way, the GTO and PMV values can be plotted in a graph.

A south facing cell is chosen to test this effect, as the south facing cell has the highest temperatures during summer.

Figure 6.18
GTO and PMV values for a South facade cell for varying ventilation



Results
The outcome of the different simulations is visualised in the graph. Here, the relation between perceived heat stress and true ventilation flow is made clear.

The true ventilation shows an exponential decrease. Where a slight change in ventilation on a flow of 50 m^3 per hour has 3 times the effect of that on ventilation flow of 80 m^3 per hour or more.

With current ventilation of 50 cubic meters, the GTO and PMV values are 3275 and 876 for a South facing cell in Zutphen.

With ventilation at almost 80 % (39 m^3/h) the GTO is almost doubled. The PMV value is more than doubled.

The values can be halved by scaling up ventilation from 50 to 73 cubic meters per hour.

Doubling the ventilation flow to 100 m^3/h will not set the GTO value to 210 or less.
The effect of scaling up ventilation becomes less on larger volumes.

Discussion
Adjusting the ventilation flows in the simulation creates these outputs. Reasons why ventilation would be lacking may also affect heat stress or cell temperatures. Adjusting the ventilation rate does not take into account why the ventilation is not performing as it should be. Therefore, possible differences with the actual heat stress are unknown.

Apart from this potential inaccuracy, these results provide valuable insights for DJI to reduce heat stress.

Conclusion
The trend line of the GTO value stresses the importance that the current ventilation functions as good as possible. Where lower ventilation flows than 50 m^3/h lead to preventable heat stress.

Now that this effect is quantified, the next step is to look at the current state of the ventilation to tackle preventable heat stress. Also, the possibilities on higher ventilation flows are discussed. This is all further discussed in Section 7.

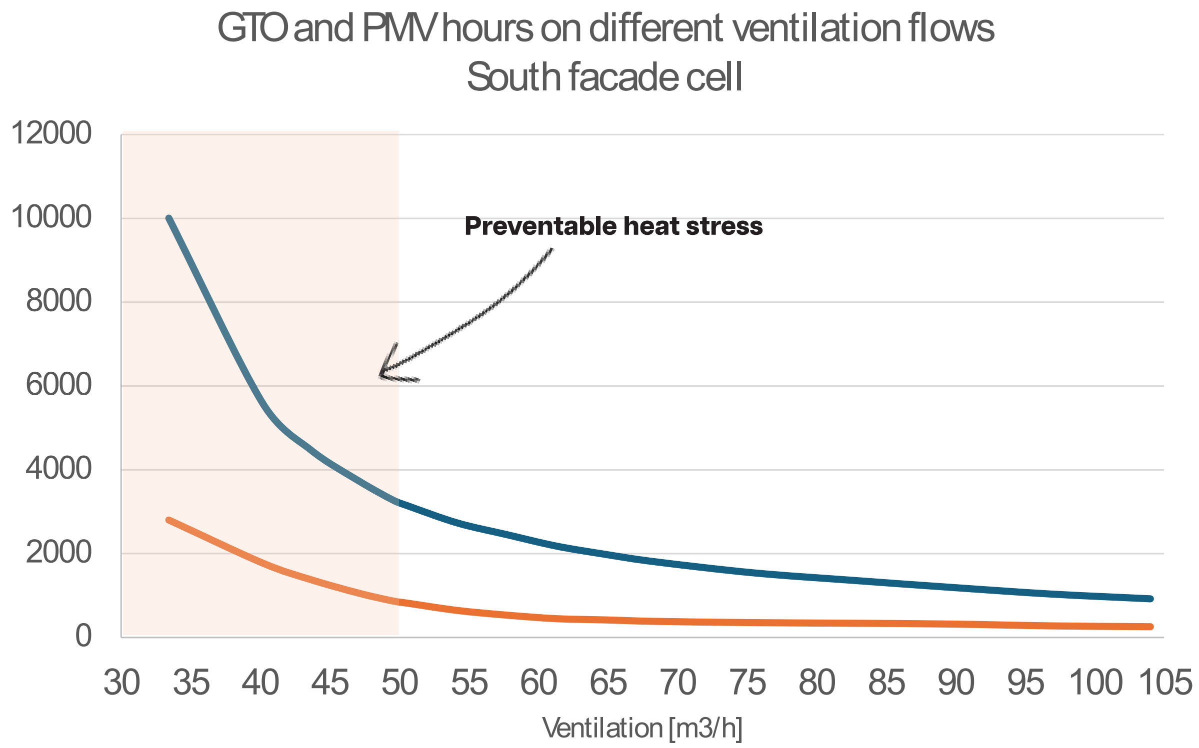


Figure 6.19
GTO and PMV values for a South facade cell for varying ventilation

6.9 Overview of potential measures

Table 6.11
Outcome data of all measures on the North facade

North					
Measure	Now	Shading Overhang	White Roof	Window Film	WR WF
GTO	1692	1590	1292	1018	727
PMV	398	368	345	327	314
Average cell temperature [*C]	23,9	23,5	23,5	23,0	22,6
Max cell temperature [*C]	33,7	33,9	33,1	32,5	31,9

Table 6.12
Outcome data of all measures on the East facade

East					
Measure	Now	Shading Overhang	White Roof	Window Film	WR WF
GTO	4707	4107	4043	2310	1866
PMV	1275	1044	1065	482	386
Average cell temperature [*C]	23,9	23,5	23,5	23,0	22,6
Max cell temperature [*C]	33,7	33,9	33,1	32,5	31,9

Figure 6.20
Outcome data of all measures on the North facade

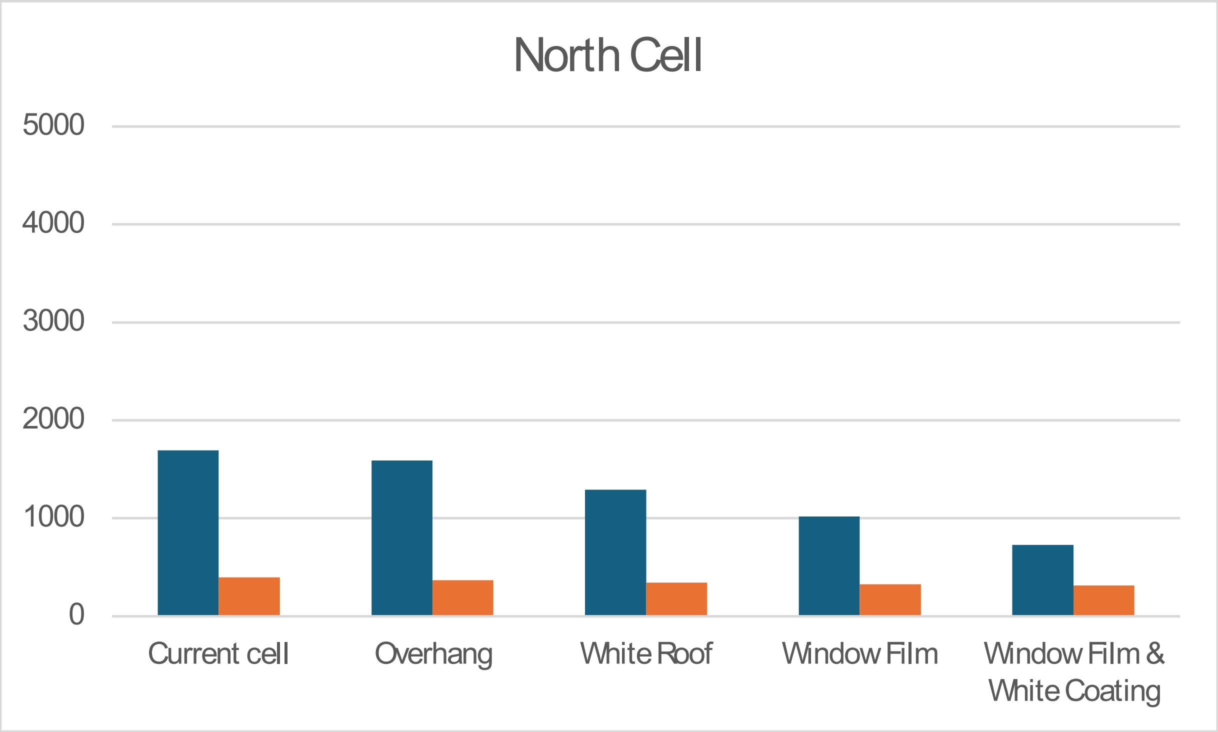


Figure 6.21
Outcome data of all measures on the East facade

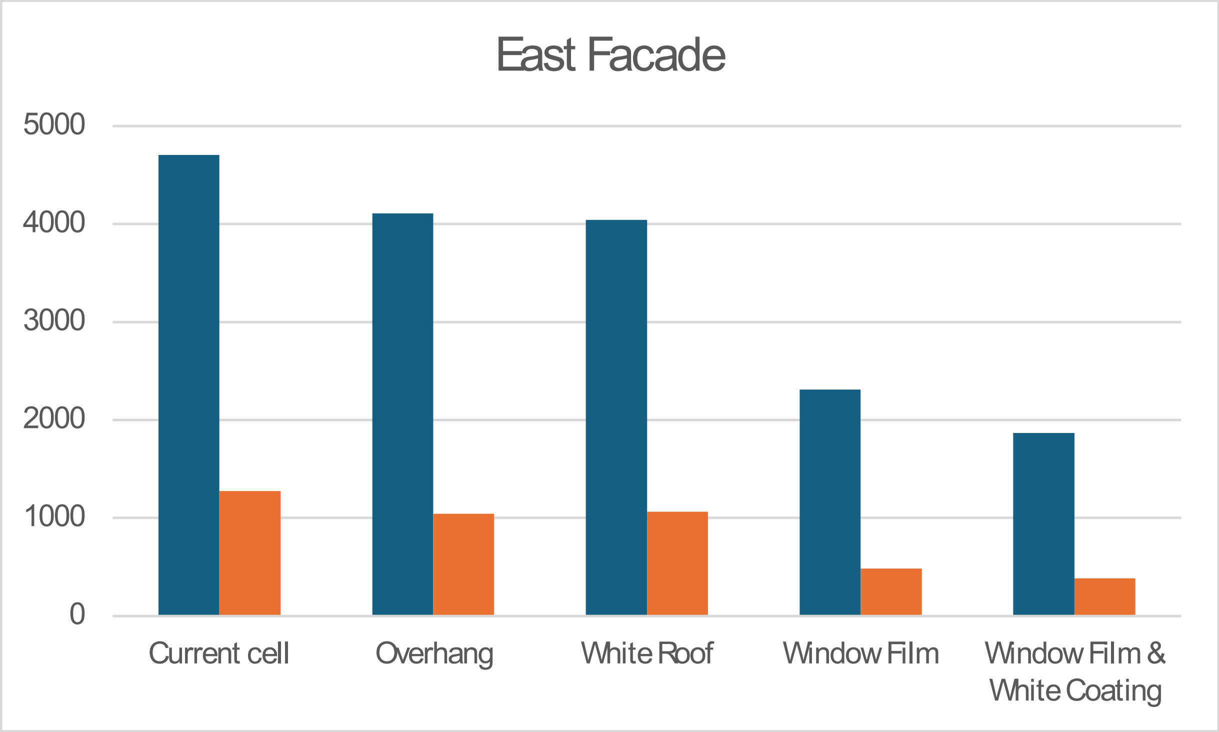


Table 6.13
Outcome data of all measures on the South facade

South					
Measure	Now	Shading Overhang	White Roof	Window Film	WR WF
GTO	3275	2950	2753	1679	1315
PMV	867	718	680	367	342
Average cell temperature [*C]	26,0	25,5	25,6	24,2	23,8
Max cell temperature [*C]	36,2	36,4	35,5	33,9	33,2

Table 6.14
Outcome data of all measures on the West facade

West					
Measure	Now	Shading Overhang	White Roof	Window Film	WR WF
GTO	3027	2704	2560	1559	1169
PMV	730	634	617	375	337
Average cell temperature [*C]	25,1	24,6	24,7	23,7	23,3
Max cell temperature [*C]	35,8	35,8	35,1	33,7	33,1

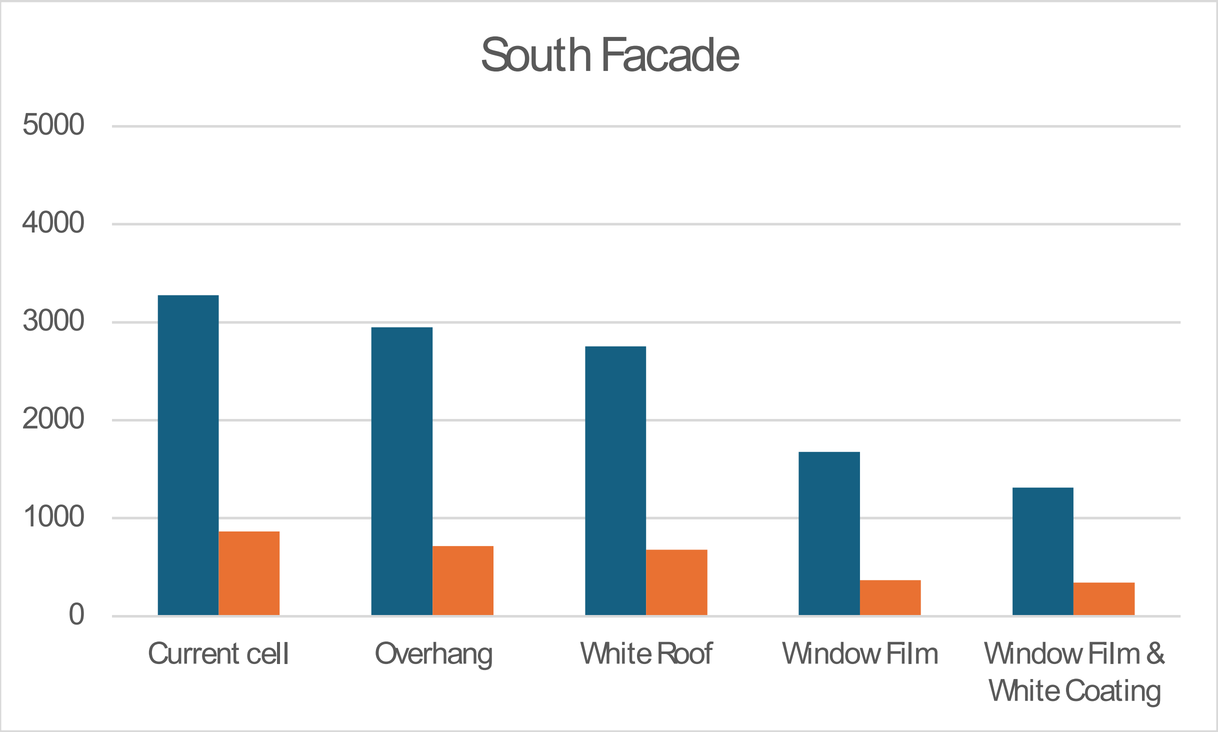


Figure 6.22
Outcome data of all measures on the South facade

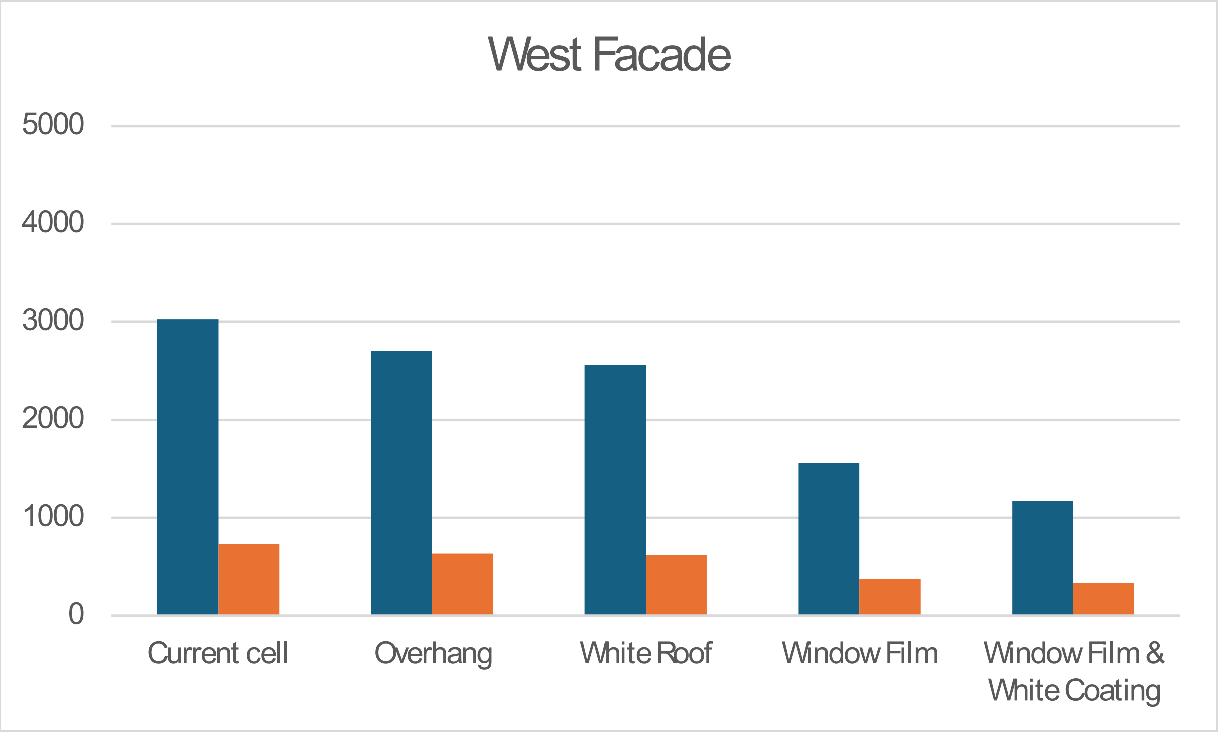


Figure 6.23
Outcome data of all measures on the East facade

Measures Explained

Section 4 provided 18 finalist ideas and concepts that seem promising in reducing heat stress in cells. This chapter elaborated each measure on feasibility, viability and costs. This way, the measures are all compared equally to create the best client advice for DJI.

Again, the measures are elaborated on following the five solution spaces. Per solution space, the measures are carefully explained in operations, costs, maintenance etc.
Beware that the numbers used for argumentation of effectiveness are calculated via the computer simulation. The validation and discussion on this data is done in section 5.

A final conclusion is drawn per measure on the question if DJI should implement this. And if so, how this should work.

7.1 Shading overhang

During this process, a shading overhang seemed as one of the most effective measures. With designs on form and dimensions already made, the simulation functioned as first testing method.

Shading overhang reach of 0,55 m would be preferred, as this is the necessary reach to stop all peak hour direct radiation. Further reach would soon be too heavy for the current facade.

Feasibility
Using specially made steel or aluminum milled connection pieces, the overhang can safely be mounted onto the window bars of PI Zutphen. As window bars of other facilities might look different, these connection pieces can be adjusted to cover this problem.
The exact weight of the overhang depends on material use and final dimensions. The window bars and facade should be able to carry all overhangs. It is unknown if this is actually the case, or how much weight can be attached to the facade. Therefore, this design may not be feasible.

Desirability
Interviews with two detainees in PI Zutphen pointed out that an overhang is desired, as it stops direct solar radiation, but not on all hours. Also, it does not influence their view too much, which is good.
From DJI's perspective, the overhang is not yet desirable. The impact on reducing heat stress was expected greater than that the outcomes of the simulation show. Validating the outcomes with available data shows a knowledge gap in the computer simulation. DJI should not invest in this measure yet, as validated and realistic simulation data is required as a first step. This is a strong recommendation.

Viability
The true effect of this measure is not yet made clear, therefore, the viability is hard to fill in just yet.
Where costs of materials and manufacturing could be analysed already, those of maintenance and installation depend on the exact design. Before this exact design can be finalised, the simulation needs to be iterated and validated more precise. Thus, viability cannot be stated just yet.

Conclusion
The simulations show heat reducing effects of around 13 percent maximum. The true potential effect of this measure needs to be further analysed and calculated, as the validation of this simulation shows a knowledge gap.
The combination of this matter, and the lower results as opposed to other measures, makes it that this is not finalised further.

An iterated computer simulation could help validate the true effects. This is strongly recommended for DJI before implementing a possible overhang.

7.2 White curtains

Stakeholder interviews showed that detainees in PI nieuwegein and PI Zutphen all complain about the curtains. (Section 2.5)
The current curtains do not feel like they keep the heat out. Instead, detainees choose to hang white linen in the window frames. This is not allowed.

White curtains reflect more solar radiation than the current dark ones. Thus, reducing solar heat gain. The computer simulation is not tested on this feature. The effect is therefore unknown.

Feasibility
Implementation of a second curtain is feasible. Since curtains are installed already, the same method can be used for a replacing set, or an additional set of curtains.

Desirability
Detainees wish to have darkening curtains, to be able to make the cell dark for sleeping and resting.

White darkening curtains exist on the market, yet these can be quite heavy. The reflecting feature of the curtains is wished for, but too heavy curtains could trap heat in the layer between the curtain and window. This is not wished for.

Viability
White curtains cost around 20-30 Euro per m2. Buying large stocks might reduce the price even further. (Gordijnen - New York Wit - Voordeelgordijnen, n.d.)

Conclusion
DJI should consider implementing white reflective curtains, since detainees state to wish these. This has positive impact on reducing heat stress.

The current darkening curtains should remain in cells. This way, detainees have two curtains, and can choose which to use when. This impacts autonomy, and reduces heat stress.

With an unknown effect in reducing heat stress, this would be advised to calculate first. An iterated computer simulation could be used for that.

Then, the costs and impact can be used for effective decision making.

7.3 Window Film

The reflective window film throws the best results for reducing heat stress of all simulated measures. This measure seems promising to implement.

Feasibility
This measure is feasible. There is companies that sell and install window films for buildings on large scale. Thus, this can be used to implement this measure. Special attention might be required to implement window film behind the window bars, on great heights. This might be challenging for these companies, which could be reflected in higher costs or implementation time.

The weight of the window films need to be carried by the facade construction. This needs to be calculated and checked.

Desirability
This measure shows the largest potential in heat stress reduction. Thus, this measure seems desirable. Reflective window films are a proven method, and the simulation outcomes are validated and realistic.

A downside of the window films is that in winter, less solar heat comes into the cell. Thus, more energy use is needed to warm up the cells. It would be recommended to know how lower heat stress outweigh higher energy use in winter. If this is positive, this measure is an absolute must.

Another great aspect is that the window film can be stored for up to 3 years. Thus, every PI can have some spare for when windows break and need replacement. As this is the case often in Zutphen, this is convenient for DJI.

Viability
The film can be placed directly on the current windows. The lifespan of the film is up to 3 years (SOLAR SCREEN®, n.d.). The film would cost approximately 9 EU/m2, meaning approximately 13 euros per cell window. With 192 cells in PI Zutphen, investment of around 2500 Euros need to be made (SOLAR SCREEN® Sonnenschutzfolie Alu 70XC 152cm X 30,5m, n.d.-b).

The film needs to be installed on the windows. This might be a difficult, thus costly operation as the windows are located behind the window bars.

As the film needs to be replaced after around three years, these costs are made again every three years.

Conclusion
Window film is the most effective measure from simulations. Thus, worth serious considering. Final conclusions are drawn in the next conclusion section on section 8.

7.4 White coating

The white coating on the roof shows better results for reducing heat stress. This measure seems promising to implement. Let's dive into specifics.

Feasibility
This measure is feasible. It is a measure that is implemented more often on buildings. There is companies that perform this implementation. There seems to be not much high buildings around PI Zutphen to whom this reflecting roof might cause irritation. The roof needs to be able to hold the weight of the coating. The coating weighs around 2,5 kg/m2 if applied double, with a lifespan of 25 years. (Polyestershoppen, n.d.) As roofs are designed with a safety factor, and this coating is designed for roofs. this should be the case. This needs to be checked.
If this would be too heavy, another option is a single layer of coating. This comes down to a lifespan of 10 years, and a weight of 1,6 kg/m2.

Desirability
This measure is desired as DJI aims to find heat stress reducing measures. This measure is quite effective in this. This measure keeps solar heat gain via the roof lower during winter also, these effects can be calculated with an iterated simulation.

Viability
The coating costs around 3-4 Euros per m2 (Polyestershoppen, n.d.) On top of this, the implementation requires costs. After installation of this coating, some maintenance might be required to keep the roof clean, as a dirty roof reduces the effect of this measure. The exact costs of implementation and maintenance are not known in detail. This is for DJI to further analyse.

Conclusion
No other measure reached so much heat stress reduction as both white coating and window film. Thus, implementation of these measures seems like an absolute must.

Out of scope for this study is the winter situation, in which cells are heated to comfortable temperatures using radiators. Measures that keep out heat gains the whole year round might cause higher energy use in winter.
In order for DJI to make the best decision with this in mind also, additional simulations or research is advised.

With additional research into the winter situation, final decision making can be done by DJI. From this study, these measures combined are the best way to effectively reduce heat stress among detainees in cells, as more than 50% is reduced. The next steps for DJI are shown in the roadmap, and elaborated in section 8.4

Figure 7.1
A white coated roof on the TU Delft campus

7.5 Table Fan

With a table fan, detainees can feel a cooling effect, lowering heat stress. The fact that detainees have autonomy over use is a big plus in desirability.

Feasibility
Providing detainees with a table fan is an easy and feasible measure. As this is already done in PI Zutphen.

Desirability
Detainees use their table fans during summer. Both interviewed detainees in PI Zutphen stated that they desire this fan, and use it daily. With no other detainees interviewed directly, a further conclusion cannot be made.
From interviews done by Roeland Kroese in his thesis, more detainees confirmed this desire.
Having seen the results of heat stress reduction, this measure is desirable for DJI. The heat gain that the fans produce are a downside, yet the lower heat stress weighs in more prominent.

Viability
The costs of handing out table fans per cell for all cells in all PIs is an extensive investment for DJI. Yet, this would cost around 10-15 Euro's per cell (Tristar Tafelventilator | Kruidvat, n.d.)
This investment is smaller as apposed to other measures.
The energy use of this measure also leads to costs for DJI.
In total, this measure has some costs attached to it, which are not as high as other measures. This measure is viable.

Conclusion
By handing out table fans to detainees, a measure with increased autonomy is provided. Detainees may choose how and when to use the measure. The air speed gives a cooling effect to detainees, leading to 44 % less heat stress hours (PMV), and 21 percent less severe heat stress.

The noise of table fans might cause irritation. But since detainees decide over this measure, this is perceived as a side effect of a desired measure, if the fan is in use.

Thus, in total, handing out table fans to detainees is a measure that needs to be taken right away. This is taken into account on the recommendations and roadmap on section 8.4.

7.6 Clothing factor / Uniform

Detainees are allowed to wear their own clothing during sports or recreation activities and in their cells. Thus, they can dress according to the indoor temperature.
During work, both detainees and PIWs sometimes have to wear an uniform. This uniform corresponds with a higher clothing factor, thus higher heat stress. With the effect of the clothing factor made visible in the outcome data on section 6.5, a different uniform can lead to lower heat stress.

The work uniforms of detainees and PIWs can be replaced with a similar uniform, made from different fabrics. Fabrics that allow better heat dissipation lead to lower insulation, thus a lower clothing factor. By aquireing uniforms in these fabrics, the uniform regulation do not require any change. Detainees and PIWs may choose themselves which version of the uniform thay want to wear.

Feasibility
This measure is feasible. There is many existing cases of uniforms in fabrics that allow better heat dissipation than regular cotton uniforms.

Desirability
In the key findings presented on page X, it is shown that PIWs desire a cooler uniform during hot weather. With this measure, DJI does not have to adapt uniform regulations.

Viability
Additional uniforms lead to new costs for DJI. The costs depend on the uniform itself, and is thus hard to predict. Before costs can be made clear, extensive research would be required first.

Figure 7.2
The uniform of PIWs is matching cloting factor 1,0 instead of 0,5

Conclusion
Uniform wear of other materials is definitely something that DJI should consider. To know exactly what approach works best, an interview study should be done among PIWs and detainees. This way, the wishes of these stakeholders are made clear in the best way.

7.7 Ice packs

Another simple measure within solution space two is handing out ice packs within the living departments.

Detainees in PI Zutphen have a fridge model that includes a small freezer compartment. With handed out ice packs, detainees can keep these cool in the freezer compartment. They can use the ice packs for the cooling effects, both directly on skin, or in combination with the table fan.

The effects of the ice pack have not been tested with the computer simulation.

Feasibility
Handing out ice packs is feasible.

Desirability
The desirability is unknown for now, as this is not directly asked during interviews or detainee surveys in this study. With the current heat stress situation, it is likely that detainees would wish for ice packs, for use of cooling down.

Viability
Ice packs are affordable and available everywhere. Thus viable.

Conclusion
Ice packs should be handed out among detainees. This simple and affordable measure can be used on different methods for cooling effects.

7.8 Bed Linen

The bed linen in the cells also function as insulation.

From ideation, ice silk bed linen came out as potential measure.

Other measures are elaborated on, and analysed in feasibility, desirability and viability.
The desirability of this measure is not known at this moment.

Conclusion
This measure is not elaborated further on. Since detainees are free to not use any bed linen if they feel to warm at night, implementation of new bed linen does not feel like the next logical step.

7.9 Electrical Devices

The inventory of electrical devices in the cell could be replaced for more efficient ones. This helps DJI in realising lower energy use, thus becoming more sustainable. The reduction in heat stress depends on how much more efficient the current devices can be.

In PI Zutphen, the ceiling lamps have been recently replaced for LED lamps, with lower energy use and heat generation to the cell.

This measure is feasible, but the desirability depends on how much effect this will have on heat stress reduction. The larger the effect, the higher the desirability is for DJI, and the higher the costs included may be.

Conclusion
DJI could analyse what energy labels and heat generation all electrical devices in cells currently have. With this data, the difference with more efficient devices can be researched. With the information on how much Watt devices can be lower, the simulation can be used to test the effect of that measures.
Only after these steps, the potential effect of this measure is made clear. Only then, this can be used for decision making.

7.10 Ventilation maintenance

The outcomes of the computer simulation plotting different heat stress outcomes per ventilation flow show the necessity to dive into the true ventilation flow.

The installed ventilation system in PI Zutphen is not able to be set on higher ventilation flows. This would be the first measure that comes to mind.

Thus, research was conducted on the current state of the ventilation system.

Available data of the W/E PI Roermond study shows that the average cell has 39 m³/h true ventilation. This is the average from 8 tested cells. Appendix 10.

This raised the impression that the ventilation system might be lacking behind. As this study focuses in PI Zutphen, data from this facility is required.
Obtained maintenance data shows the state of the ventilation in PI Zutphen.

For PI Zutphen, the maintenance report of the entire facility shows that out of 189 cells, only 44 had a correct ventilation rate of 50 m³/h or above.

The average ventilation rate is 41 m³/h in Zutphen, at the moment of maintenance.

After maintenance, 64 cells were still not meeting ventilation criteria, and showed lower flows than 50 m3/h.

Thus, the ventilation is lacking behind. This causes preventable heat stress. This is visualised in the right page in figures 7.3 and 7.4.

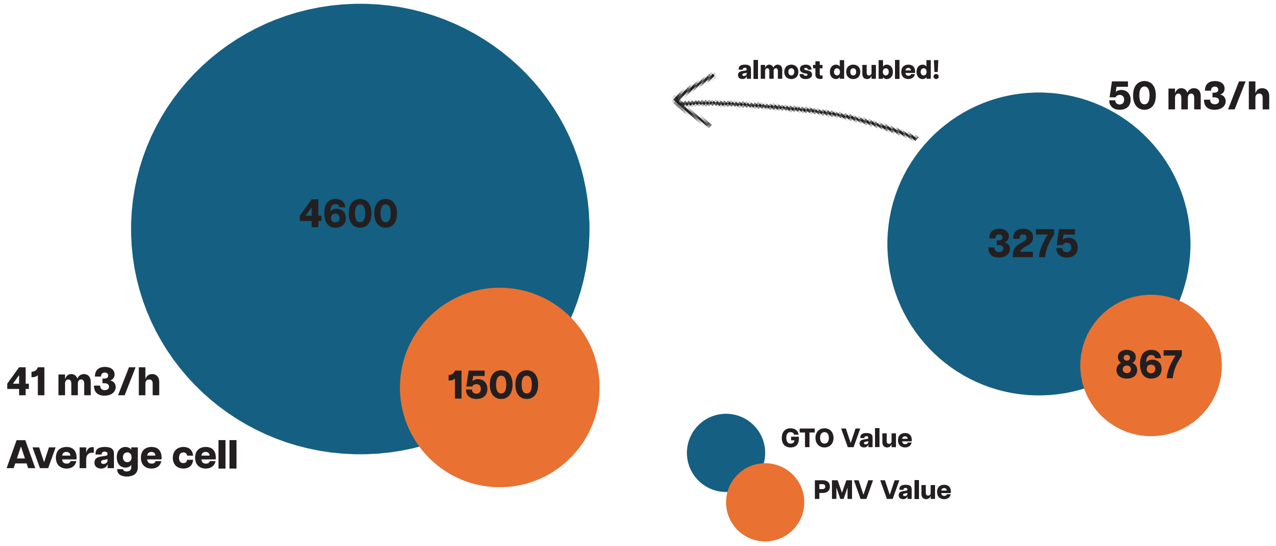


Figure 7.3
The heat stress of poorly ventilated cells visualised

PI ZUTPHEN	Wing A				
Cell	Demanded ventilation flow	Pre maintenance	Post maintenance	% Pre	% Post
1	100	88	107	0,88	1,07
2	50	54	60	1,08	1,2
3	50	118	120	2,36	2,4
4	50	51	61	1,02	1,22
5	50	66	79	1,32	1,58
6	50	40	58	0,8	1,16
7	100	100	121	1	1,21
8	50	53	82	1,06	1,64
9	50	46	49	0,92	0,98
10	50	96	132	1,92	2,64
11	50	44	55	0,88	1,1
12	100	53	64	0,53	0,64
13	100	58	66	0,58	0,66
14	50	33	55	0,66	1,1
15	50	44	60	0,88	1,2

Figure 7.4
A screenshot of maintenance data of PI Zutphen, wing A

Let's dive into the specifics of the maintenance.

Maintenance
Maintenance is conducted one a year in PI Zutphen. This is done in October, just after the summer heat (Personal contact, Dennis Smalbrugge, Facility Manager, PI Zutphen).

This maintenance includes the following
- Cleaning the ventilation grille in the cells
- Changing the ventilation filters
- Cleaning the ventilation canals
- Checking, possibly adjusting, the ventilation valves

The maintenance is much needed to keep the ventilation working efficiently, to stay on or above 50 m3/h.

The ventilation grille should be cleaned by detainees themselves, as detainees are able to reach those.
The rest of the system is cleaned only during maintenance one a year.

The main reasons that the ventilation is lacking behind are:

1. Detainees are allowed to smoke in cells. This shortens the lifespan of the filter compared to cells where detainees do not smoke.

2. The ventilation grilles should be cleaned regularly, so that dust does not enter the filter behind it. This is poorly done by detainees, stated the Facility Manager of PI Zutphen. Also, detainees might not know how or why this is important.

This way, filters get too dirty too soon.
As an effect, the maintenance is not enough to reduce heat stress.

On the next page, the MOSCOW method is used to present possible maintenance measures lowering heat stress.

Measures to get detainees to clean their grilles better are covered from section 7.11 onwards.

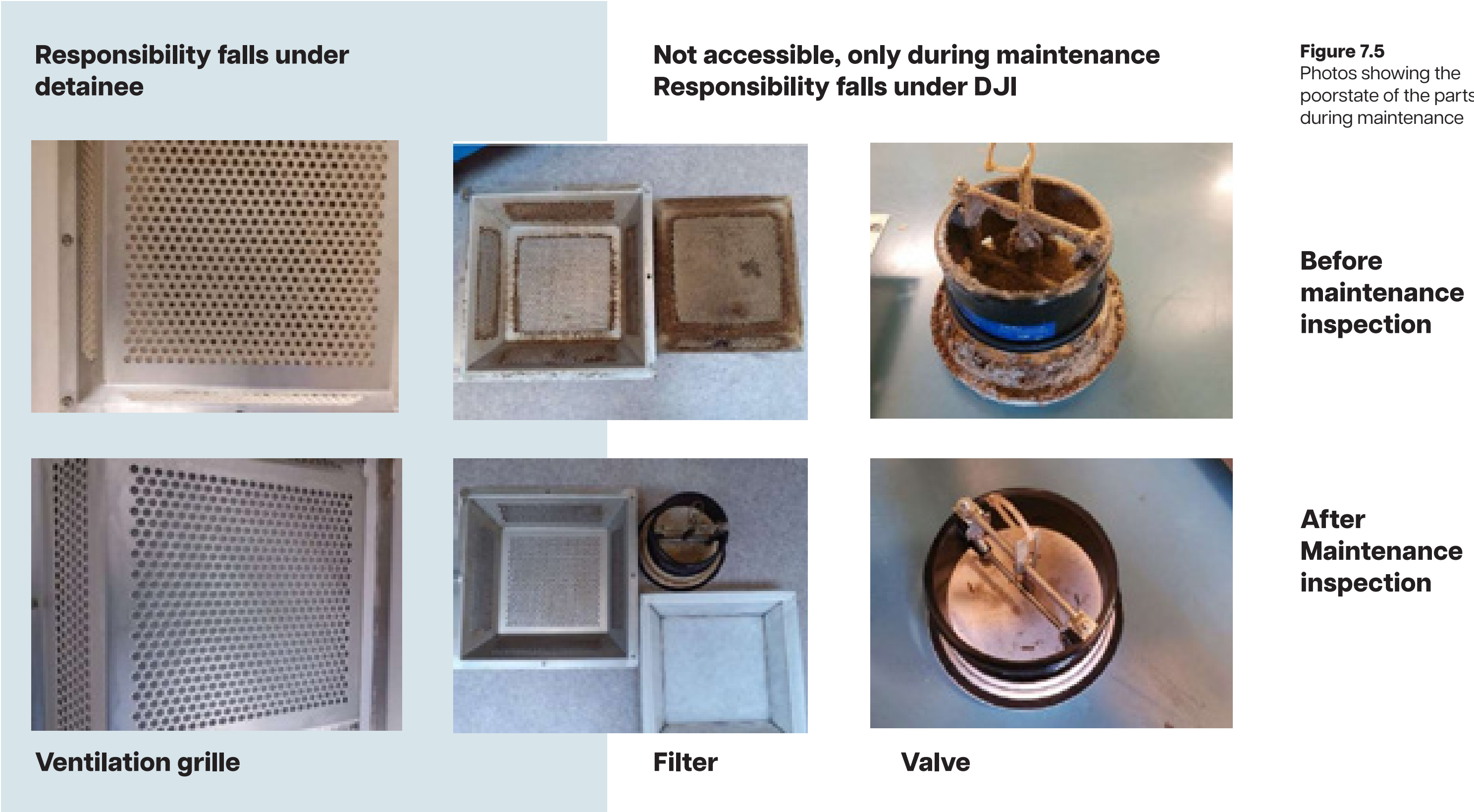


Figure 7.5
Photos showing the poorstate of the parts during maintenance

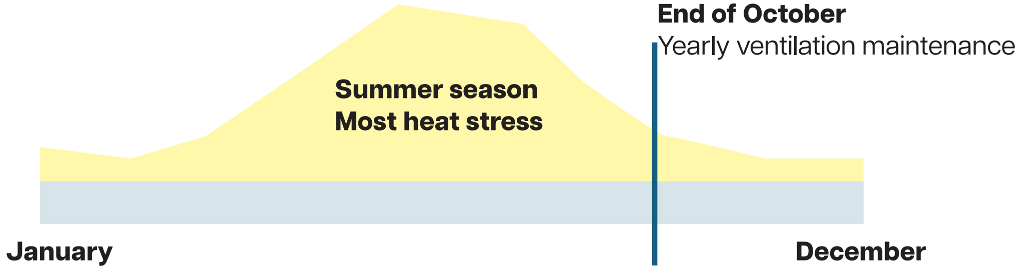


Figure 7.6
Schematic visualisation of mainenance moment

Must have	Could have
The maintenance must be changed to yearly, in April. This way, the cells are better prepared for the summer, and no extra costs have been made.	The ventilation should be checked and cleaned more often per year. At least before summer, and during summer. This effectively tackles preventable heat stress.
It would be desirable for detainees if the filter is changed more often per year, and if DJI checks the ventilation flow on a monthly base	Live flow meters in a board room of DJI. This way, when ventilation in cell X starts to lack, this can be fixed immediately
Should have	**Nice to have**

Figure 7.7
MOSCOW schedule fot additional ideas on maintenance

Feasibility
Upgrading the maintenance plans is a feasible and easy measure for DJI to take. The current maintenance needs to be planned in differently or more often, to effectively reach results already.

Desirability
This measure is the foremost desirable measure for DJI, as lacking maintenance causes preventable heat stress.
A ventilation system with the correct ventilation flow is necessary to have before implementing measures. If this is not rightfully done, too demanding measures might be implemented, that are possibly too effective if the ventilation is meeting the requirements later.

As detainees all complain about low ventilation, this measure must be the first action to take.

Viability
The viability of this measure depends on what approach is taken. For DJI to choose an approach, some more research might be needed first. Once known how the ventilation can be kept on track the best, the costs can be made clear. Whatever the outcome is, the costs attached need to be invested, as proper ventilation is a wish and demand for DJI and detainees.

The maintenance per cell comes down to 202 euros (Dennis Smalbrugge, Facility Manager, PI Zutphen), this includes a new filter. More frequent maintenance on 192 cells is asking for high investments. Thus, other measures to reach the correct ventilation flow are also necessary to analyse.

Conclusion
In total, DJI could reconsider the reasons the ventilation lacks behind.
The simulation data clearly shows that this must be tackled.

Changing the moment maintenance happens is an absolute must. Apart from this, the filters could be changed more often to reduce heat stress. The specific filter and its lifespan is unknown during this study.

The price of filter replacement and maintenance per cell is high. Thus, more frequent maintenance might be tough to realise for DJI. Since the filter is located behind the ventilation grille, this step requires maintenance crew to replace a filter, causing higher costs.
This can be made easier. This is explained in section 7.15.

7.11 Educational package

Almost half of all detainees suffer from mild intellectual disabilities (inrichtingen, 2024). On top of this, their level of education and general knowledge is almost always lower than the national average (de Maeyer 2005). This might cause detainees to lack knowledge on heat prevention and understanding the connection between heat stress and their behaviour. Participation of detainees in educational courses leads to improvements of wellbeing, and contributions to self-worth (Brosens et al., 2015)

Detainees have some influence on the heat stress in their cell. Note that the 'size of the influence' is not quantified, yet the effect still remains.
As discussed above, detainees have impact on the state of their ventilation. By cleaning the grilles and the cell, the filter stays cleaner longer, resulting in better ventilation and lower heat stress.

This link may be unknown for detainees, and without the this link, they are unable to reduce heat stress themselves.
Also, general knowledge on preventing heat from coming is might be below average for some. Thus, educating how detainees can keep the heat out, by explaining when to open the window grilles, close the curtains and be less active during hot times.

Note here that this study did not explore this in depth, but as these small influences help in increasing autonomy in detention, the wellbeing will likely rise, while heat stress might be reduced simultaneously.

Behaviour change is hard to reach, maybe even harder among detainees. The ADKAR principle is advised.

A **Awareness**
Awareness of the need of change.
The educational package offers knowledge on heat stress and how to prevent this. Awareness is raised that behaviour of detainees and PIWs has effects on the heat stress and quality of life in detention.

D **Desire**
With this link made clear, desire to change for the better can be raised. This is a crusial step, as behaviour change is easier reached if the person desires it himself. In this way, detainees will want to clean more often for example.

K **Knowledge**
With awareness and desire amond detainees. The education gives knowledge on how to change.

A **Ability**
The knowledge acts as a tool that detainees als PIWs can use to feel their influence, and work on bettering their situations. Thus, the ability of change is born.

R **Reinforcement**
The education package is most effective if the knowledge is reinforced. This could be done by multiple education sessions during summer, to keep the knowledge up to date.

Implementing education for detainees is feasible. The desirability is not directly felt among detainees now, but with the ADKAR principle, desirability can be made clear. The viability of this measure is hard to predict, but high costs are very unlikely.

As clean cells and grilles help in a better functioning ventilation system, cleaning behaviour needs to be encouraged by DJI.

The cells are equipped with standard cleaning supplies, including only a bucket, mop and towel (Goederen Gevangeniswezen, n.d.). Other cleaning supplies like a vacuum cleaner are available in the living department, and is shared with all detainees.

The detainees are made clear that the cells need to be cleaned by themselves, and PIWs should make sure detainees do this from time to time, yet no explanation is given.

Full explanation on cleaning the cells might be overkill (althought still handy), but instructions on keeping the ventilation grille and window grille clean is important. Any additional essential tools for these actions need to be provided to all cells.

Conclusion
Education on heat stress, and the influence that PIWs and Detainees can have on reducing this, will likely help in raising the wellbeing of detainees while lowering heat stress. The autonomy will increase, leading to better self-worth. The effects of this measure are hard to quantify, but DJI can asses this over time to perfect this measure even further over time.

Besides education, the cleaning rituals of the cell and grilles should be provided to detainees.

Further research on this method is advised, to implement the right education package. This is shown in the roadmap.
Concepts that may help in reaching this goal are elaborated in section 7.14.

7.12 Daily Schedule

The problem can also be framed differently. Detainees are exposed to heat stress because they are in closed cells for many hours a day. A different daily schedule could be researched for lower heat stress.

This might include more or differently timed time slots where detainees may shower, go for sports outside, or spend time in the living departments.

Ideas that would fall under this category are presented in the ideation cards, in appendix 5. These ideas are not further analysed or researched, mainly due to possible extra safety risks of these actions.

Conclusion
Maybe reducing heat stress is in line with reducing hours spent on cells.
As heat protocols change the regulations and daily schedules on periods of hot weather, these protocols can be analysed and expanded with more measures to keep detainees and PIWs cooler. For this solution, further research is needed first.

7.13 Computer simulation

The measures in this study are now all assessed on their value for DJI to reduce heat stress.

The computer simulation that is made to assist in this process is this studies main product. This computer simulation can and should be iterated to gain further insights in additional measures, or on other PIs and situations.

The same assessment is thus made on this product.

Feasibility
This product is made with free accessible software. The Internet provides enough guidance for users to understand and iterate on the simulation. Also, there is people who are far more experienced and educated on the use of this software. This means that a far more accurate simulation is within reach.

Desirability
The simulation outcomes are desirable for comparing measures to one another, as long as this simulation is properly validated. The current simulation is based on assumptions, and validated with two similar studies. With those steps, the simulation outcomes are proven valuable for DJI to already help in decision making.

By iterating on the simulation, and reaching a new simulation that is based on less assumptions, this product can become even more desirable. When made by professionals, the simulation can reflect the true energy flows and predict the best possible measures precisely. With the versatility of this product, iterating this product to become even more insightful than the current simulation is very desirable for DJI.

Viability
The simulation software is free, and using the product costs only time and effort. On short term, this product shows insightful data on the current heat stress and potential measures. On the longer term, this product can be iterated to become a 1:1 simulation of the whole PI. Once this accuracy of a computer simulation is reached, this becomes viable on the long term also.

Apart from decision making on heat stress reducing measures, this software also offers great features to be used for all renovation plans. Using a iterated product of PI Zutphen, all renovation plans can be elaborated on.

Conclusion
The value of the computer simulation is proven with this study. This value can grow when DJI iterates this simulation into a more precise model of the entire PI. This is strongly recommended for further use around heat stress reducing measures, both now and for renovations.

This is shown on the Roadmap on section 8.4.

Further concepts

In this section, some concepts are presented. These are meant to ease maintenance and cleaning rituals. This is based on key takeaways from the research done during this study. The concepts are elaborated as a vision, and a conclusion is drawn on their potential. These concepts are not iterated, tested with stakeholders or prototyped.

These concepts are all discussed with Facility Manager of PI Zutphen, and client Bas Kolkman.

7.14 Encouraging cleaning

Cleaning one's ventilation grille and window grille is a responsibility for detainees. When discussing the maintenance with the Facility Manager of PI Zutphen, the conclusion was made that proper instructions on how to clean these are not provided. This can be seen as one of the causes why detainees lack in cleaning those. With a broad variety in different backgrounds of detainees, and their capabilities in taking care of themselves and hygiene, instructions on cleaning could help massively to some detainees. This is also elaborated in the educational package, in section 7.11.

As an example, the facility manager stated that grilles need to be cleaned with a dry cloth, not a wet one. This information is little known, causing detainees that clean the grilles to do this faulty sometimes. This may cause the filter to get wet, which is not desired apparently.

This combined with the fact that most detainees do not clean their cells and grilles often stresses the necessity of proper cleaning instructions for detainees.

This can be done in a number of ways. The education package could include a cleaning demonstration. Also, the GedeCo (Detainee committee, see stakeholder map on section 1.2) could play a role in sharing this knowledge. Apart from these two methods, a cleaning sign can be installed in the cell. This could take shape as a sign that is mounted on the cell door, or next to the grille on the wall. This is shown in a simple illustration in figure 7.8.

Figure 7.8
Left page:
Possible locations for a cleaning sign in the cell

Figure 7.9
Right page:
Simple illustrations explaining this vision

The ventilation grille should be cleaned often by detainees, so that the grille is dust free at all times. While the cleaning action might be easy, and education can incentivise detainees to be more proactive in the cleaning of their grilles, a bright orange grille could help in drawing attention, and providing feedback on when to clean.

The pictures of dirty grilles found during maintenance tell a lot: the grilles get super dusty. This way, the colour of the grille changes, and is not so bright anymore. This colour difference is easy to spot now that the photos are next to another, but the degradation of the grille is more subtle of course.
The orange grille will catch attention. Also, the grille could be painted shiny orange so that a layer of dust and filth would quickly make the grille look less orange and shiny. This could make it more obvious for detainees to start cleaning better. his idea is not tested in the PI with detainees.

Conclusion
Opportunities lie in encouraging detainees to clean the grilles better. This research pointed out that the knowledge linking cleaning behaviour and rituals to less heat stress is limited. Thus, introduction and education could be helpful to help in this. For this to be most efficient, additional research needs to be made. These images function as an inspirational vision in how this could potentially be realised. Efforts should be made on researching how cleaning could be incentivised among detainees. This could be an add-on to the aforementioned education package, to get detainees to clean their grilles better within their own autonomy.

7.15 Visible filters

The filter in the ventilation grille is mounted behind the grille itself. This way, the state of the filter is uneasy to see through the tiny holes of the grille. With no active monitoring of the true ventilation flow in each cell, the state of the ventilation is made invisible for detainees and the PI staff.

This can be changed by swapping the order of components.

The ventilation grille is professionally mounted to the wall with special screws. This way, detainees cannot take this apart and hide contraband behind this part. Currently, the filter is installed behind this grille.

In the new configuration, the grille can be mounted onto the wall, with the same special screws. The filter is not placed behind this feature, but right over it.
This way, the filter is seen at all times. Detainees can clean the filter by using a dry cloth or a vacuum cleaner. When the filter is not cleaned in time, the holes of the ventilation grille behind it will become visible, making it clear for detainees that action is required again.
Besides cleaning the filters. The state of the filter is made more clear to PIWs. When the filter gets dirty, the PIWs point this out to detainees to get them to clean this. When the state is not good enough anymore, replacing the filter is easier, as it is not concealed behind the grille anymore. This way, the replacing requires less time and effort, making it a cheaper operation.

The replacement of filters could even be considered as a task for PIWs or trained detainees. By including detainees in this maintenance, the necessity of cleaning grilles and filters is made even more clear potentially.

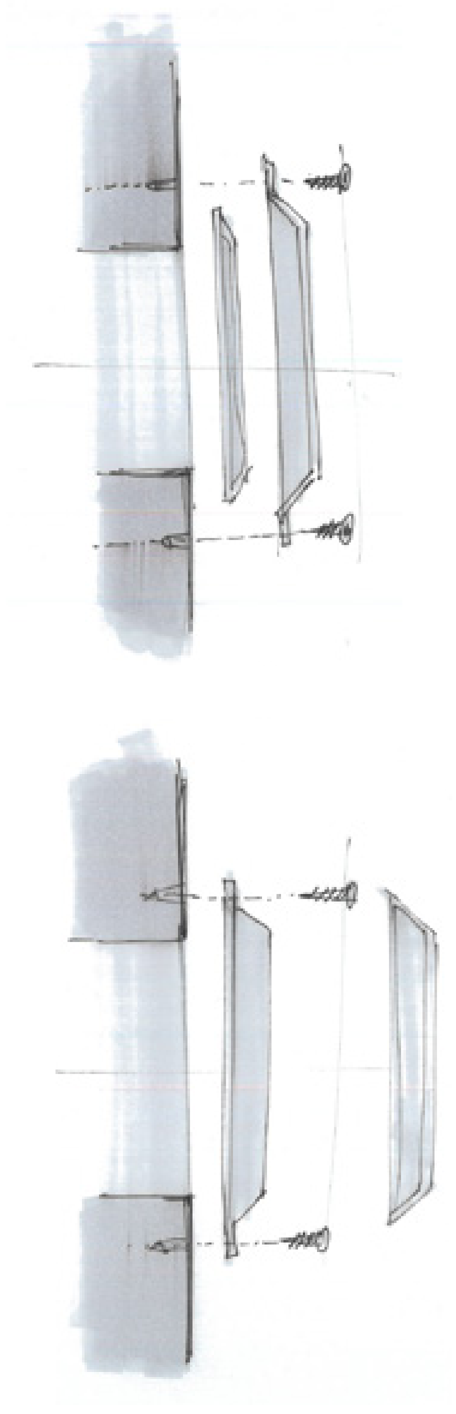


Figure 7.10
Left page:
(Top) Current configuration
(Bottom) New possible configuration

Figure 7.11
Right page: the visible difference between an new and dirty filter

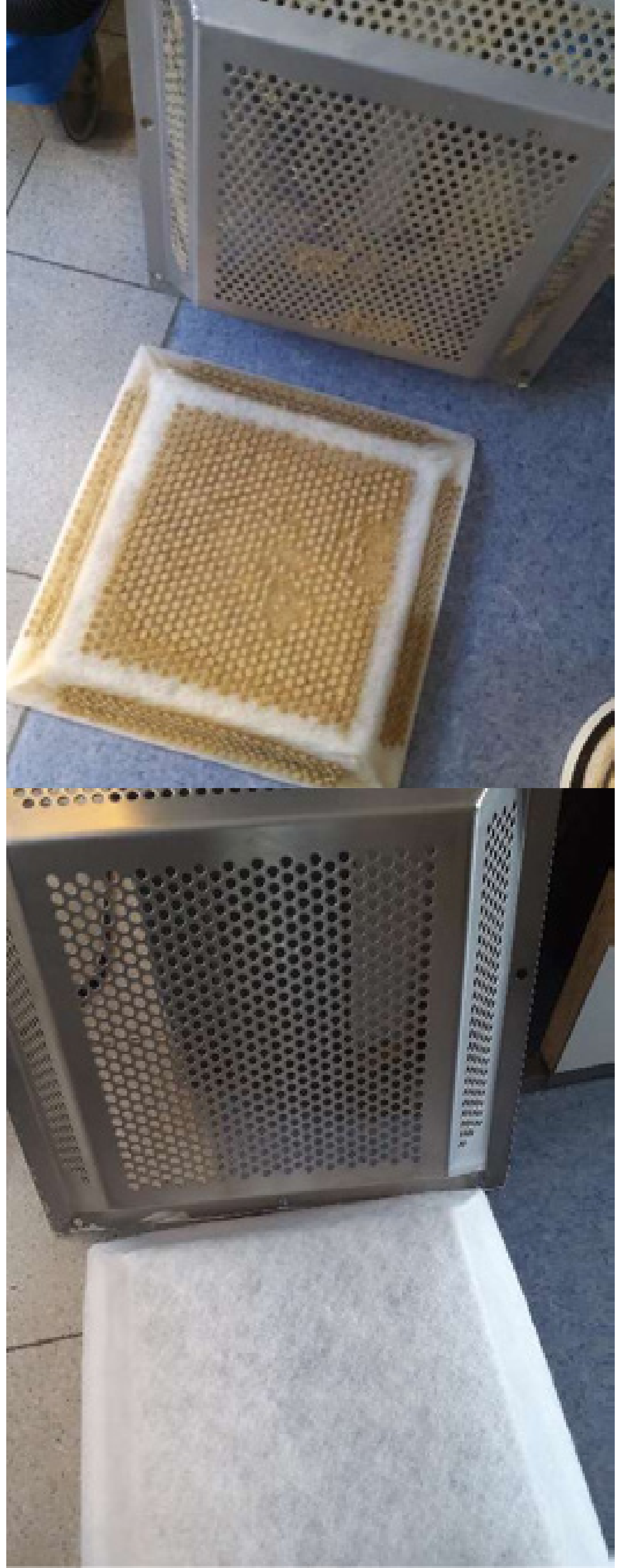
A side effect of this measure could be that the vulnerable filter is exposed. Cleaning actions could accidentally tear the filter open. As no tests with this measure have been done, this is unknown at this point.

The feasibility of this new configuration depends on a few aspects, that need further ideation or research. With close attention to contraband and safety within a PI, the exact aspects of a further ideated configuration need to be properly checked on safety aspects.

This study proves that filter replacement or cleaning should be done more prominently. Therefore, this vision shows a desirable feature for DJI. The question is if this can be realised bearing in mind the contraband and safety matters. For that, more research would be required before concluding the desirability.

The viability depends on the specifics. The filter needs to be attached some way over the grille. This could have some costs included. In total, this could be viable since the ease of maintenance is made larger. Depending on a new schedule for filter replacement, this design could save loads of time and costs this way.

Conclusion
Besides updating the maintenance program and working towards cleaner ventilation grilles via education on cleaning rituals, a measure like this could be valuable for DJI as costs of maintenance could be lowered a lot potentially. Thus, further iterating on this vision is a strong recommendation for DJI.



7.16 Increased draft in cells

Complaints are made that the window grille is often not causing noticeable draft in cells. This is due to two things, shows the interviews.
First, draft is only felt if the wind is directed on the facade, which is rarely the case.
Second, the grilles are not cleaned properly, thus only letting in little fresh air.

The air flow through the grille can be increased by applying small fans onto the opening of the window grille hatch. These fans work on electricity and suck in more air.

These fans could spin in both directions, and in different speeds. This way, this is versatile and could work both to get in fresh air as to suck it out.

This vision shows a way how draft can be enhances, for cooling effects. The specifics of this design need qualitative studies on what is desired by all stakeholders.

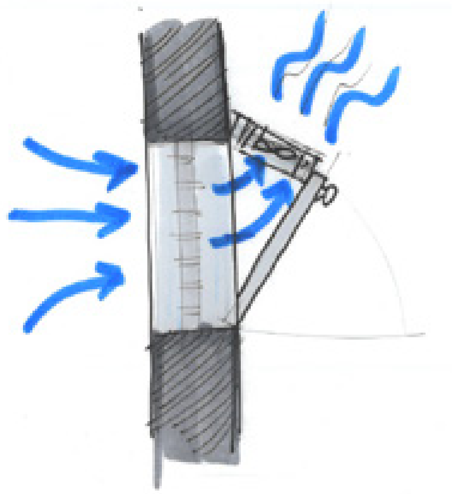
Apart from researching desirability, the effects on the ventilation need additional research, as this would likely affect that.

Installation of fans built in onto the window grille is definitely a possibility, and therefore feasible. The exact dimensions and materials care for how this measure is implemented exactly.

The viability depends on the effect. Additional research is needed to further assess these aspects.

Conclusion
This concept comes from complaints on the window grilles showing no noticeable effects. With an idea such as this one, this could be changed. This functions as an idea, as this is not properly researched yet. This could be done by DJI.

Before an implementation like this one would be needed, the grilles need to be cleaned more often first. This can be reached with the education package. Also, the table fan in the cell created draft in the cell. Handing those out is easier, and more desirable for DJI and detainees. This is a better first step.



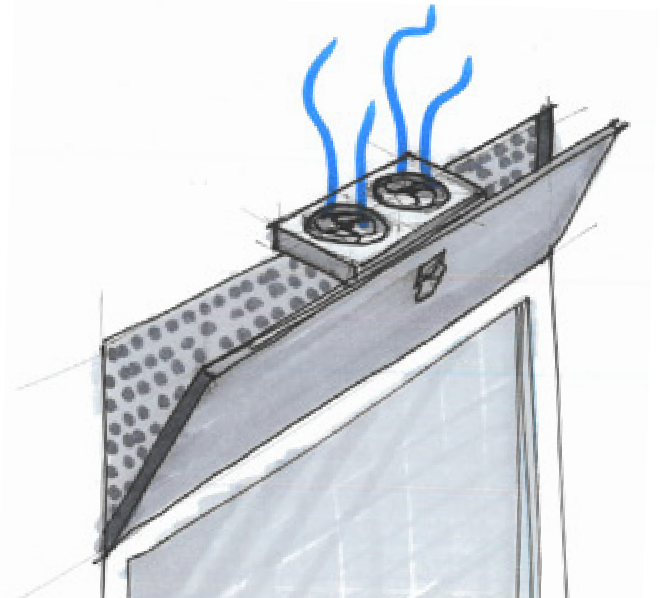


Figure 7.12
Simple drawings of the elaborated vision.

8.1 Conclusion

With this study, different measures are explored and analysed. With the computer simulation based on assumptions the current heat stress in cells is analysed. The validation of the computer simulation made clear that the model is mainly to be used for comparison of measures. The exact numbers that the simulation predicts on the effectiveness of measures depends on the inaccuracies around assumptions. Therefore, the simulation data is meant for insights for decision making.

The outcome data of different measures is taken into account to choose the best implementations. Apart from the simulations, additional measures are elaborated in section 7. These measures are not (yet) tested with a simulation, but show aspects where DJI could reduce heat stress also. This includes policy changes and behavioural change via education.

Lastly, performing research on measures for cleaner and better functioning ventilation canals lead to concepts of possible products that aid in this cause. This way, heat stress is also reduced. These concepts are pitched, but need further iterations and finalising work.

The specific outcomes of the measures is shown in the future vision section on the next page.

RQ1
Who is experiencing heat stress and how is this causing problems for DJI?

Detainees experience heat stress during the summer months. Available cell temperature shows that temperatures of 27 *C and higher happen easily, and heat is trapped for long periods. Experiences of detainees confirm this image. Heat stress leads to negative effects on mental, physical and psychological wellbeing. This all affects safety in the PI. Besides detainees, PIWs also experience heat stress, and feel lower safety. The main focus of this study is on detainees and heat stress in cells, but this is also taken along.

RQ2
What measures could be implemented and what impact do these measures have?

Reflective window films halve the incoming solar radiation, resulting in only around half the heat stress severity, and almost 2 degrees Celsius lower average temperatures in cells. Apart from this measure, white coating also scores high. The exact numbers are visible in section 6.
Apart from a large measure like these two, the ventilation maintenance needs an upgrade. Further measures are pitched and assessed in this report

RQ3
What steps are required for DJI to reduce heat stress before renovations?

This study could be the start of developing a more iterated simulation. This can be used for further measures and renovation planning. The steps required until that time are discussed in section 8.2 and 8.3 and visualised in 8.4.

8.2 Future vision

RQ 3.1
What next steps and measures should DJI take to reduce heat stress

A future vision can be scaped by summarising the steps that DJI should take the coming years, up until the renovations.

Looking back into the five solution spaces, some measures have a great impact. These need to be seriously considered.

Firstly, the ventilation flow needs to be checked and controlled more often. If this is done correctly, half of current heat stress can be prevented. The simulation shows how much preventable heat stress is present for different heat flows. Thus, the computer simulation can be used to help DJI in setting up the best maintenance routine. Within this study, different options are pitched for this measure. DJI can use this knowledge in decision making on these next steps.

Education can lead to better wellbeing and more autonomy among detainees. Education must be implemented, to reduce ventilation lacking behind also.

Secondly, there are architectural measures that show great results in the simulations.

Reflective window films can reduce the solar heat gain with almost 50 %. This leads to around 50% reduction in heat stress severity, and up to 60 percent less heat stress hours. This exceptionally high reductions make this measure an absolute must for DJI to implement.

Before taking that step, the winter situation needs to be analysed to know the downside of this measure in winter, which is definitely smaller than the positive effects in summer.

The white coating on the roof lowers heat stress severity also, making the combination of these measures desirable. The true effects of the white coating are less high as not all cells are connected to the roof directly, and cells have heat flows through them also, which is not taken into account in the simulation.

These measures combined lead to a large reduction of heat stress, as is shown in section 6.4. With some recommendations presented, DJI should move forward in implementing these measures for PI Zutphen as soon as possible.

Besides these architectural measures, DJI should implement easy, low effort measures. Even though their effects are not tested with the simulations, it is not debatable that these will have heat reducing effects. Even more importantly, these measures increase autonomy among detainees, since they are used when and however they like.

These measures are the following:
Provide table fans to detainees. Hand out ice packs for cooling effects. White reflective curtains should be installed in cells, additionally to the current darkening set of curtains.
Lastly, the pitched concepts can be used as inspiration for DJI.

Conclusion RQ's
The three sub questions are answered fully in the text of these sections. No short summarisations are made in these blue boxes.

8.3 Recommendations

RQ 3.2
What further research is needed for implementing these measures?

RQ 3.3
How can DJI use this study for effective renovations?

For reaching the best heat stress reducing measures, the following recommendations are in place:

Further research on a better maintenance regime of the ventilation canals. This is needed to get all preventable heat stress out of the system. Within this study, possible options of better maintenance are pitched, together with an educational approach, to aid that measure. In the future, more research on this aspect is needed to implement these measures correctly, leading to the correct ventilation flows.

Setting up education within the PI. This shows great potential from this study, but needs further work to be implemented.

Setting up implementation plans for reflective window films, and white coated roofs. Some additional research must be done to know the effects of these measures during winter.

Iterating the computer simulations, to get rid of assumptions. When the computer simulation is more precise and more effectively validated, this tool is super useful for further renovations. Therefore, DJI should aim for a computer simulation that is representing the entire living department (or building), and takes on less assumptions. With this model, the effects of measures can be predicted more in depth.

Assessing the impact of implemented measures to keep track of the current heat stress problematics. With installing temperature sensors, and detainee surveys, the heat stress problems can be made more insightful with more data. This helps in future research on heat stress.

** The future vision and recommendations are made into a visual. This is the roadmap on page X.

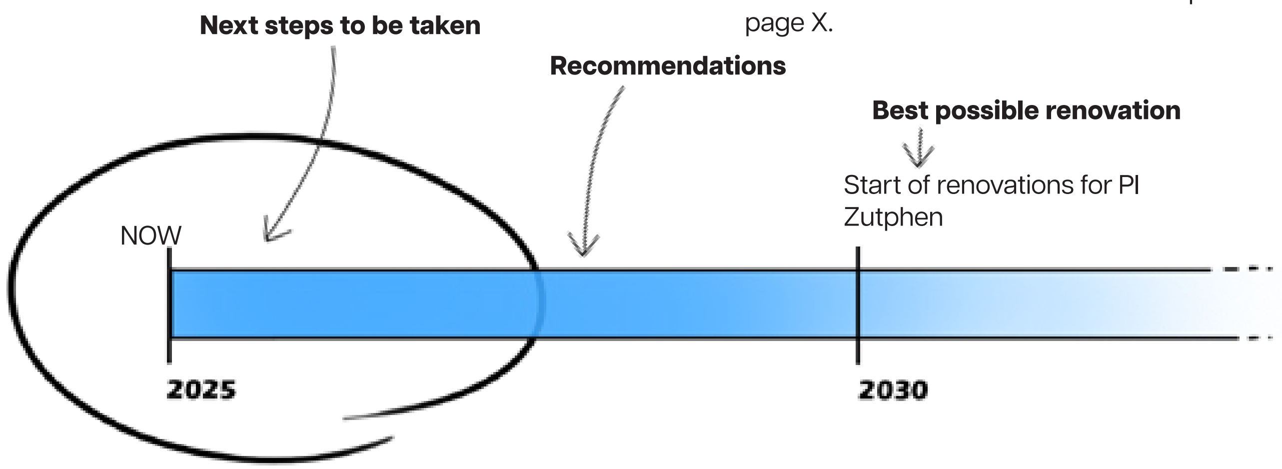


Figure 8.1
Future steps and recommendations on timescale

8.4 Roadmap

Problems

Detainees and PIWs suffer from heat stress

Problem statement DJI:
How can DJI reduce heat stress with a solution that is implementable now, before renovations?

What is really the problem?

Core of the problem:
DJI is focussed on exploring solutions in building technical aspects and renovations. The current problems leading to heat stress are not identified properly, causing preventable heat stress.

New Problem statement:
How can DJI reduce heat stress right now, ánd find the heat stress reducing measures, for now and renovations?

What factors show potential in reducing heat stress, now or for renovations?

1 **Ventilation**
The current ventilation is not functioning as desired, leading to preventable heat stress

2 **Heat stress education**
Knowledge on preventing and dealing with heat stress is lacking. causing preventable heat stress.

3 **implement measures to reduce heat stress**
In depth data on the effects of different measures on heat stress is not complete yet.

Solutions

Designing sun shading overhang. as this seems to have potential in reducing heat stress before renovations

Small noticeable effect of an overhang, data hard to validate
Other measures should be tested and compared

Setting up a Computer simulation
To quantify heat stress in cells for different variations

Using simulation data, the impact of ventilation flow and maintenance are shown

Current maintenance at the start of the summer, more maintenance moments and filter replacement

Implementing more structural maintenance on ventilation canals and filters

supervision on detainees actually cleaning cells and ventilation grilles

Assesing these effects, and measure remaining heat stress problems

Decision making on window films and white coating

Adressing knowledge and purpose for detainees and employees, so they can deal with heat stress and gain autonomy

Setting up and executing an effective heat protocol

Facilitate detainees with tools for heat prevention

Detainees should keep their own cells and ventilation grilles clean

Use Computer simulation
To quantify heat stress in cells for different variations

Compare different outcomes of measures in computer simulation to help decision making

Iterate simulation, and check winter situation of potential effects also

Implement the best further combination of measures
Additional measures during renovations.

Renovations

8.5 Reflection

With previous experience and great experience on designing for the wellbeing of detainees, I started off this project with high motivation. This was combined with the vision of working towards a large prototype of a sun shading device for onto the cell window bars. This vision motivated me and had me enthusiastic in the first half of the project.

Around that time, the project proceeded different than anticipated. The computer simulation was a real challenge, which cost me loads of time and effort. After pushing through and getting experienced in EnergyPlus, I could simulated the effects of an overhang. After quite some iterations, this made us steer into another direction. Other measures show more impact in reducing heat stress, therefore I figured focusing on simulating these measures is more desirable.
I feel a bit frustrated at times that I missed out on building something big, but I learned a lot of new skills. The simulation is something I am proud of of reaching this outcome. In retrospect, this was as much of a motivator for me as I hoped building a large prototype would be.

I learned a lot from validating the simulation. I think this is the highlight of this study. This is required for DJI to continue with this approach, and I think I have managed to show all steps and chosen approaches.

I had hoped to validate the effects of the overhang more in detail, working towards a detailed explanation why this outcome is realistic and how realistic.

All in all, I look back on this project with a big smile. I enjoyed all contact with everybody during the process. The coach meetings inspired me, just like the client meetings.
Walking around in the PI and chatting with PIWs, detainees and other staff was a great experience.

I might go to prison more often to make a difference there.. but not as detainee!

9 References

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Design brief
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Context
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