

Low Energy Solution for a High Temperature Problem

Problem Definition

Research Questions

Methodology & Results
SQ1

Methodology & Results
SQ2

Discussion & Conclusion

Problem Definition

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Discussion & Conclusion

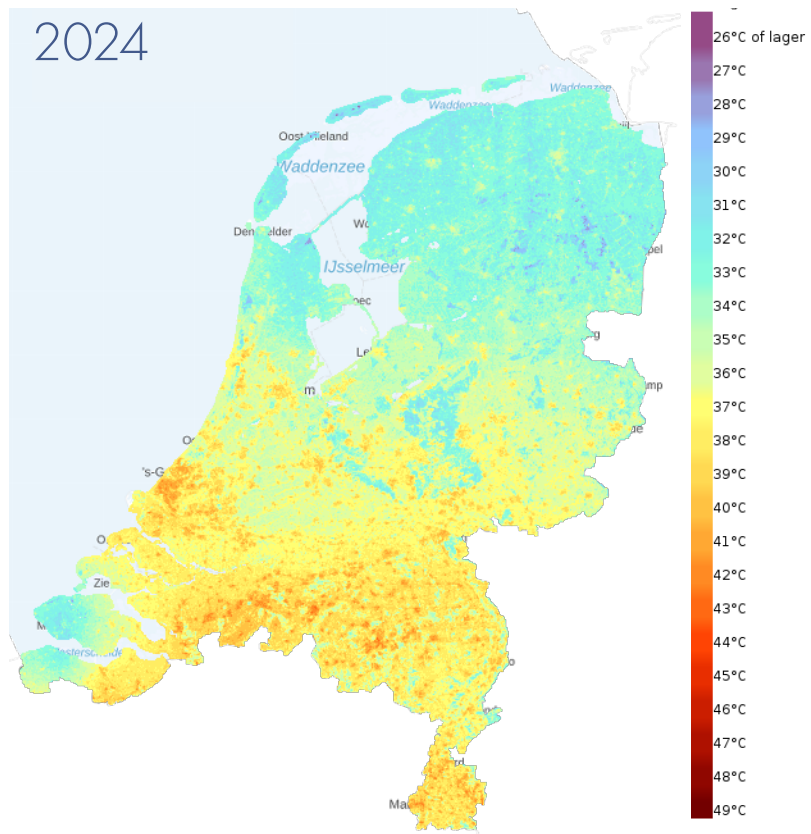
Problem Definition

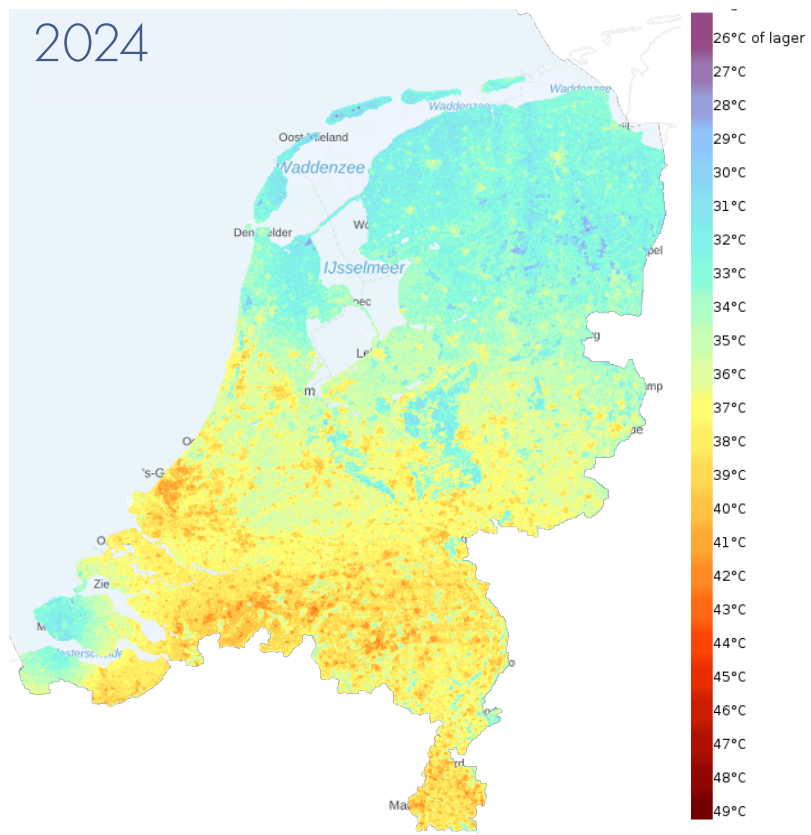
Research Questions

Methodology & Results
SQ1

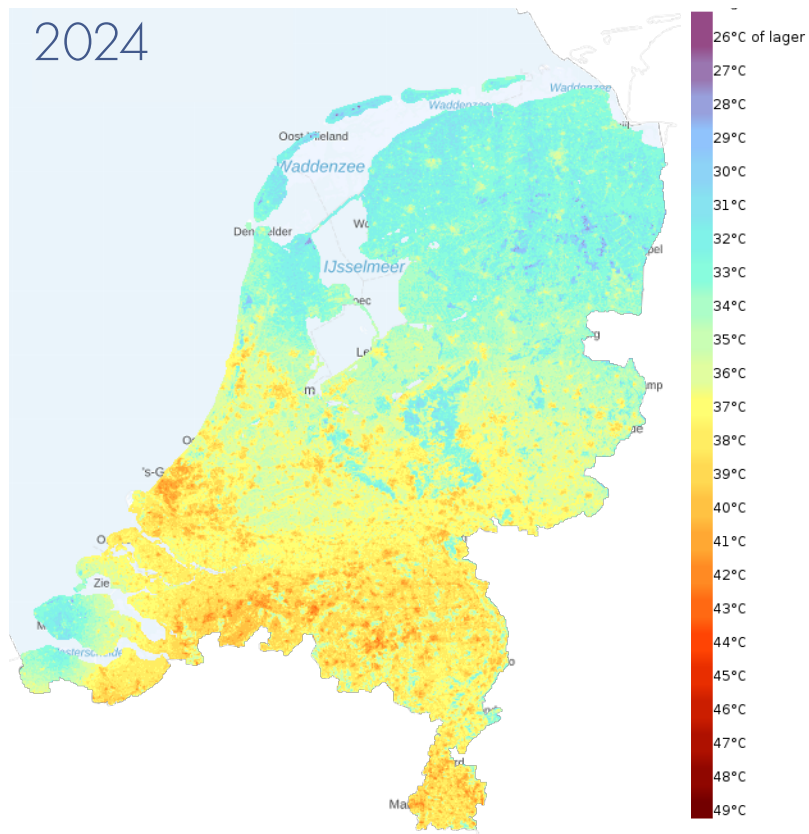
Methodology & Results
SQ2

Discussion & Conclusion

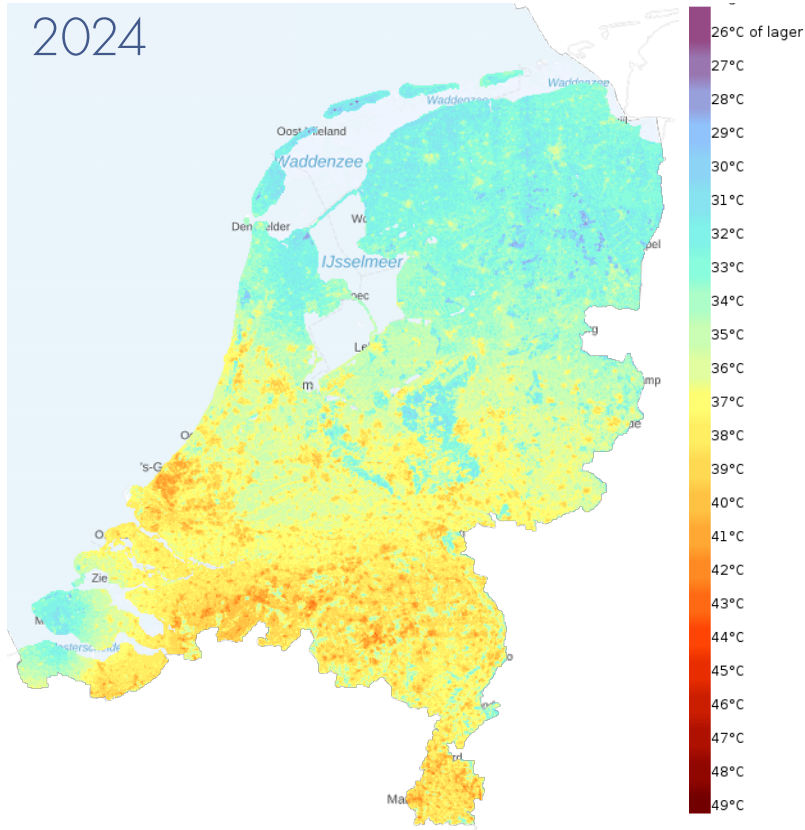




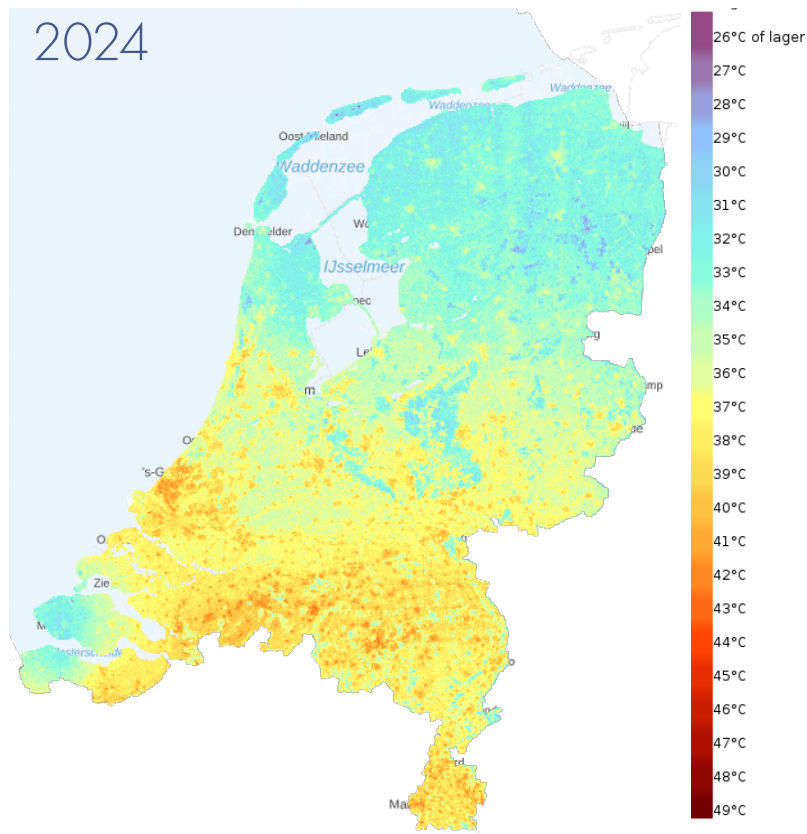
- Sweating



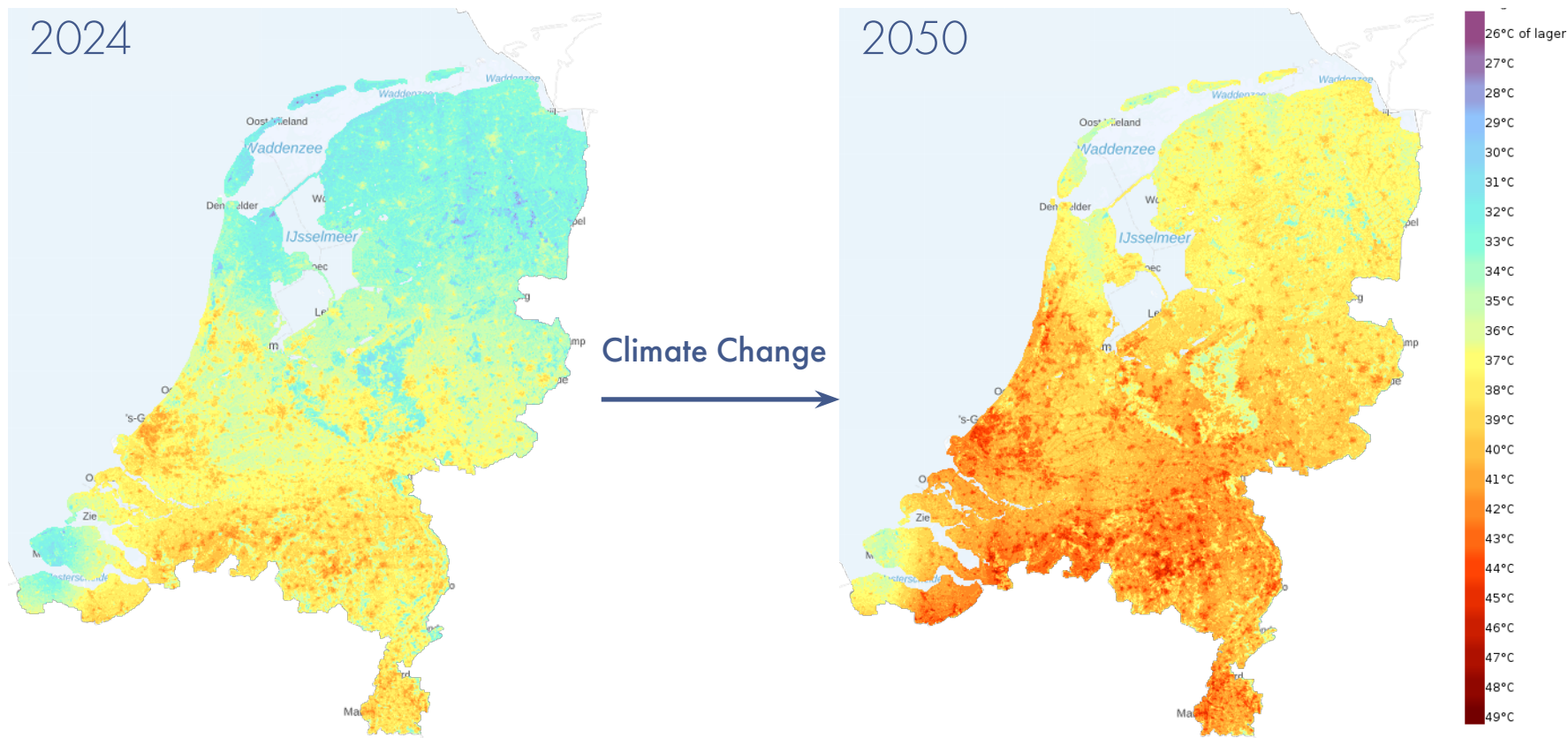
- Sweating
- Trouble Sleeping



- Sweating
- Trouble Sleeping
- Lack of Concentration



- Sweating
- Trouble Sleeping
- Lack of Concentration
- Higher Mortality Rates



(Klimaat-effectatlas, 2024)

Solution?

Cooling

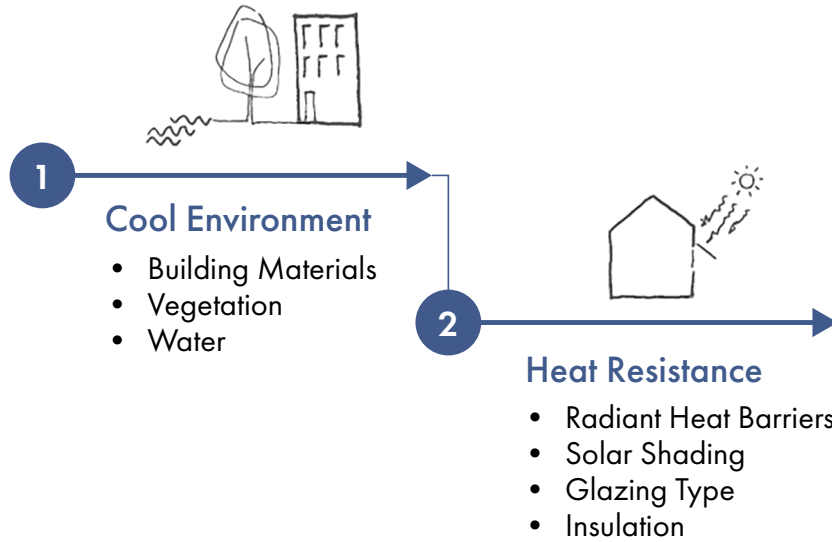


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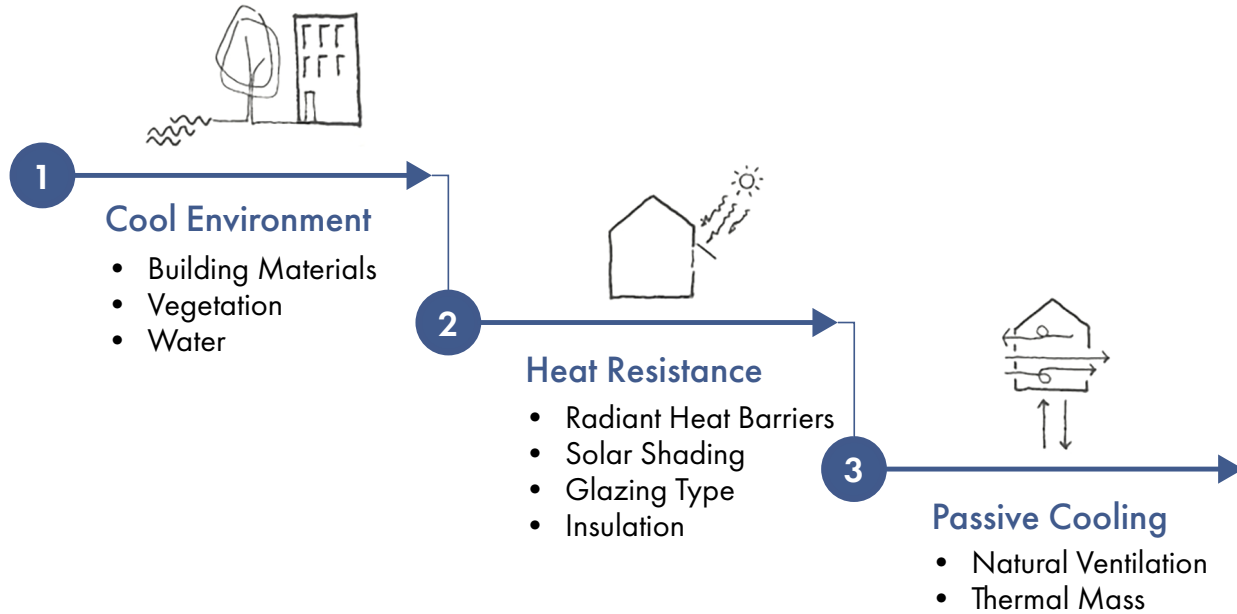
Cool Environment

- Building Materials
- Vegetation
- Water

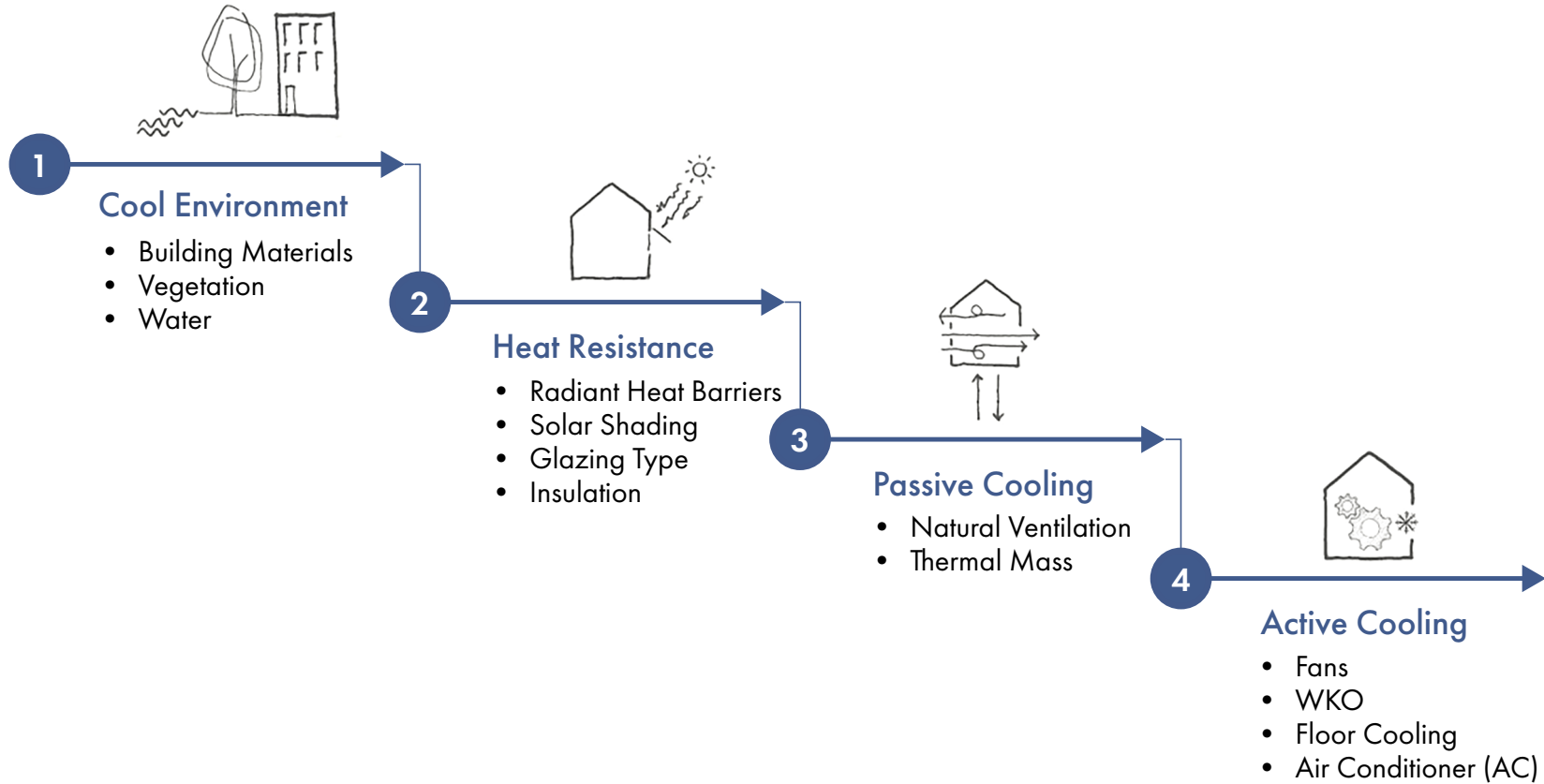
(Alders et al., 2025; Oropeza-Perez and Østergaard, 2018)



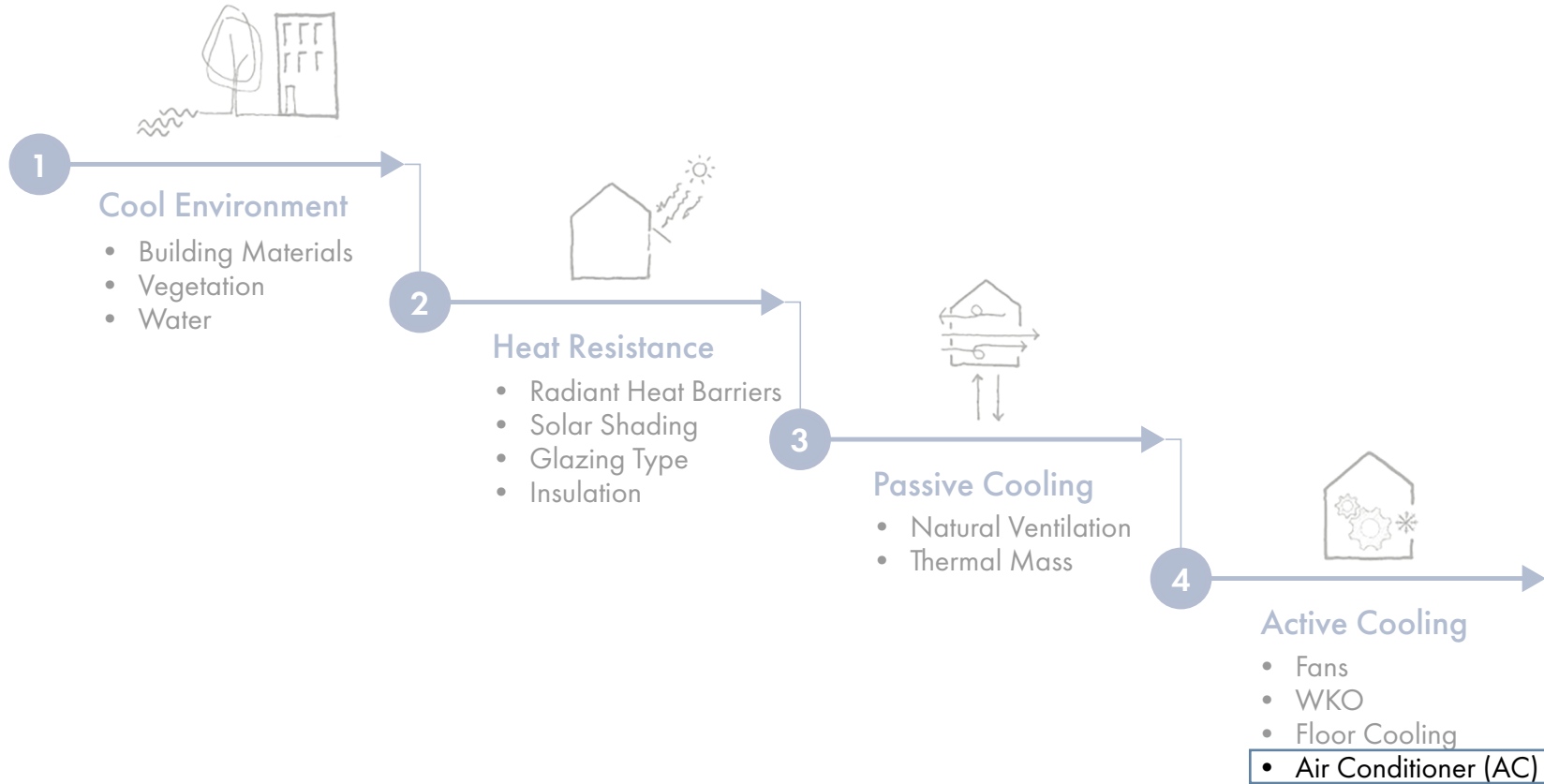
(Alders et al., 2025; Oropeza-Perez and Østergaard, 2018)



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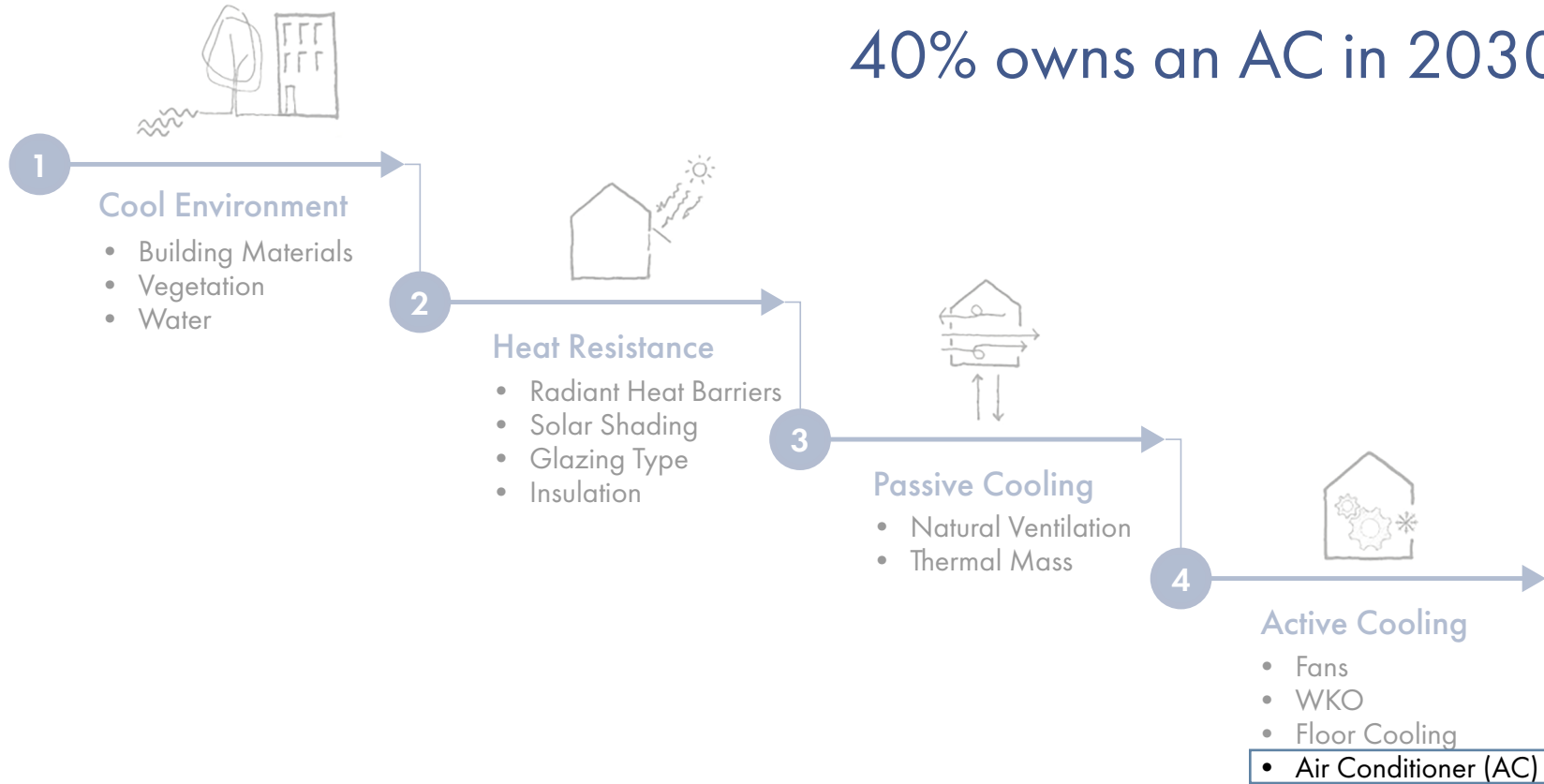


(Alders et al., 2025; Oropeza-Perez and Østergaard, 2018)



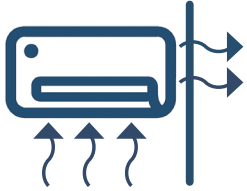
(TNO, 2024)

40% owns an AC in 2030



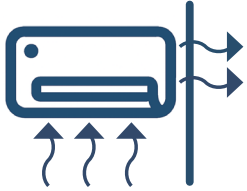
(TNO, 2024)

Air Conditioner (AC)



Release Heat to the
Outdoor Environment

Air Conditioner (AC)

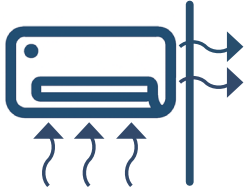


Release Heat to the
Outdoor Environment



Increase of Energy
Consumption

Air Conditioner (AC)



Release Heat to the
Outdoor Environment



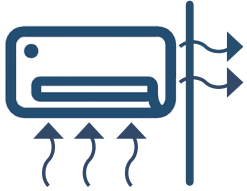
Increase of Energy
Consumption

Air conditioner running
for 8 hours



- 10 refrigerators
- charging more than 100 laptops
- 8 dishwasher cycles

Air Conditioner (AC)



Release Heat to the
Outdoor Environment

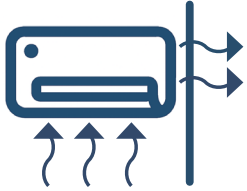


Increase of Energy
Consumption



Higher Energy Bills

Air Conditioner (AC)



Release Heat to the
Outdoor Environment



Increase of Energy
Consumption

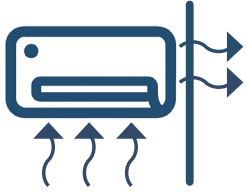


Higher Energy Bills



Contains Greenhouse
Gas Refrigerants

Air Conditioner (AC)



Release Heat to the
Outdoor Environment



Increase of Energy
Consumption



Higher Energy Bills



Contains Greenhouse
Gas Refrigerants



Increased Risk of Grid
Congestion

How **effective** are **passive and low-energy cooling strategies** in providing **heat resilience** in **existing residential buildings** in the **Netherlands** during **summer periods** under **future climate conditions**?

SQ1. Interview & Questionnaire

Stakeholder Perspectives on
Effective Cooling Strategies

SQ2. Building Simulations

Ranking of Cooling Strategies
on Effectiveness

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Stakeholder Perspectives

Questionnaire

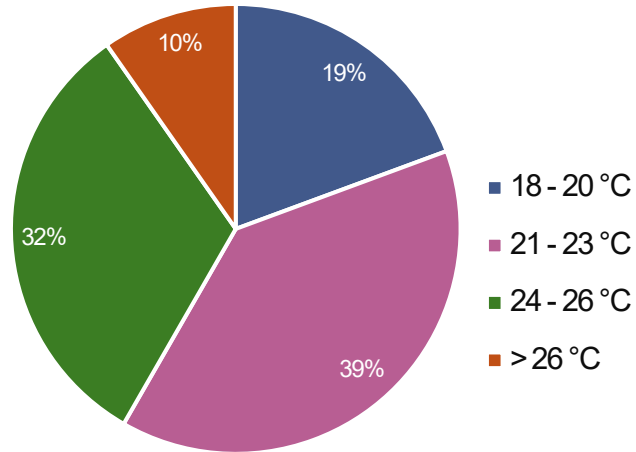
- 66 Residents

Interviews

- Architect
- Physiologist
- Overheating Specialists (4x)
- Housing Associations (3x)
- Technical Advisors (2x)

Perception of Thermal Comfort

Questionnaire

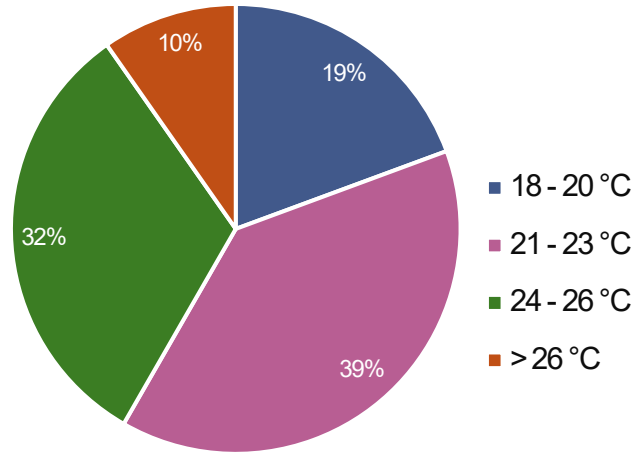


Maximum Comfortable Indoor Temperature during summer

Perception of Thermal Comfort

Questionnaire

Interviews



→ 25 °C

Maximum Comfortable Indoor Temperature (own work, 2025)

(Own work, 2025)

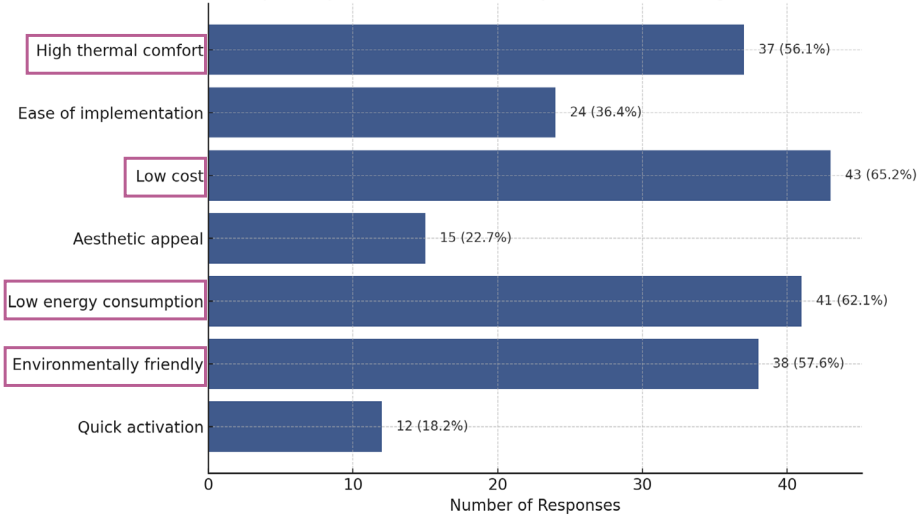
Reason to Implement Cooling Strategies

Questionnaire



Questionnaire

Top 3 Aspects Considered Important in Cooling Solutions

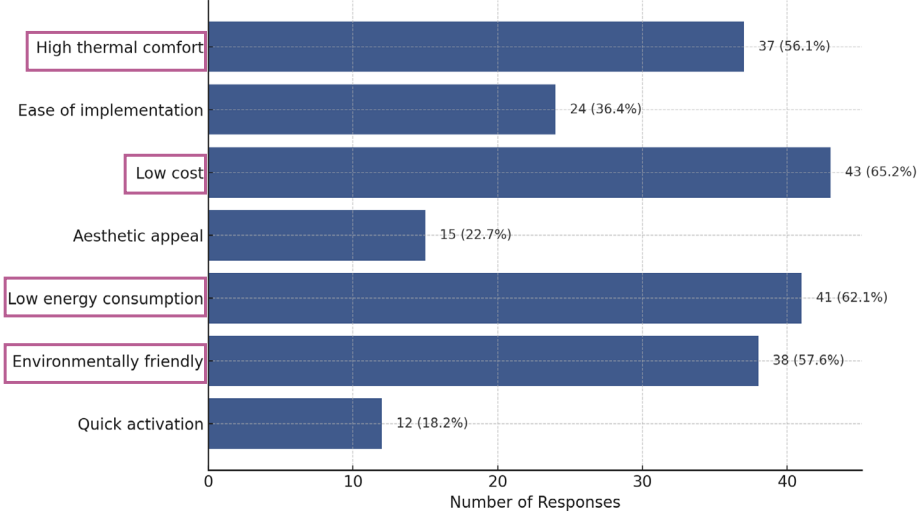


(Own work, 2025)

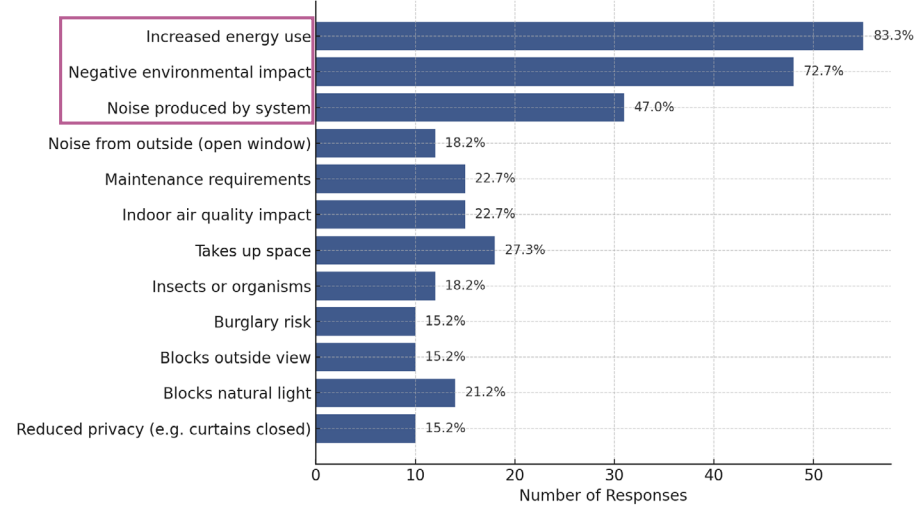
Reason to Implement Cooling Strategies

Questionnaire

Top 3 Aspects Considered Important in Cooling Solutions



Perceived Negative Side Effects of Cooling Strategies



(Own work, 2025)

Reason to Implement Cooling Strategies

Interviews

Reduction of CO₂ Emissions

(Own work, 2025)

Reason to Implement Cooling Strategies

Interviews

Reduction of CO₂ Emissions

Energy Savings

(Own work, 2025)

Reason to Implement Cooling Strategies

Interviews

Reduction of CO₂ Emissions

Energy Savings

Lower Energy Bills

(Own work, 2025)

Reason to Implement Cooling Strategies

Interviews

Reduction of CO₂ Emissions

Energy Savings

Lower Energy Bills

Low maintenance

(Own work, 2025)

Reason to Implement Cooling Strategies

Interviews

Reduction of CO₂ Emissions

Energy Savings

Lower Energy Bills

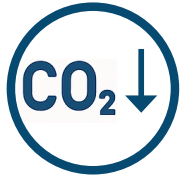
Low maintenance

Low Investment Costs

(Own work, 2025)

Reason to Implement Cooling Strategies

Questionnaire



Reduce CO2 Emissions



Lower the Energy Consumption



Quiet



Affordable



Environmentally Friendly



Low Maintenance

(Own work, 2025)

Interviews

Questionnaire



No mandatory regulations for implementing cooling in existing buildings

SQ1. Interview & Questionnaire

Stakeholder Perspectives on
Effective Cooling Strategies

SQ2. Building Simulations

Ranking of Cooling Strategies
on Effectiveness

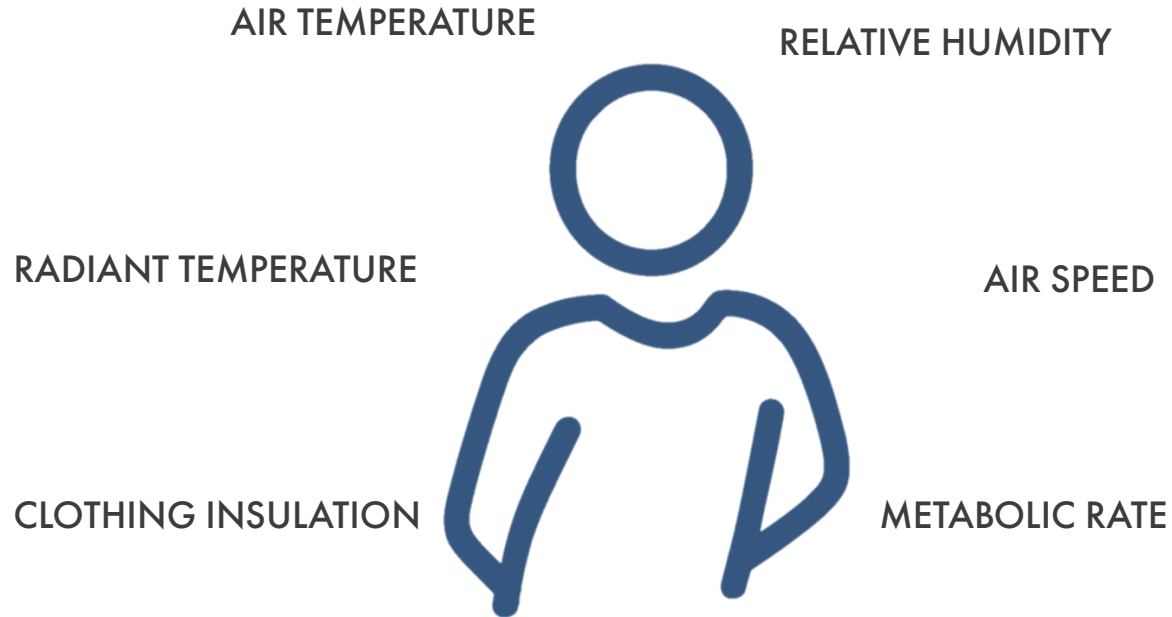


(Fanger, 1970)

AIR TEMPERATURE



(Fanger, 1970)



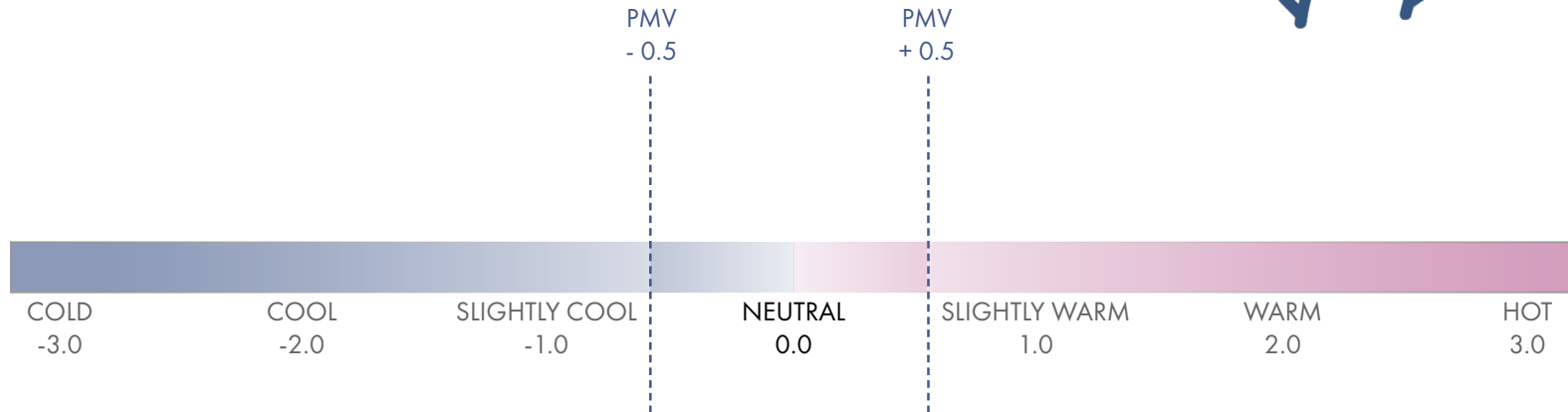
(Fanger, 1970; Interviews, 2025)

Predicted Mean Vote (PMV)



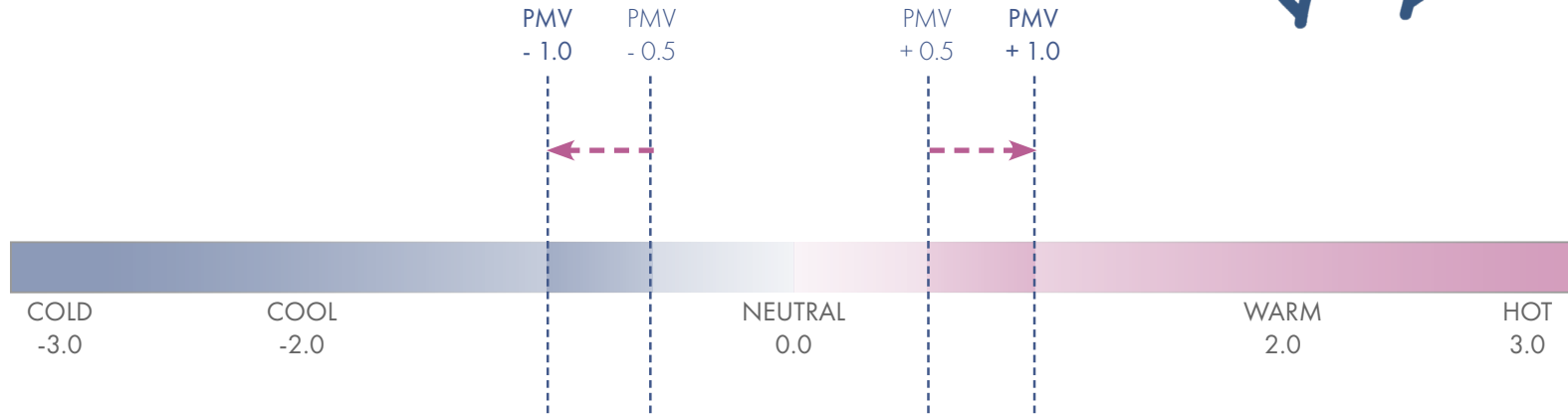
(Fanger, 1970)

Thermal Comfort



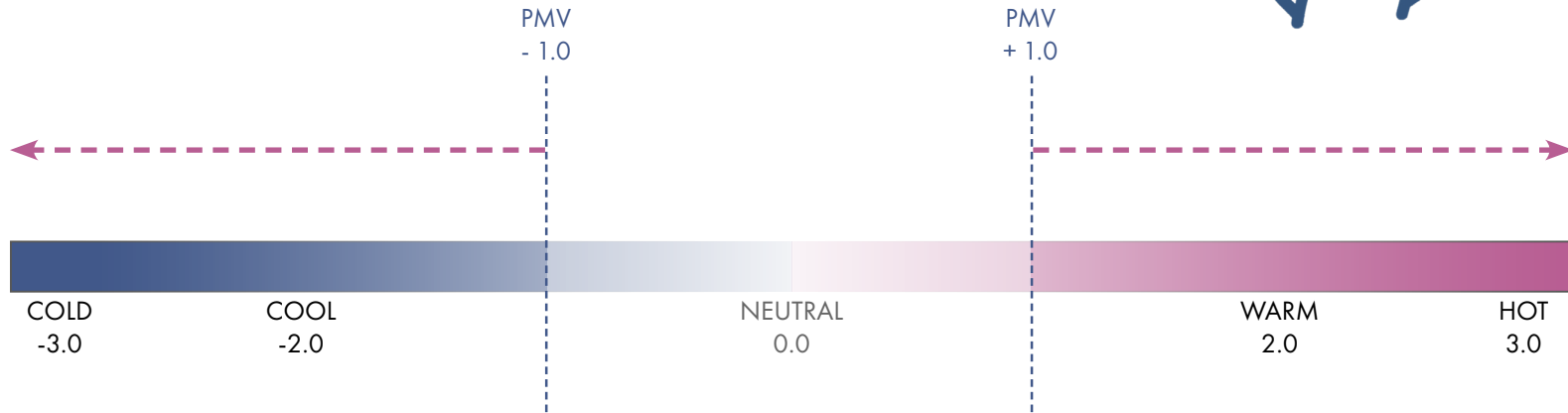
(Fanger, 1970)

Thermal Discomfort



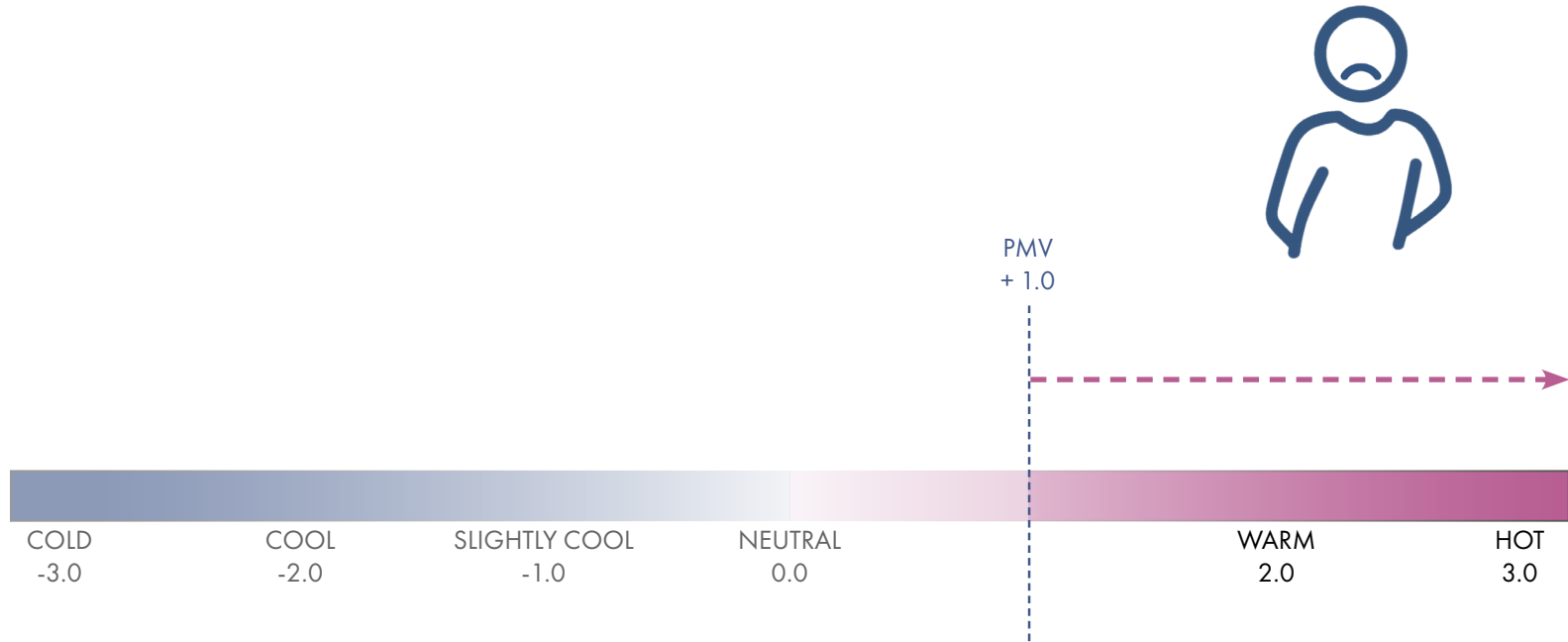
(Fanger, 1970)

Thermal Stress

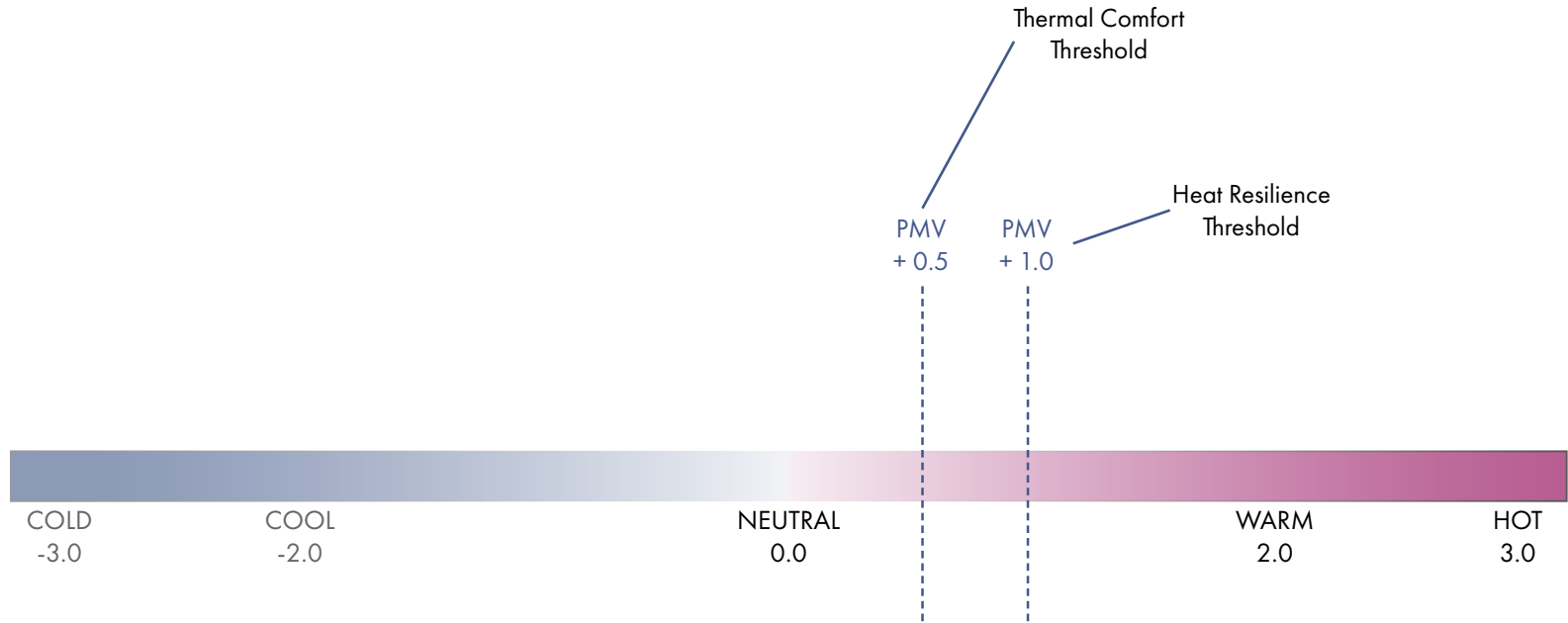


(Fanger, 1970)

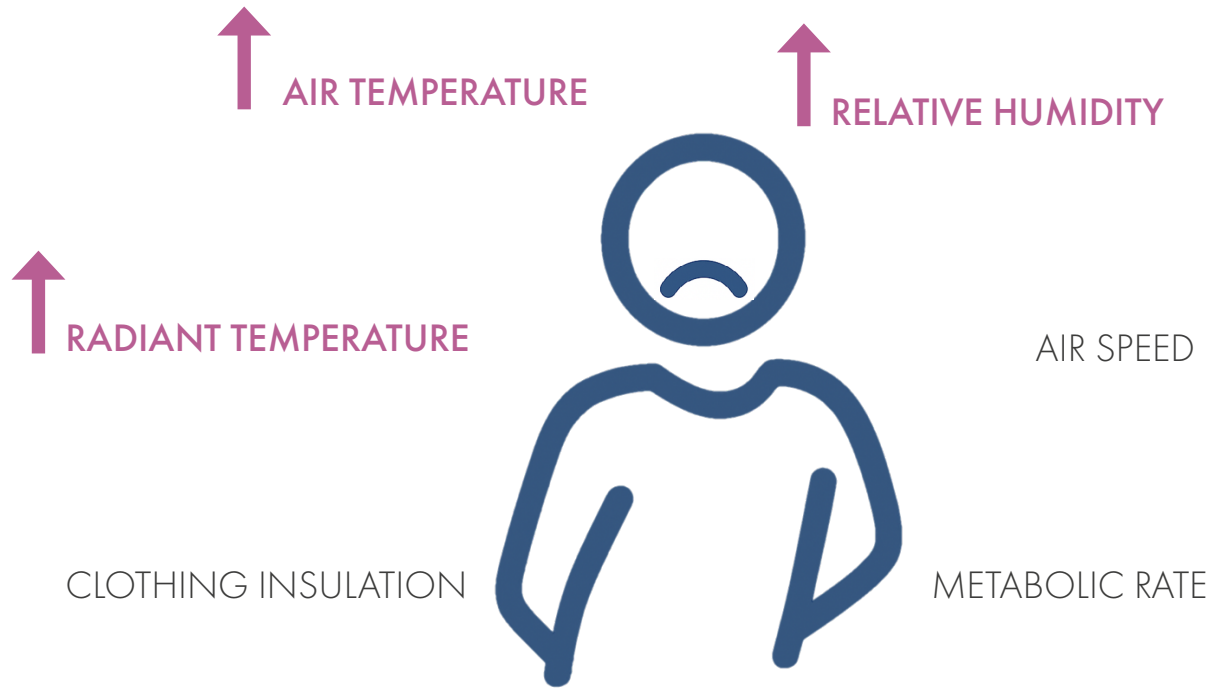
Thermal Heat Stress

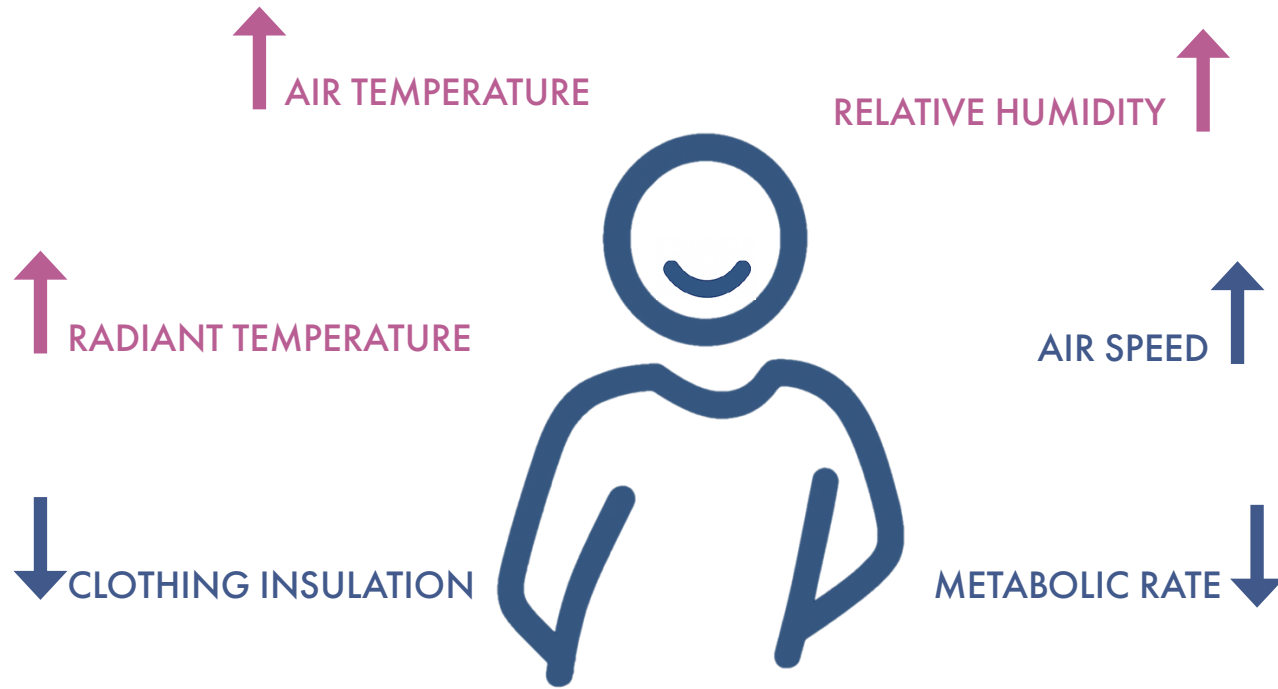


(Fanger, 1970)

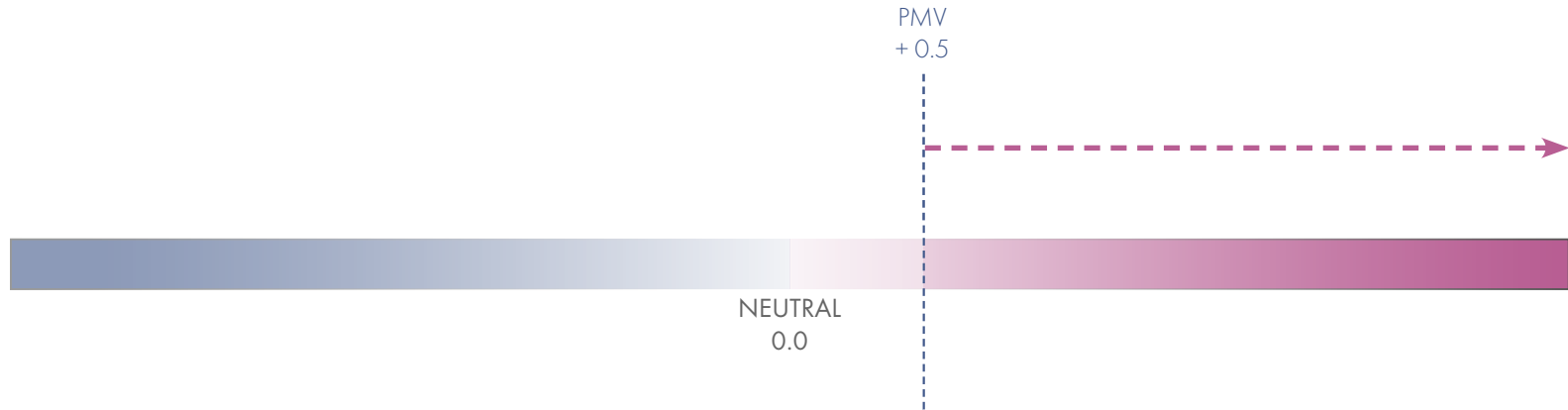


(Fanger, 1970)





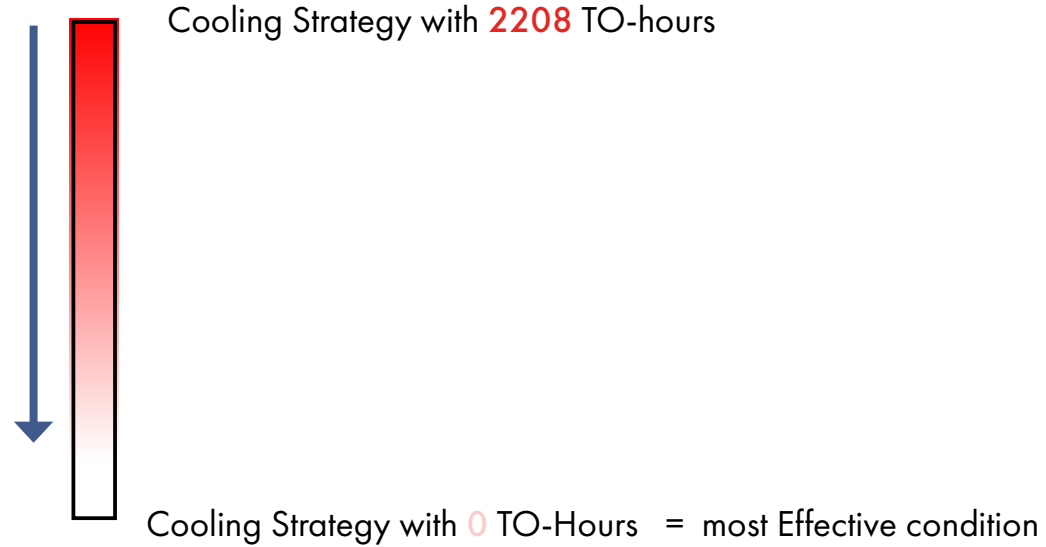
TO-Hours = 1 Hour during Summer that the Average Person
Experiences **Discomfort** (PMV > 0.5)
TemperatuurOverschrijdings - Uren



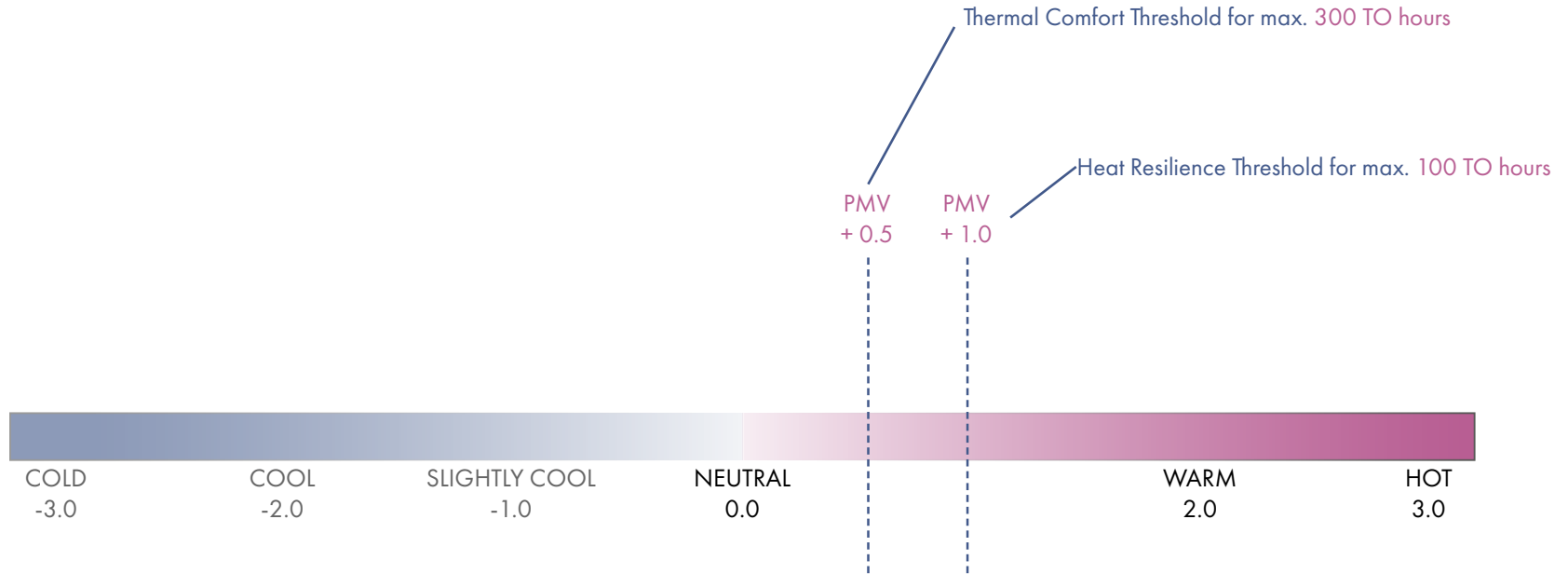
(Alders et al., 2024)

Cooling Strategy with 2208 TO-hours

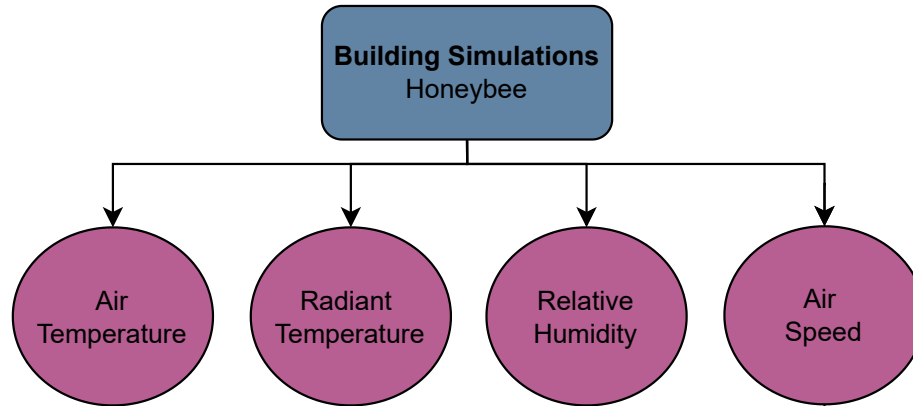
Ranking Effectiveness

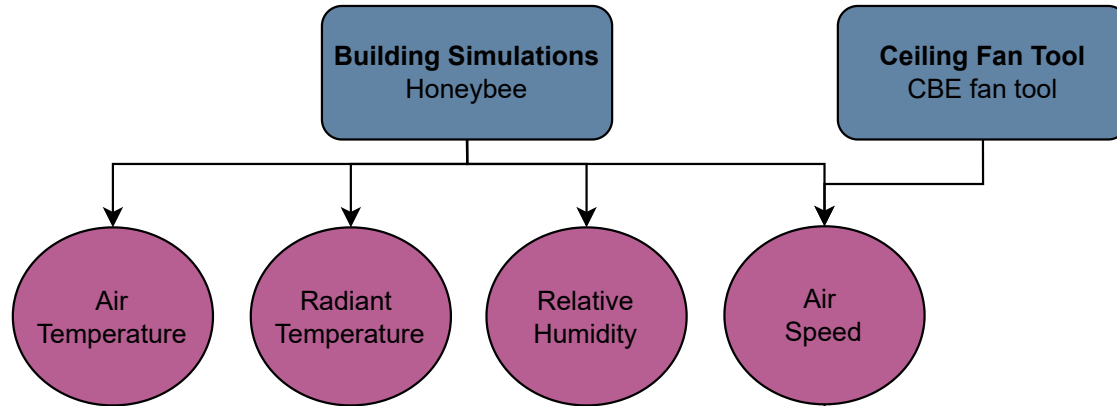


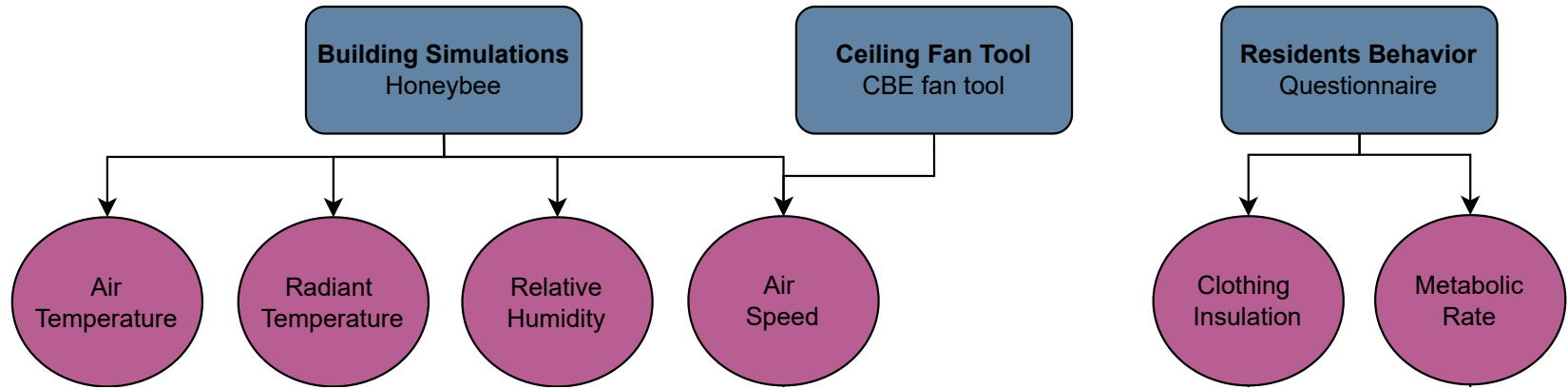
Effective and Compliant with Thresholds

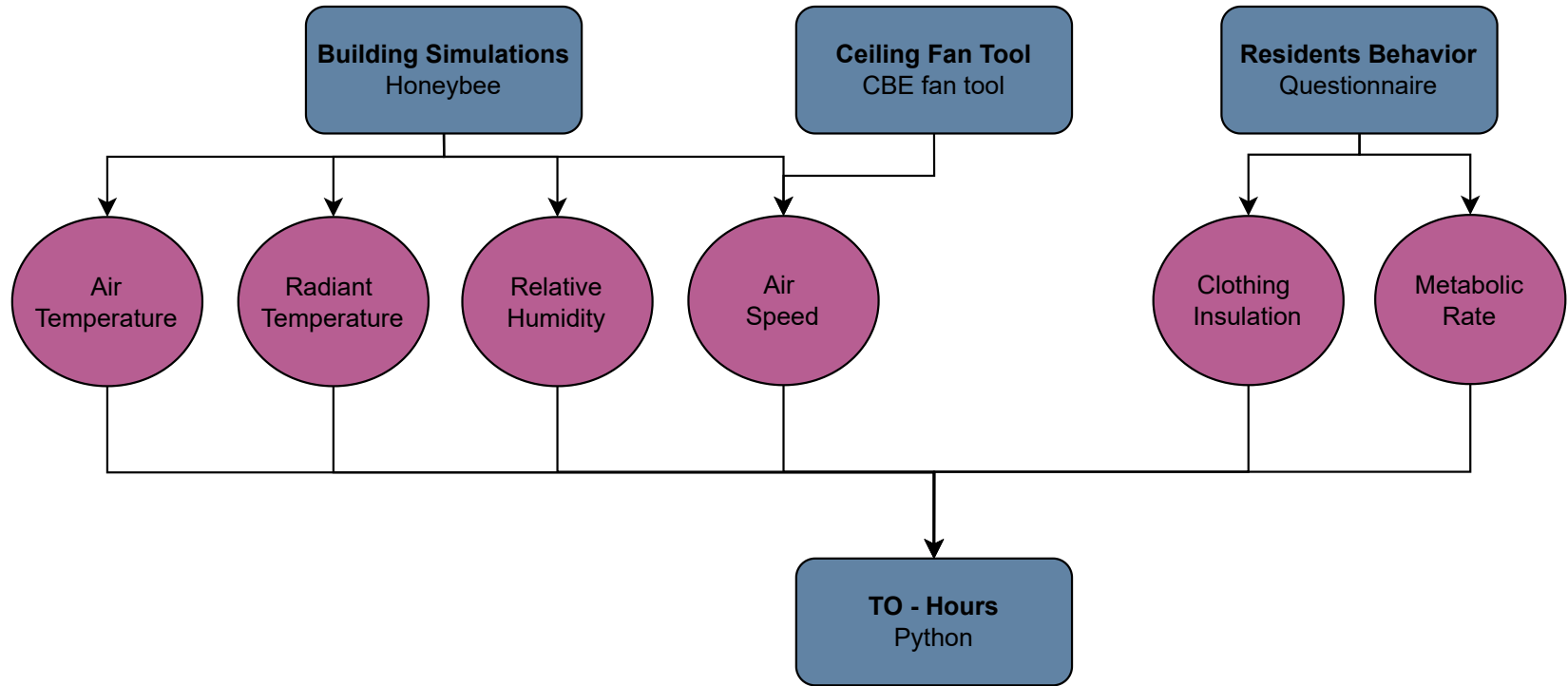


(Fanger, 1970)

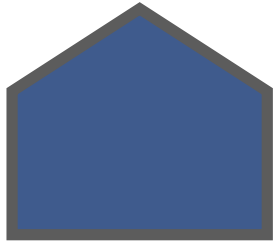




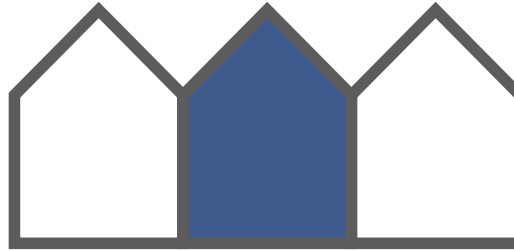




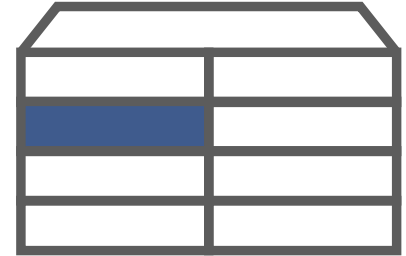
Building Types



Detached (Vrijstaand) Residence
Built before 1964



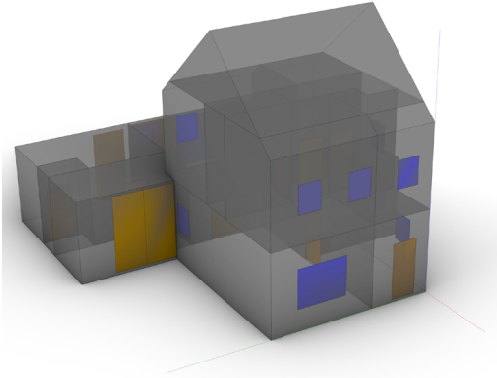
Terraced (Rijties) Residence
Built between 1975 - 1991



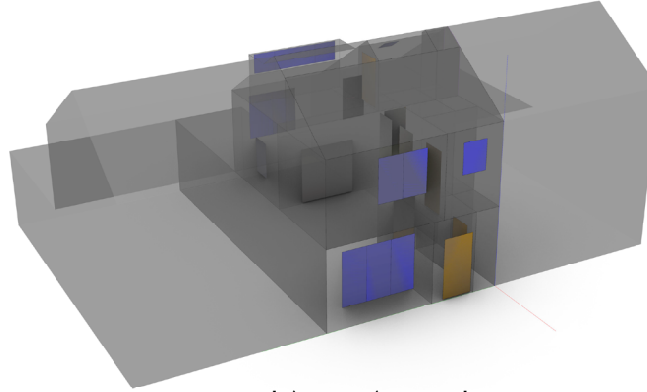
Apartment (Galerij) Residence
Built between 1965 - 1974

(RVO, 2023)

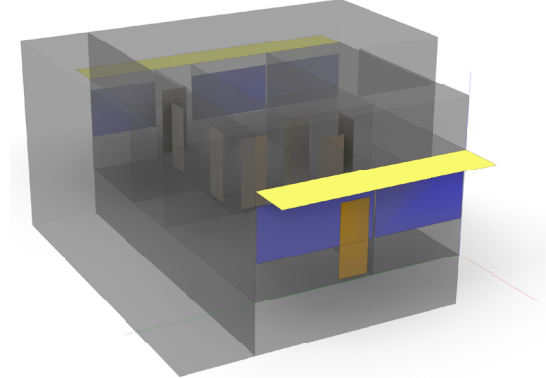
Building Types



Detached (Vrijstaand) Residence
Built before 1964

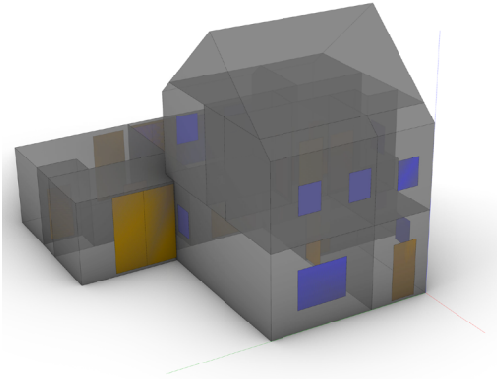


Terraced (Rijtjes) Residence
Built between 1975 - 1991

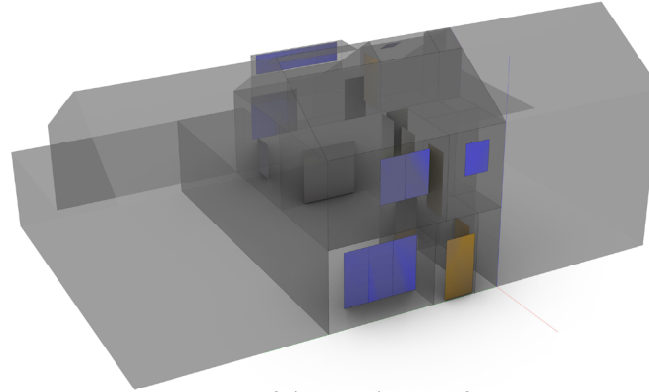


Apartment (Galerij) Residence
Built between 1965 - 1974

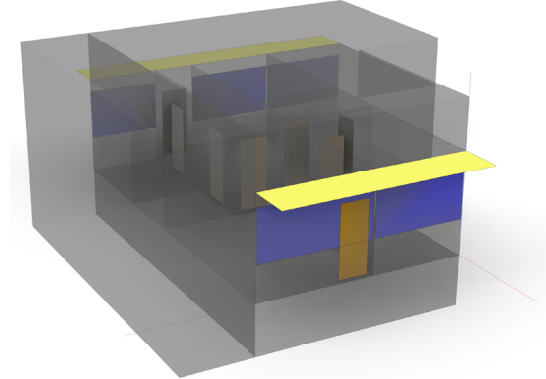
Building Types



Detached (Vrijstaand) Residence
Built before 1964



Terraced (Rijtjes) Residence
Built between 1975 - 1991



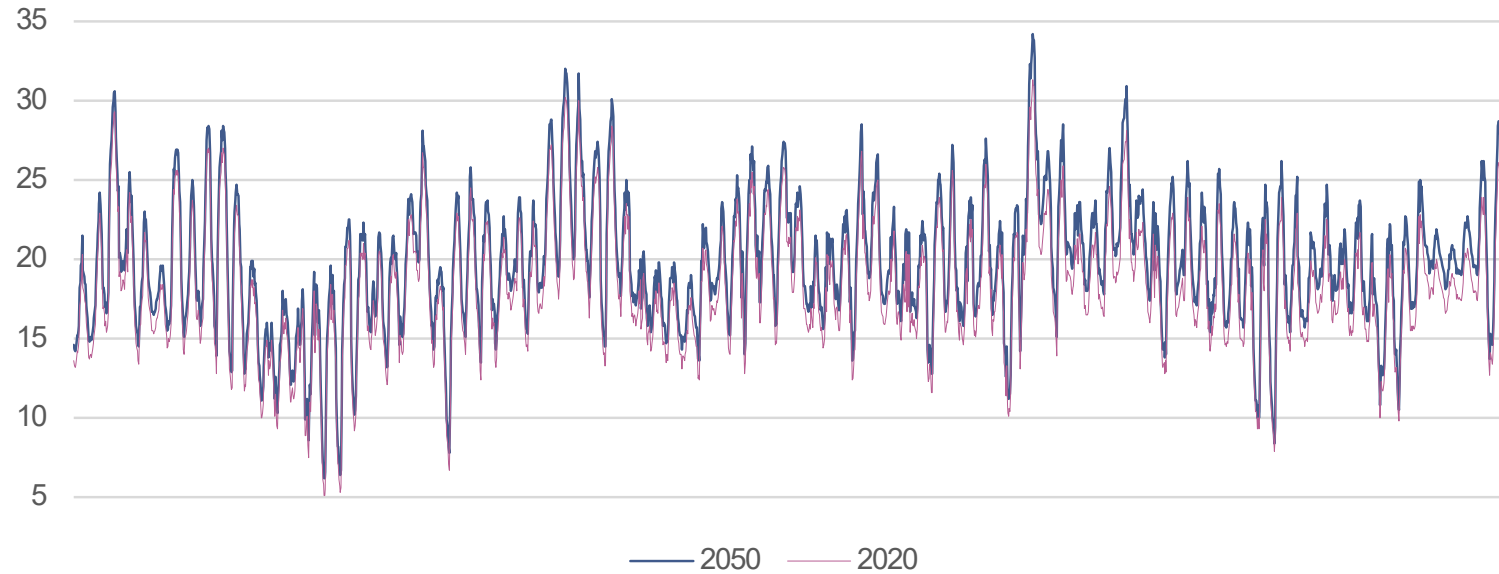
Apartment (Galerij) Residence
Built between 1965 - 1974

Representing 1.2 of 8 million Residence in the Netherlands

(RVO, 2023)

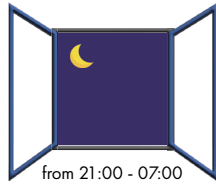
Outdoor Temperatures

+ 2 °C

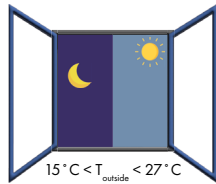


(Bessembinder et al., 2023; Heiranipour et al., 2024)

Night Ventilation

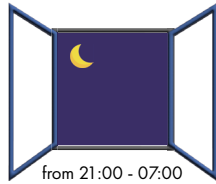


Temperature based Ventilation



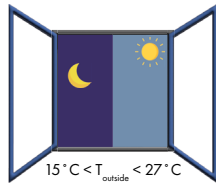
Cooling Strategies

Night Ventilation



Single-Sided Ventilation

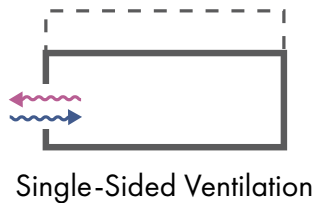
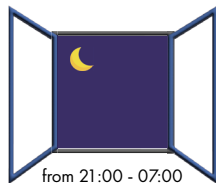
Temperature based Ventilation



Cross Ventilation

Cooling Strategies

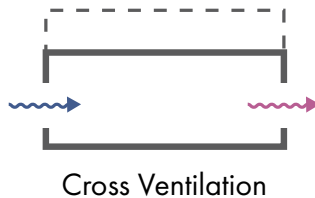
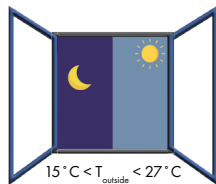
Night Ventilation



Current Construction



Temperature based Ventilation

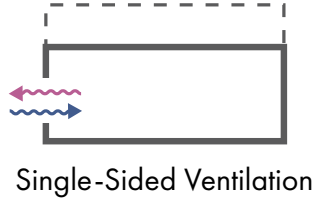
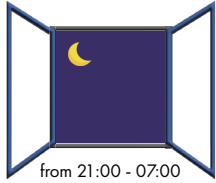


Renovated Construction

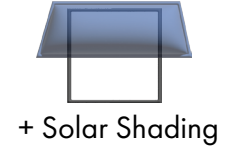


Cooling Strategies

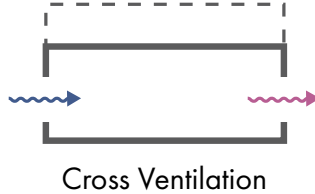
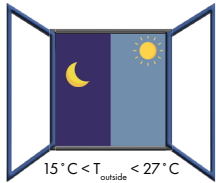
Night Ventilation



Current Construction

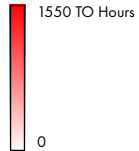
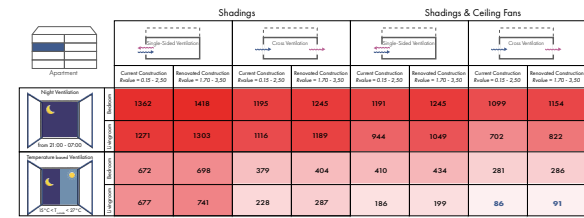
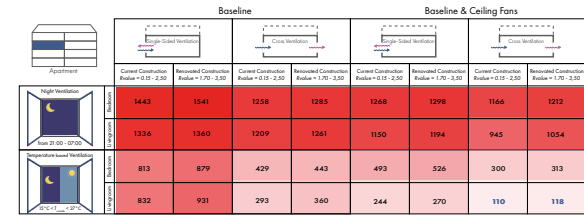
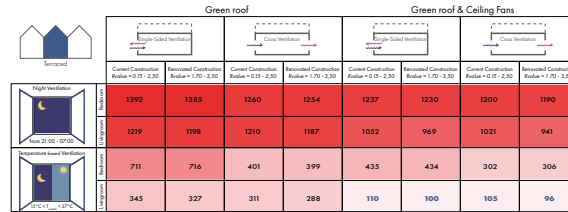
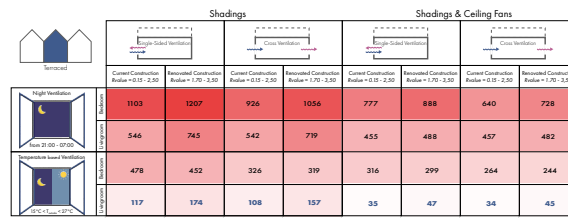
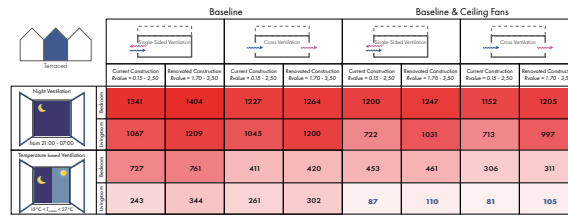
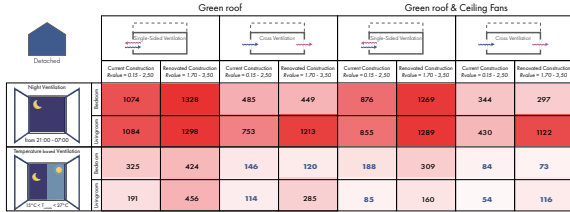
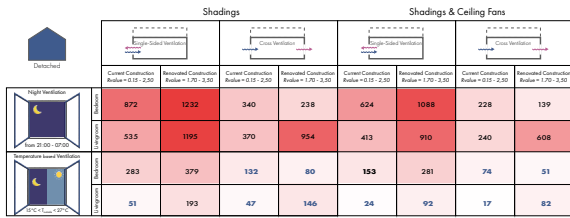
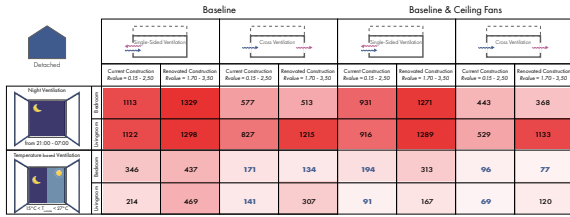


Temperature based Ventilation



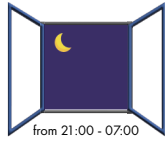
Renovated Construction





X = compliance

Night Ventilation



+



Single-Sided Ventilation

+

Current Construction



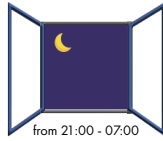
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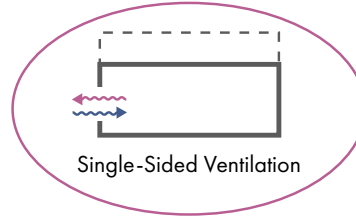
Ceiling Fan



Night Ventilation



+

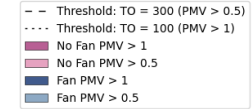
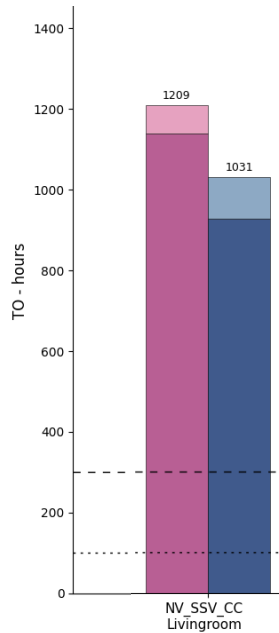


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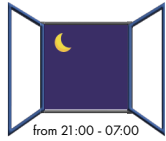
Current Construction



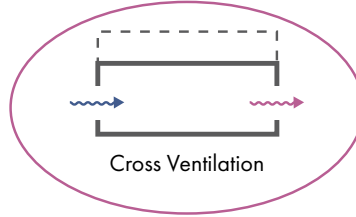
±



Night Ventilation



+

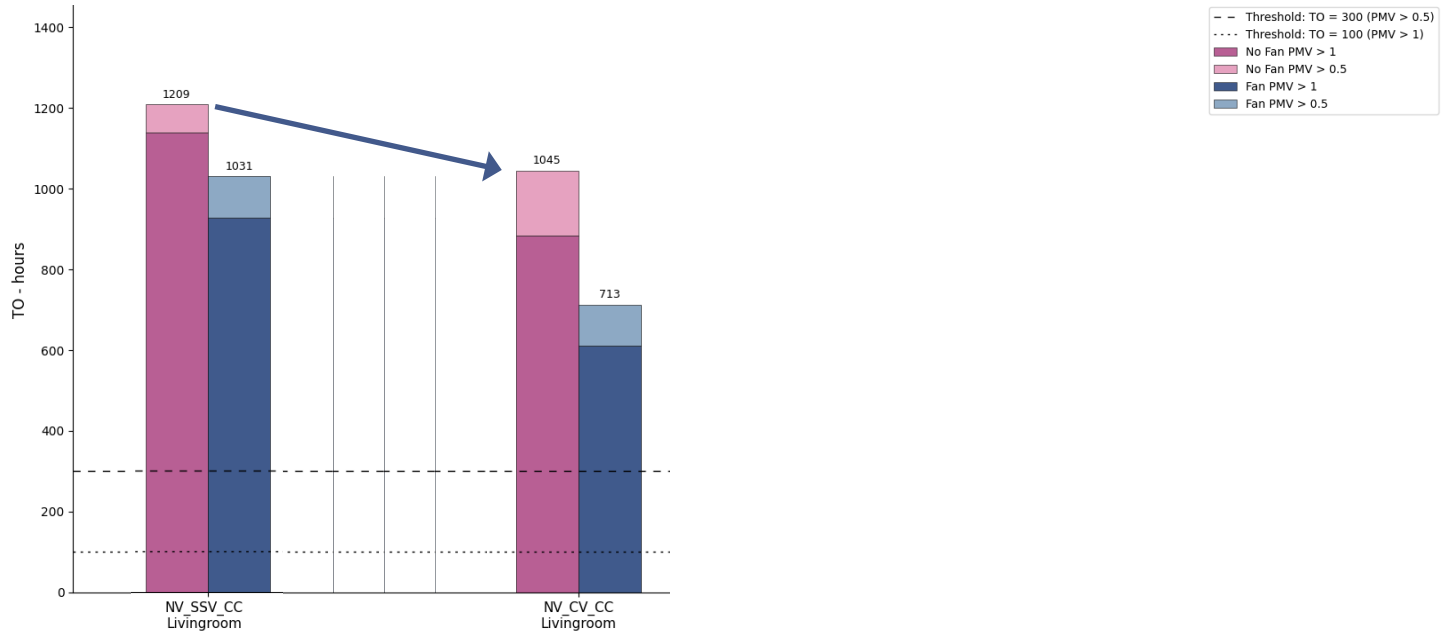


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Current Construction

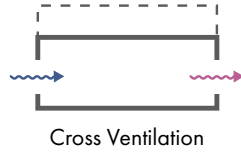


±





+

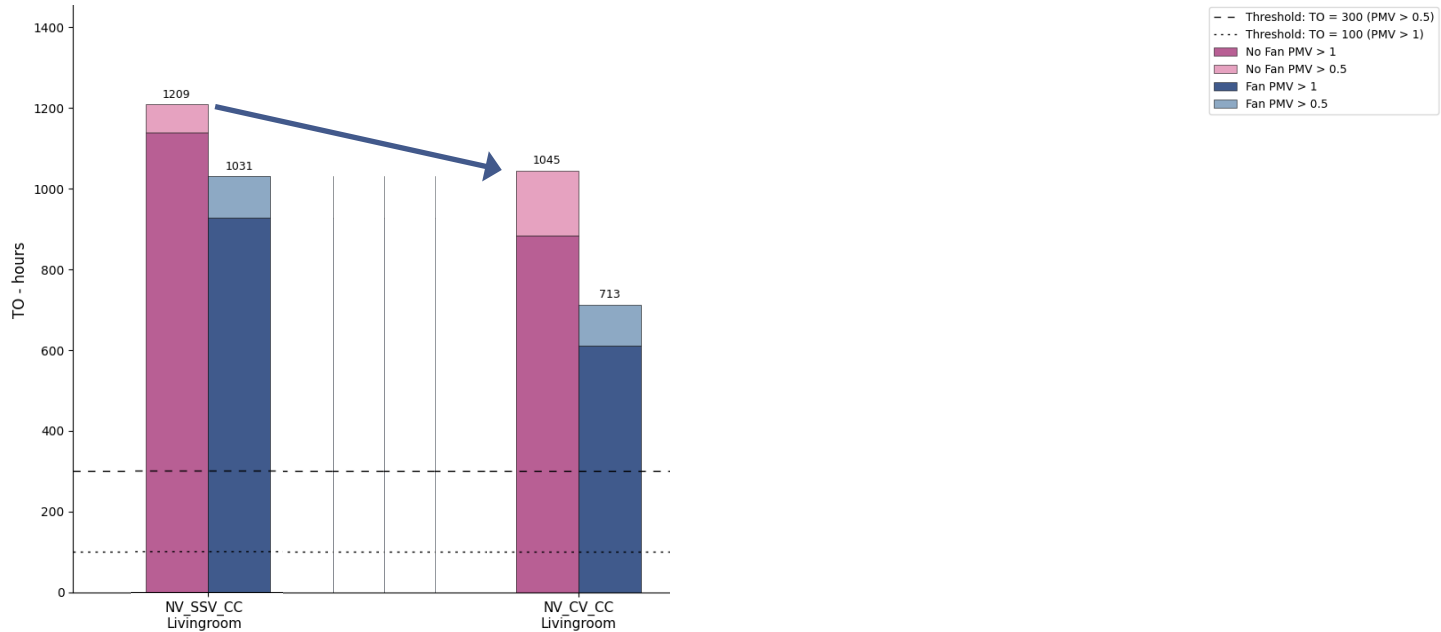


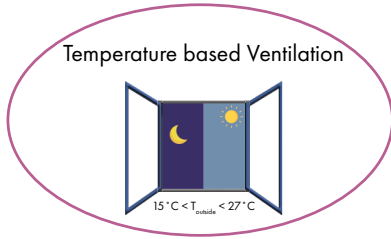
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Current Construction

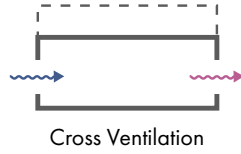


±





+

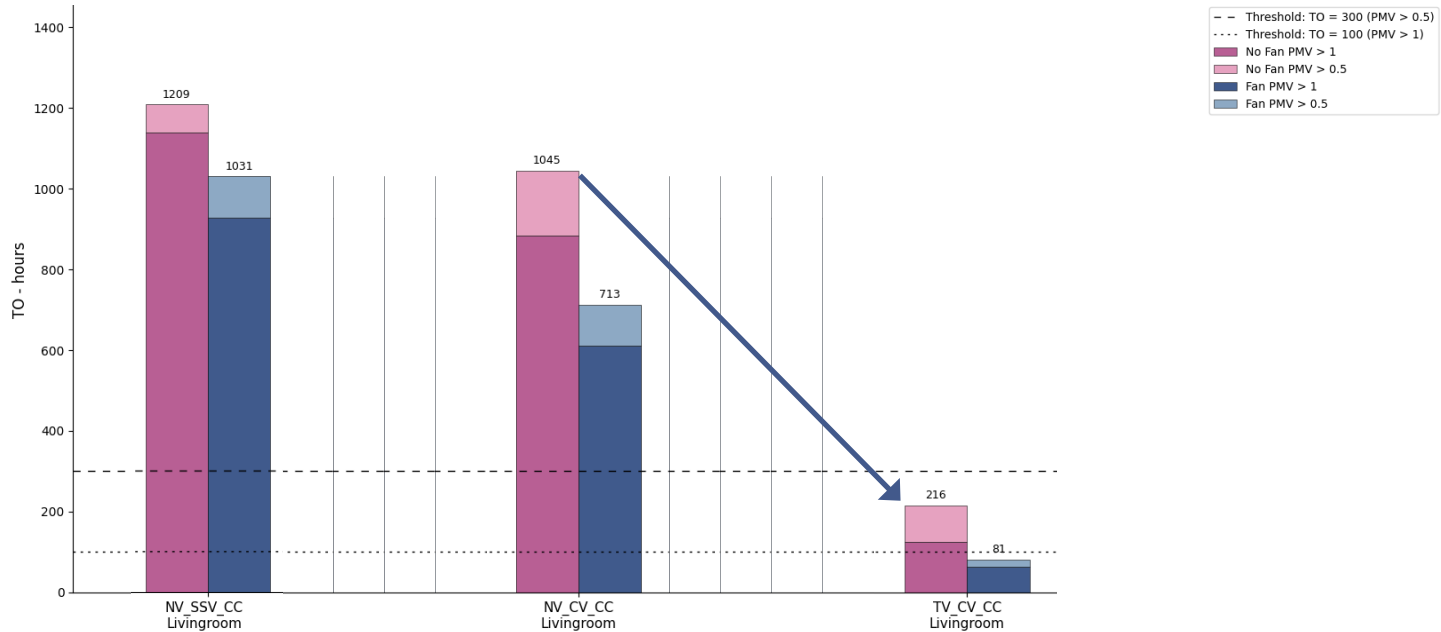


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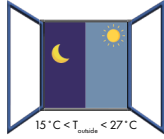
Current Construction



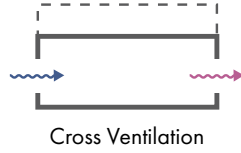
±



Temperature based Ventilation



+

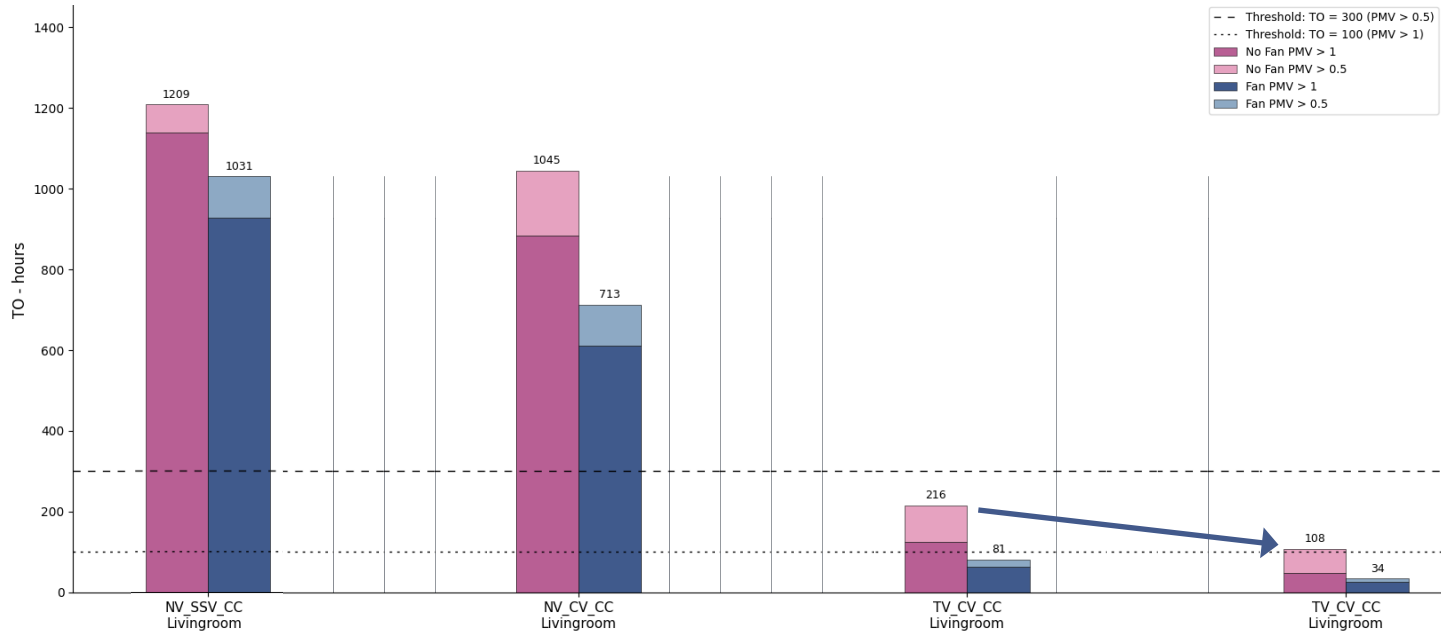
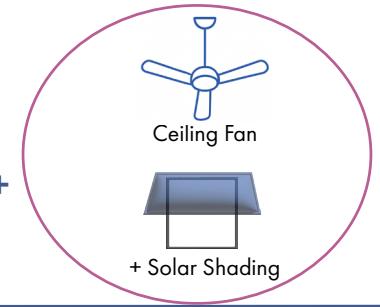


+

Current Construction

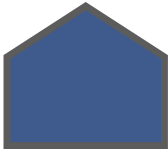


+



Ranking Effectiveness Bedroom & Livingroom

1.



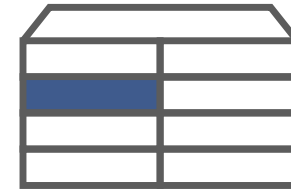
Detached House
(Vrijstaande Woning)

2.



Terraced House
(Rijtjeswoning)

3.

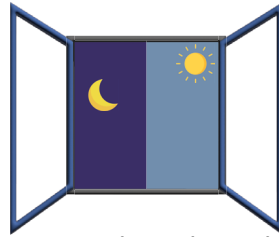


Apartment
(Galerij woning)

Most Effective
Option

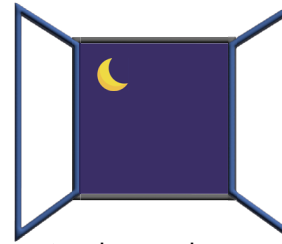
Ranking Effectiveness Bedroom & Livingroom

1.



Temperature based Ventilation

2.



Night Ventilation

Most Effective
Option

Ranking Effectiveness Bedroom & Livingroom

1.



Cross Ventilation

2.

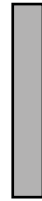


Single-Sided Ventilation

Most Effective
Option

Ranking Effectiveness Bedroom & Livingroom

1.



Current Construction

2.

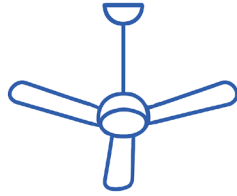


Renovated Construction

Most Effective
Option

Ranking Effectiveness Bedroom & Livingroom

1.



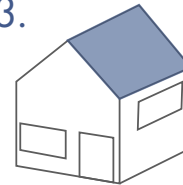
Ceiling Fan

2.

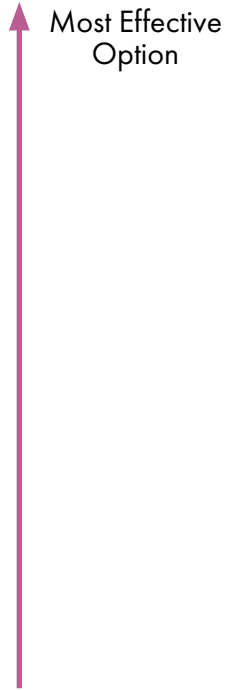


Solar Shading

3.

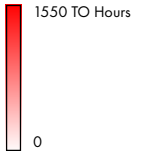
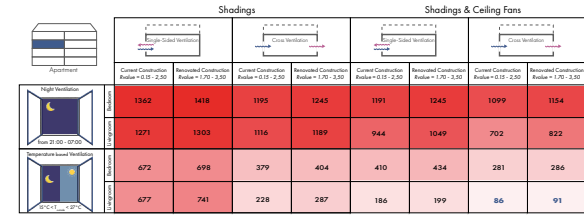
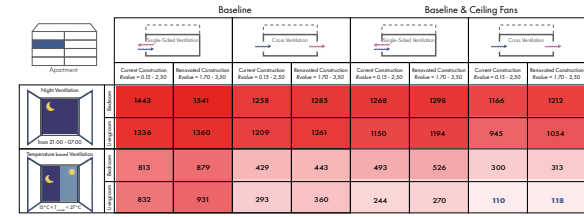
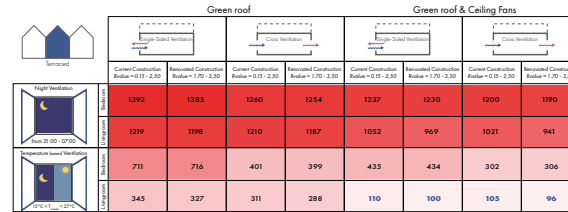
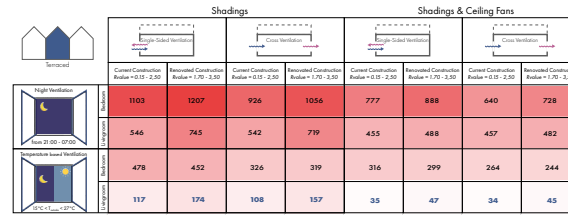
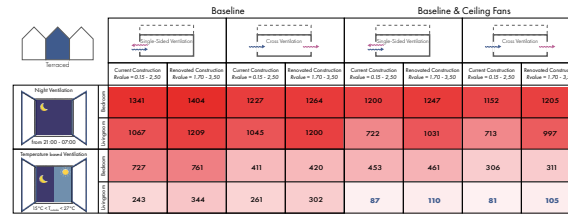
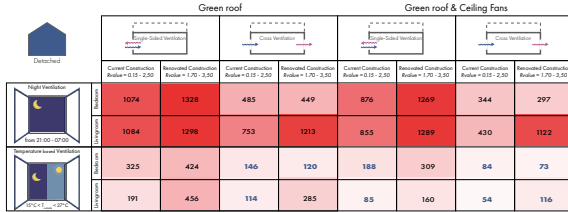
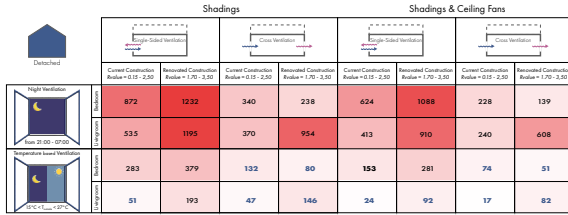
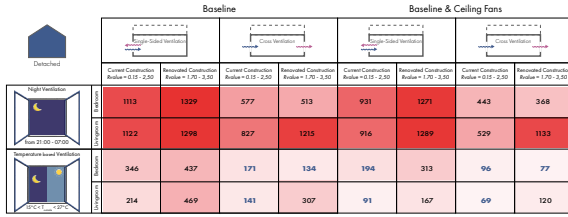


Green Roof



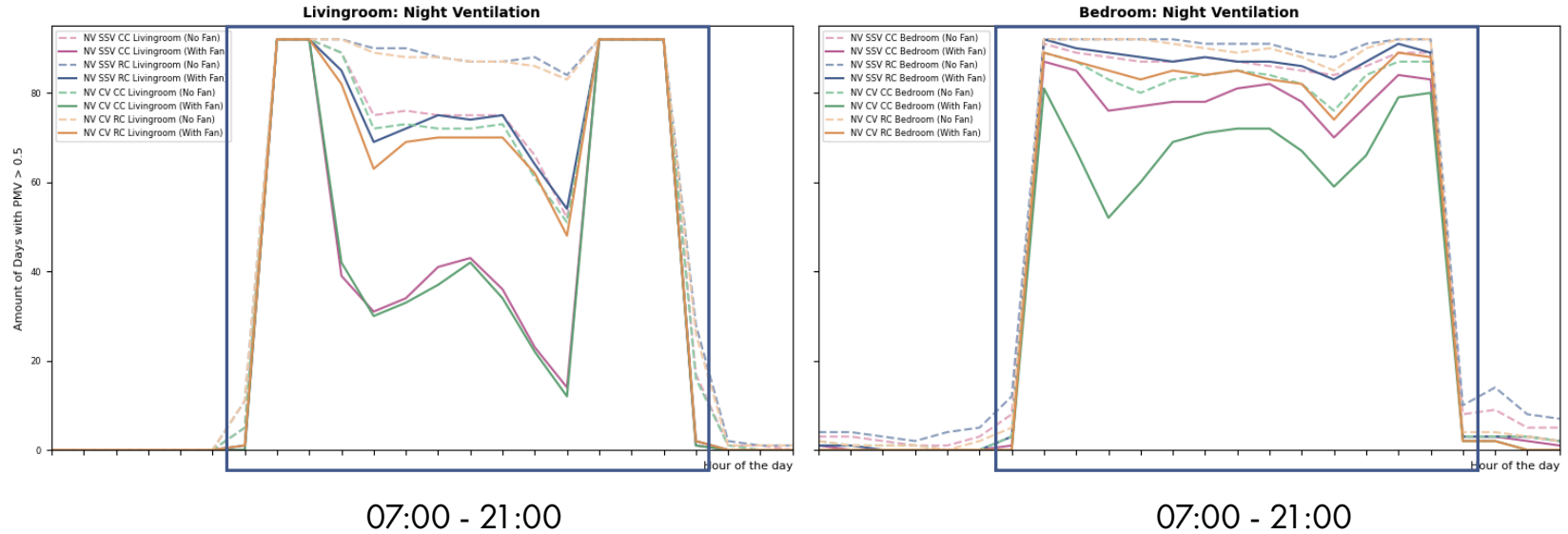
Most Effective
Option

Is it Effective Enough?

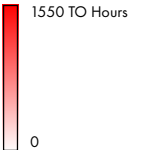
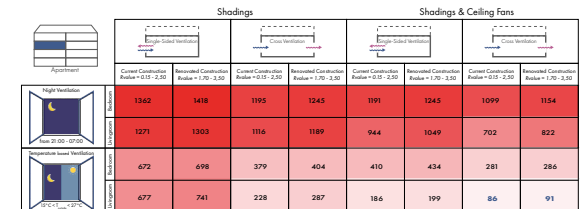
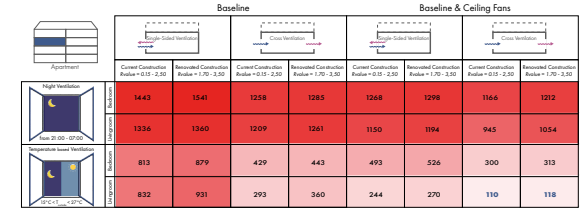
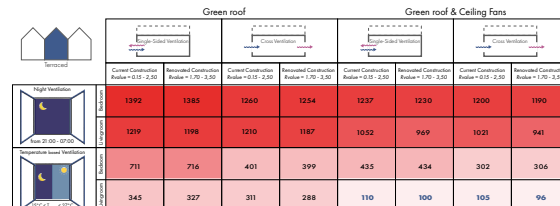
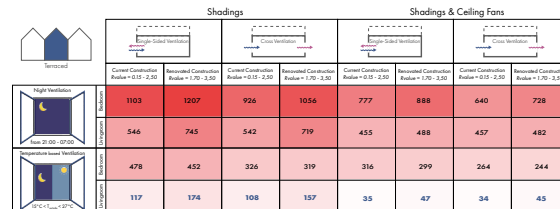
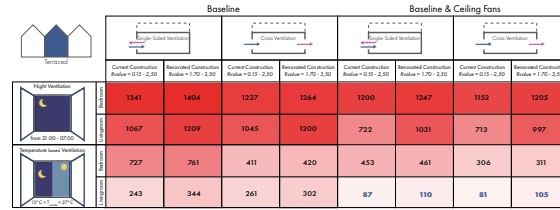
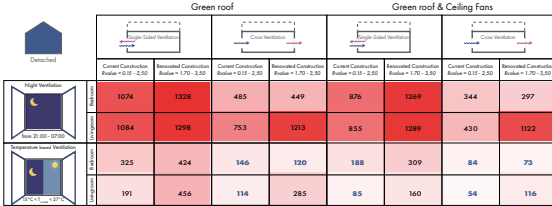
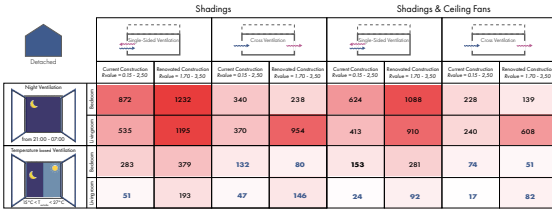
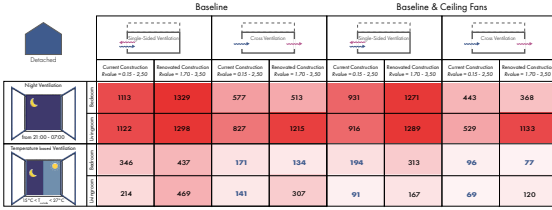


X = compliance

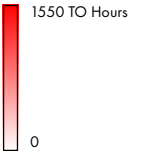
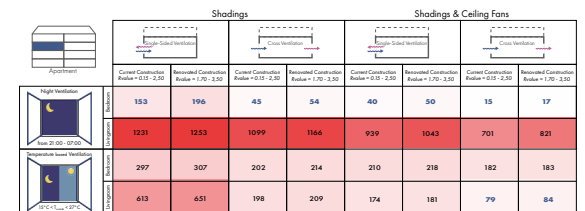
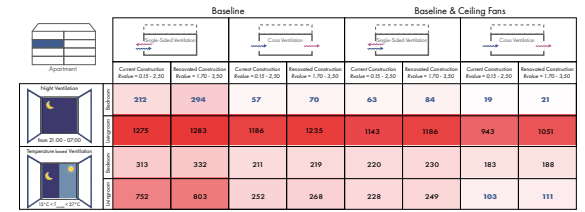
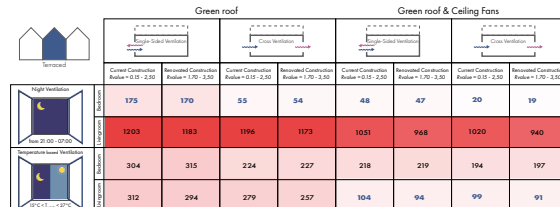
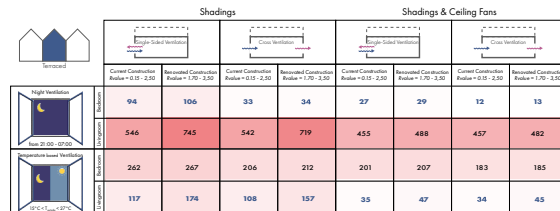
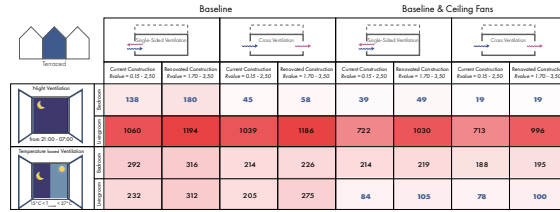
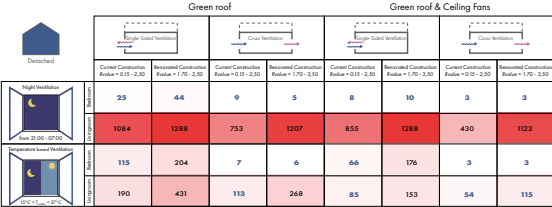
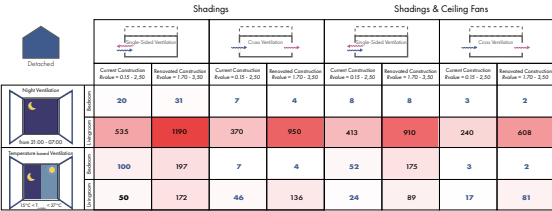
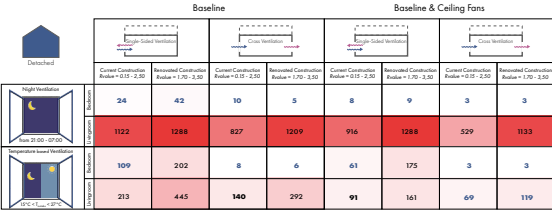
Moment of TO Hours during the Day



Is it Effective Enough?



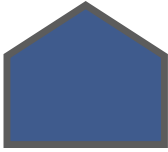
X = compliance



X = compliance

Ranking Effectiveness Bedroom & Livingroom

1.



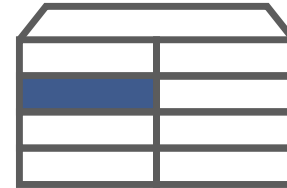
Detached House
(Vrijstaande Woning)

2.



Terraced House
(Rijtjeswoning)

3.



Apartment
(Galerij woning)

Most Effective
Option

Ranking Effectiveness Bedroom & Livingroom

1.



Cross Ventilation

2.

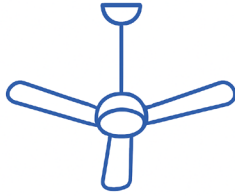


Single-Sided Ventilation

Most Effective
Option

Ranking Effectiveness Bedroom & Livingroom

1.



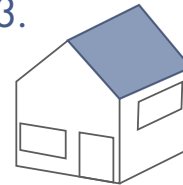
Ceiling Fan

2.



Solar Shading

3.

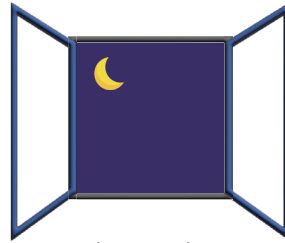


Green Roof

Most Effective
Option

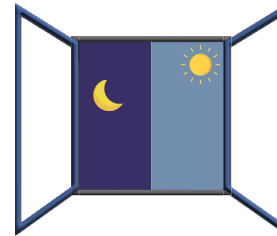
Ranking Effectiveness for the Bedroom

1.



Night Ventilation

2.



Temperature based Ventilation

Most Effective
Option

Ranking Effectiveness for the Bedroom

1.



Renovated Construction

2.

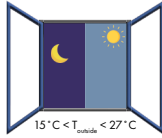


Current Construction

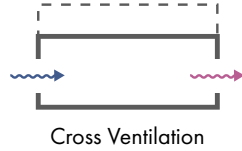
Interpretation of the Results

Livingroom:

Temperature based Ventilation



+



+

Current Construction



+



Ceiling Fan

+

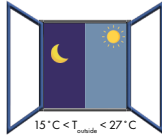


+ Solar Shading

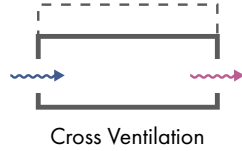
Interpretation of the Results

Livingroom:

Temperature based Ventilation



+



+

Current Construction



+



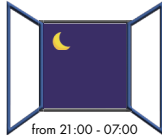
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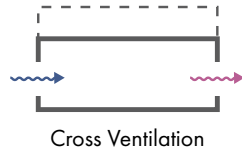
+ Solar Shading

Bedroom:

Night Ventilation



+



+

Renovated Construction



+



+

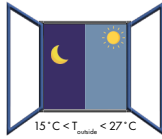


+ Solar Shading

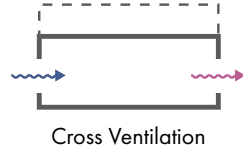
Interpretation of the Results

Livingroom:

Temperature based Ventilation



+



+

Current Construction



+



Ceiling Fan

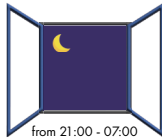
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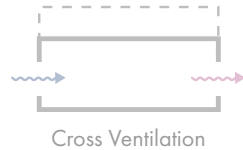
+ Solar Shading

Bedroom:

Night Ventilation



+



+

Renovated Construction



+



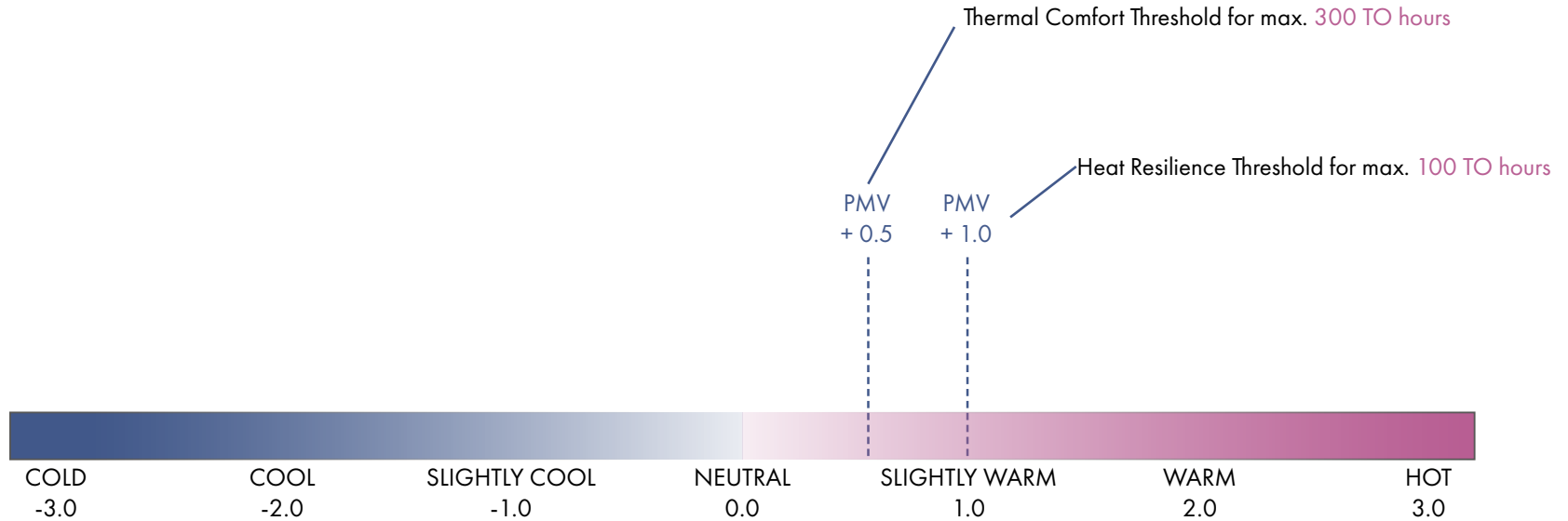
Ceiling Fan

/



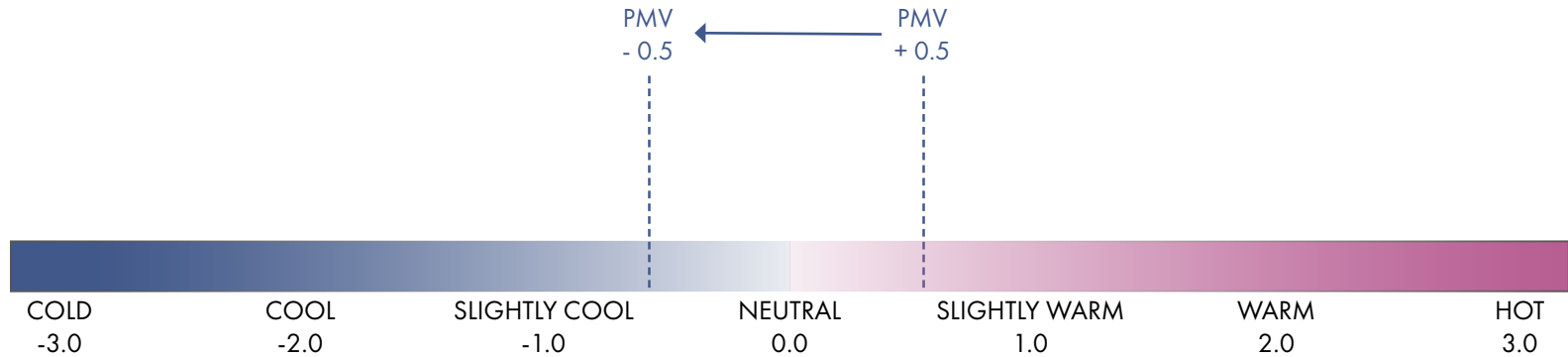
+ Solar Shading

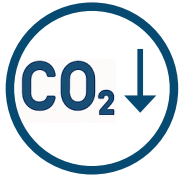
Interpretation of the Results



Interpretation of the Results

Expierence of being slightly Cool but
feeling more Comfortable





Reduce CO2 Emissions



Lower the Energy Consumption



Quiet



Affordable



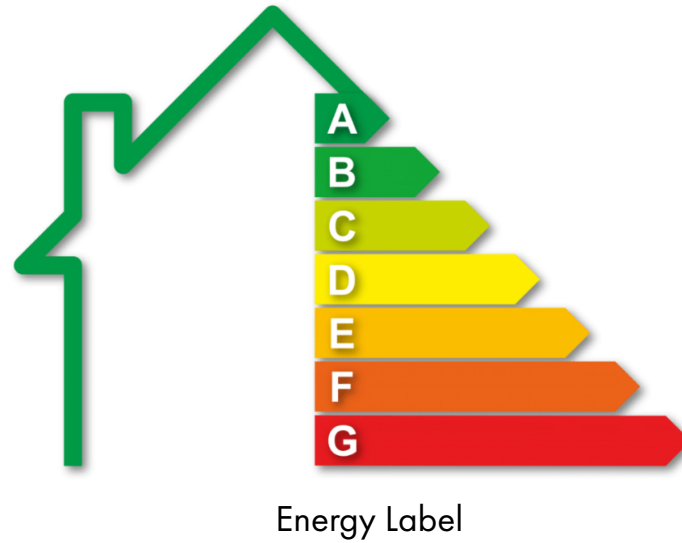
Environmentally Friendly

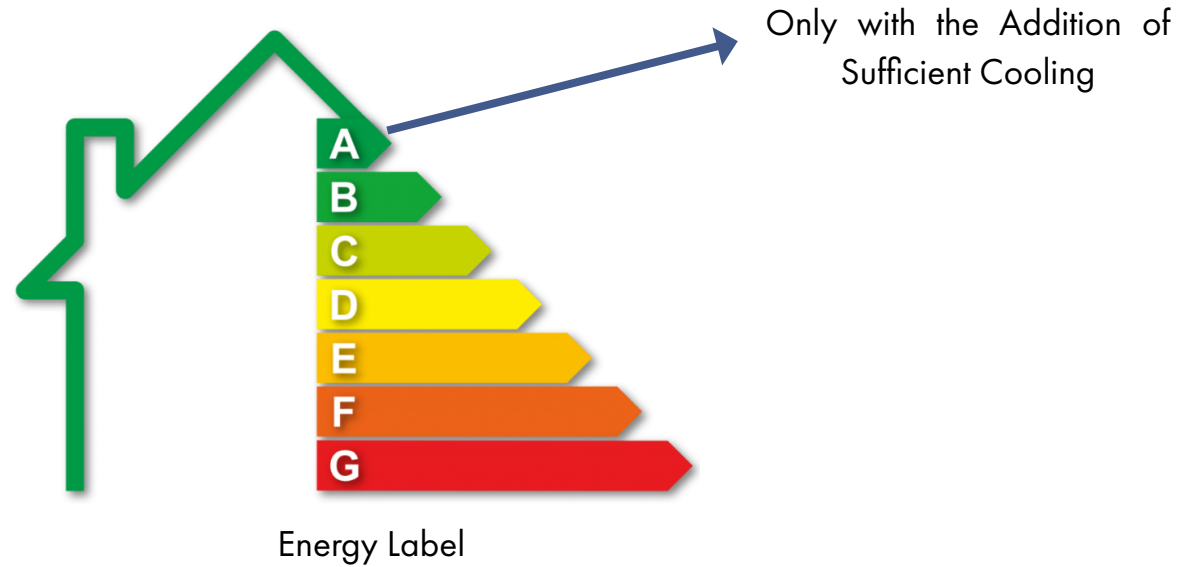


Low Maintenance



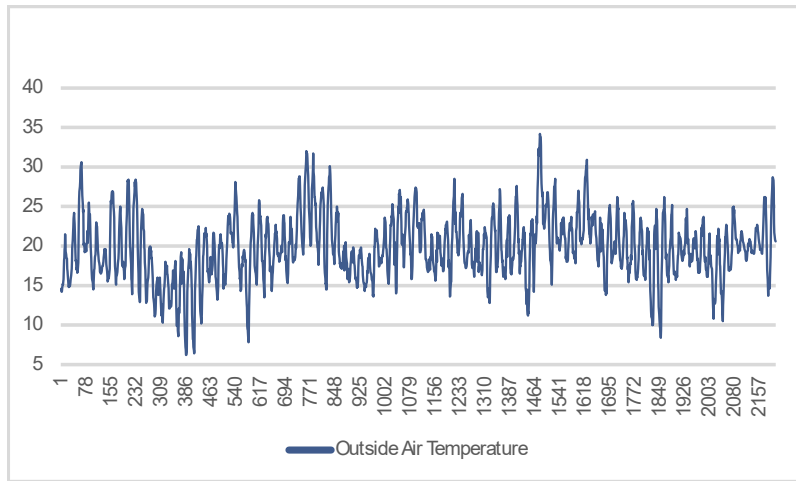
No mandatory regulations for implementing cooling in existing buildings



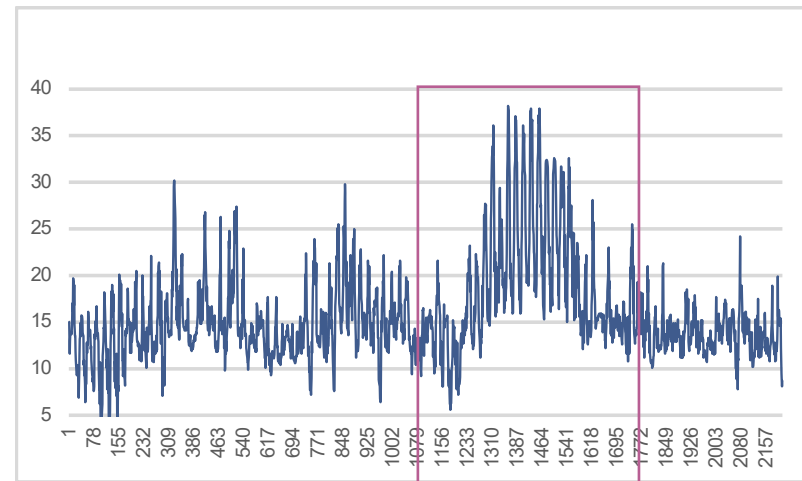


Low Energy Solution for a High Temperature Problem

Low Energy Solution for a High Temperature Problem



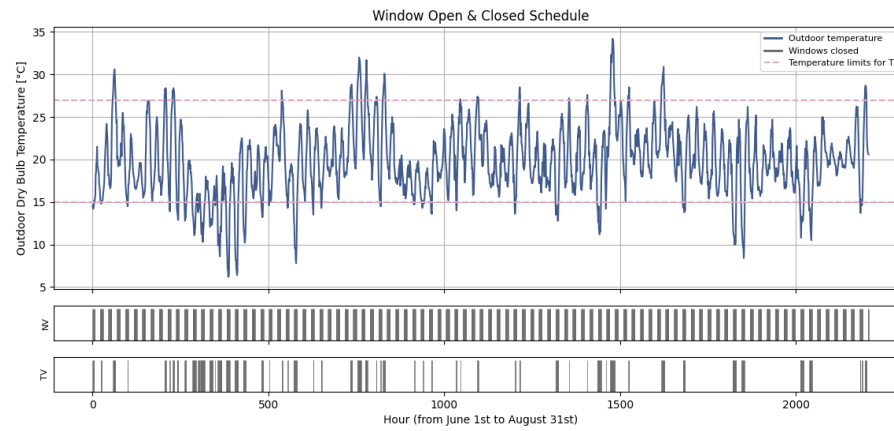
2050 - Typical Meteorological Year



2050 - Heatwave scenario

	Assumptions	Thresholds	Corresponding PMV	Max. Acceptable Exceedance
TO / GTO (NEN-EN-ISO 7730)	$T_{\text{air}} = \text{MRT}$ $v = 0.1 \text{ m/s}$ $\text{RH} = 50 \%$ $M = 1.2$ $I_{\text{clo}} = 0,7$	$T_{\text{operative}} = 26 \text{ }^{\circ}\text{C}$	$\text{PMV} \geq 0.5$	TO = 300 hours GTO = 450 hours
		$T_{\text{operative}} = 28 \text{ }^{\circ}\text{C}$	$\text{PMV} \geq 1.0$	TO = 100 hours
SET* (ASHRAE 55-2017)	$T_{\text{air}} = \text{MRT}$ $v = 0.1 \text{ m/s}$ $\text{RH} = 50 \%$ $M = 1.0$ $I_{\text{clo}} = 0,4$	$T_{\text{operative}} = 28 \text{ }^{\circ}\text{C}$	$\text{PMV} \geq 0.5$	-
		SET* = 27 °C		
		$T_{\text{operative}} = 30 \text{ }^{\circ}\text{C}$	$\text{PMV} \geq 1.0$	120 °C SET* - hours
		SET* = 28 °C		

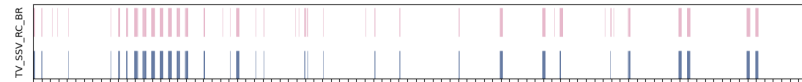
(RVO, 2018; Huizenga et al., 2024)



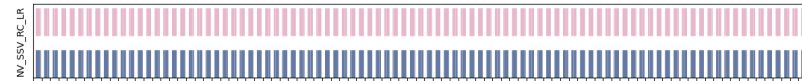
Night Ventilation (NV) - Bedroom



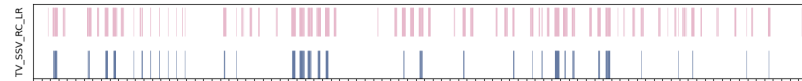
Temperature based Ventilation (TV) - Bedroom



Night Ventilation (NV) - Livingroom



Temperature based Ventilation (TV) - Livingroom



Housing type	Usable Area (m ²)	Building Height (m)	Ground Floor Area (m ²)	Closed Facade (m ²)	Sloped / Flat Roof (m ²)	Window / Door (m ²)
Detached House up to 1964	153,28	9,00	89,59	131,12	84,42 / 29,31	28,36 / 8,04
			R 0,15	R 0,35	R 2,50 / R 0,85	U 1,80 / U 3,40
Terraced House 1975- 1991	113,6	9,00	49,15	37,86	58,40 / 0,00	18,17 / 4,55
			R 0,52	R 1,30	R 1,30 / R 1,30	U 2,90 / U 3,40
Apartment 1965- 1974	84,00	23,50	84,00	23,94	-	20,07 / 4,47
			R 0,17	R 0,43	-	U 2,90 / U 3,40

Appendices

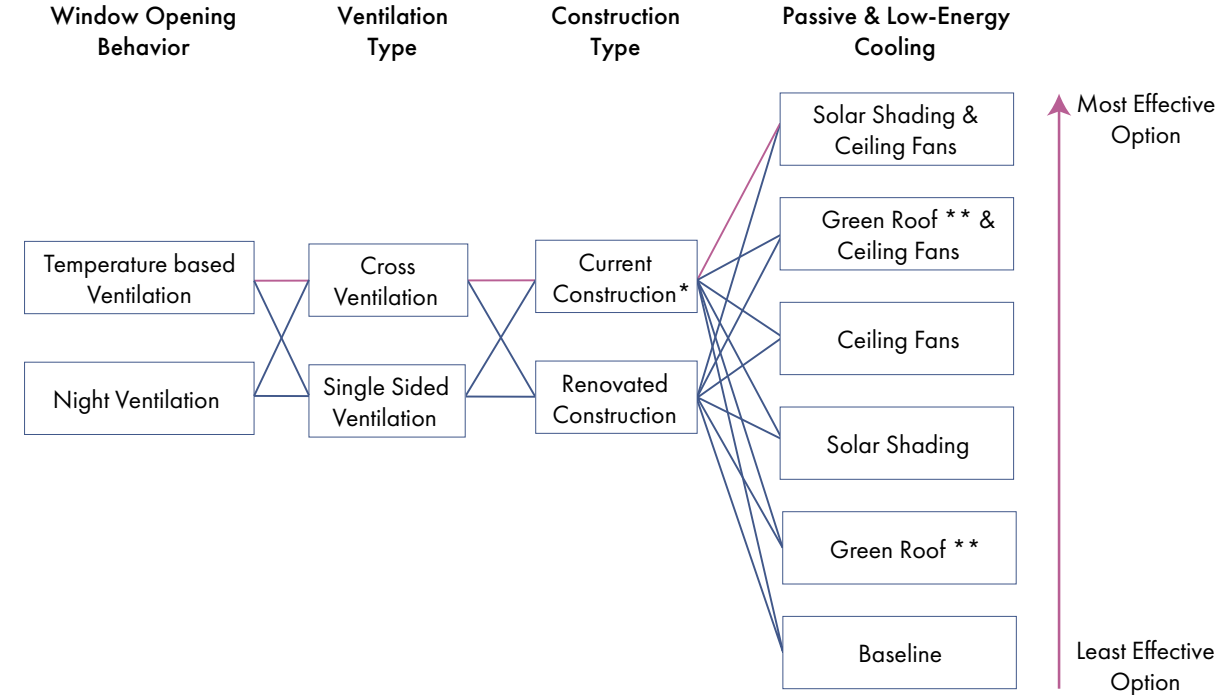
Bedroom Factors:

T_{air}	= Dynamic
MRT	= Dynamic
v	= Dynamic (+ 1.16 m/s with Fan)
RH	= Dynamic
MET	= 0.7
I_{clo}	= 1.5

Livingroom Factors:

T_{air}	= Dynamic
MRT	= Dynamic
v	= Dynamic (+ 1.16 m/s with Fan)
RH	= Dynamic
MET	= 1.1
I_{clo}	= 0.30

Appendices

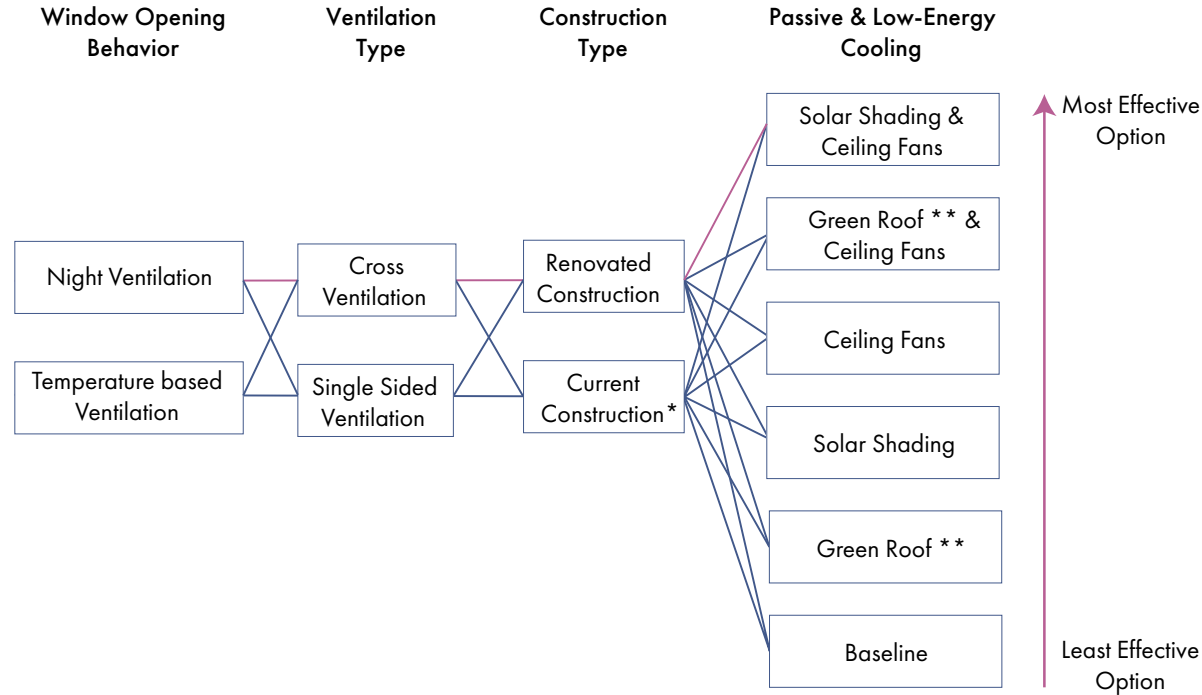


— = The most effective combination of cooling strategies

* Exception for the bedroom scenarios in detached and terraced buildings, where the combination of renovated construction and cross ventilation proves more effective than the current construction variant.

** Green roof only applicable to detached and terraced residential buildings.

Figure 5.1 - Effectiveness Ranking of Cooling Strategies and Their Possible Combinations (Own work, 2025)



— = The most effective combination of cooling strategies

* Exception for the bedroom scenarios in the apartment, where the combination of current construction and cross ventilation proves more effective than the renovated construction variant shown in this figure.

** Green roof only applicable to detached and terraced residential buildings.

Figure 5.8 - Effectiveness Ranking of Cooling Strategies and Their Possible Combinations (bedroom) (Own work, 2025)

Appendices

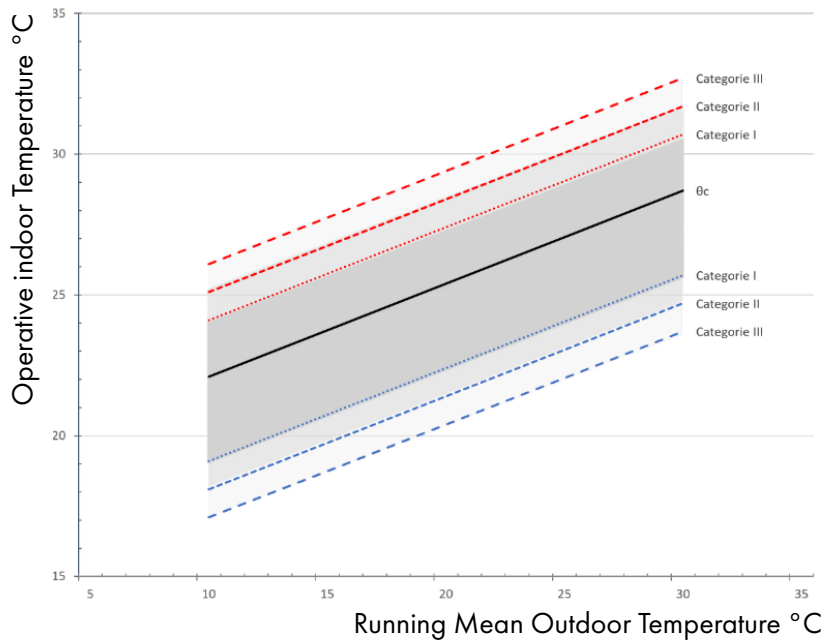


Figure 2.2 - Temperature limits of Adaptive Comfort Model (Alders et al., 2024)

Category	Lower Limit $\theta_{\min}$	Upper Limit $\theta_{\max}$
I	$\theta_c - 3$	$\theta_c + 2$
II	$\theta_c - 4$	$\theta_c + 3$
III	$\theta_c - 5$	$\theta_c + 4$