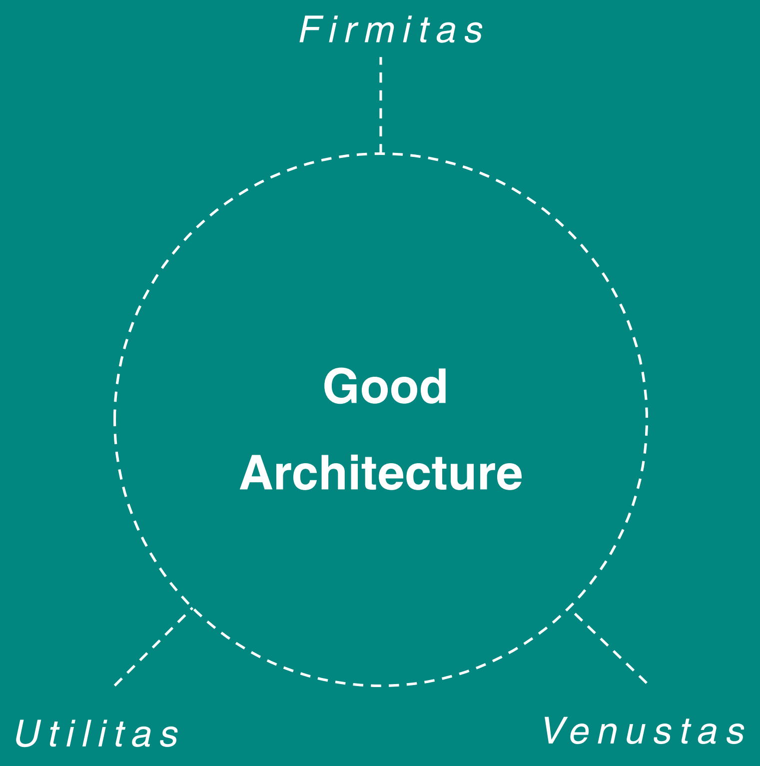
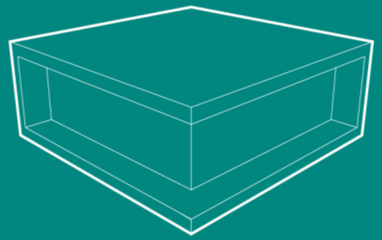
What is good **Architecture** ?


Firmitas
Good
Architecture
Utilitas
Venustas

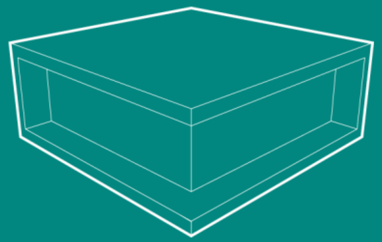
Utilitas *Firmitas* *Venustas*

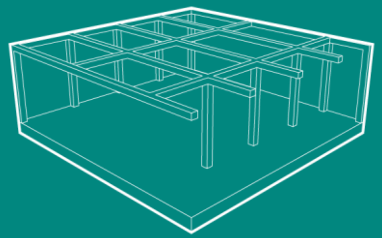


Function

Firmitas

Venustas

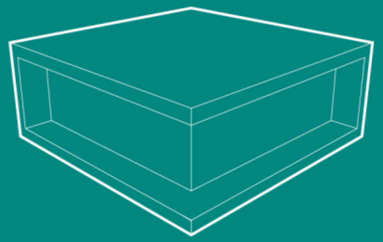




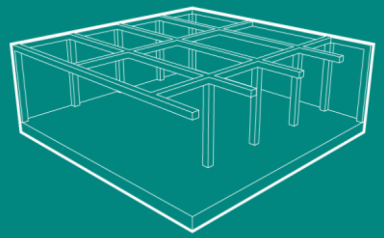
Function

Robustness

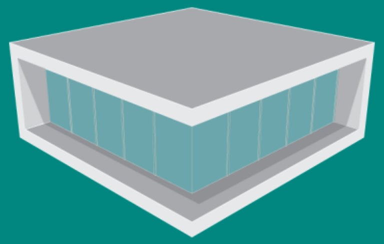
Venustas



Function



Robustness



Aesthetics

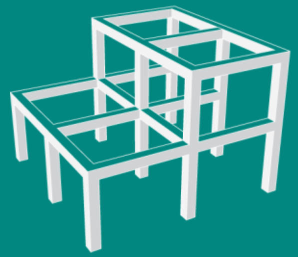
Robustness

/rə(ʊ)ˈbʌstnəs/

The ability to withstand or overcome adverse conditions or rigorous testing.

Robustness

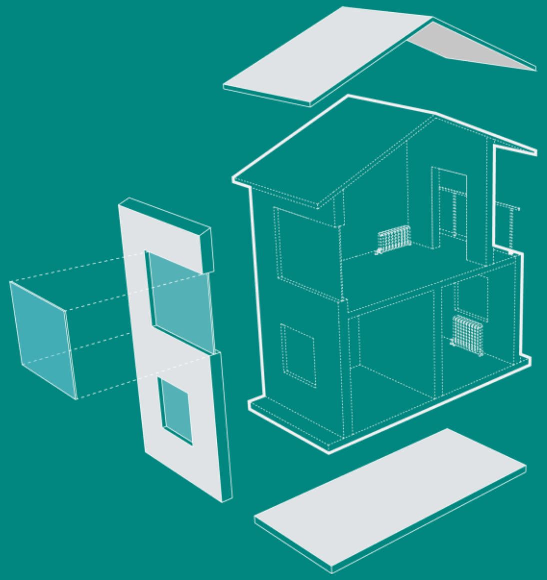
Design keeping the future in mind !!!



Structural Integrity

Comfort ?

Climate Change

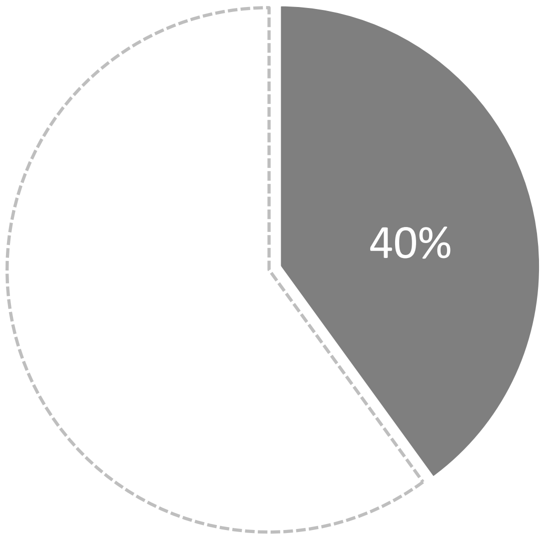


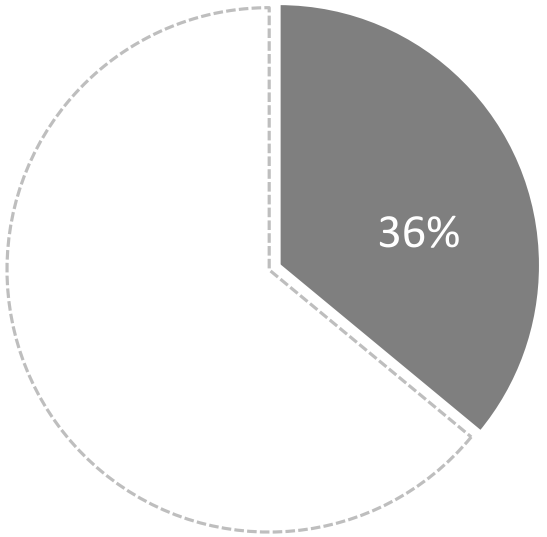
Robustness of Building Envelope

Investigating Robust Design Solutions for Energy Efficient Educational Buildings in Future Climate Scenario

P5 | Prateek Wahi

Problem Statement | Research Questions | Analysis | Results | Conclusions | Designer’s Tool



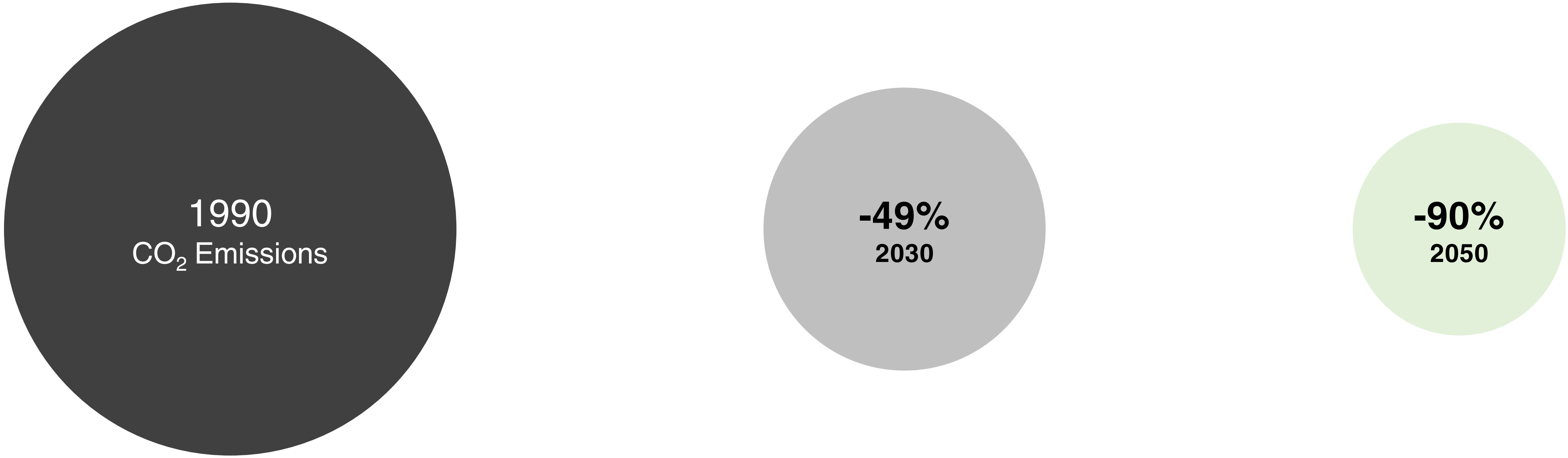


40% *of total primary* ***energy.***

36% *of* ***CO_2*** *emissions*

Tichaona Dande, 2018
European Commission, 2019

Netherlands Climate Agreement



Climate Agreement, Government.nl

1990
CO_2 Emissions

-49%
2030

-90%
2050

New construction and renovation in **the Netherlands** must achieve

45-80% energy reduction.

Reduction of heat consumption in buildings by

80% till 2050.

Climate Agreement, Government.nl
Gvozdenovic, Maassen, Zeiler, & Besselink, 2015, p.100

Reduce energy Consumption

for space heating as low as possible.

Highly insulated building envelopes :

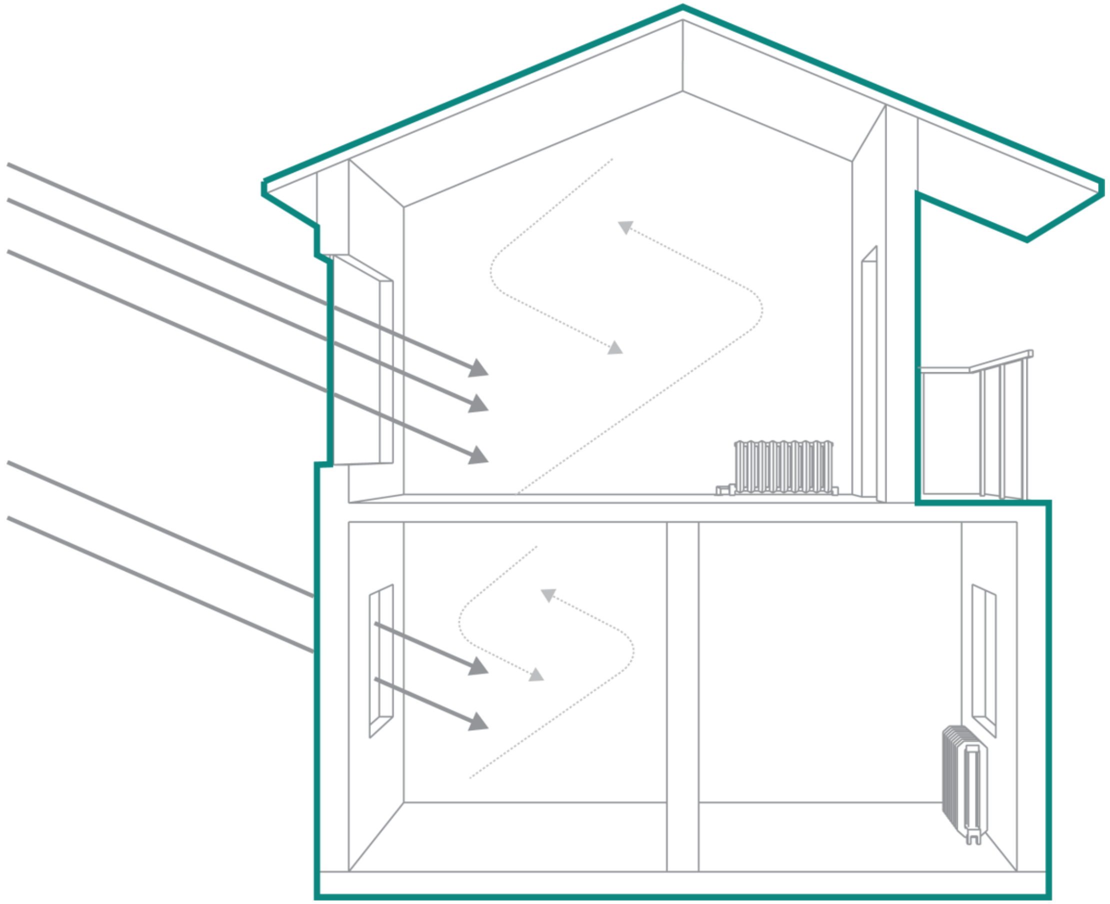
Reduce heat loss due to transmission.

Increase airtightness :

Reduce heat loss due to ventilation.

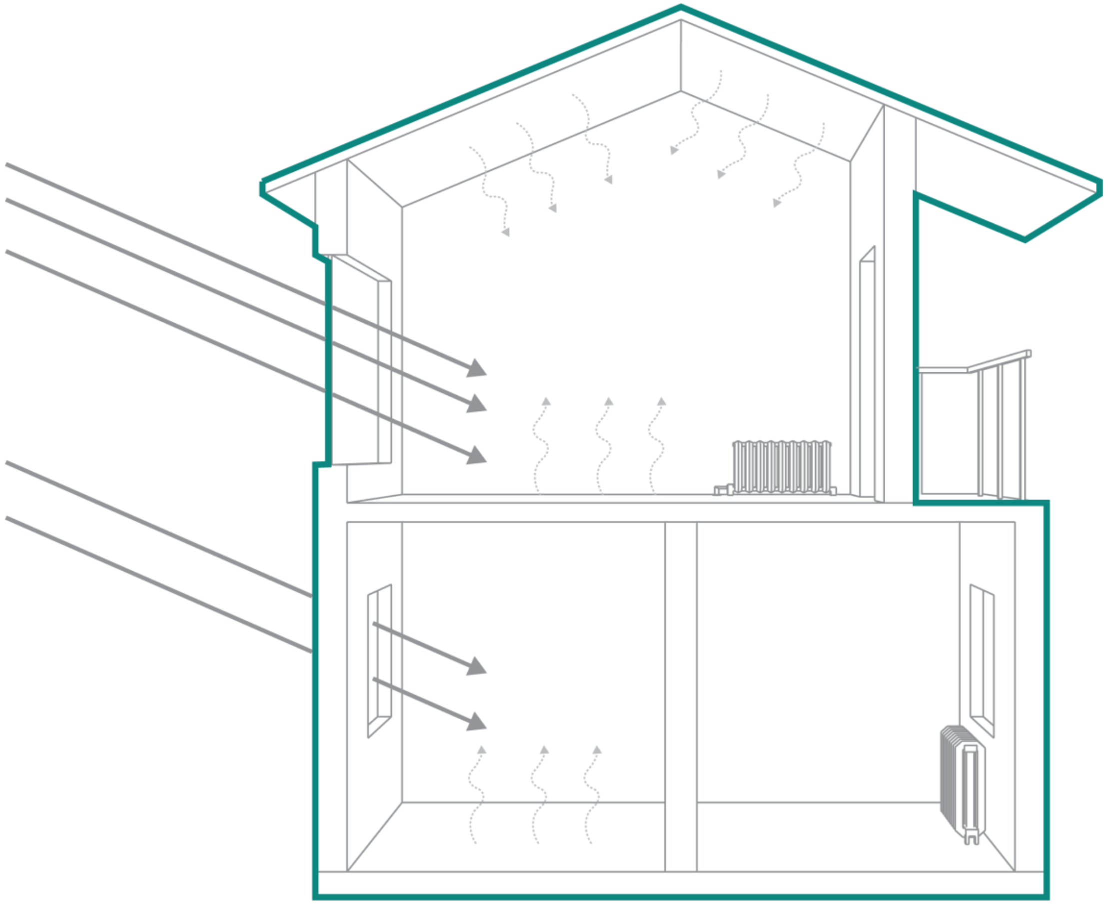
Glazing Surface :

Maximize solar gain



In summers , due to high insulations and airtightness of the building envelope , the heat gained during the day is unable to escape .

Risk of Overheating



Attia, 2018b; Barbosa, Bartak, Hensen, Loomans, 2015; Kazanci & Olesen, 2016

Overheating is one of the primary causes of **thermal discomfort** , which in worst case scenario may also lead to **illness or death**

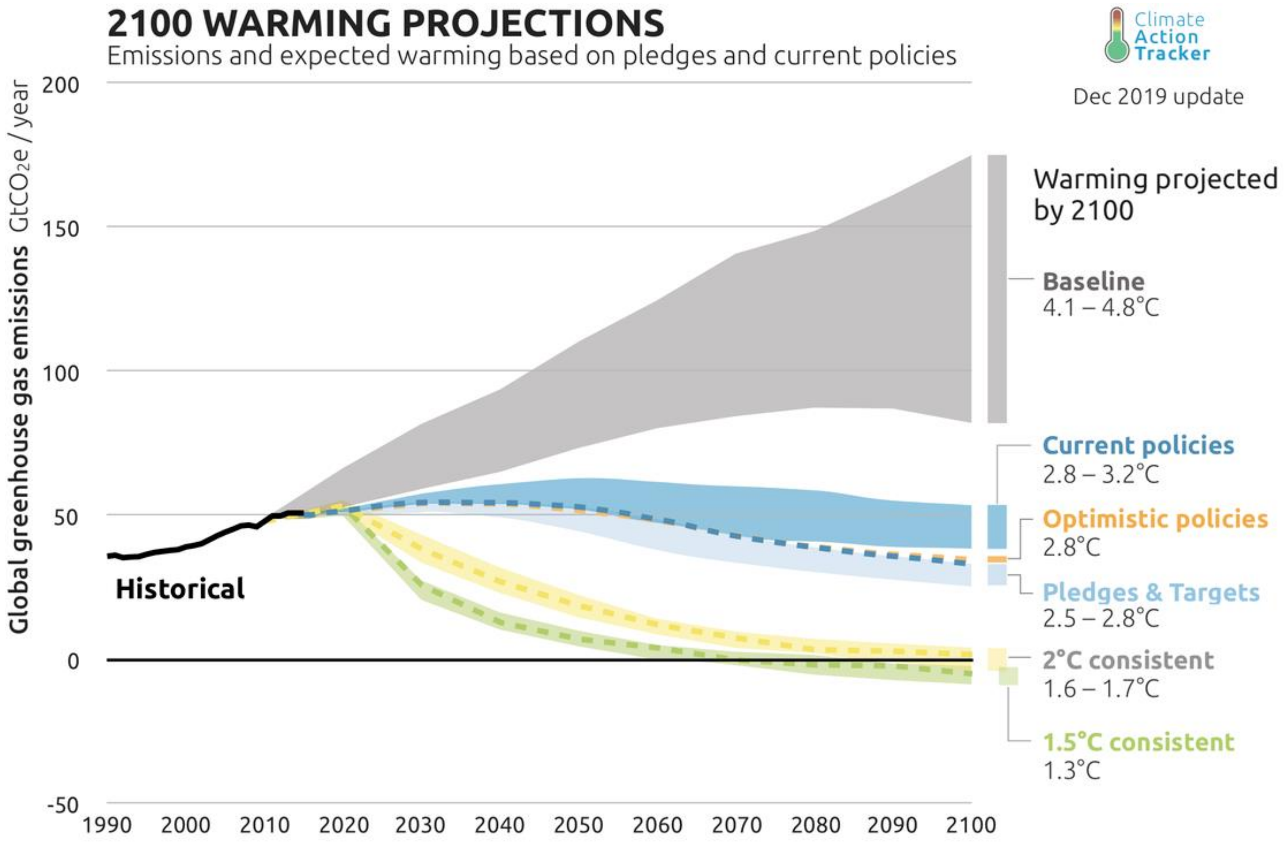
In **July 2019** Maximum Temperature reached in the Netherlands was **40˚C ,**.

2,964 deaths **400** more than average.

Correlation between **elevated temperature** and **increased death rates.**

Hamdy, Carlucci, Hoes, & Hensen, 2017
Garssen, Harmsen, & de Beer, 2005;
CBS, n.d.

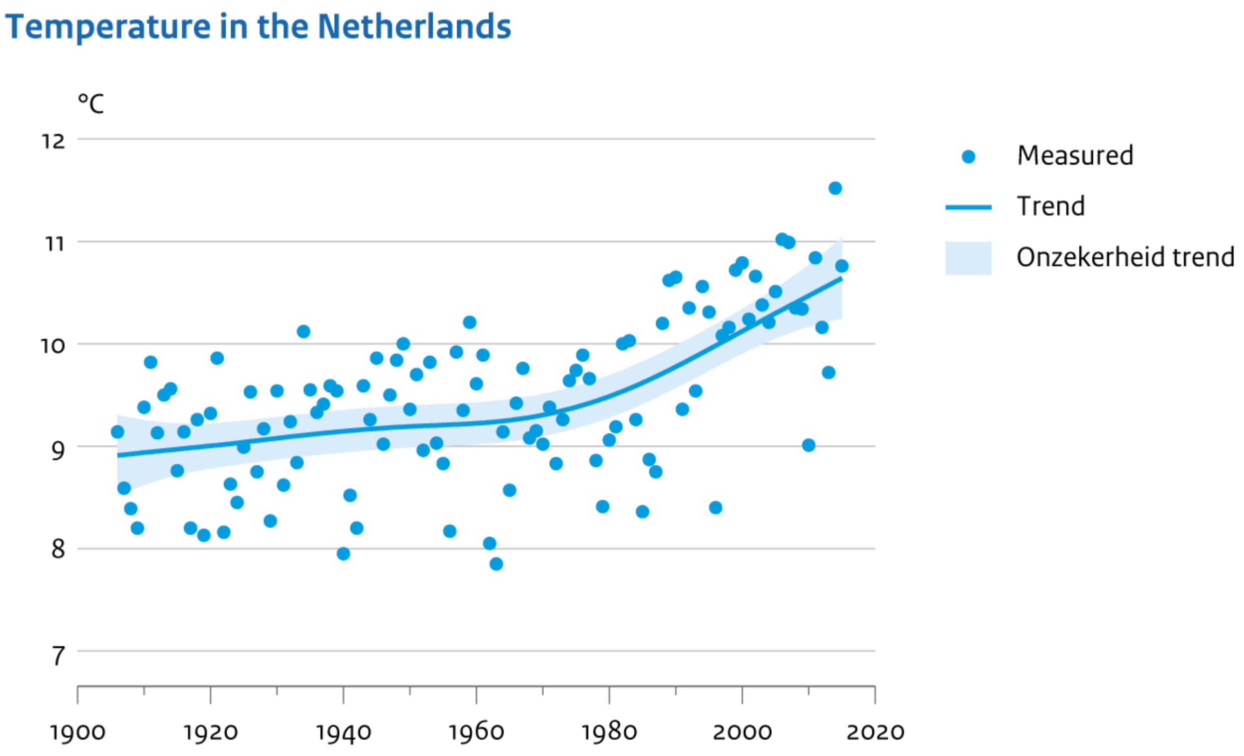
Global Temperature has risen to **.9˚C** since late 19th century. It is estimated to rise above **4.0˚C** by the end of this century,



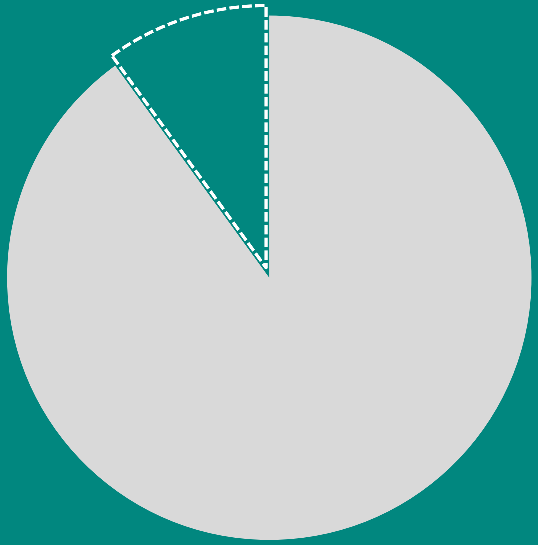
Climate action tracker.org
climate.nasa.gov
Stocker et al., 2013, p. 1031

Annual mean temperature of Netherlands

has risen to **1.7˚C** since **1906.**



KNMI, 2016



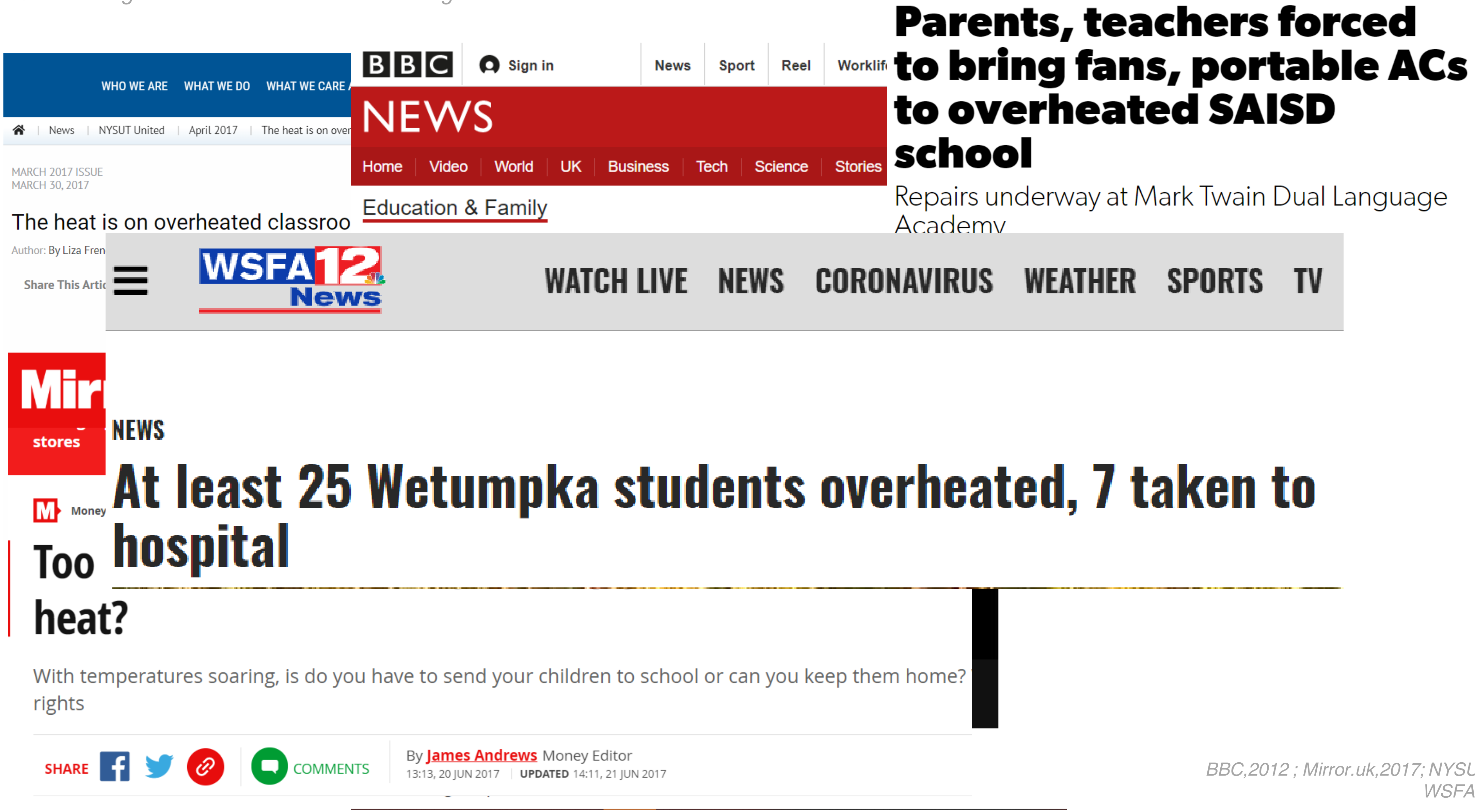
90% of the occupants spend their time indoors ,

for **students** its even **more.**

Heracleous & Michael, 2018; Jenkins et al., 2009

With the **increasing** risk of **climate change** and its effects **on indoor thermal comfort**,
it is imperative to **study** the risk **of overheating** in an **energy efficient educational buildings**.

Heracleous & Michael, 2018; Jenkins et al., 2009



WHO WE ARE WHAT WE DO WHAT WE CARE

News | NYSUT United | April 2017 | The heat is on over

MARCH 2017 ISSUE
MARCH 30, 2017

The heat is on overheated classroo

Author: By Liza Fren

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NEWS

At least 25 Wetumpka students overheated, 7 taken to hospital

Mirr stores

Money

Too heat?

With temperatures soaring, is do you have to send your children to school or can you keep them home? rights

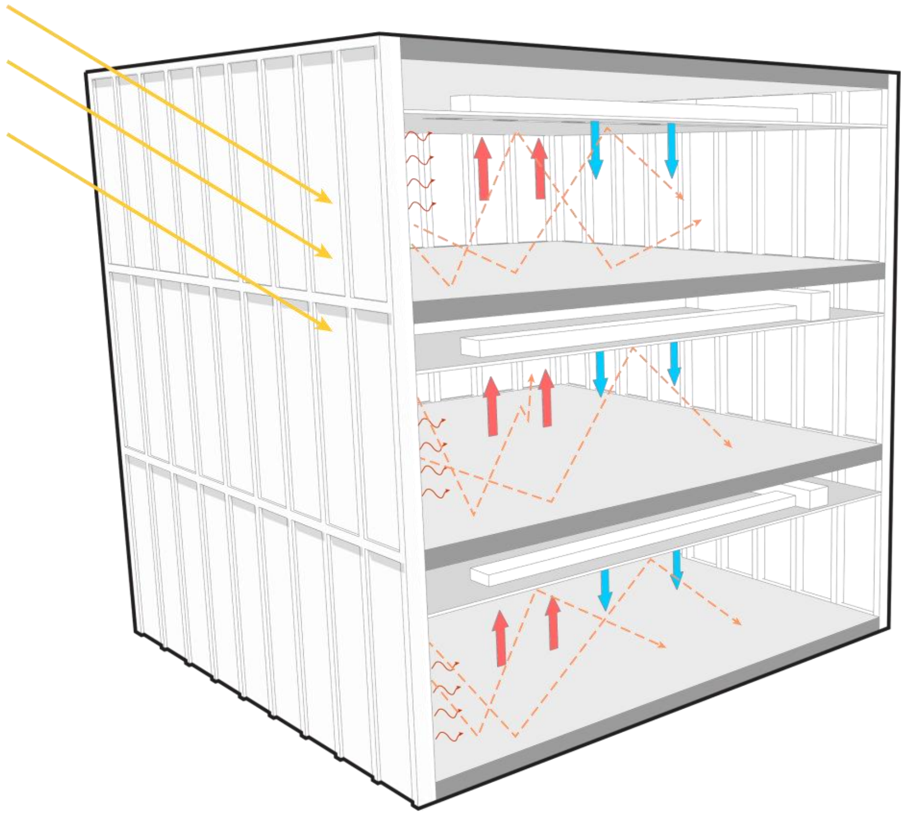
SHARE COMMENTS

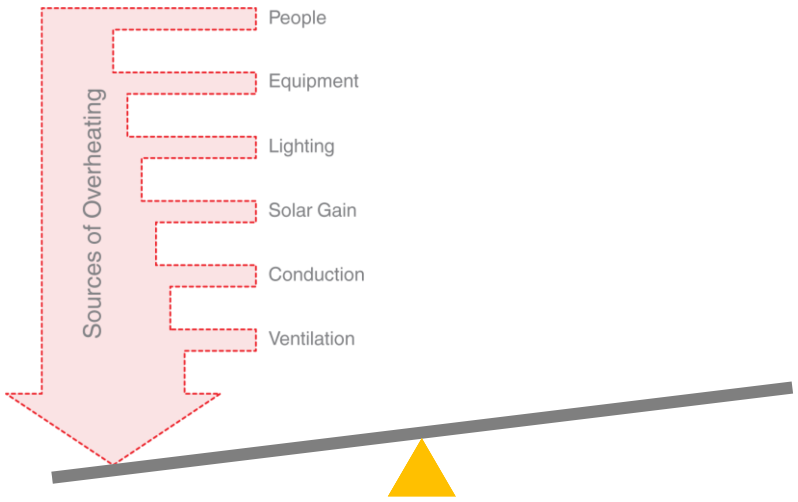
By James Andrews Money Editor
13:13, 20 JUN 2017 | UPDATED 14:11, 21 JUN 2017

BBC,2012 ; Mirror.uk,2017; NYSUT,2017; WSFA12,2019

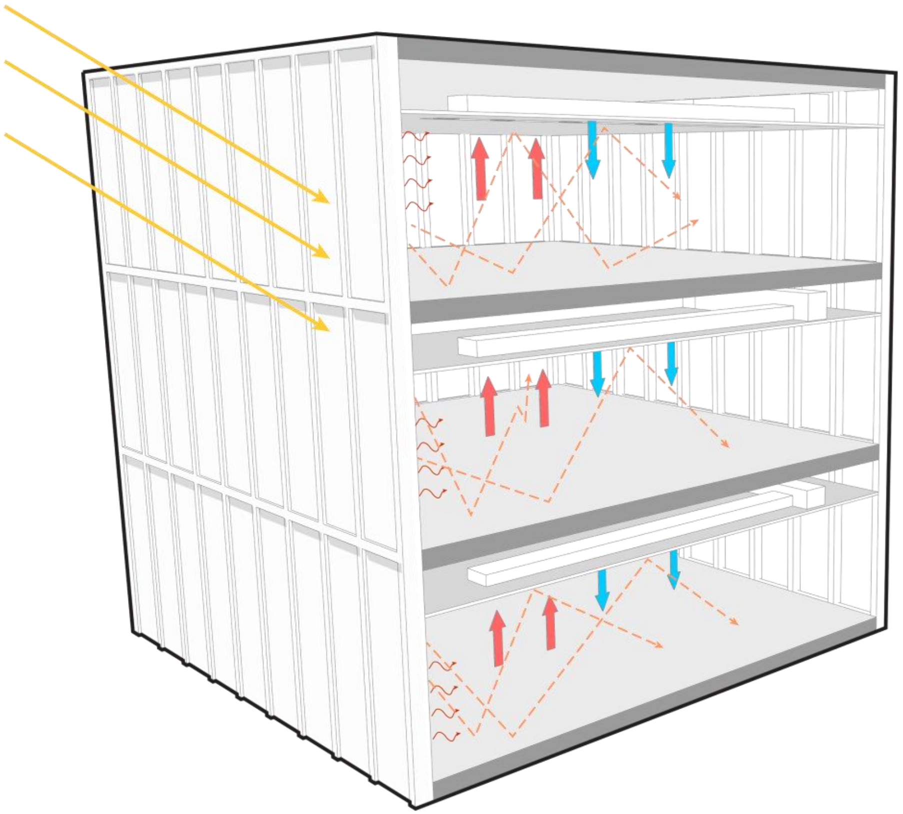
How to reduce **overheating** ?

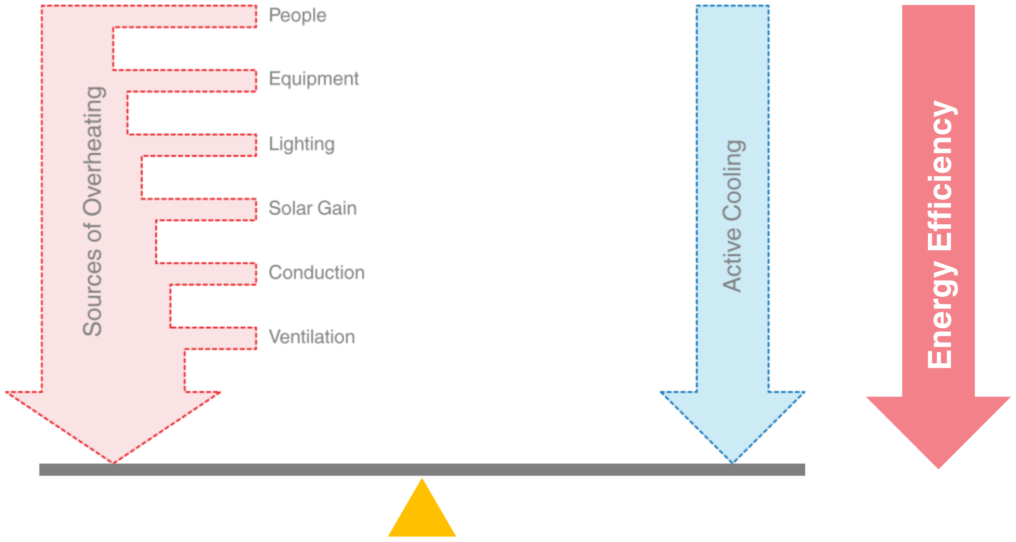
Cooling



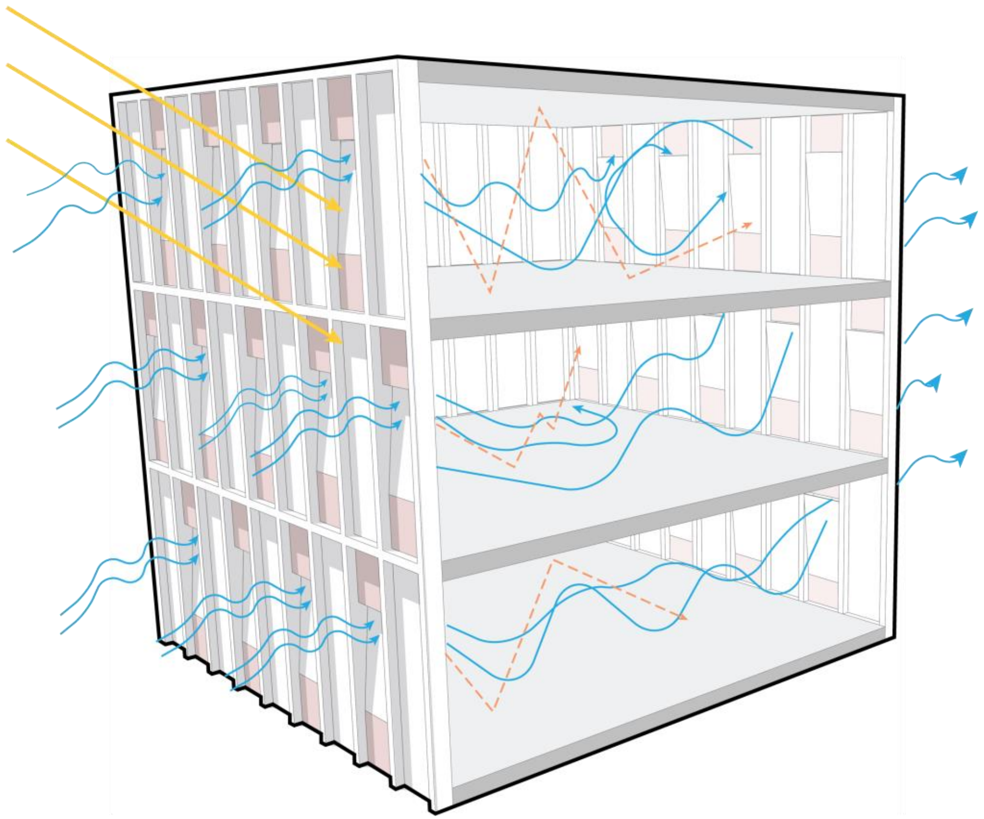


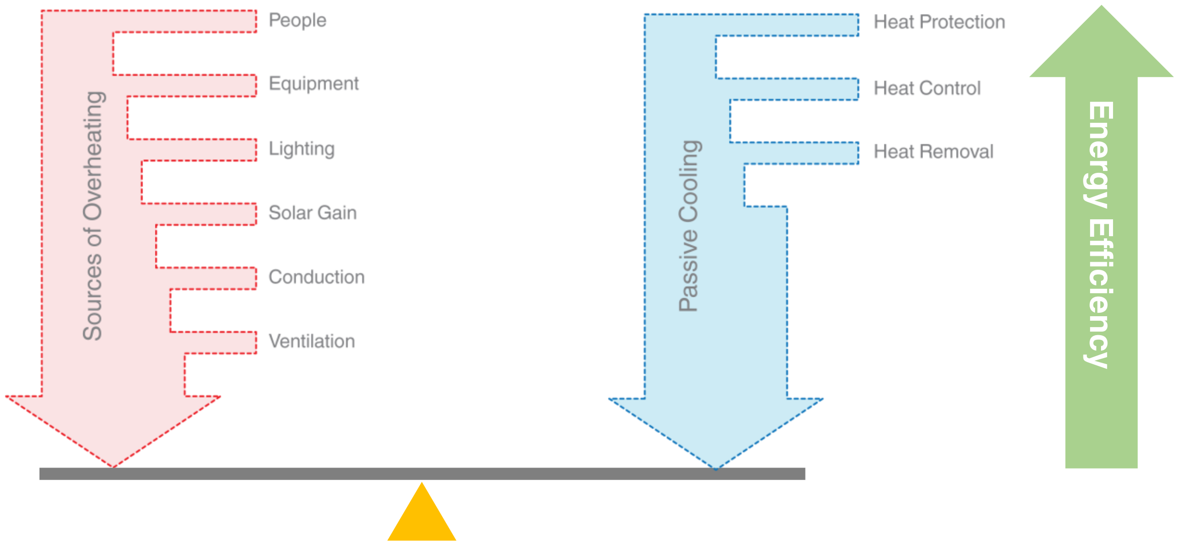
Zero Carbon Hub , 2012
Graphics Adapted from Gething&Puckett,2013





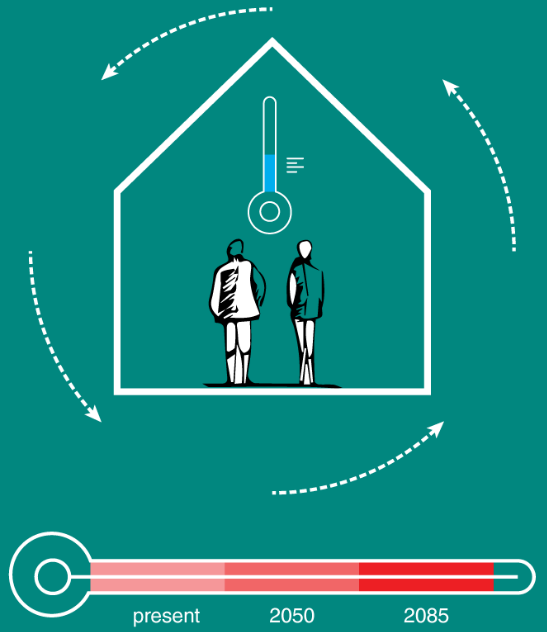
Zero Carbon Hub , 2012
Graphics Adapted from Gething&Puckett,2013





Zero Carbon Hub , 2012
Graphics Adapted from Gething&Puckett,2013

“Climate Change is a moving target”



The strategies must adapt to the change in the Climate

Passive strategies provides opportunities to interact and adapt to external climate

Gething&Puckett,2013
Knaack, U., Klein, T., Bilow, M., & Auer, T. ,2014

Can **passive strategies** reduce **overheating** in **Future** ?

The buildings we design, will stand for next 50 – 100 years.

With the projected rise in temperature due to climate change,
the risk of overheating in the future may become severe in energy efficient educational buildings.

It is imperative to consider the uncertainties of
changing climate in low energy buildings.

Therefore, the buildings we design must be

robust

for future climate change.

Therefore, the buildings we design must

perform as expected in presence of uncertainties

of future climate change.

What are the ***adaptive strategies*** *in a temperate climate, applicable to* ***building envelope*** *facilitating* ***robustness*** *of* ***energy efficient educational buildings*** *by reducing the risk of* ***overheating*** *in* ***future climate change scenario****?*

Building Envelope

What are the influential parameters corresponding to building envelope design?

Building Envelope

Overheating

What are the factors that contribute to the overheating of space?

How to assess overheating ?

What are the future scenarios to be considered for evaluation?

Building Envelope

Overheating

Case Studies

What are the potential spaces which may overheat in case study buildings ?

What is the extent of overheating in present and future climate scenarios ?

Building Envelope

Overheating

Case Studies

Adaptive Strategies

What are the adaptive design/passive design strategies in temperate climate available for building envelope?

Building Envelope

Overheating

Case Studies

Adaptive Strategies

Robustness Evaluation

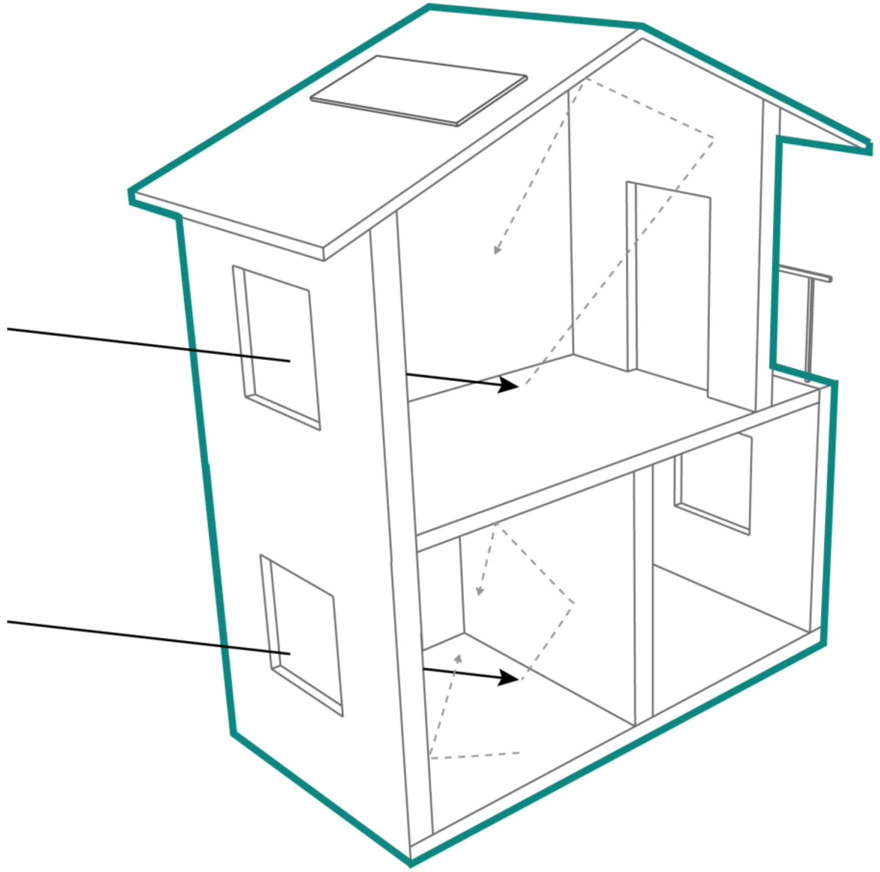
How to evaluate the robustness of different design solutions in mitigating overheating problems in the present and future climate scenarios?

How robust are different passive design building envelope solutions?

Physical barrier or interface between the **conditioned interior space** and the **external environment.**

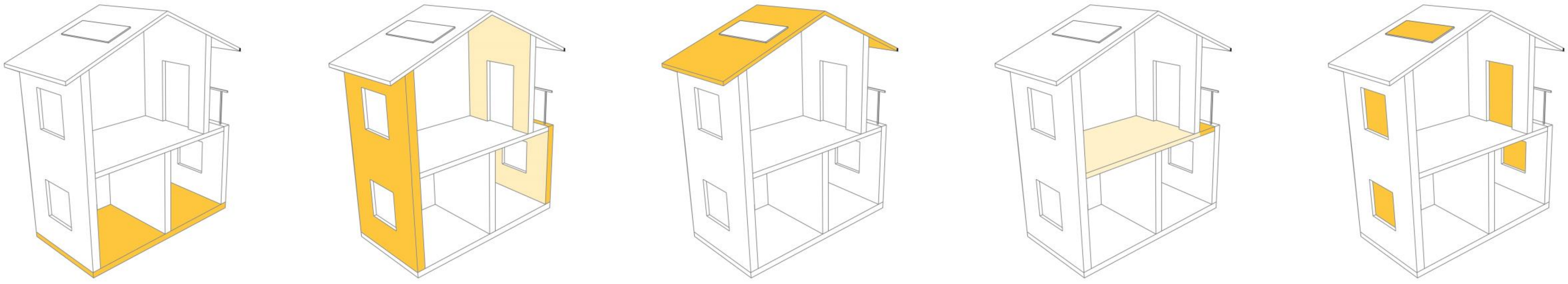
Regulate Heat loss or gain to **maintain comfort** and **energy efficiency**.

An **efficient building envelope** design can **reduce** up to **60%** of **heating** or **cooling loads**.



International Energy Agency, 2013

Components of Building Envelope



Ground Floor	External Wall (Façade)	Roof	External Floor	Openings & Glazing

Al-saadi, 2006;
Knaack, Klein, Bilow, & Auer, 2014

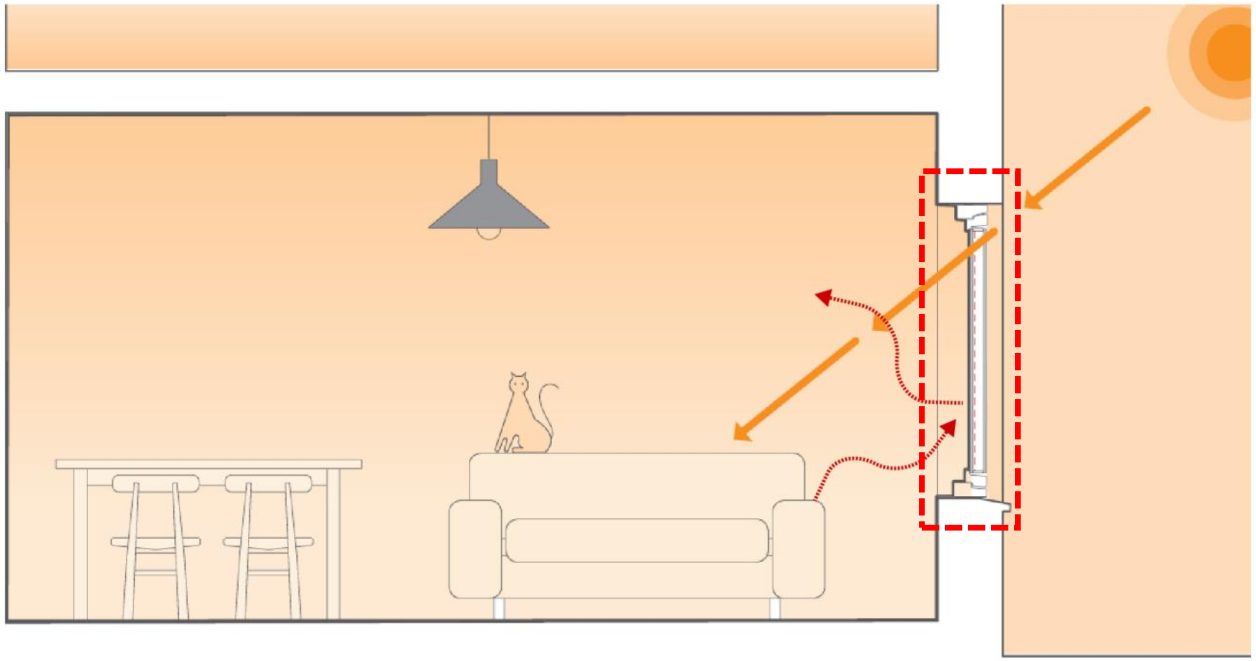
What is Overheating ?

Accumulation of **warmth** within a building to an **extent** where it causes **discomfort** to the **occupants.**

Zero Carbon Hub , 2012

Sources of Heat gain

1. External Heat Gain

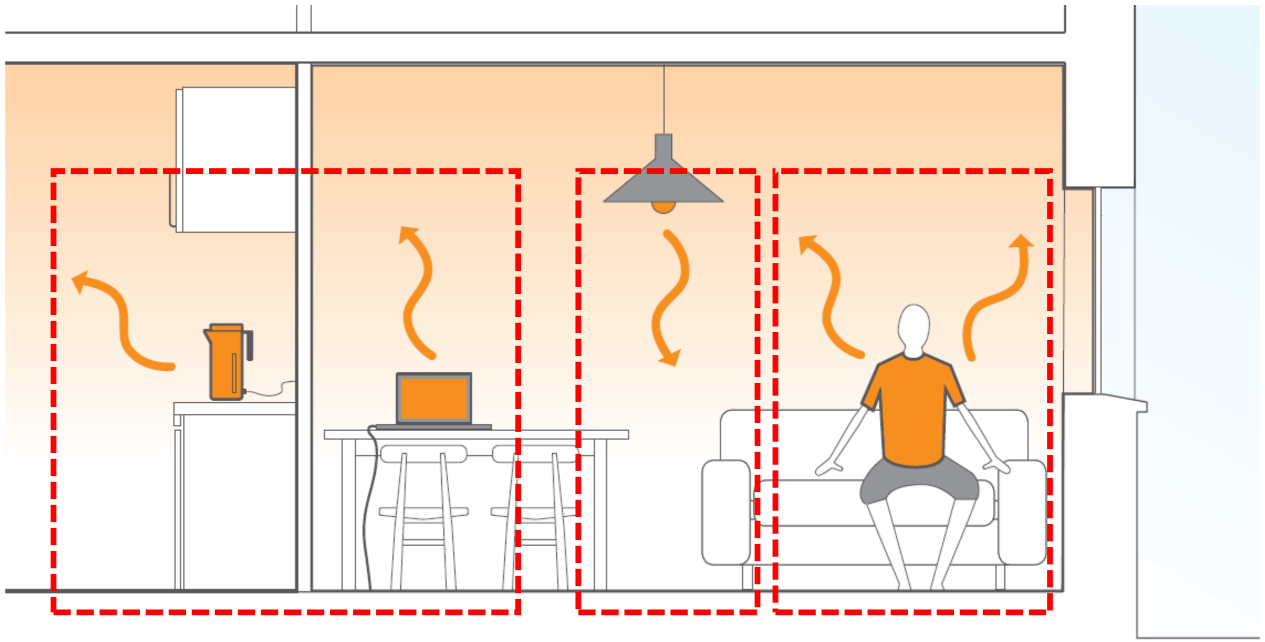


Zero Carbon Hub , 2012

Sources of Heat gain

1. External Heat Gain

2. Internal Heat Gain



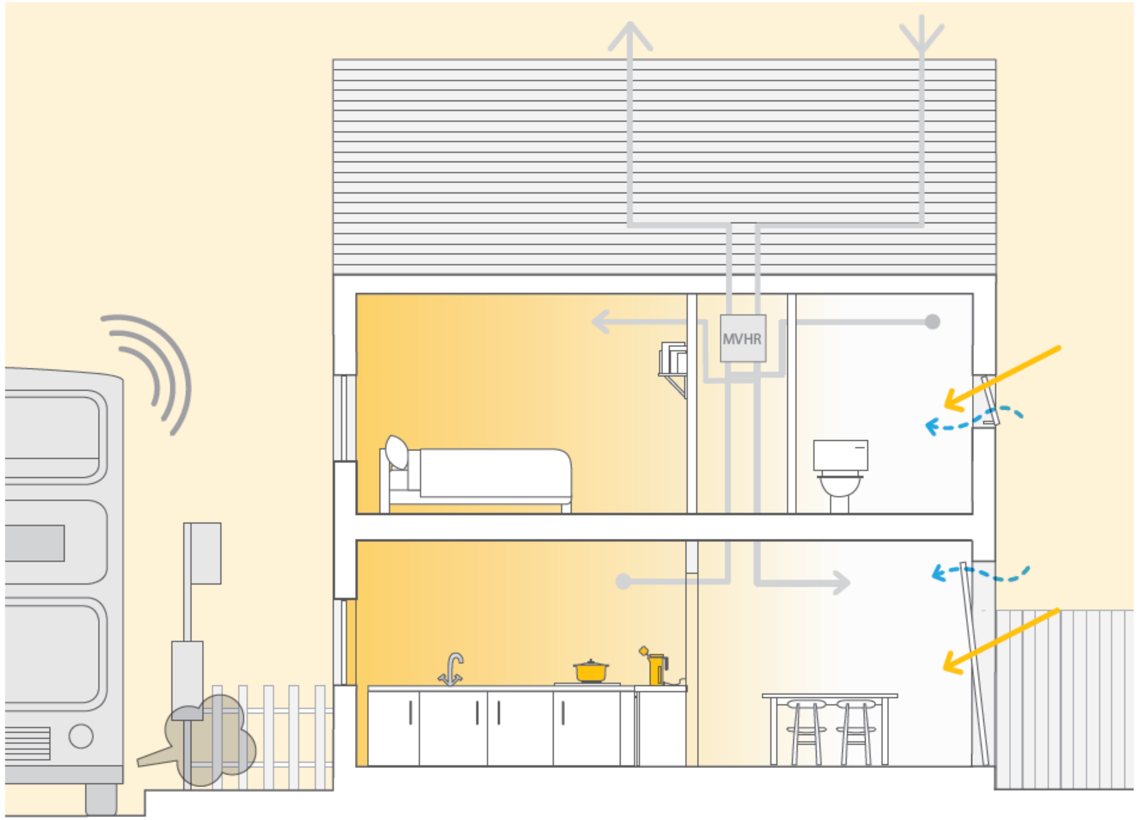
Zero Carbon Hub , 2012

Sources of Heat gain

1. External Heat Gain

2. Internal Heat Gain

3. Inadequate Ventilation



NHBC, 2012

Cumulative Effects

1.Site Context

2.Urban Heat Island Effect

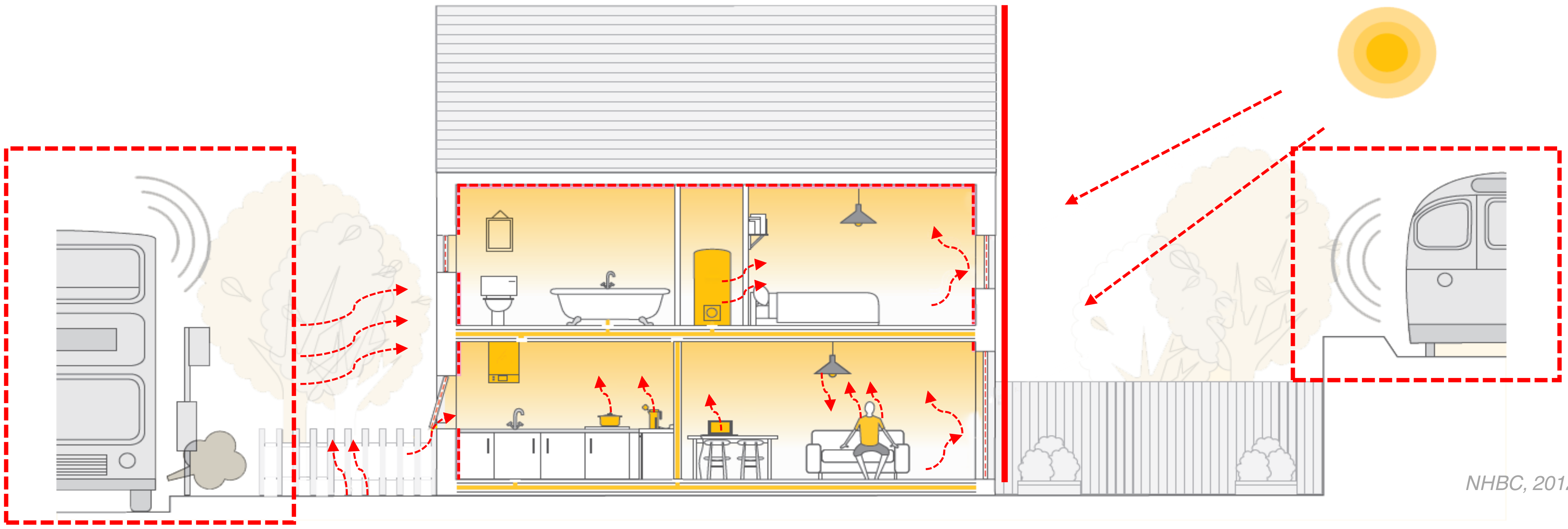
3.Orientation and Lack of Shading

4.External Heat Gain

5.Internal Heat Gain

6.Building Envelope

7. Increase in outdoor air temp.



NHBC, 2012

How do you assess **overheating** ?

Analytical

TO*july* Method

Dynamic

ATG Method

Tojuly *(Analytical)*

Temperature overrun in the month of July

TOjuly is a **static heat balance method** which **calculates** the **need for cooling** in the month of **July** as an **indicator of excess heat.**

Higher the **TOjuly** value , **Higher** is the **risk of overheating**

0-2	Low Risk of Overheating
2-4	Medium to High Risk
>4	Very High Risk

Source:
NEN 5128:2003, NEN 7120:2012 and NTA 8800

Tojuly *(Analytical)*

Advantages

- Quick method to indicate if the space will overheat or not.
- Reduces time invested into dynamic simulations
- Can be applied at early design stage.

Limitations

- Does not indicate the extent of overheating.
- Developed for residential use only.
- Does not consider any dynamic behavior.

Source:
NEN 5128:2003, NEN 7120:2012 and NTA 8800

ATG Method (Dynamic)

Based on **Adaptive Comfort Model** and comply with European standard **EN-15251**

Hybrid Method to evaluate both **mechanically cooled** and **naturally ventilated buildings/spaces**

According to **ISSO 74** and fresh school guidelines, **educational buildings** must comply with Class B .

*Use of **Operative Temperature** and **outdoor running mean temperature** for past 7 days to analyse thermal comfort.*

Determining the type of buildings/spaces :

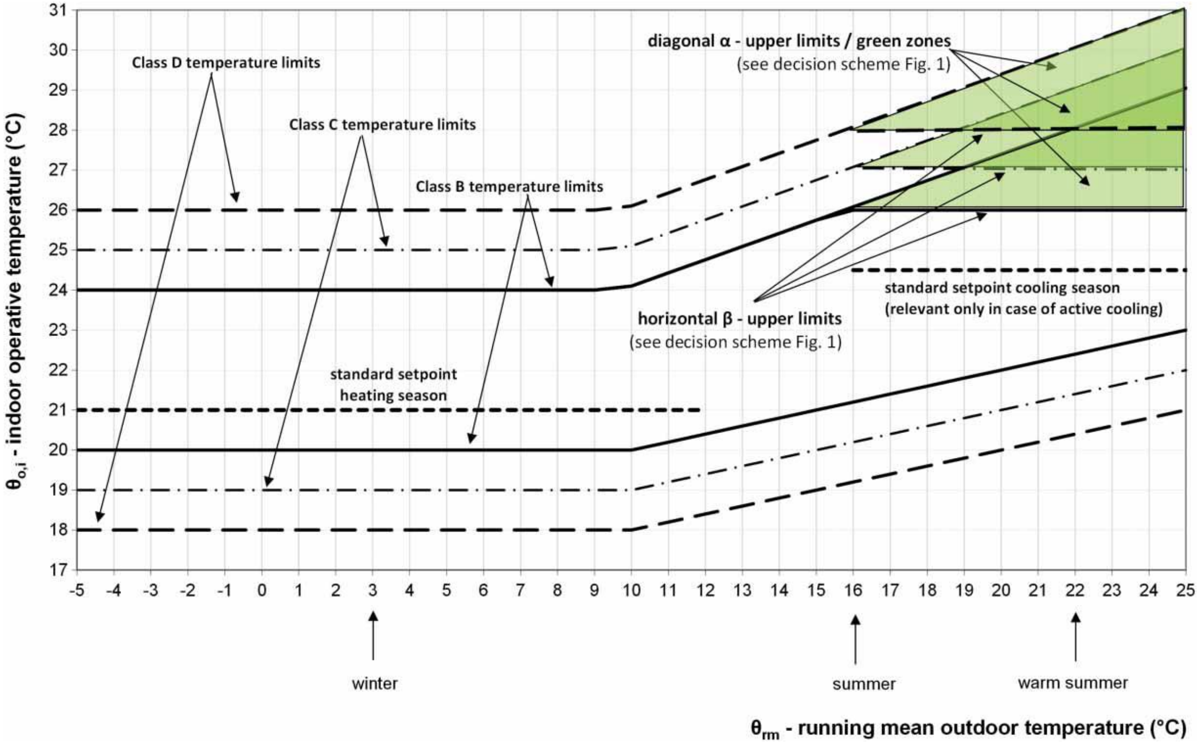
- **Alpha Buildings :** Natural Ventilated buildings
- **Beta Buildings :** Mechanically ventilated buildings

Band Width Classification	
Class A	*High Expectation , Extra Sensitivity (hospitals)*
Class B	*Common Expectation, New Buildings*
Class C	*Older buildings*
Class D	*Temporary use buildings*

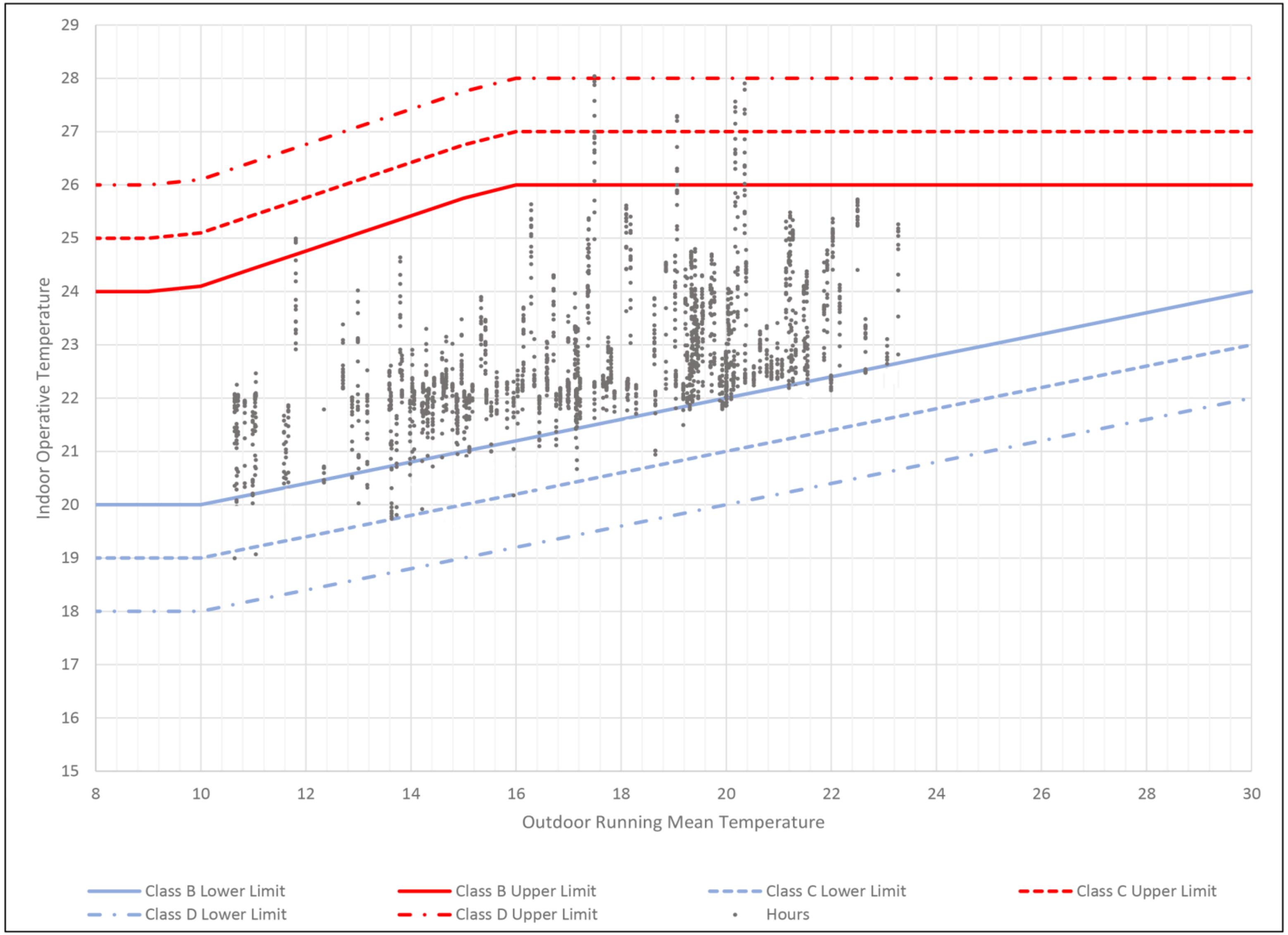
ISSO 74,24
Kurvers & Leijten, 2019

ATG Method (Dynamic)

Class (bandwidth)	Setpoint limit	Requirements indoor operative temperature (°C) Winter	In-between-seasons	Summer	Percentage Dissatisfied (%)	PMV analogy (bandwidth)
General	Setpoint line	21		24.5		
A	Upper limit	Same as class B (requires options available for occupant control with ± 2 K)			Max. 5%	-
	Lower limit	Same as class B (requires options available for occupant control with ± 2 K)				
B	Upper limit	24	18.8+0.33*T_{out}+1	Type β:26 Type α: 18.8+0.33*Tout+1	Max. 10%	-0.5 < PMV < +0.5
	Lower limit	20	20+0.2*(T_{out}-10)			
C	Upper limit	25	18.8+0.33*Tout+2	Type β:27 Type α: 18.8+0.33*Tout+2	Max.15%	-0.7 < PMV < +0.7
	Lower limit	19	19+0.2*(T_{out}-10)			
D	Upper limit	26	18.8+0.33*Tout+3	Type β:28 Type α: 18.8+0.33*Tout+3	Max. 25%	-1.0 < PMV < +1.0
	Lower limit	18	18+0.2*(T_{out}-10)			

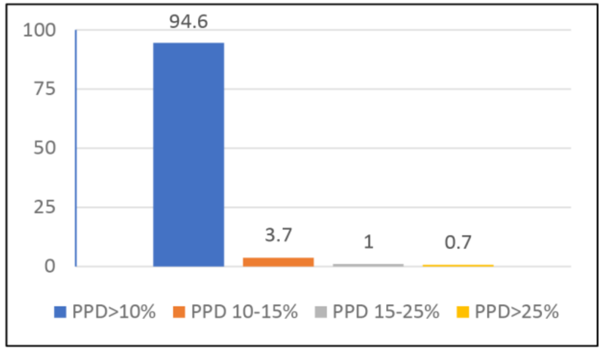


ISSO 74,24
Kurvers & Leijten, 2019



Building :	**Pulse**
Room No.	Hall 10
Room Type	**Beta**
Temp. Type	Operative
Analysis Period	**May-Sept**
Occupied Hours	2448
Thermal Performance	**Good**
Class	Class B

Comfort Bandwidth	No. of Hours	% of Time
Class B	2317	94.6
Class C	91	3.7
Class D	24	1
Above D	16	0.7



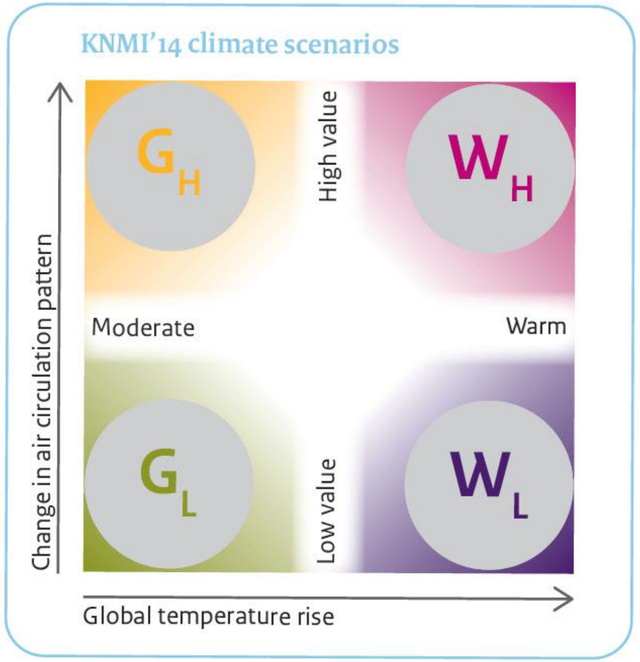
Future Climate Scenarios

Dutch Meteorological Institute **(KNMI)** has provided **four climate change scenarios** based on changes in circulation pattern and global temperature rise.

W_h Climate change Scenario is the **worst case scenario**

Developed for two time horizons

2050 and **2085**



Source: KNMI,2015

Pulse Building , TU Delft Campus

- First Energy Neutral Building on the campus
- Completed : September 2018
- Gross Floor Area : 4700 m^2
- Multifunctional University Building.
- Educational spaces, seminar rooms, self-study spaces, multi-cuisine cafeteria with a capacity of 200 people.

Image: qbiqwallsystems.com

Melanchthon Kralingen, Rotterdam

- Newly constructed building replacing original building from 1970's.
- Completed : 2018
- Gross Floor Area : 4230 m^2
- Designed according to fresh school guidelines .
- Currently, houses 345 students.

Image: Kaw archietcts

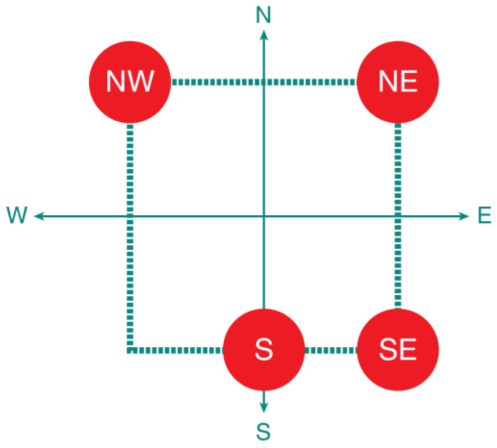
	Pulse , TU Delft	Melanchthon, Rotterdam
Facade (Opaque)	R-Value 7m^2.K/W	R-Value 4.5m^2.K/W
Roof		R-Value 6 m^2.K/W
Ground Floor	R-Value 5 m^2.K/W.	R-Value 3.5 m^2.K/W
External Floor		R-Value 6 m^2.K/W
WWR	.75	.6
Glazing	Triple IGU	HR++
U-Value	.8 W/m^2.K	1.1 W/m^2.K
G-value	.40	.35
VLT	<=.70	<=.70
Infiltration	0.15 L/s per m^2 at 10Pa	0.42 L/s per m^2 at 10Pa
Shading	Internal Blinds (NE) Textile Shading (SW)	Overhangs, Sidefines External Roller blinds
Heating / Cooling	ATES Radiative systems :Climate Ceilings	District Heating Natural Ventilation
Ventilation	Mechanical supply and exhaust	MVHR with summer bypass Windows
Lighting	9 W/m^2	8 W/m^2
Occupancy	8:00 – 0:00 (all week)	9:00 – 16:00 (5 days)

Source: CRE, TuDelft, Wolf+Dikken Advisors

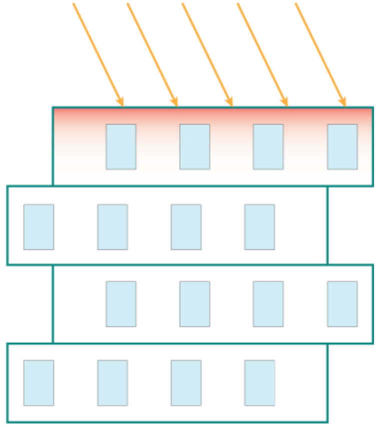
Identification of Spaces which may Overheat

Empirical Studies

Teaching Spaces

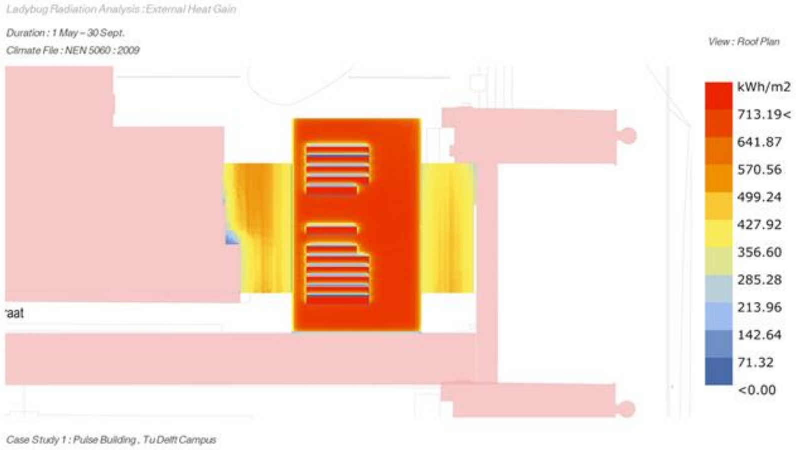


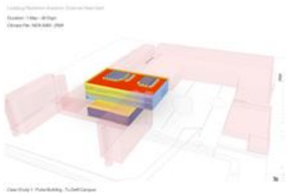
South, South-East,
North-East , North-West

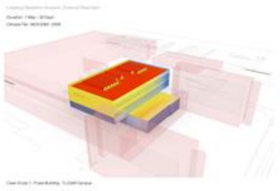


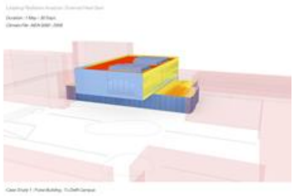
Top Floors

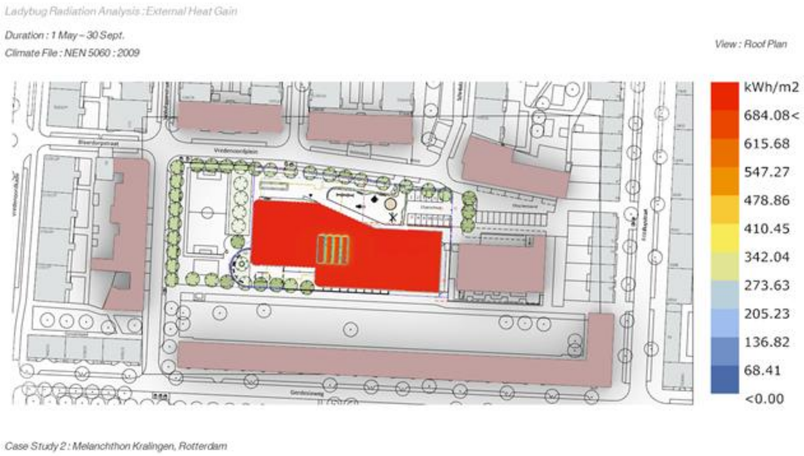
Empirical Studies → Radiation Analysis → Identification of potential spaces which may overheat





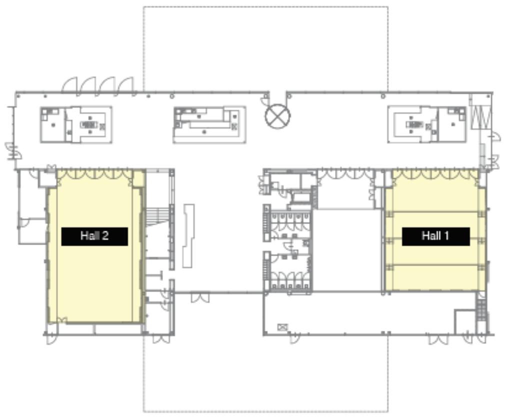




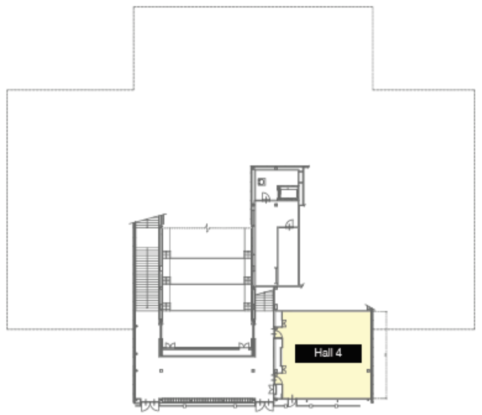


Pulse Building

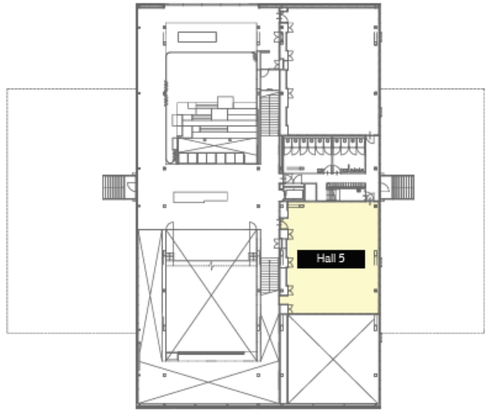
Melanchthon School , Rotterdam



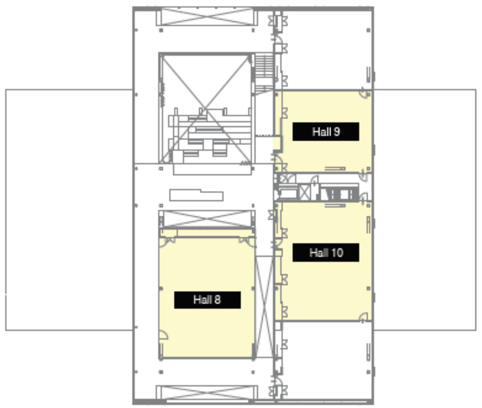
Hall 1 and Hall 2 on Ground Floor



Hall 4 on Intermediate Floor

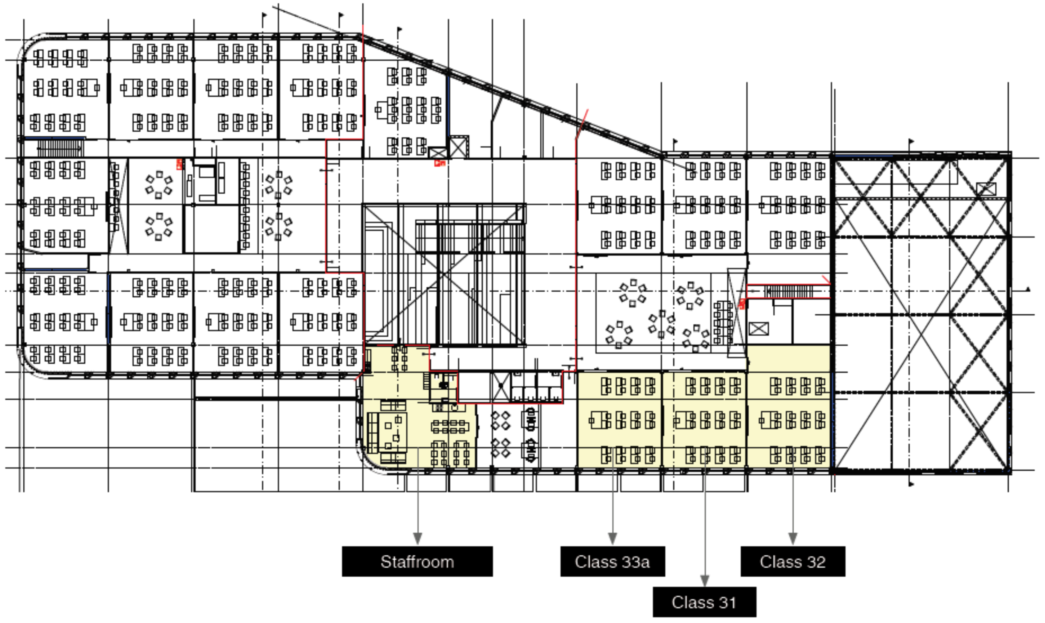


Hall 5 on First Floor

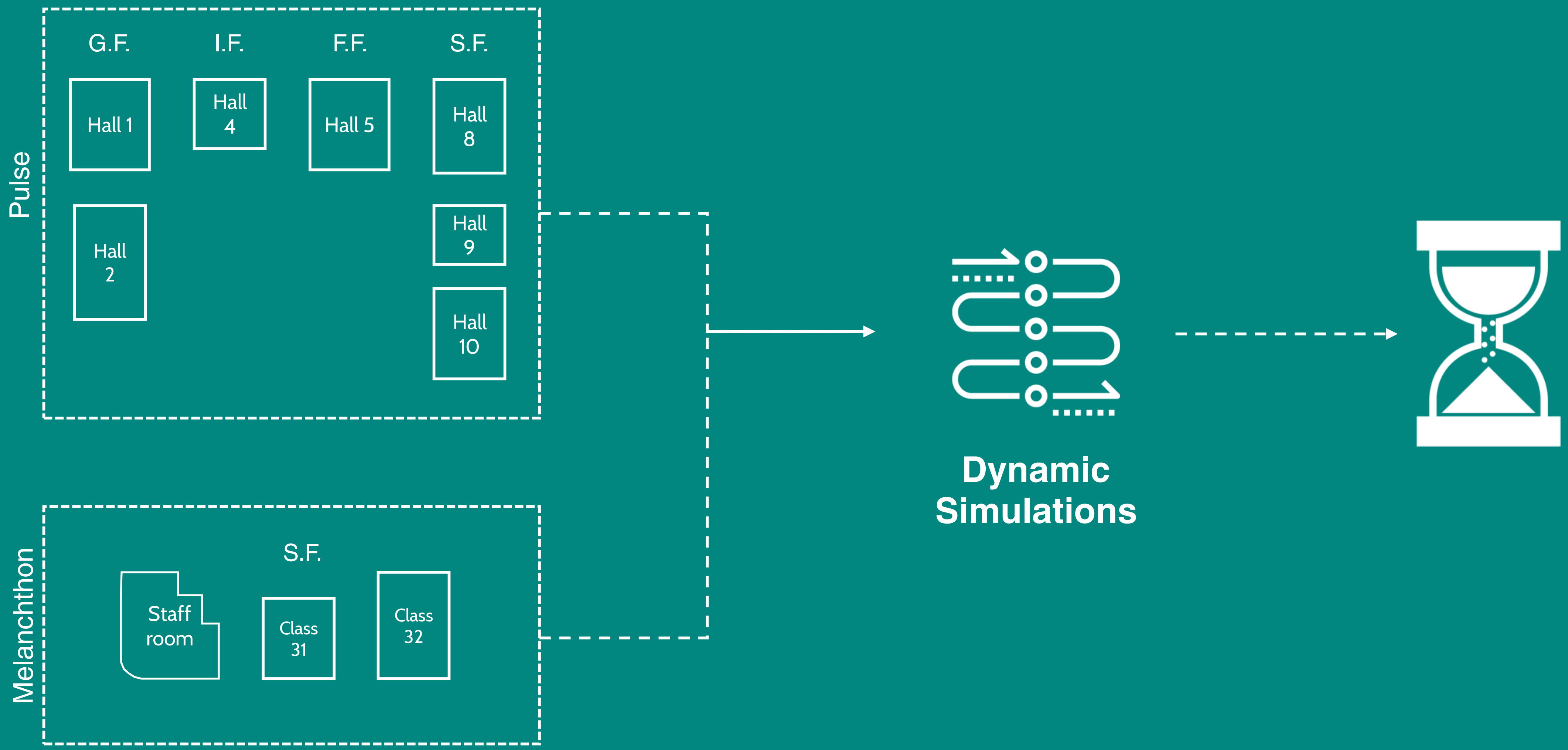


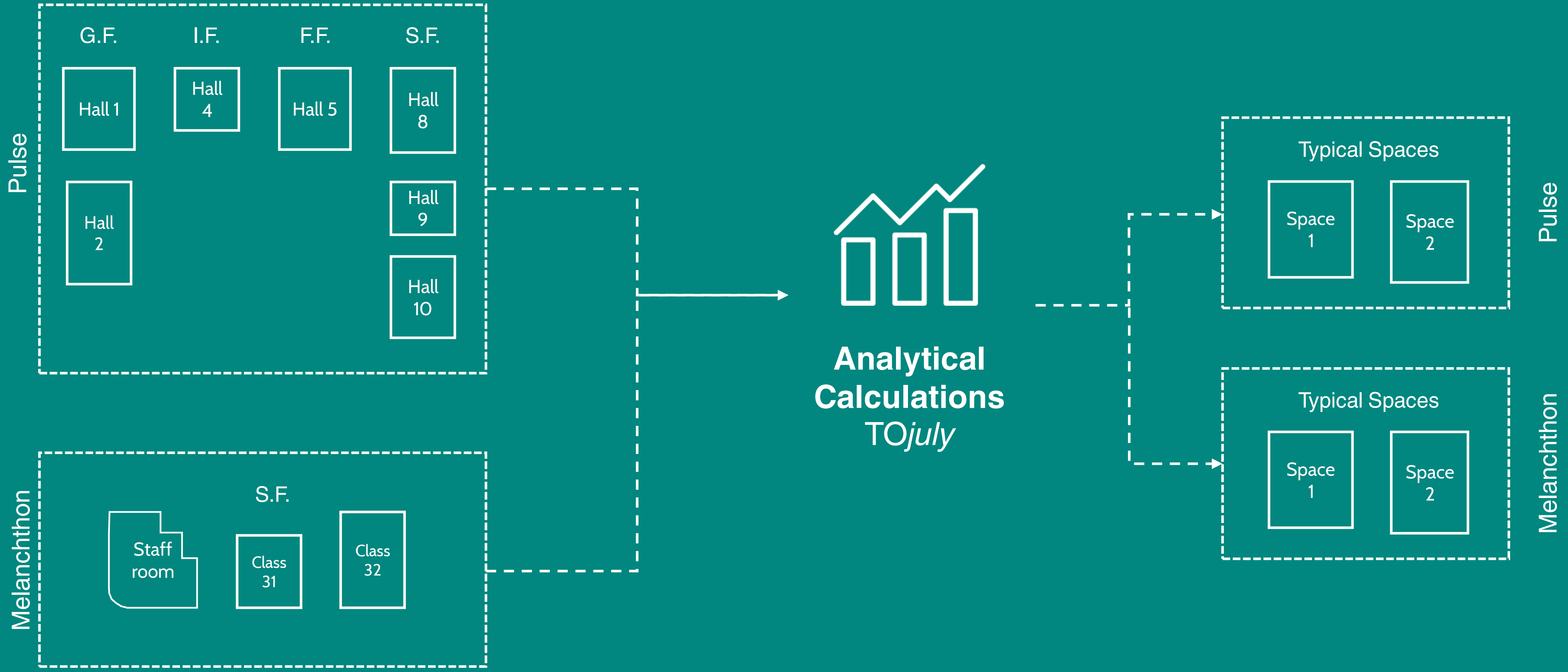
Hall 8,Hall9 and Hall 10 on Second Floor

Pulse Building



Melanchthon School , Rotterdam


Pulse
G.F.
I.F.
F.F.
S.F.
Hall 1
Hall 4
Hall 5
Hall 8
Hall 2
Hall 9
Hall 10
Melanchthon
S.F.
Staff room
Class 31
Class 32
Dynamic Simulations


Pulse
G.F.
I.F.
F.F.
S.F.
Hall 1
Hall 4
Hall 5
Hall 8
Hall 2
Hall 9
Hall 10
Melanchthon
S.F.
Staff room
Class 31
Class 32
Analytical Calculations
TOjuly
Typical Spaces
Space 1
Space 2
Pulse
Typical Spaces
Space 1
Space 2
Melanchthon

TOjuly

Challenge 1

Simplified Excel Tool

Challenge 2

Residential

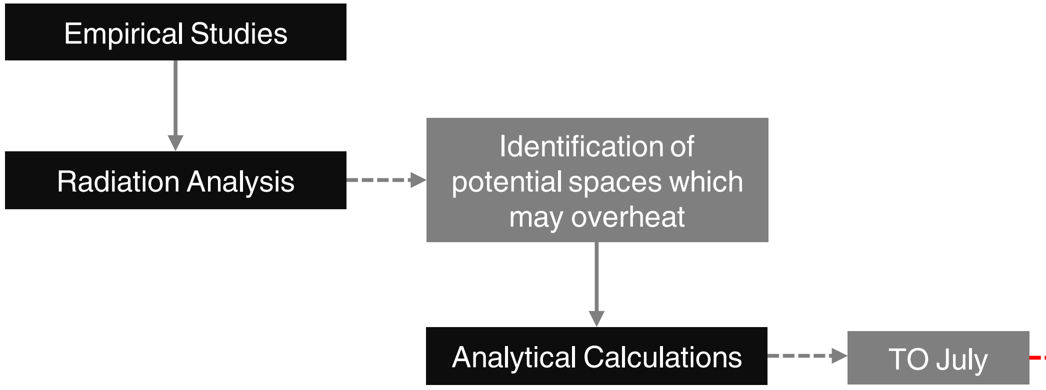
Educational

Challenge 3

Validation

The **simplified method** can be used for **predicting risk for overheating** in **educational buildings**.

The **method cannot** be **validated for corner spaces**.

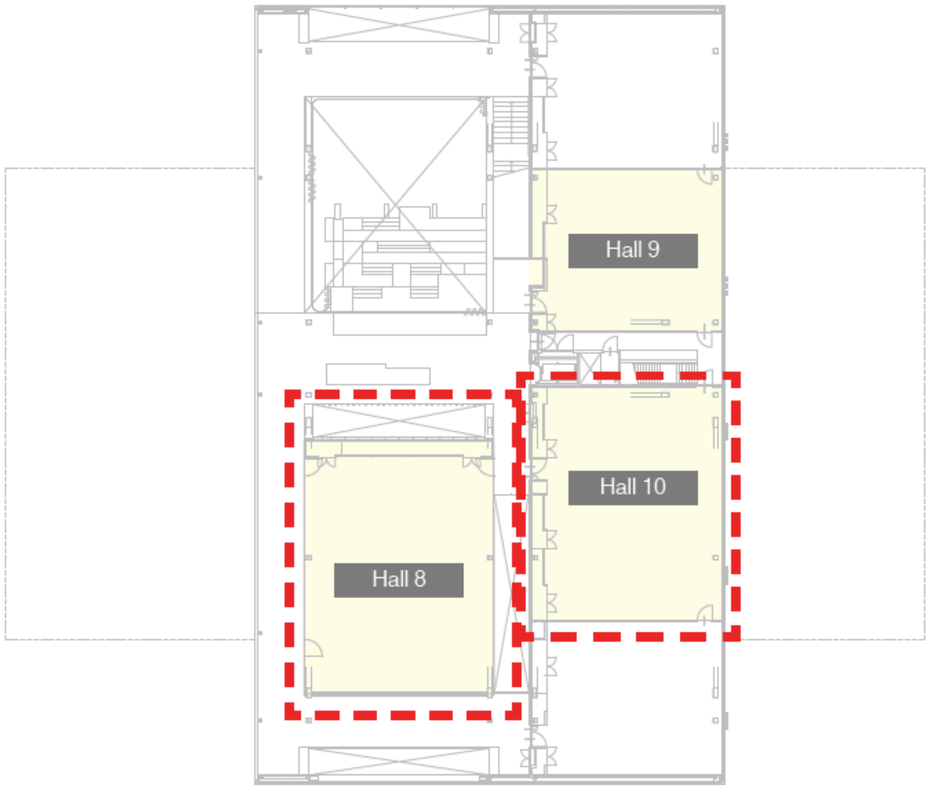


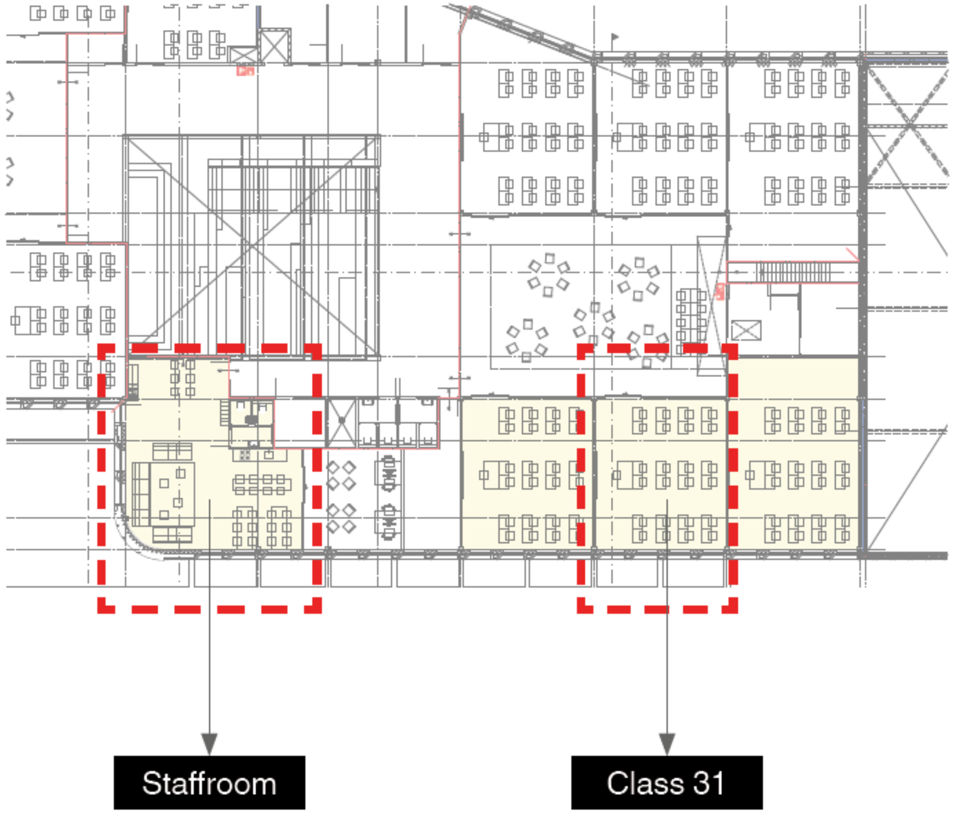
TOjuly Value indicates the probability of excess temperature.

Ideally TOjuly value should not be greater than 1.

If TOjuly is greater than 1 , dynamic simulation tools are required to analyse the risk of overheating.

The overheating assessment was done using ATG method.


Hall 9
Hall 10
Hall 8


Staffroom
Class 31

Empirical Studies

Radiation Analysis

Identification of potential spaces which may overheat

Analytical Calculations

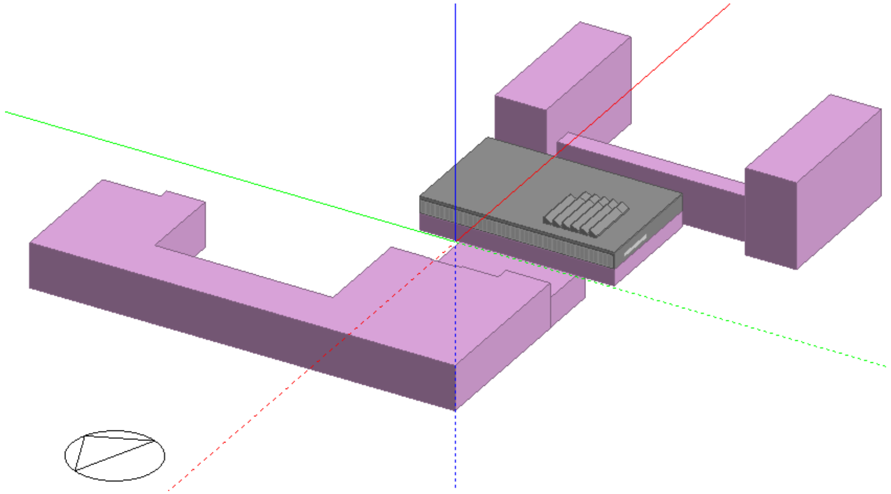
TO July

Identification of Typical Spaces

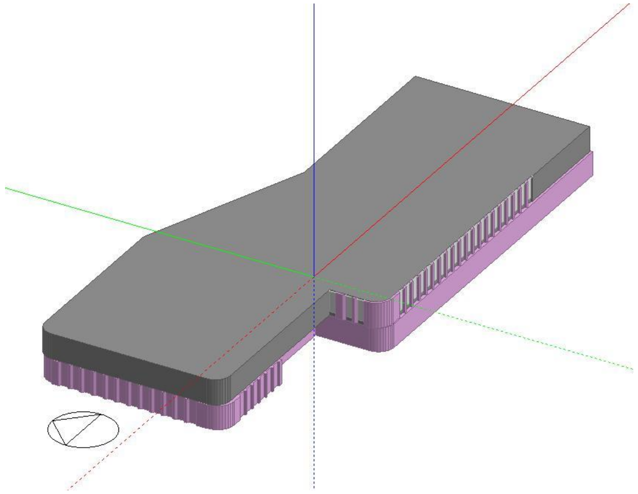
Dynamic Calculations

Dynamic Calculations

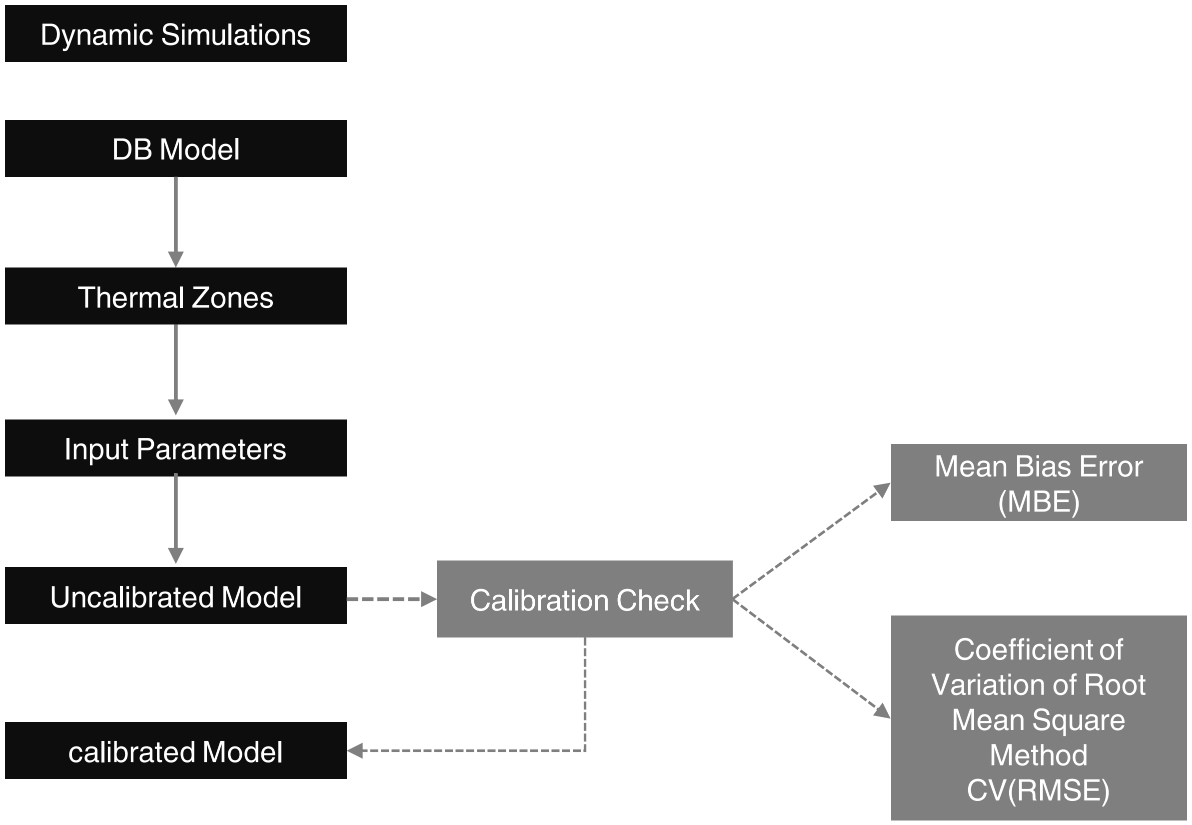
- DB Model
  - Thermal Zones
    - Input Parameters
      - Construction Data
        - Wall Insulation
        - Roof Insulations
        - Openings
      - Activity Data
        - Occupancy Profile
        - Lighting
        - Internal Loads
      - Ventilation
        - HVAC/Natural Vent.
        - Infiltration Rates
      - Heating/Cooling
        - Set-Point/Set Back
        - Cooling Power

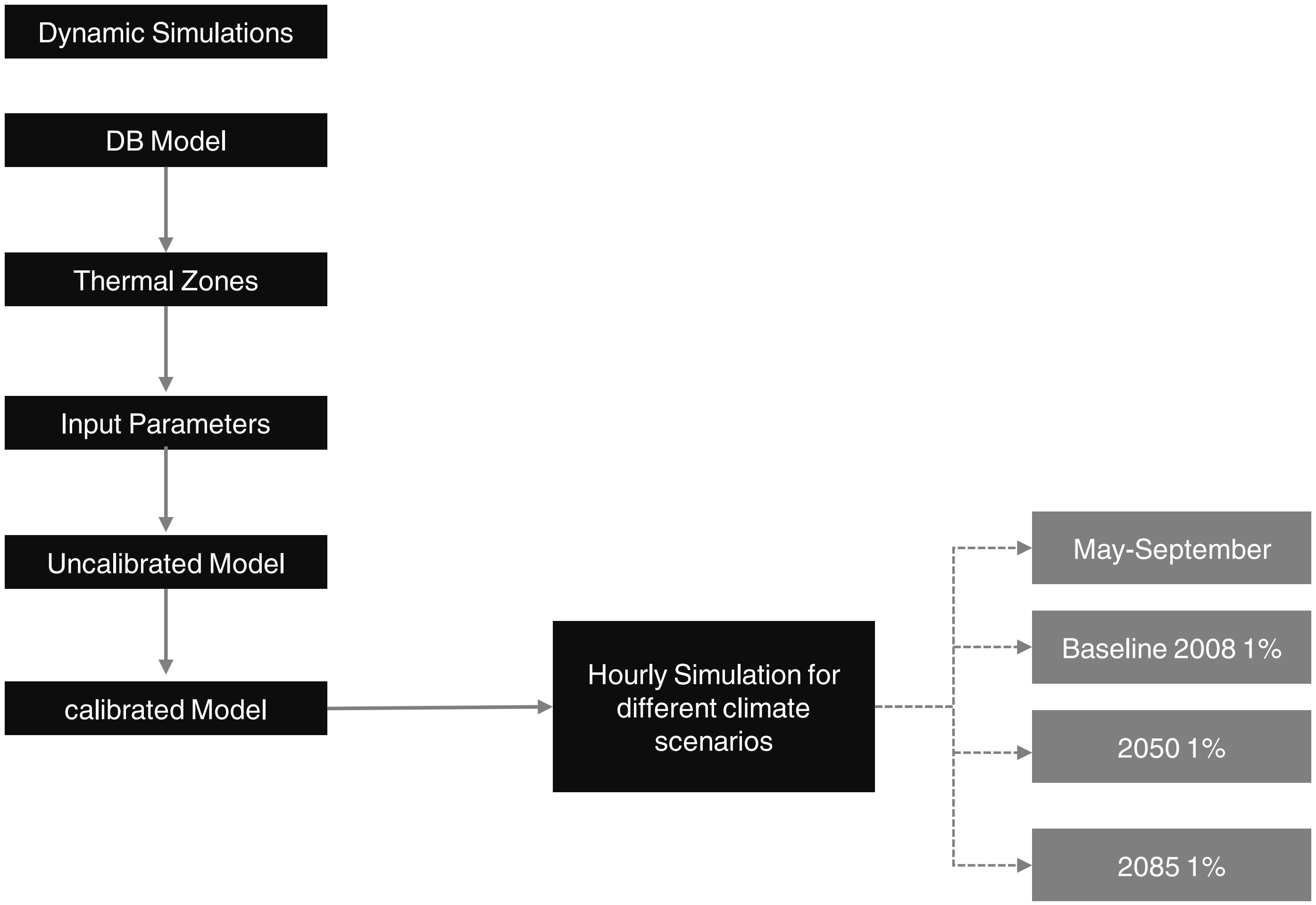


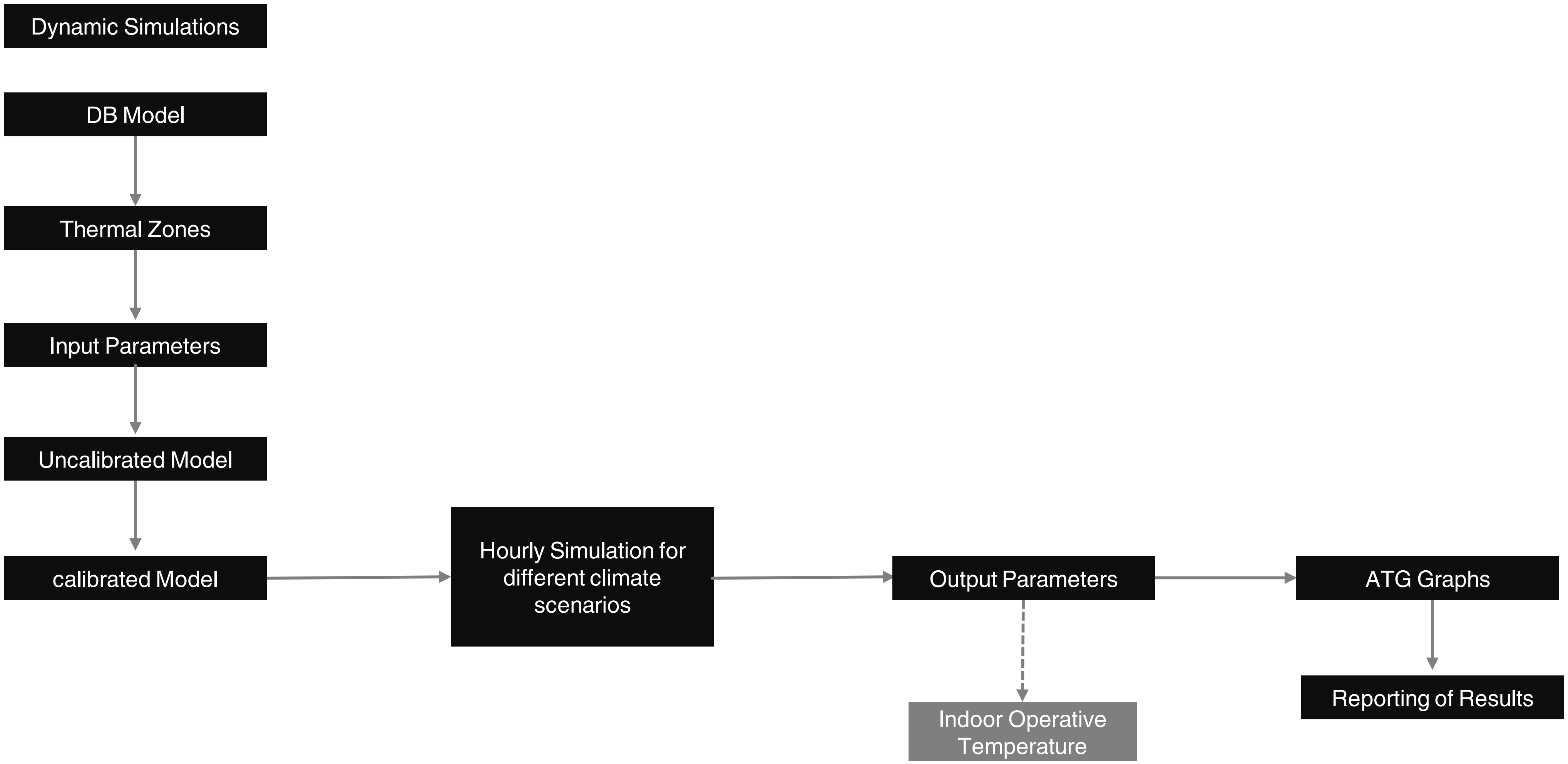
Pulse Building



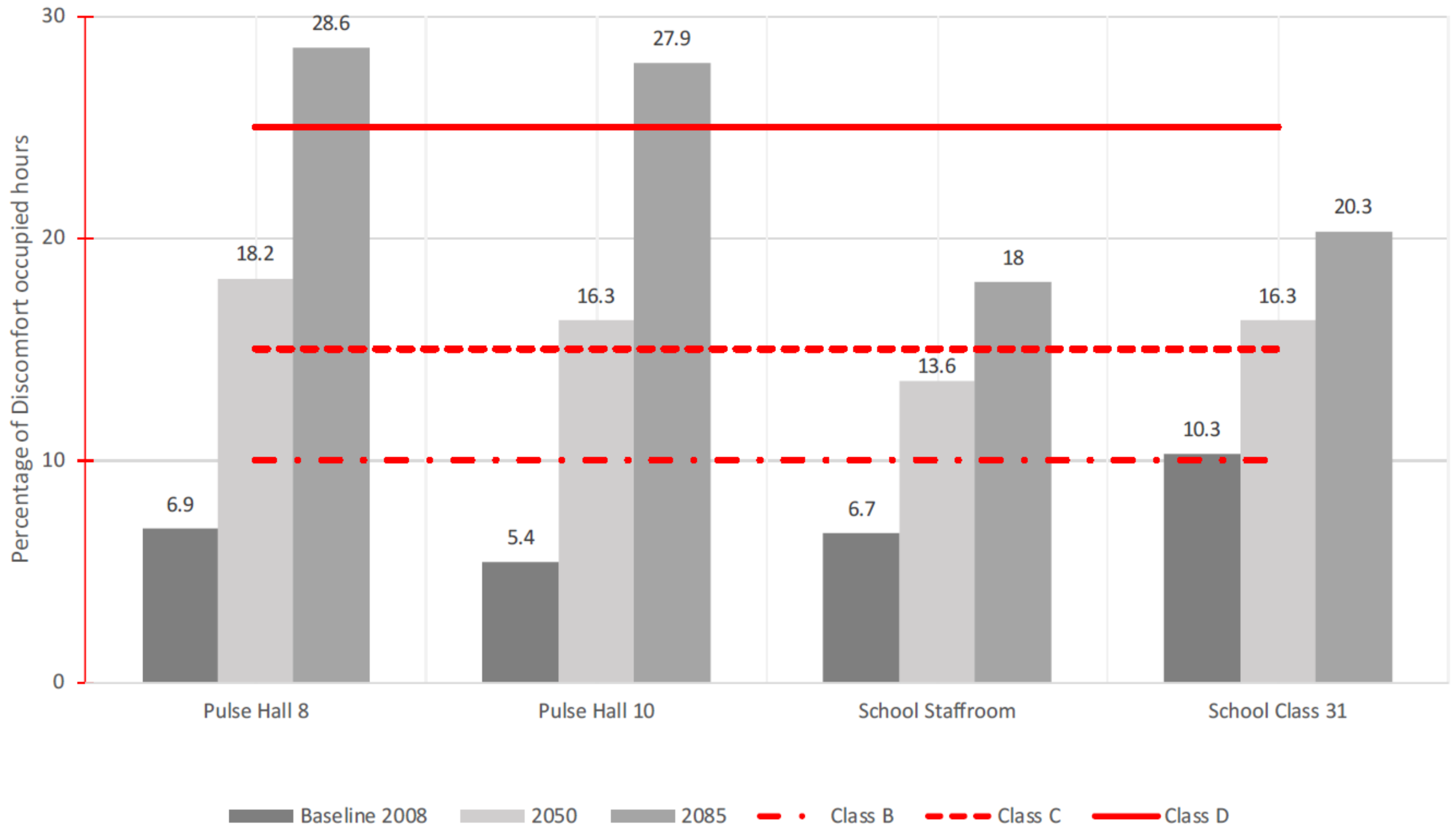
Melanchthon School , Rotterdam


Dynamic Simulations
DB Model
Thermal Zones
Input Parameters
Uncalibrated Model
Calibration Check
calibrated Model
Mean Bias Error (MBE)
Coefficient of Variation of Root Mean Square Method CV(RMSE)


Dynamic Simulations
DB Model
Thermal Zones
Input Parameters
Uncalibrated Model
calibrated Model
Hourly Simulation for different climate scenarios
May-September
Baseline 2008 1%
2050 1%
2085 1%


Dynamic Simulations
DB Model
Thermal Zones
Input Parameters
Uncalibrated Model
calibrated Model
Hourly Simulation for different climate scenarios
Output Parameters
Indoor Operative Temperature
ATG Graphs
Reporting of Results

- According to Dutch Regulations, a **minimum of Class B** has to be maintained
- Pulse Building has higher risk of overheating in future.
- The School building performs better in latter part of the century

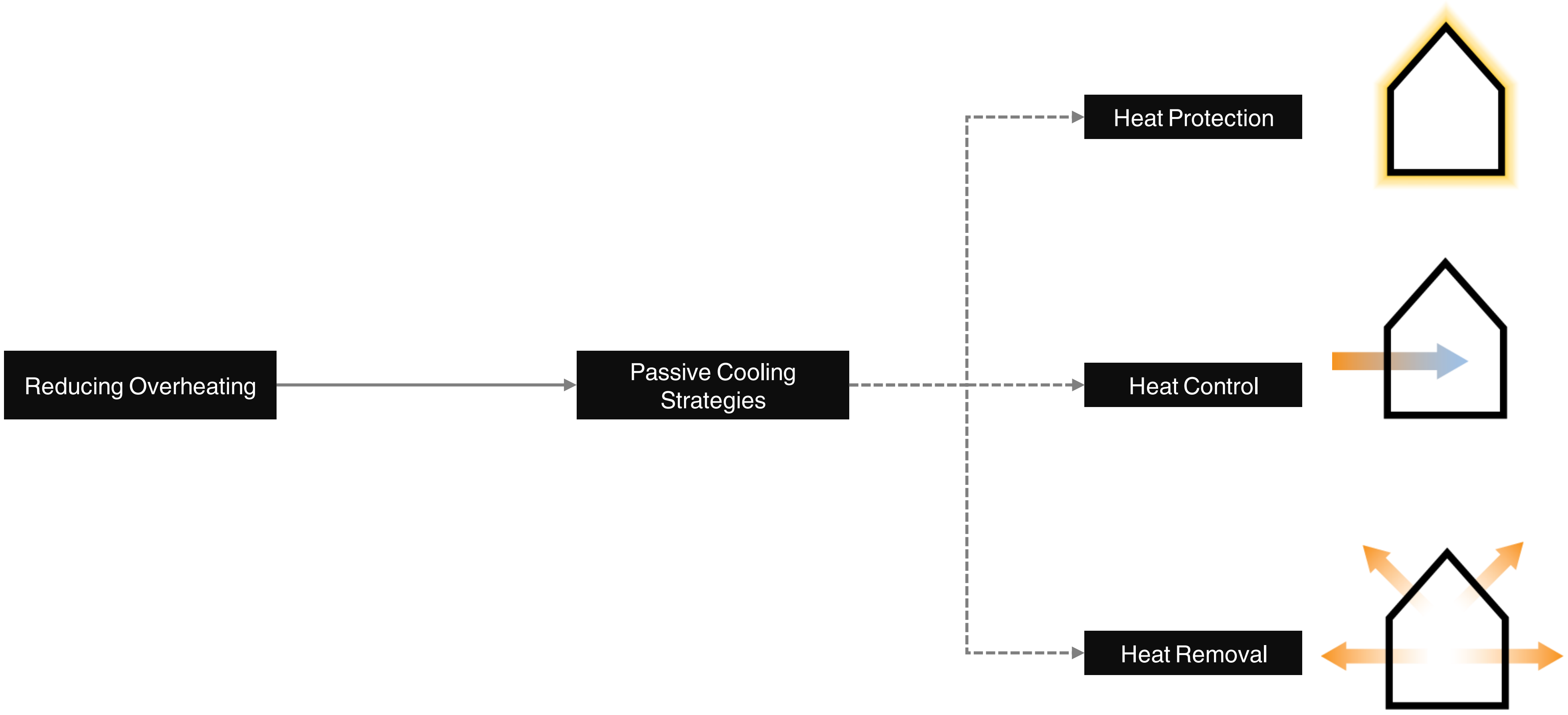


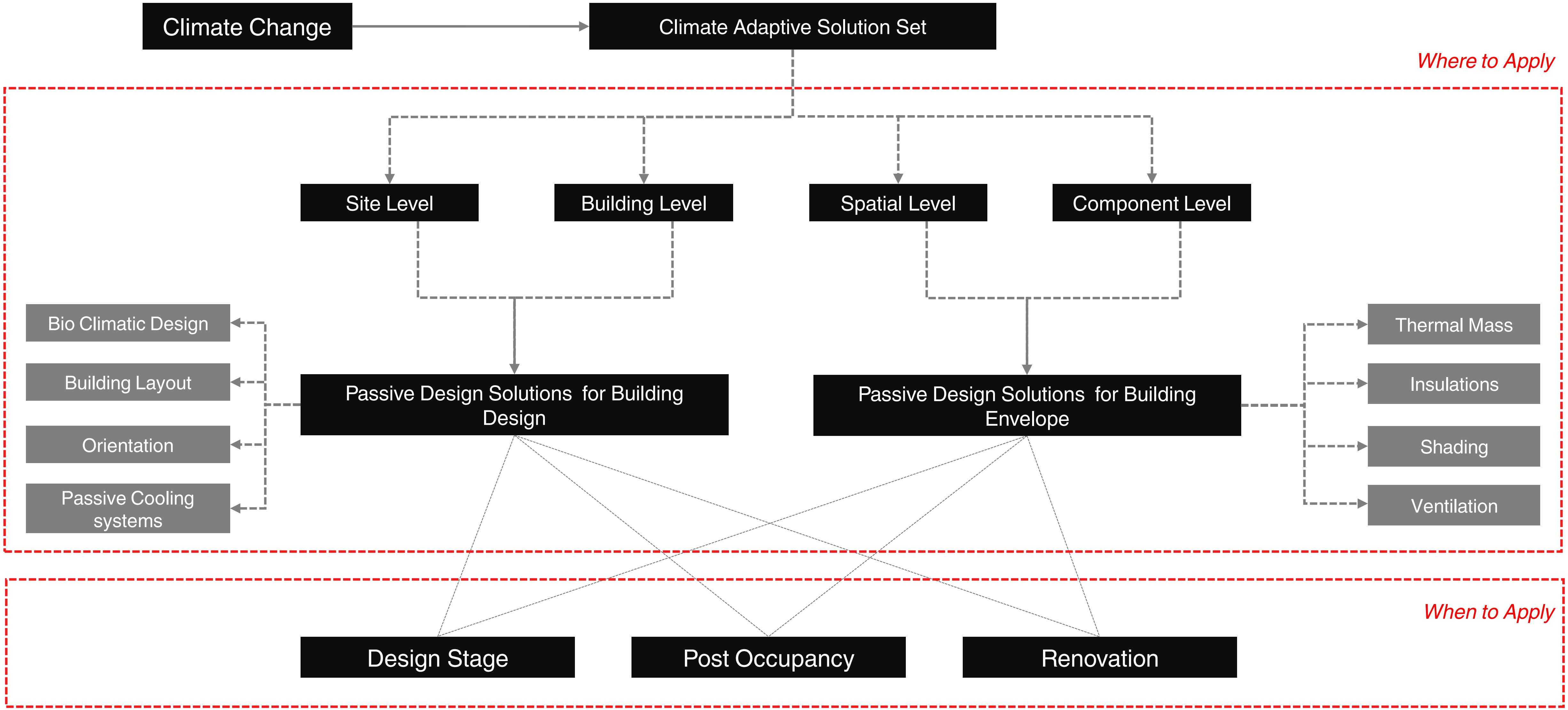
Naturally Ventilated buildings adapt better to external climate as compared to Mechanically controlled.

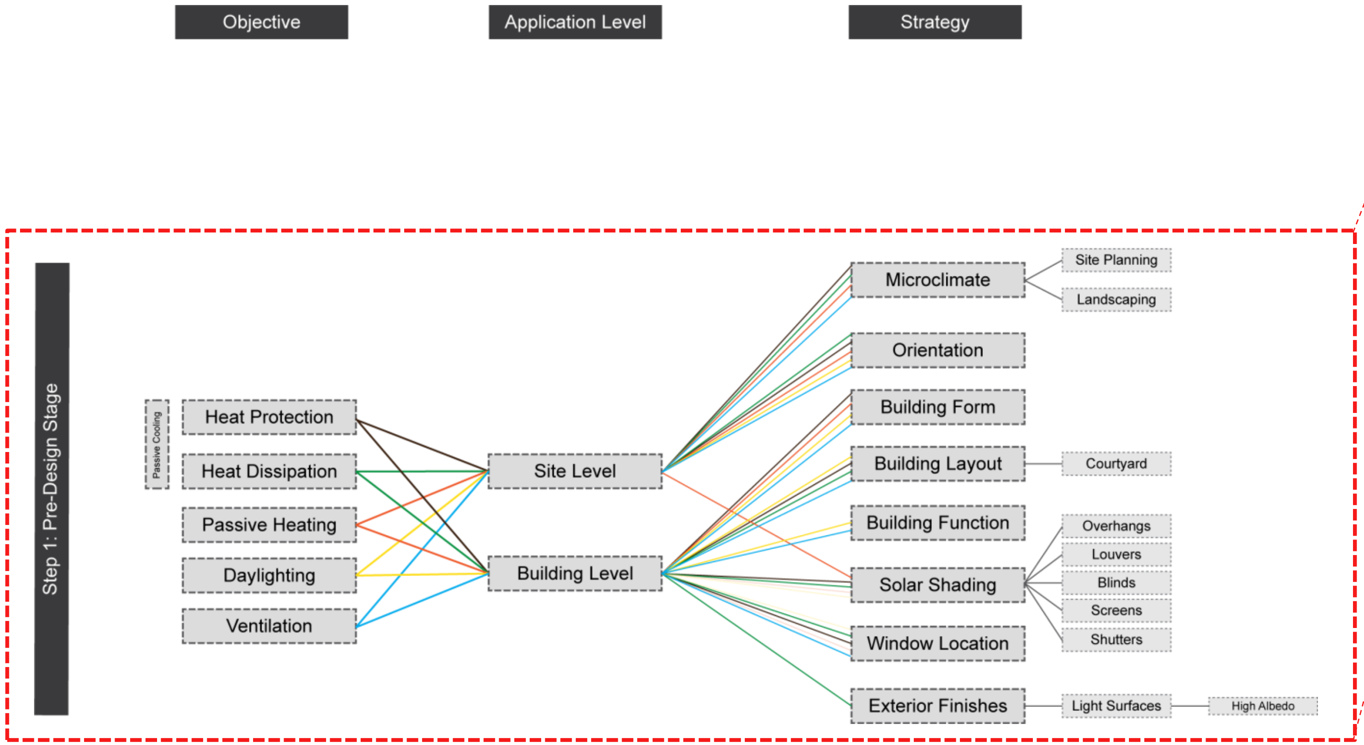
Integrated Passive design of Melanchthon School and allowing the occupants to adapt.

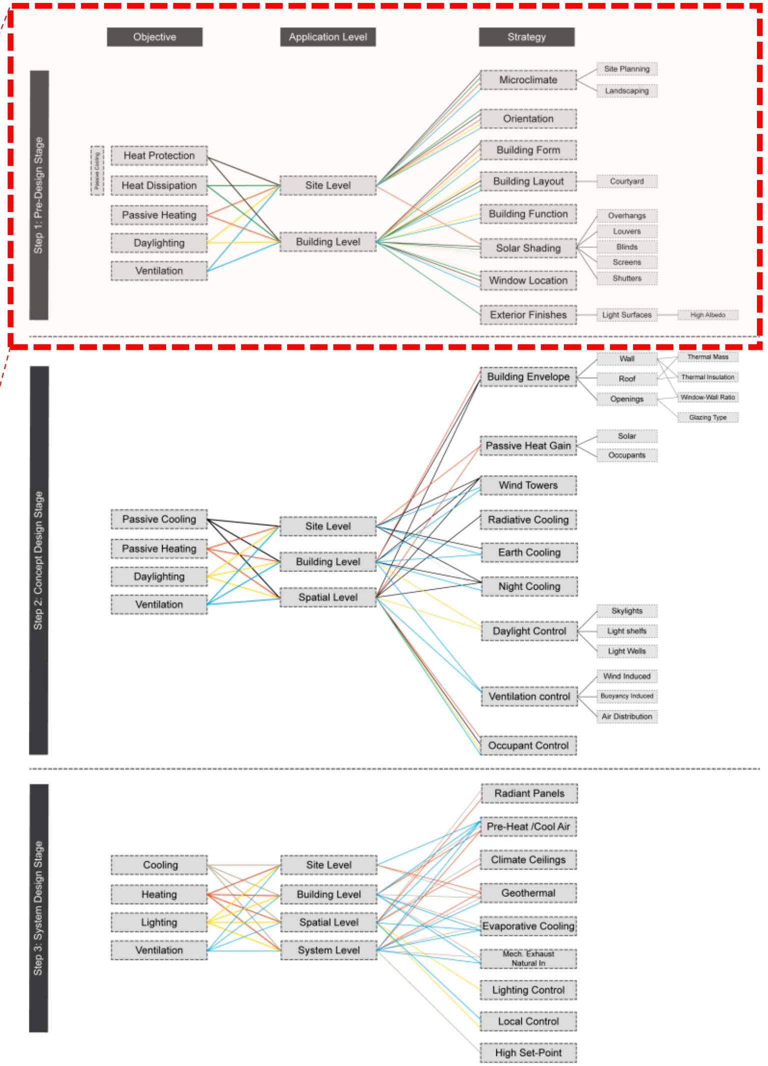
However, the occupancy and operation of Pulse and Melanchthon is different

Adaptive Strategies

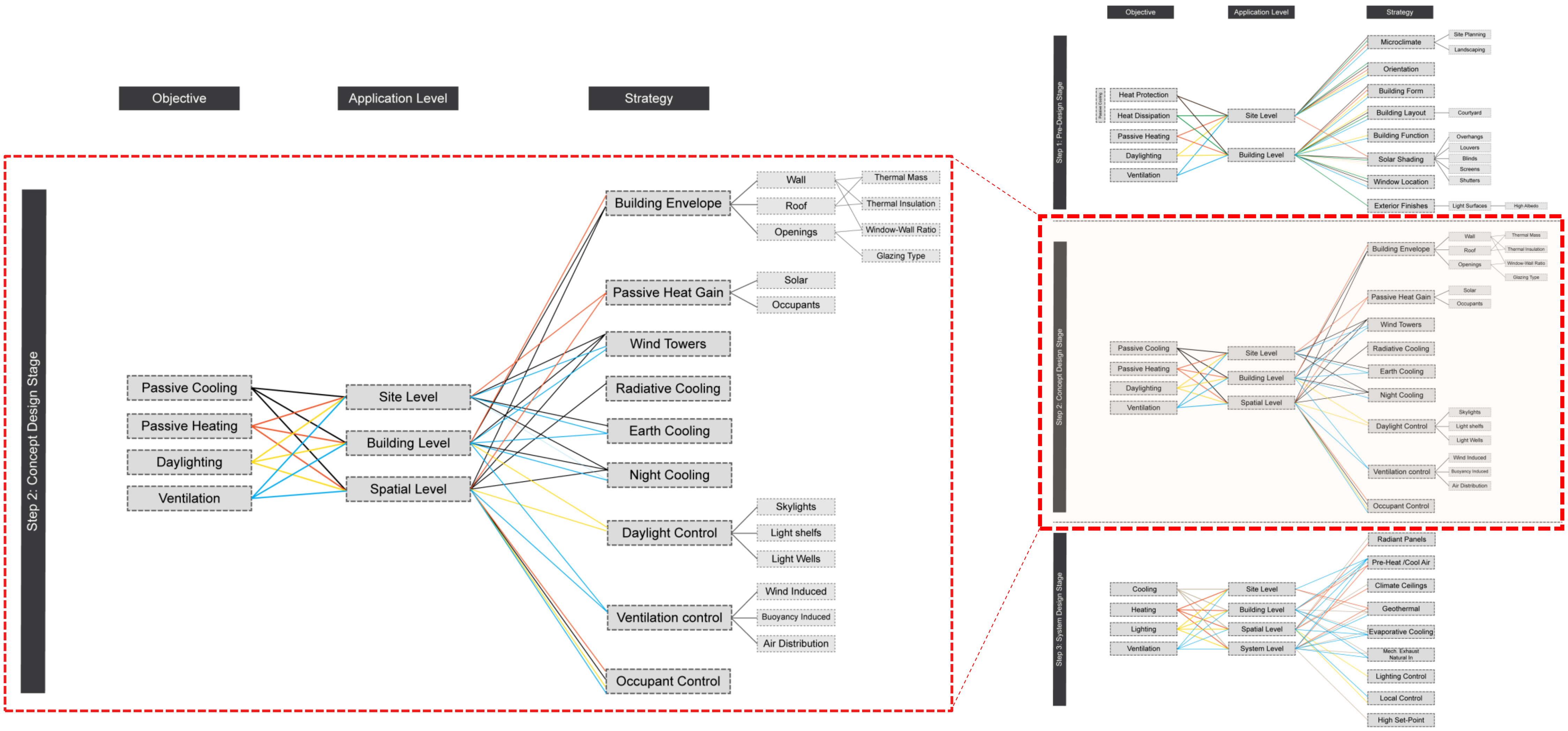

Reducing Overheating
Passive Cooling Strategies
Heat Protection
Heat Control
Heat Removal


Climate Change
Climate Adaptive Solution Set
Where to Apply
Site Level
Building Level
Spatial Level
Component Level
Bio Climatic Design
Building Layout
Orientation
Passive Cooling systems
Passive Design Solutions for Building Design
Passive Design Solutions for Building Envelope
Thermal Mass
Insulations
Shading
Ventilation
When to Apply
Design Stage
Post Occupancy
Renovation

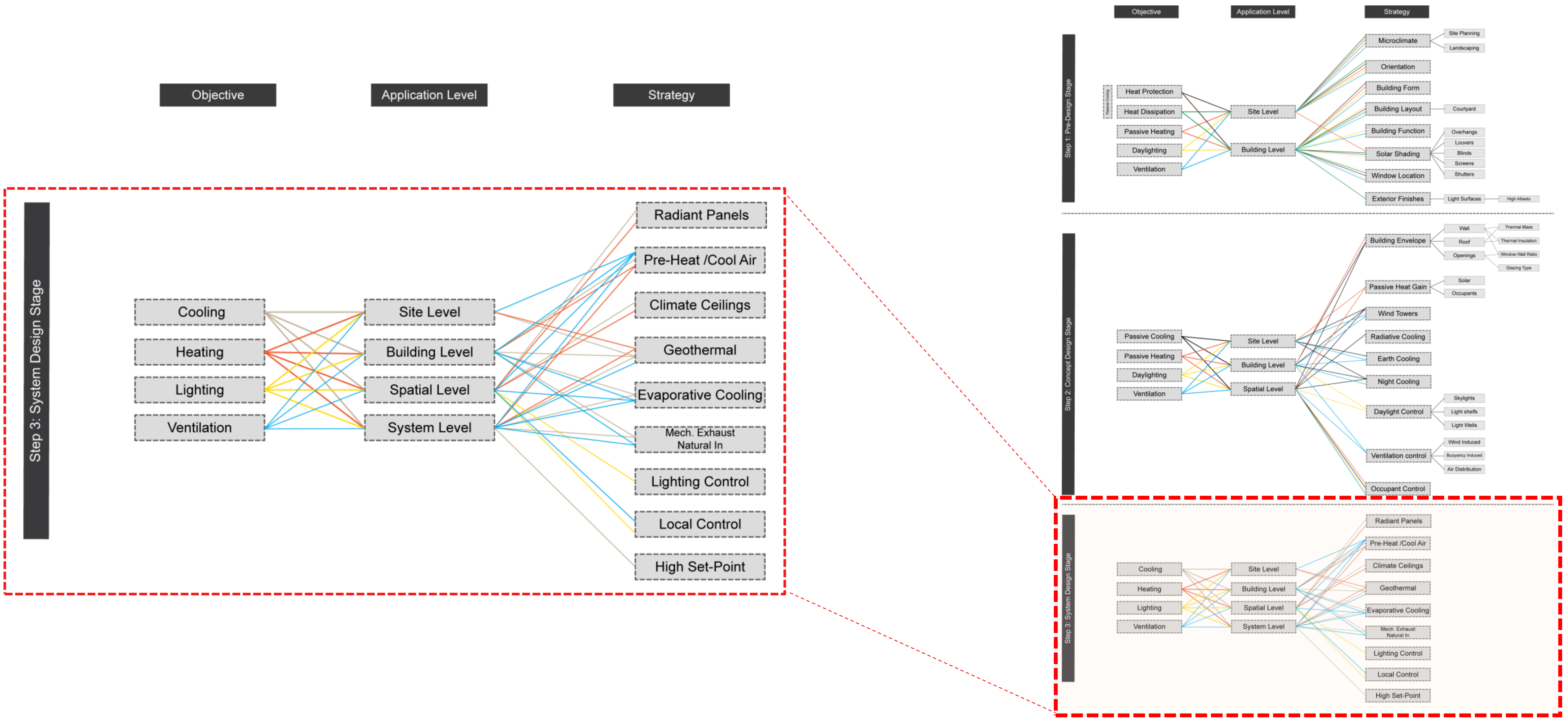




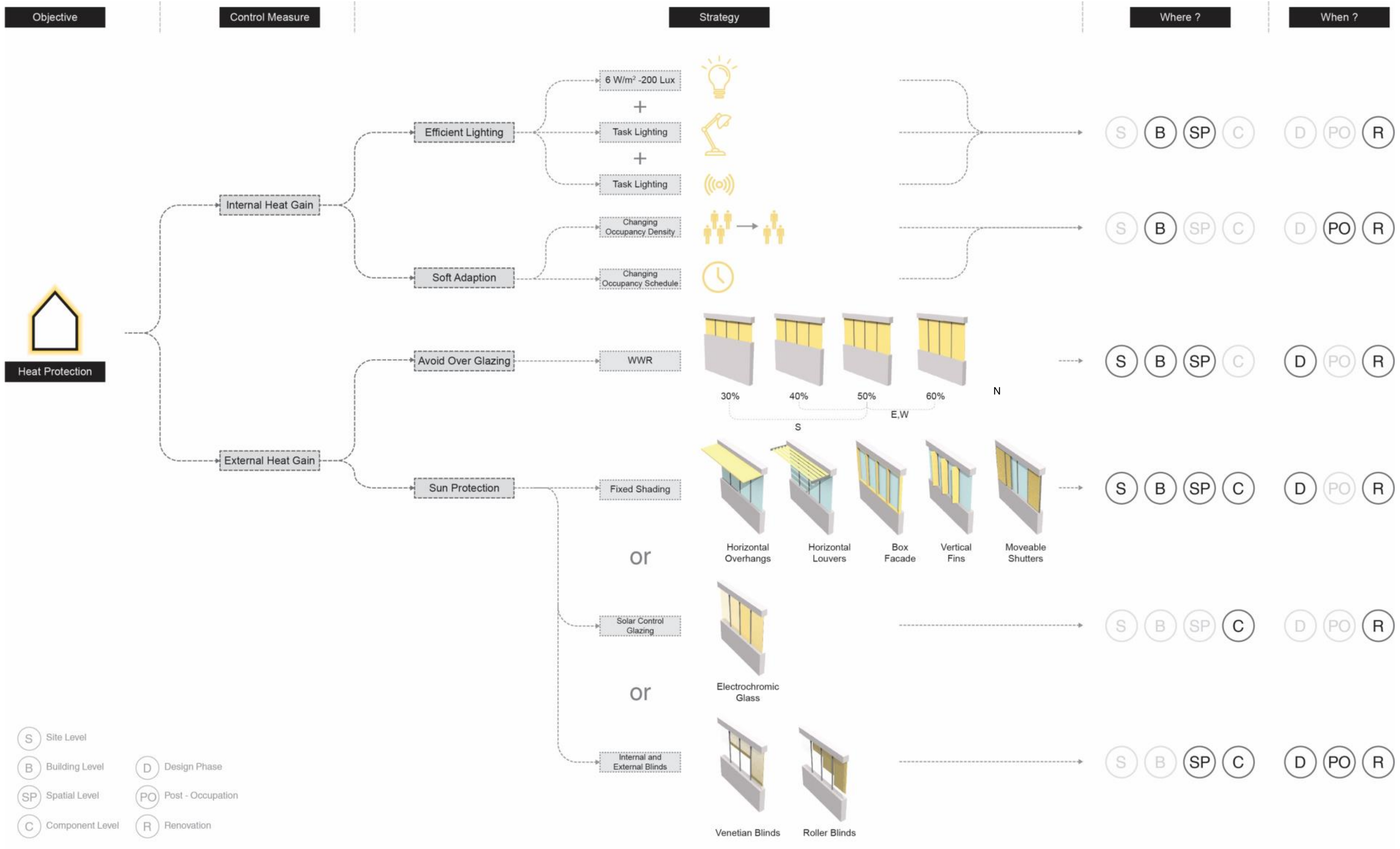
Source:
Engel & Roaf, 2019; Freewan, 2016; Heiselberg, 2006; Prieto et al., 2018

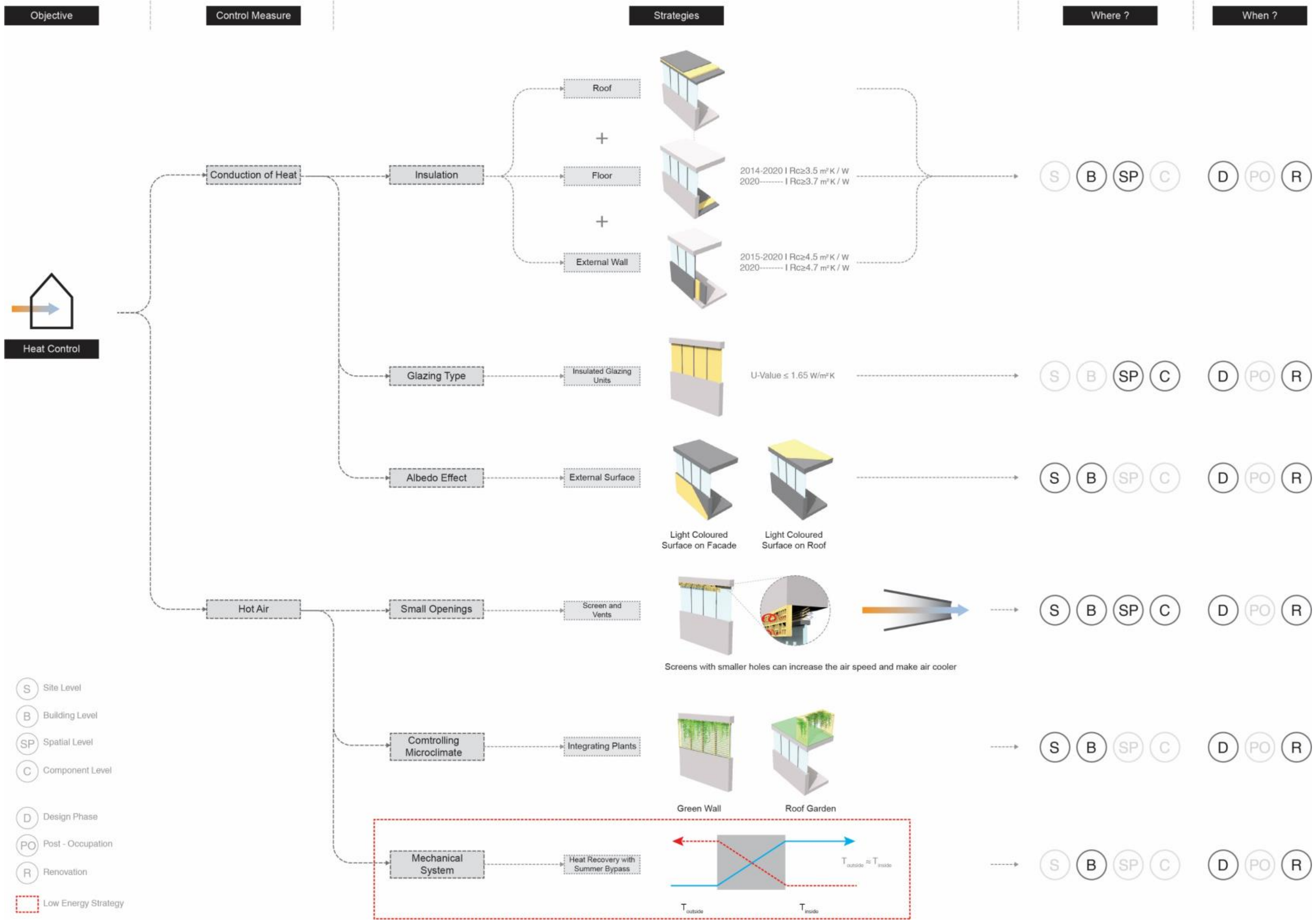


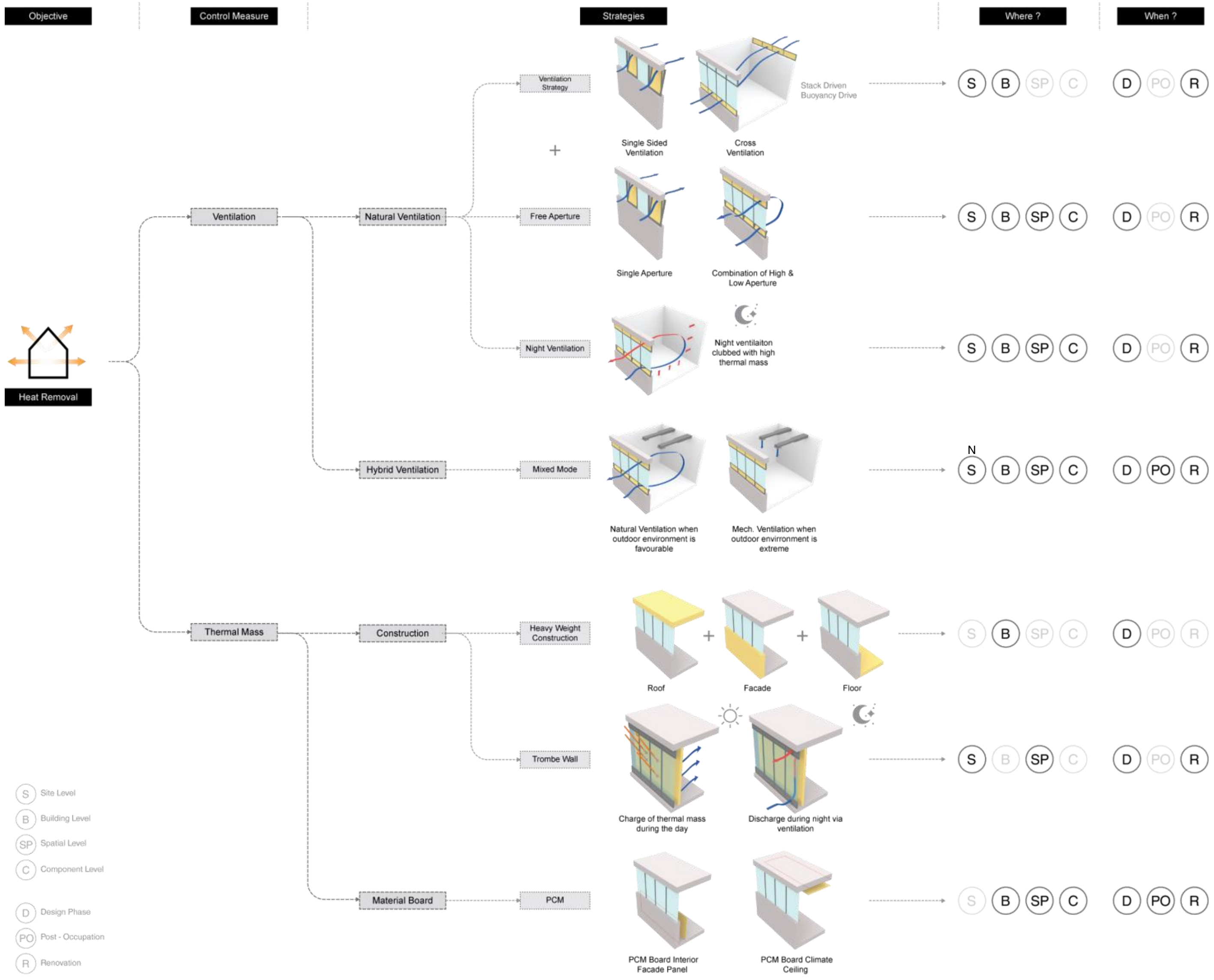
Source:
Engel & Roaf, 2019; Freewan, 2016; Heiselberg, 2006; Prieto et al., 2018



Source:
Engel & Roaf, 2019; Freewan, 2016; Heiselberg, 2006; Prieto et al., 2018


Objective
Control Measure
Strategy
Where ?
When ?
Heat Protection
Internal Heat Gain
External Heat Gain
Efficient Lighting
Soft Adaption
Avoid Over Glazing
Sun Protection
6 W/m² -200 Lux
+
Task Lighting
+
Task Lighting
Changing Occupancy Density
Changing Occupancy Schedule
WWR
30%
40%
50%
60%
N
E,W
S
Fixed Shading
Horizontal Overhangs
Horizontal Louvers
Box Facade
Vertical Fins
Moveable Shutters
or
Solar Control Glazing
Electrochromic Glass
or
Internal and External Blinds
Venetian Blinds
Roller Blinds
S B SP C
D PO R
S Site Level
B Building Level
SP Spatial Level
C Component Level
D Design Phase
PO Post - Occupation
R Renovation


Objective
Control Measure
Strategies
Where ?
When ?
Heat Control
Conduction of Heat
Insulation
Roof
+
Floor
+
External Wall
2014-2020 I Rc≥3.5 m²K / W
2020-------- I Rc≥3.7 m²K / W
2015-2020 I Rc≥4.5 m²K / W
2020-------- I Rc≥4.7 m²K / W
Glazing Type
Insulated Glazing Units
U-Value ≤ 1.65 W/m²K
Albedo Effect
External Surface
Light Coloured Surface on Facade
Light Coloured Surface on Roof
Hot Air
Small Openings
Screen and Vents
Screens with smaller holes can increase the air speed and make air cooler
Comtrolling Microclimate
Integrating Plants
Green Wall
Roof Garden
Mechanical System
Heat Recovery with Summer Bypass
S B SP C
D PO R
S Site Level
B Building Level
SP Spatial Level
C Component Level
D Design Phase
PO Post - Occupation
R Renovation
Low Energy Strategy


Objective
Control Measure
Strategies
Where ?
When ?
Heat Removal
Ventilation
Thermal Mass
Natural Ventilation
Hybrid Ventilation
Construction
Material Board
Ventilation Strategy
+
Free Aperture
Night Ventilation
Mixed Mode
Heavy Weight Construction
Trombe Wall
PCM
Single Sided Ventilation
Cross Ventilation
Stack Driven Buoyancy Drive
Single Aperture
Combination of High & Low Aperture
Night ventilaiton clubbed with high thermal mass
Natural Ventilation when outdoor environment is favourable
Mech. Ventilation when outdoor environment is extreme
Roof
Facade
Floor
Charge of thermal mass during the day
Discharge during night via ventilation
PCM Board Interior Facade Panel
PCM Board Climate Ceiling
S B SP C
D PO R
N
S Site Level
B Building Level
SP Spatial Level
C Component Level
D Design Phase
PO Post - Occupation
R Renovation

40 Different Strategies

$^{40}C_3$

Selecting solutions

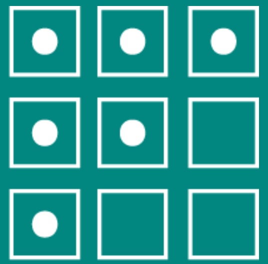
9,880

Combinations

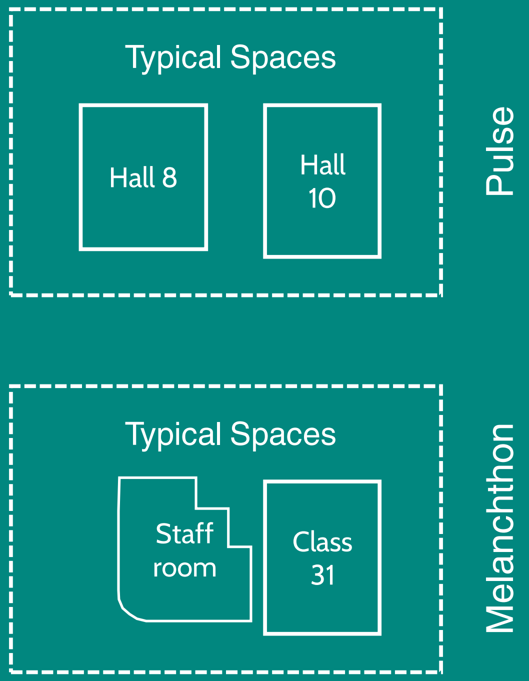

40 Different Strategies
Analytical
Dynamic
Reduction in % of
Discomfort Hours

350

Simulation Runs

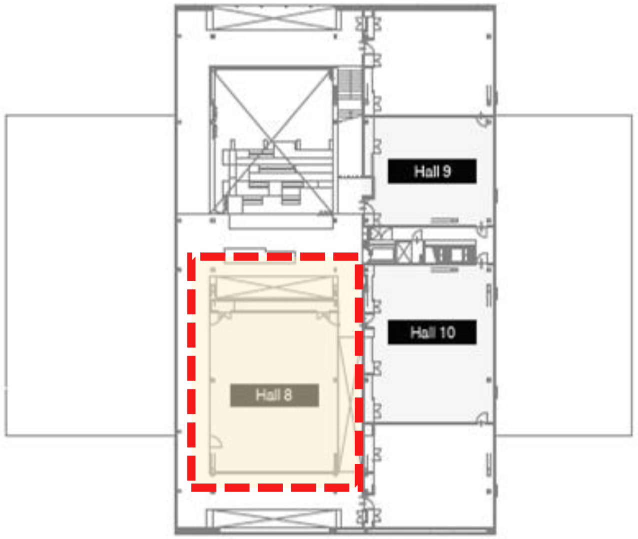


Solution Packages

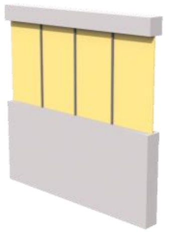


Identified Spaces

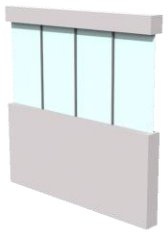
Pulse Hall 8



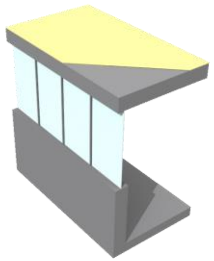
7 Solution Sets



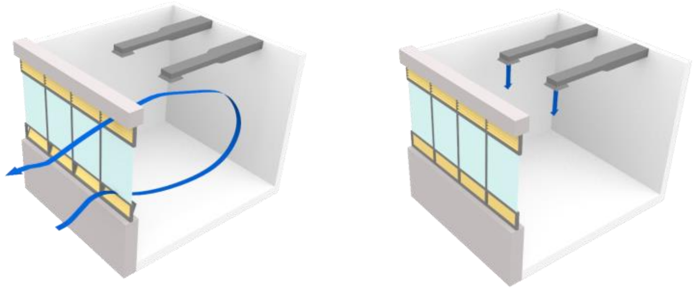
WWR



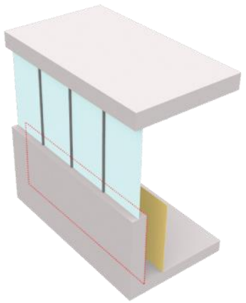
Reducing U-Value



White Surfaces on Roof

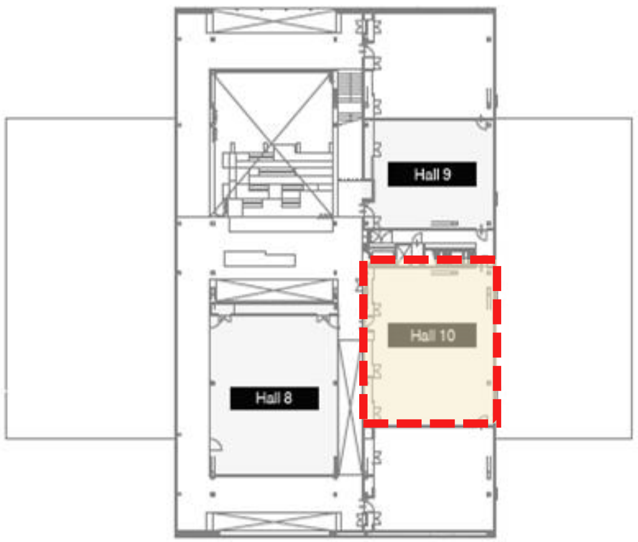


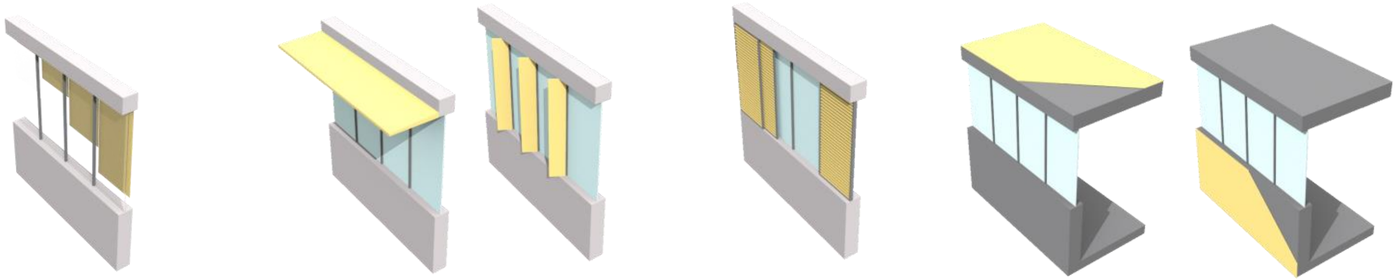
Mixed Mode Ventilation



PCM Panels

Pulse Hall 10: Existing Facade



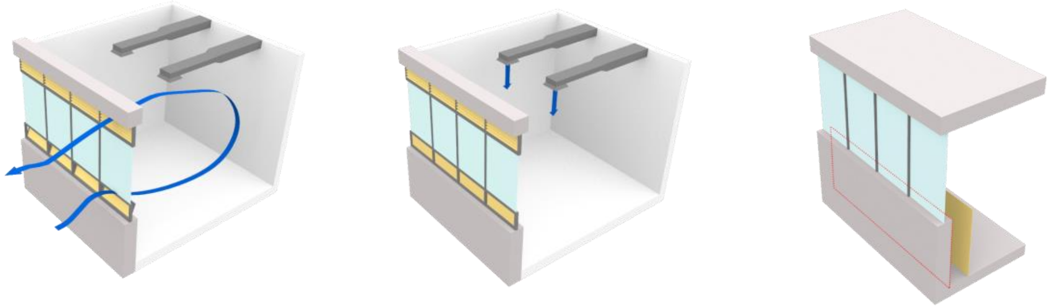


External Blinds

Overhang & Side fin

Shutters

White Surfaces on roof and facade

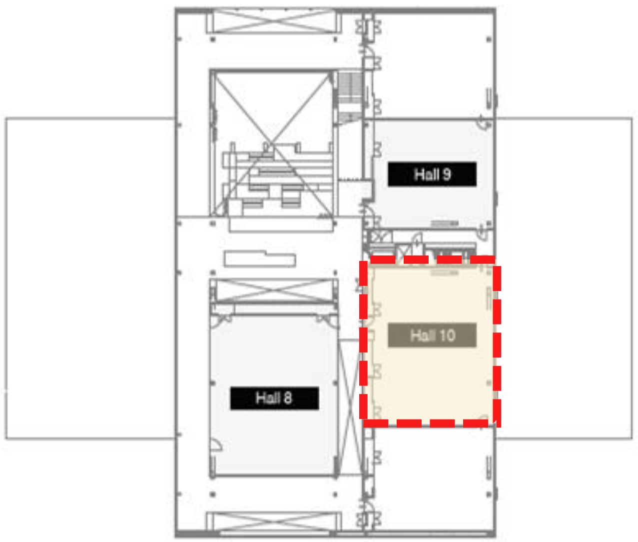


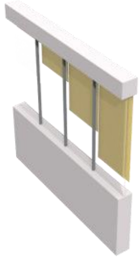
Mixed Mode Ventilation

PCM Panels

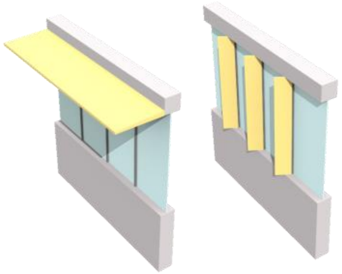
10 Solution Sets

Pulse Hall 10 : WWR 50%

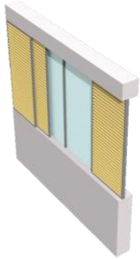




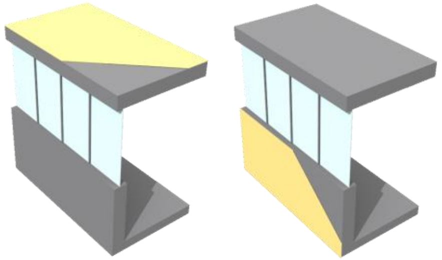
External Blinds



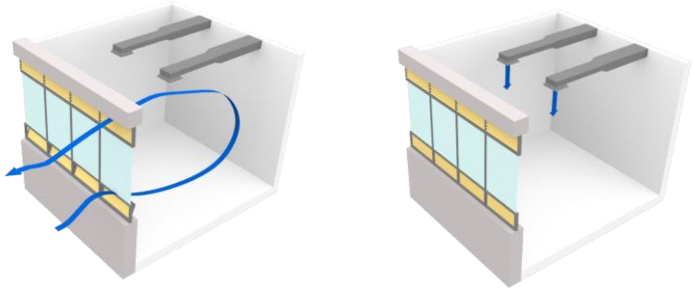
Overhang & Side fin



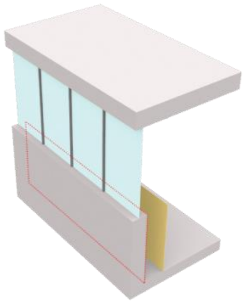
Shutters



White Surfaces on roof and facade



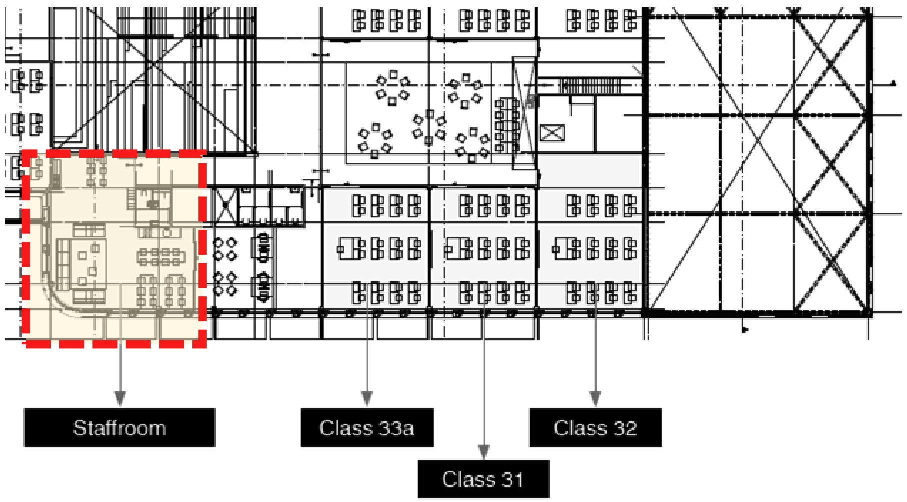
Mixed Mode Ventilation



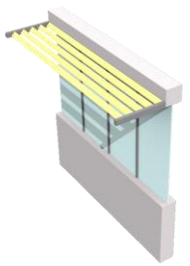
PCM Panels

8 Solution Sets

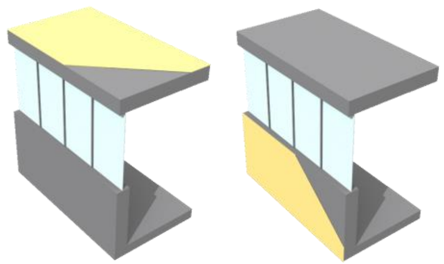
Melanchthon School: Staffroom



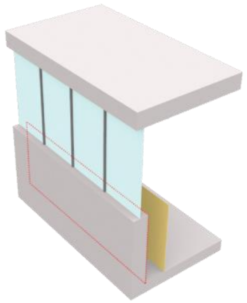
4 Solution Sets



Overhangs (Pergola)

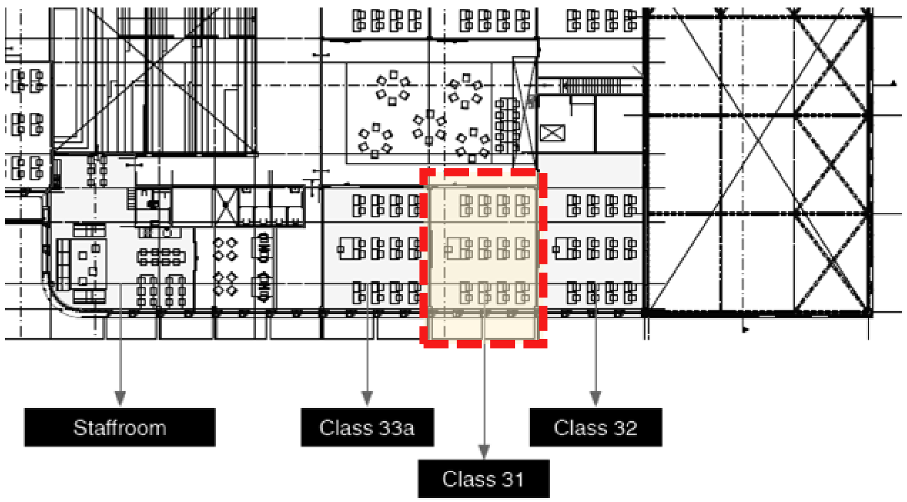


White Surfaces on roof and facade

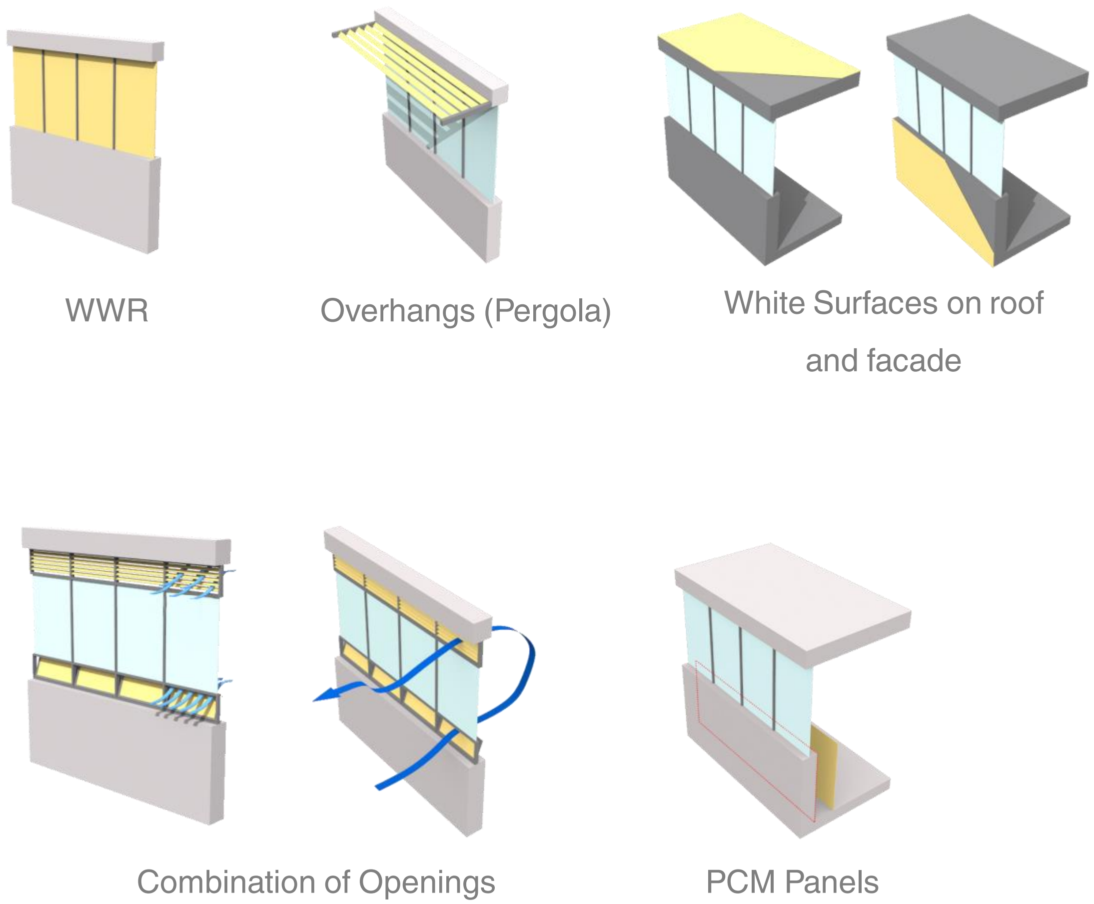


PCM Panels

Melanchthon School: Class 31



6 Solution Sets



Robustness Evaluation

What is a Robust Design ?

A design with minimum performance variability under the presence of uncertainties.

Assessment of Robust Design

A design with minimum performance variability under the presence of uncertainties.

Solutions Set

Attia, 2018b; Hamdy et al., 2017
Rajesh Kotireddy et al., 2017a, 2017b, 2018, 2019

Assessment of Robust Design

A design with minimum performance variability under the presence of uncertainties

Solutions Set

Performance Indicator → Overheating Thresholds → *The percentage of discomfort hours exceeding Class B upper limit depending on alpha or beta type of space, by plotting ATG Graphs*

Assessment of Robust Design

A design with minimum performance variability under the presence of uncertainties

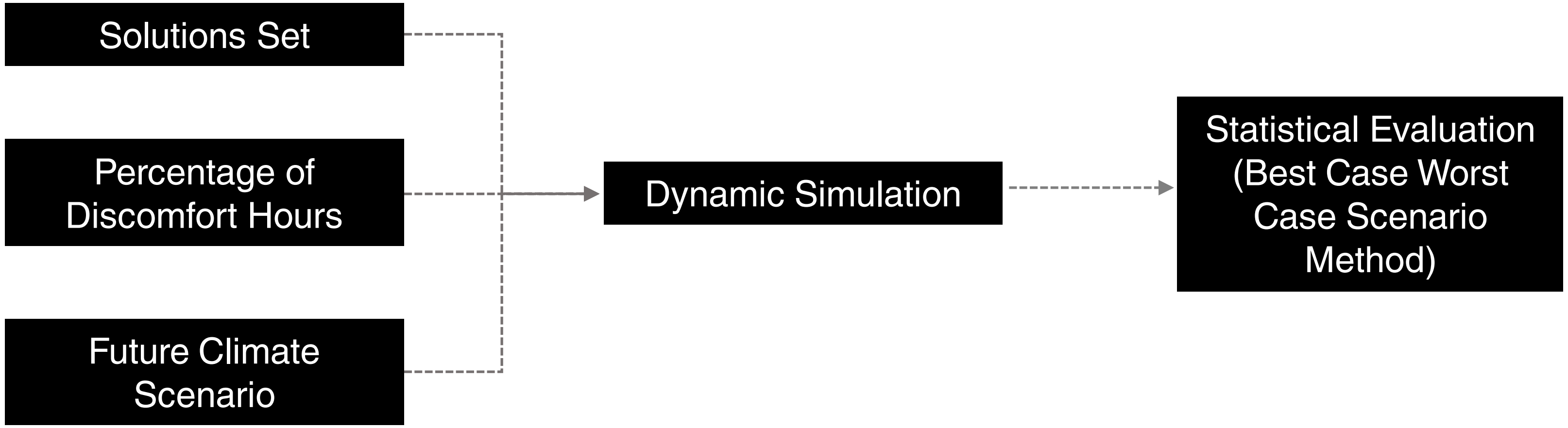
Solutions Set

Performance Indicator

Future Climate Scenario

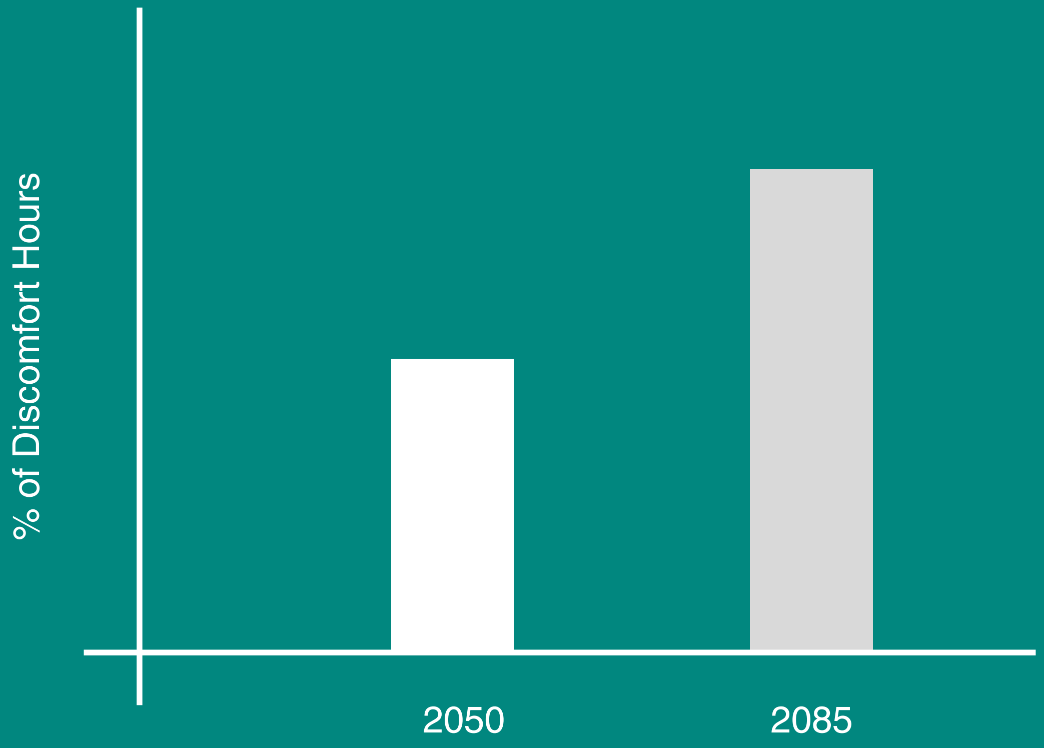
The worst case scenario (Wh) of climate change for 2050 and 2085

Assessment of Robust Design



Parameters for Evaluation ***Building Performance Simulations*** ***Robustness Evaluation Method***

Design Options

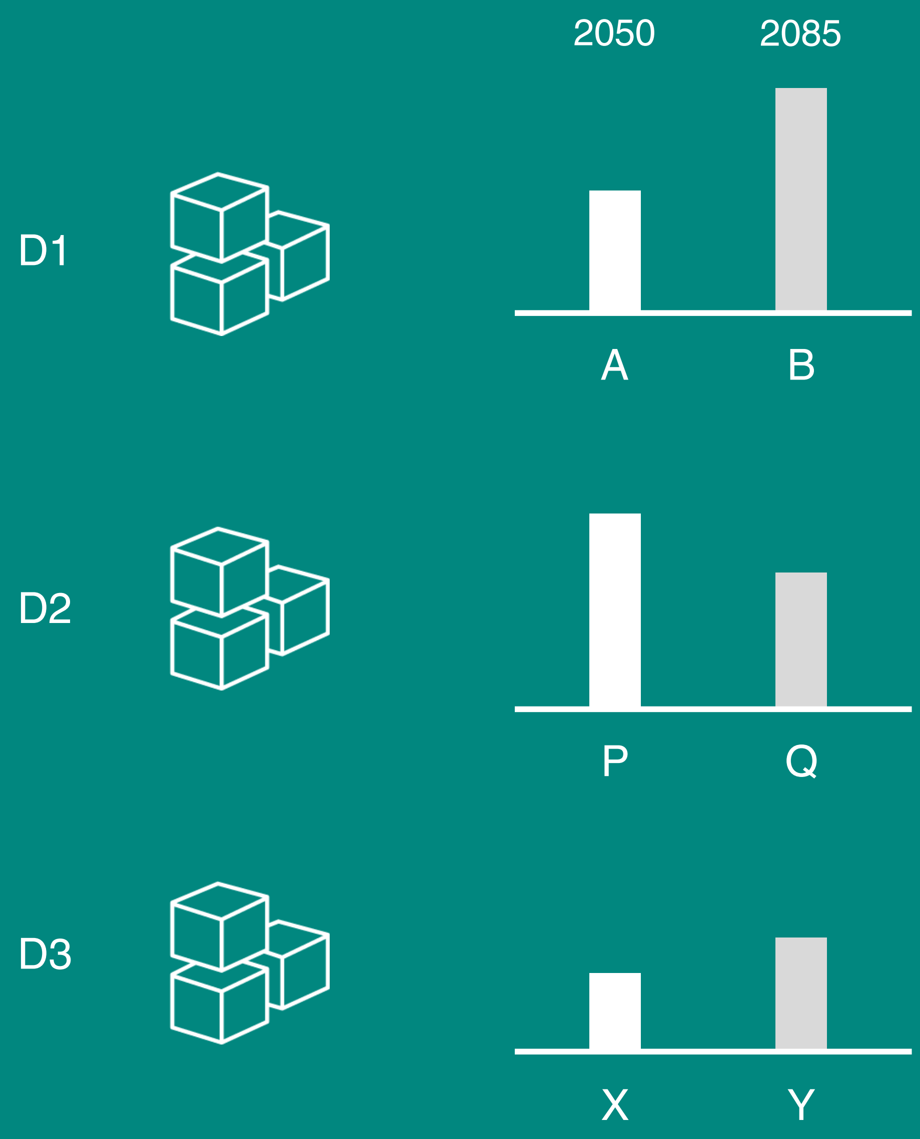


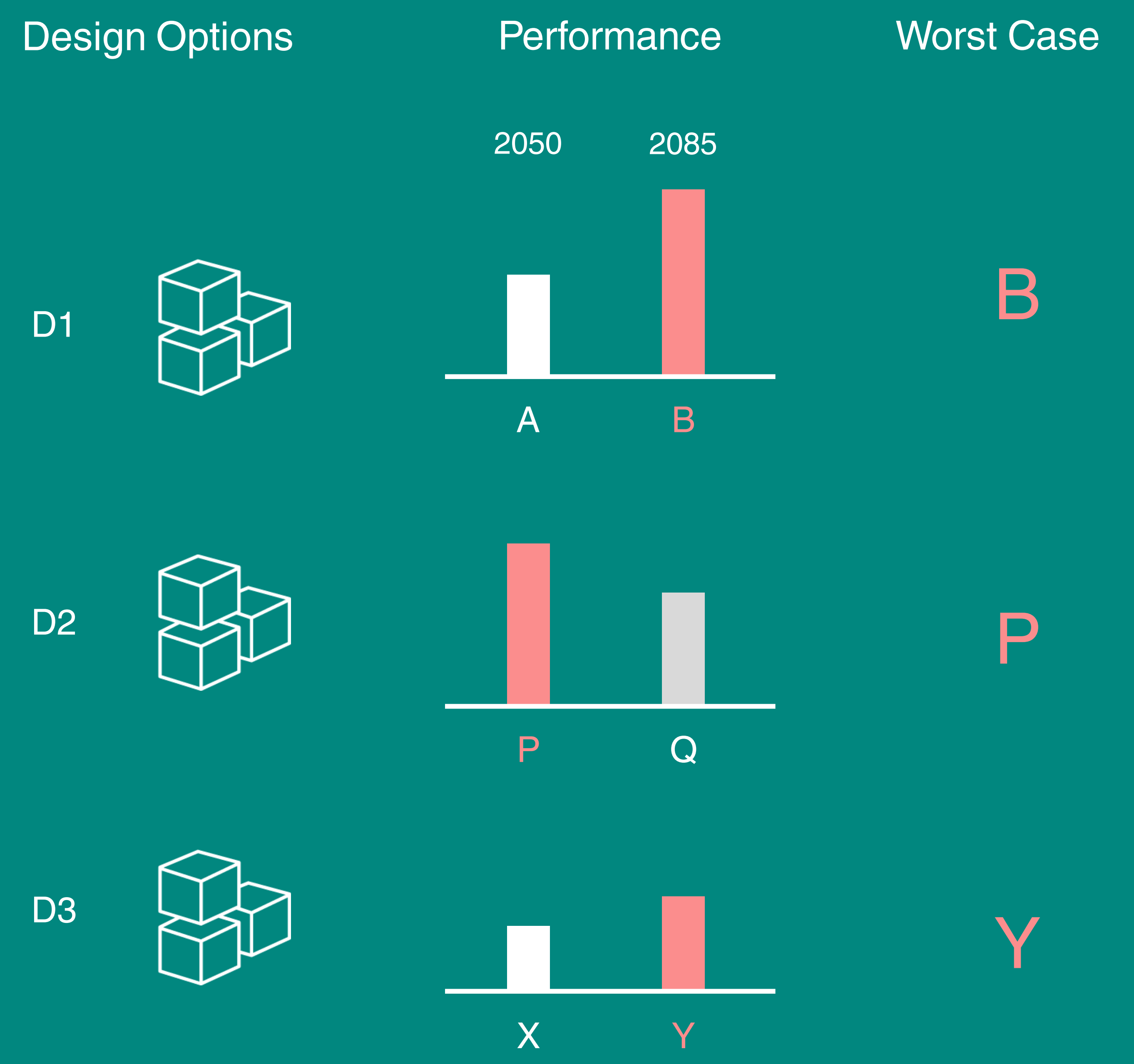
Performance

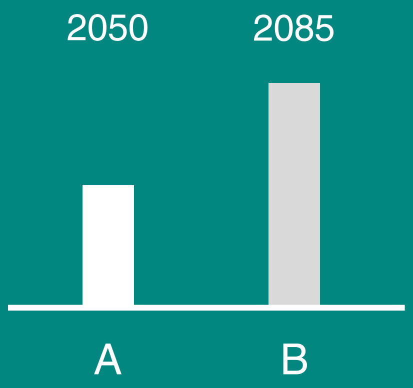
Design Options

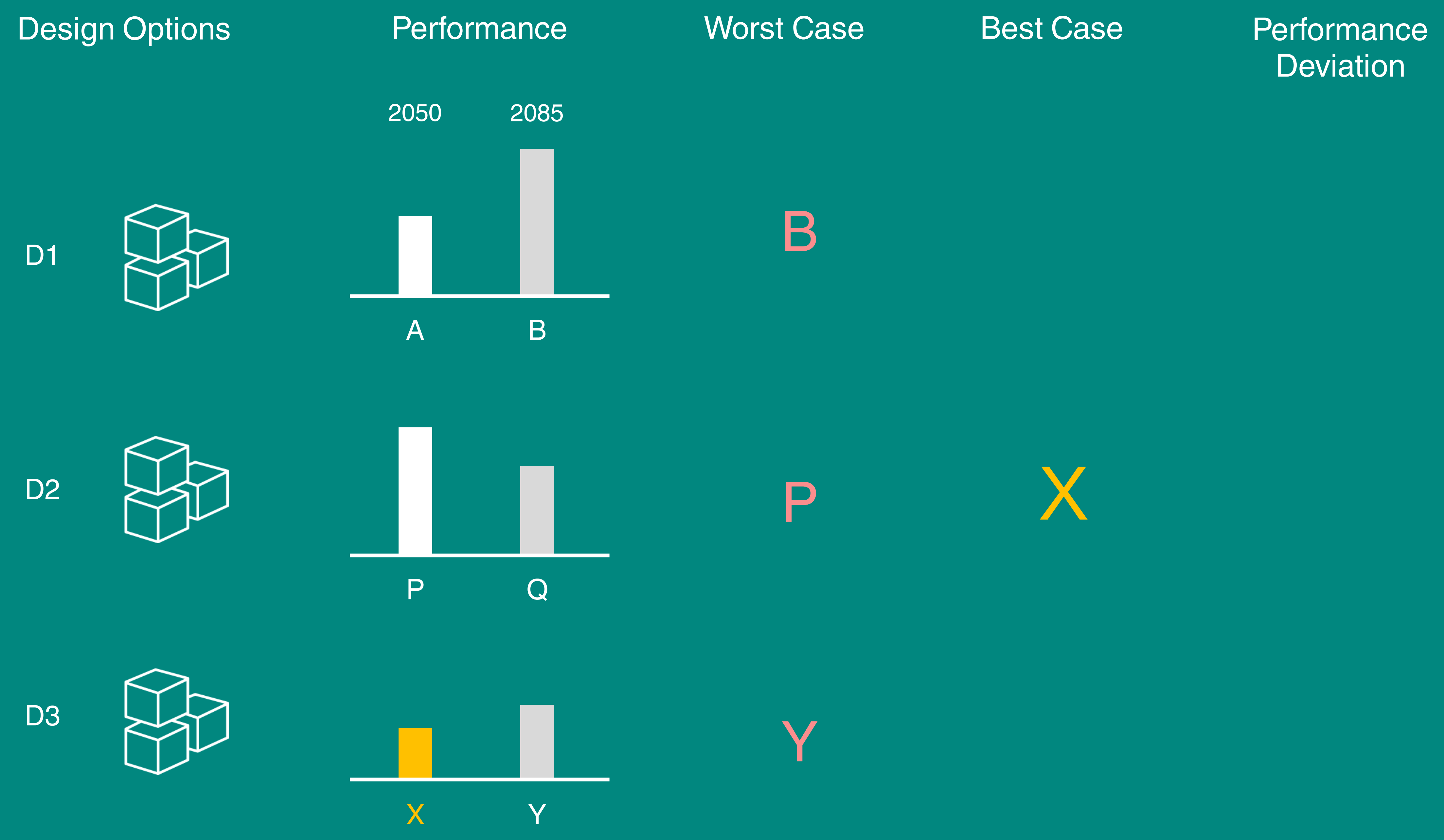
Performance

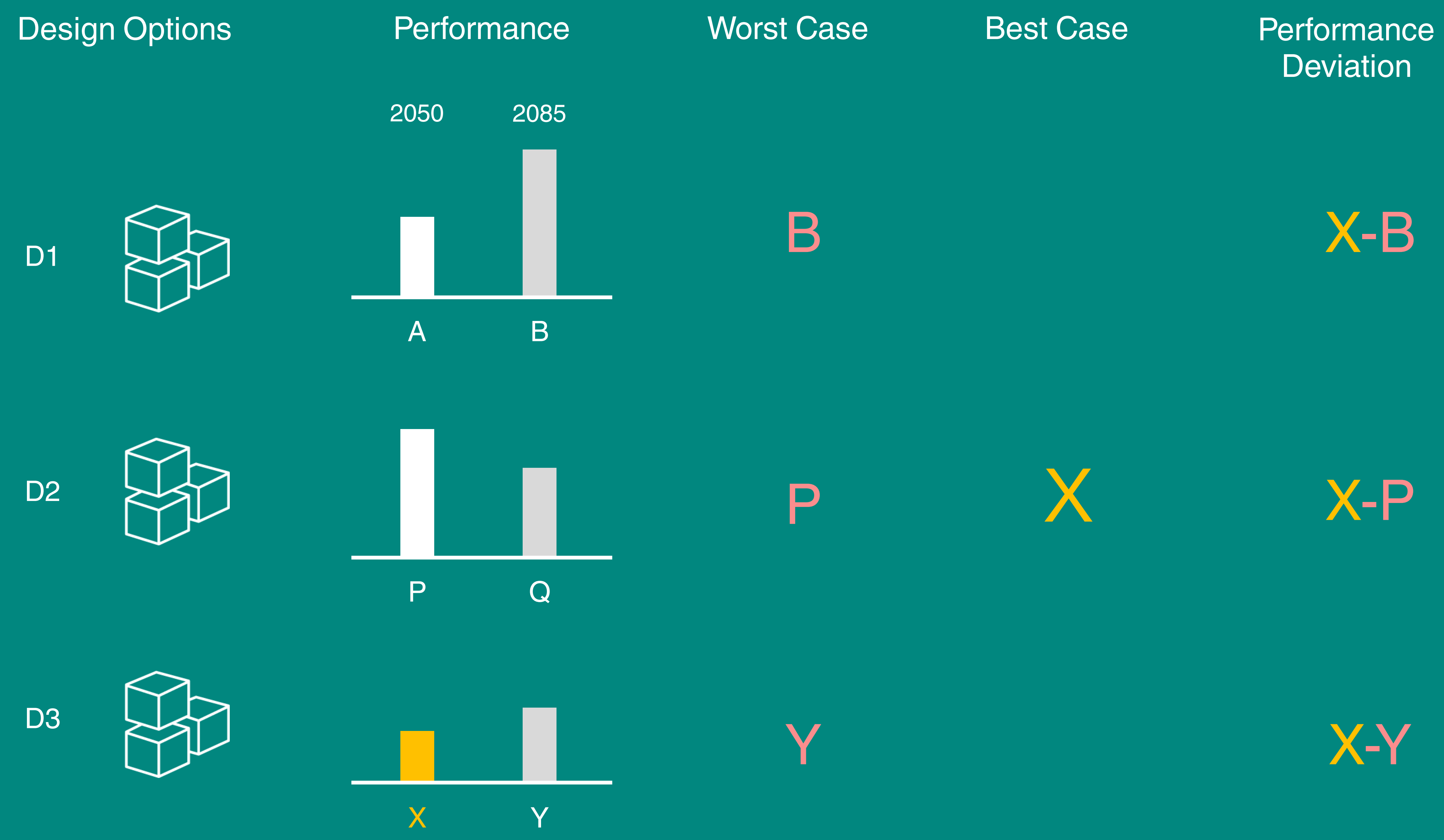
Worst Case




Design Options
Performance
Worst Case
2050
2085
D1
A
B
B
D2
P
Q
P
D3
X
Y
Y

Design Options		Performance	Worst Case	Best Case
D1			B	
D2			P	
D3			Y	


Design Options
Performance
Worst Case
Best Case
Performance Deviation
2050
2085
D1
A
B
B
D2
P
Q
P
X
D3
X
Y
Y


Design Options
Performance
Worst Case
Best Case
Performance Deviation
2050
2085
D1
A
B
B
X-B
D2
P
Q
P
X
X-P
D3
X
Y
Y
X-Y


Design Options
Performance
Worst Case
Best Case
Performance Deviation
2050
2085
D1
A
B
B
X-B
D2
P
Q
P
X
X-P
D3
X
Y
Y
X-Y

Assessment Method

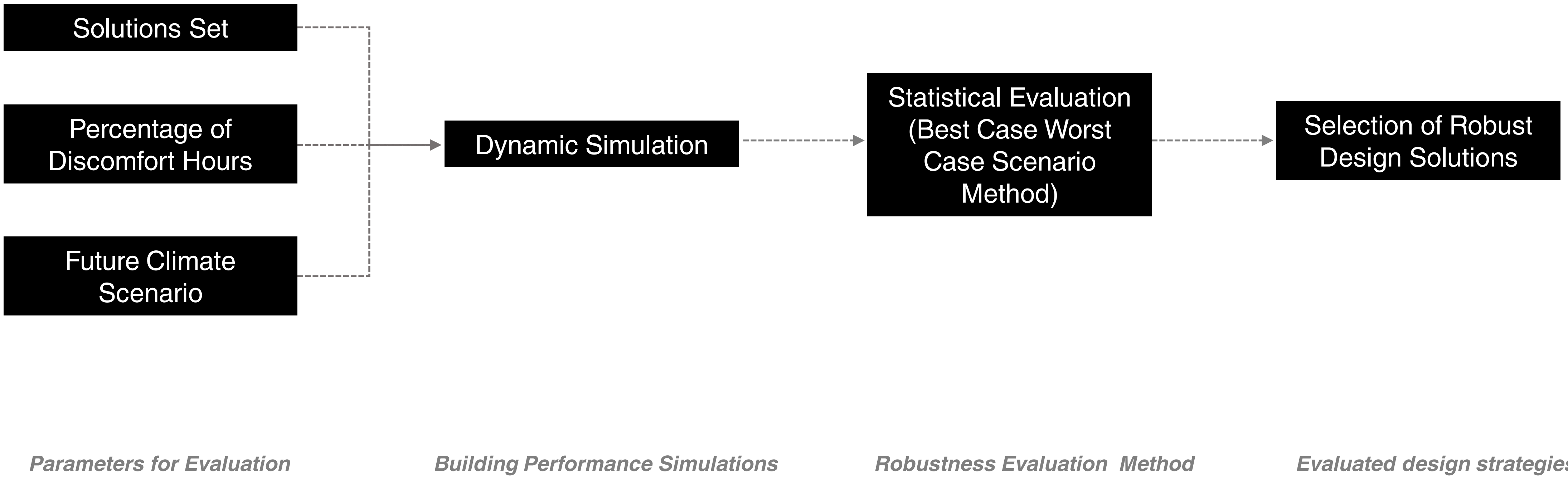
Best Case Worst Case Method

- Difference between the best performance of the entire design space and worst performance of design across considered scenarios.
- Robust Design is a design with minimum performance deviation

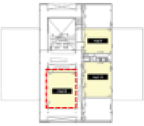
Best Case -Worst Case Method					
Design code	**Climate Scenario**		**Worst-Case Performance (WC)**	**Best-Case Performance (BC)**	**Performance Deviation (WC-BC)**
	2050	2085			
C1	$P1_{2050}$	$P1_{2085}$	$\max(P1_{2050},P1_{2085})$	$\min(P1_{2050},P1_{2085}, P2_{2050},P2_{2085},P3_{2050},P3_{2085},\ldots Pn_{2050},Pn_{2085})$	WC1 - BC1
C 2	$P2_{2050}$	$P2_{2085}$	$\max(P2_{2050},P2_{2085})$		WC2 - BC2
C 3	$P3_{2050}$	$P3_{2085}$	$\max(P3_{2050},P3_{2085})$		WC3 - BC3
...	...	...	...		....
C n	Pn_{2050}	Pn_{2085}	$\max(Pn_{2050},Pn_{2085})$		WCn - BCn
				Robust Design	**min(WC-BC)**

Adapted from the works of
Rajesh Kotireddy et al., 2017a, 2017b, 2018, 2019

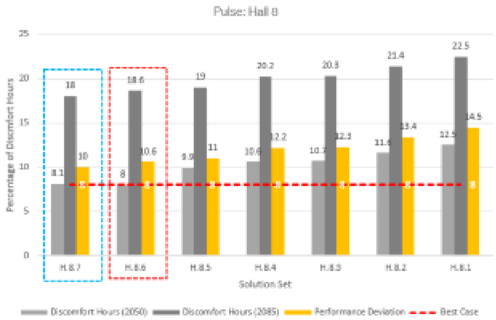
Assessment of Robust Design



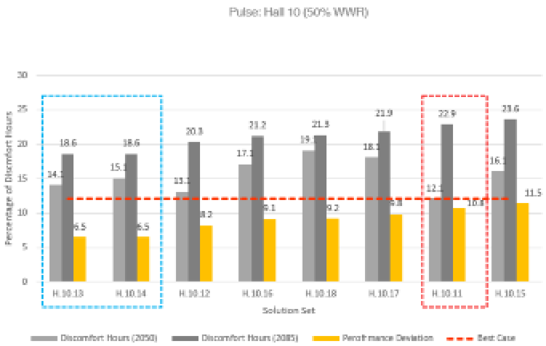
Adapted from the works of
Attia, 2018b; Hamdy et al., 2017
Rajesh Kotireddy et al., 2017a, 2017b, 2018, 2019

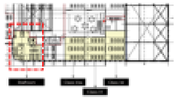


Code	Solution Set	Remarks
H8.1	Reduce U-Value of partition Walls	U-value to 1.66 W/m2K
H8.2.	Reduce U-Value of partition Walls	U-Value to 1 W/m2K
H8. 3.	Reduced U-Value + White Surfaced Roof	WWR 70% from 100%
H8. 4.	Reduced U-Value + White Surfaced Roof+ WWR 70%	R-Value of opaque parts increased 3 m2K/W
H8. 5.	Reduced U-Value + White Surfaced Roof+ WWR 70%	G-value of transparent parts to .4
H8. 6.	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode	Opening skylight windows
H8. 7	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode + PCM Panels	PCM modelled as 80 mm concrete

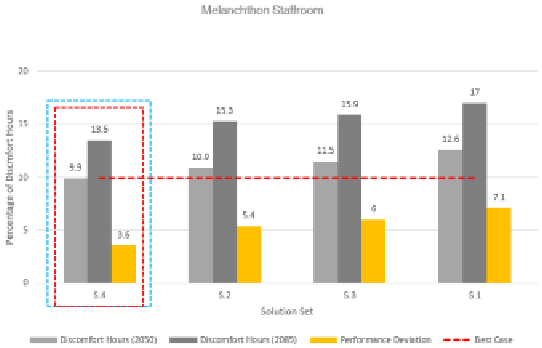


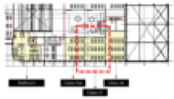
Code	Solution Set	Remarks
H10.11	WWR 50% + White Surfaced roof and Facade	
H10.12	WWR 50% + White Surfaced roof and Façade + External Roller Blinds	
H10.13	WWR 50% + White Surfaced roof and Facade+ 0.5 m overhang and 0.36 m sidefins.	
H10.14	WWR 50% + White Surfaced roof and Facade+ shutters	
H10.15	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels	Existing two windows openings with 40% operable area operating through out the day PCM modelled as 80 mm concrete
H10.16	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	
H10.17	WWR 50% + White Surfaced roof and Facade+ mixed mode +PCM Panels+0.5 m overhang and 0.36 m sidefins.	
H10.18	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+ shutters	



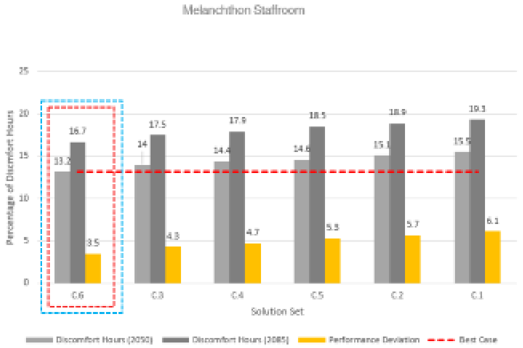


Code	Solution Set	Remarks
S.1	White Surfaced roof and Facade	
S.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
S.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
S.4	White Surfaced roof and Facade+2 m width pergola +PCM Panels	extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete

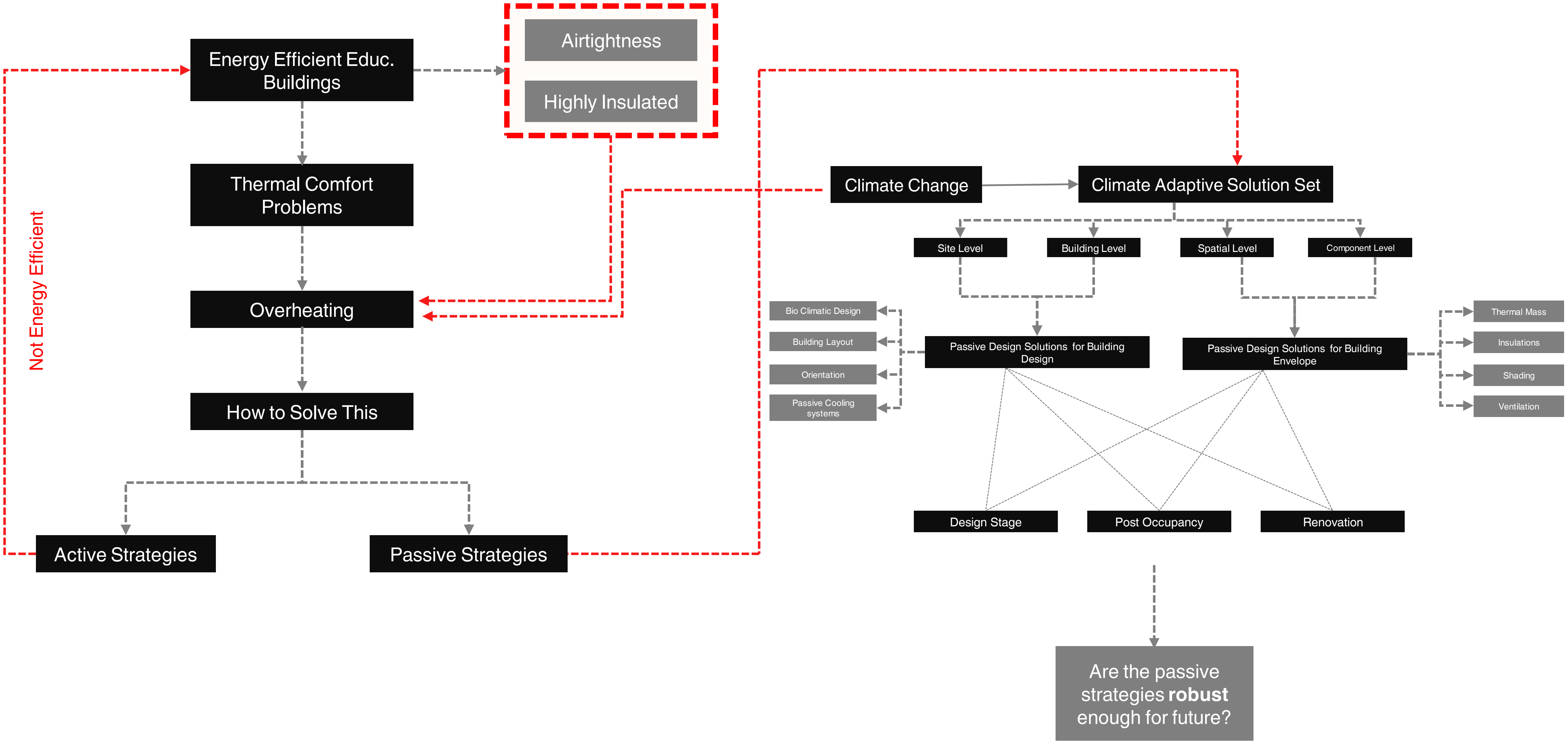




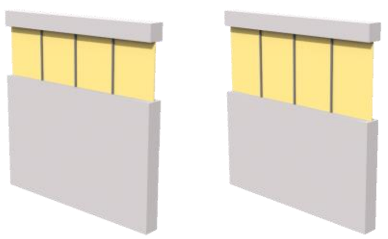
Code	Solution Set	Remarks
C.1	White Surfaced roof and Facade	
C.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
C.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
C.4	White Surfaced roof and Facade +PCM Panels+ WWR 50%	PCM modelled as 80 mm concrete
C.5	White Surfaced roof and Facade +PCM Panels + combination of openings	BMS controlled Ventilator at top with manual opening windows at the bottom PCM modelled as 80 mm concrete
C.6	White Surfaced roof and Facade +PCM Panels+ combination of openings+ 2 m width pergola	BMS controlled Ventilator at top with manual opening windows at the bottom extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete



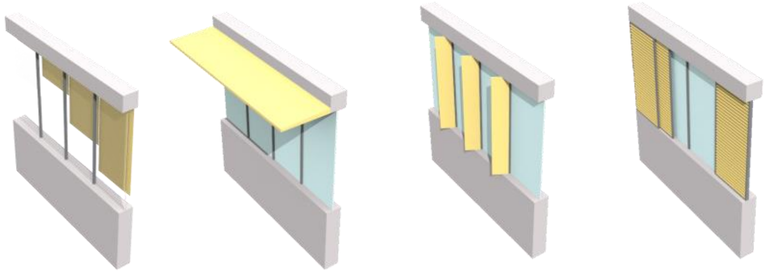
Recap


Energy Efficient Educ. Buildings
Airtightness
Highly Insulated
Thermal Comfort Problems
Overheating
How to Solve This
Not Energy Efficient
Active Strategies
Passive Strategies
Climate Change
Climate Adaptive Solution Set
Site Level
Building Level
Spatial Level
Component Level
Bio Climatic Design
Building Layout
Orientation
Passive Cooling systems
Passive Design Solutions for Building Design
Passive Design Solutions for Building Envelope
Thermal Mass
Insulations
Shading
Ventilation
Design Stage
Post Occupancy
Renovation
Are the passive strategies **robust** enough for future?

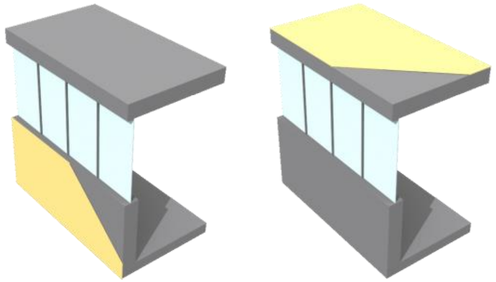
What are the **adaptive strategies** in a temperate climate, applicable to **building envelope** facilitating **robustness** of **energy efficient educational buildings** by reducing the risk of **overheating** in **future climate change scenario**?



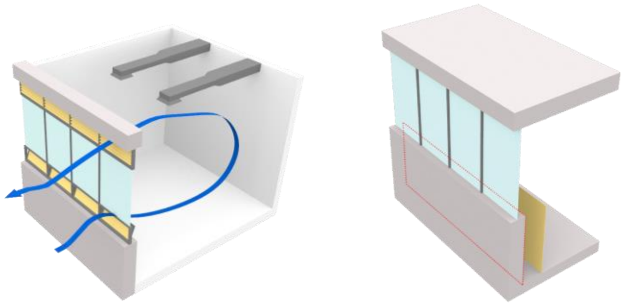
Reducing WWR



Shading Strategies

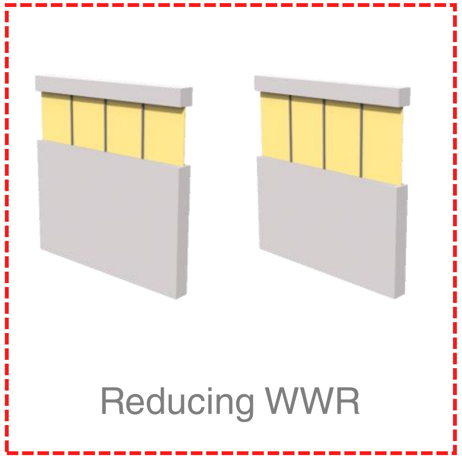


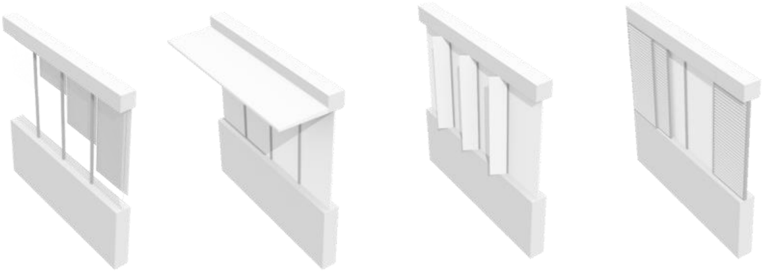
White Surfaces

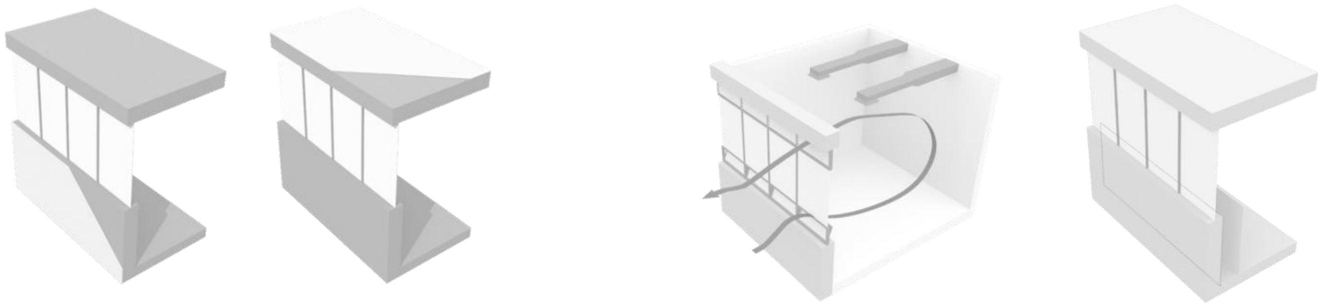


Mixed Mode + PCM Panels

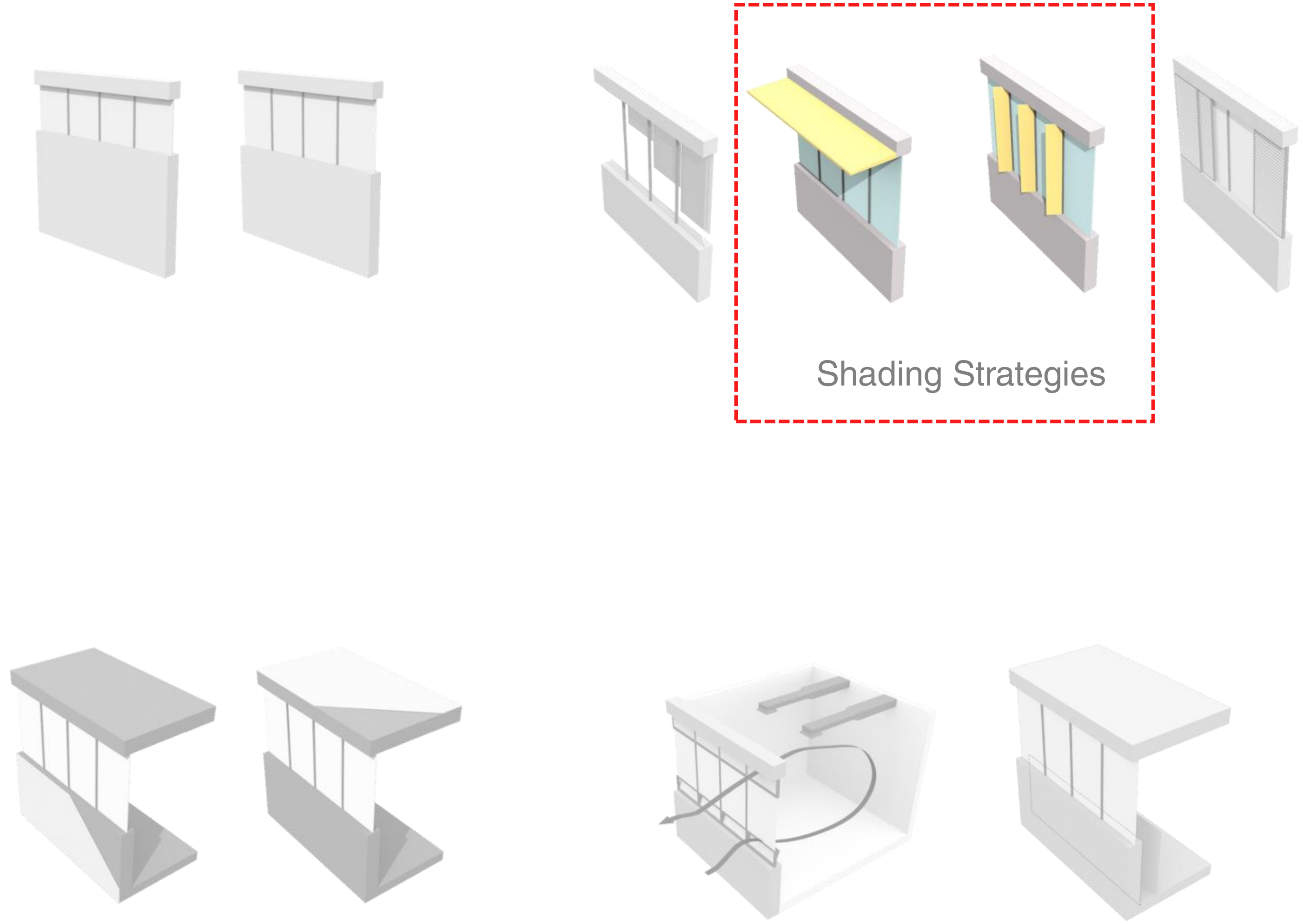
Robust Design solutions applicable on the Building envelope.



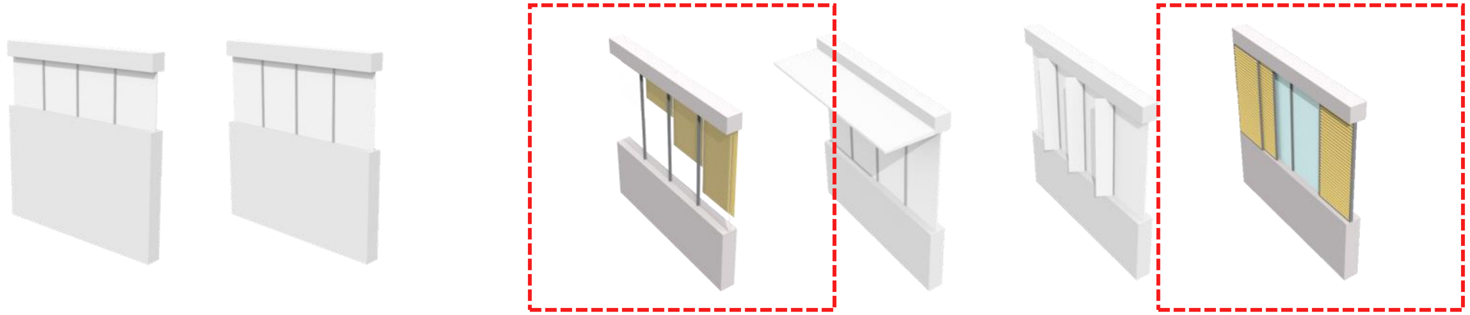




Reducing WWR can affect the daylight quality

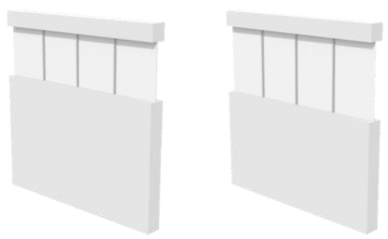


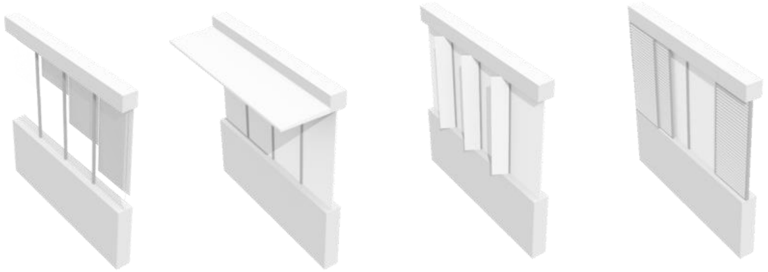
Combination of overhangs and side fins perform better as compared to individual application

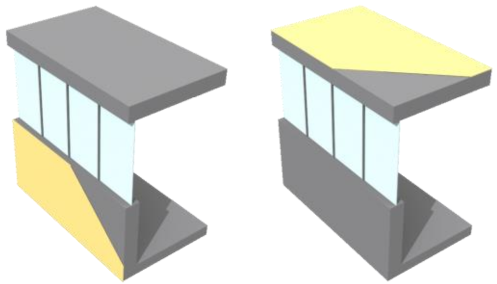


Shading Strategies

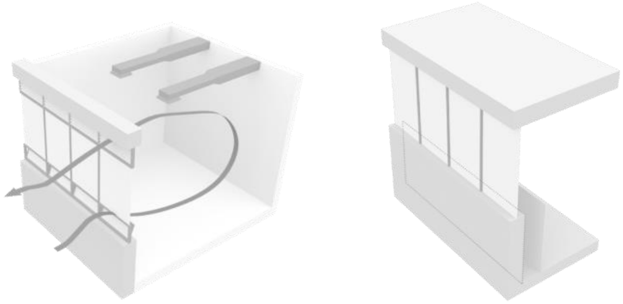
Moveable Shading devices perform slightly better as compared to fixed shading.



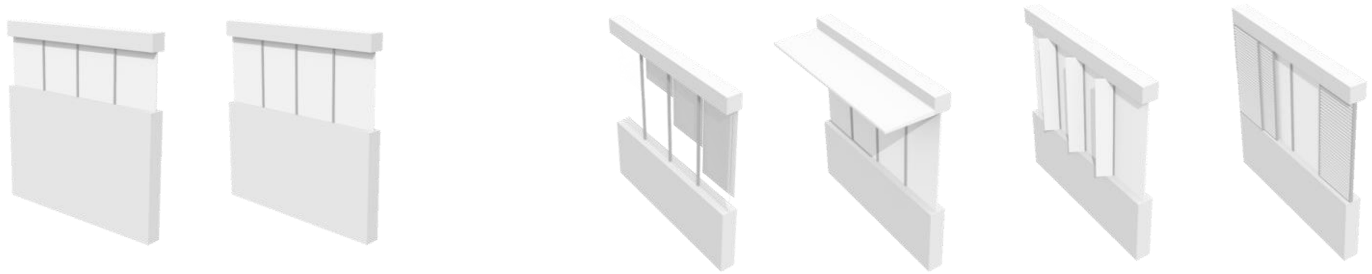


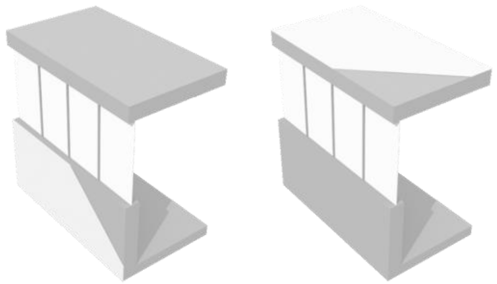


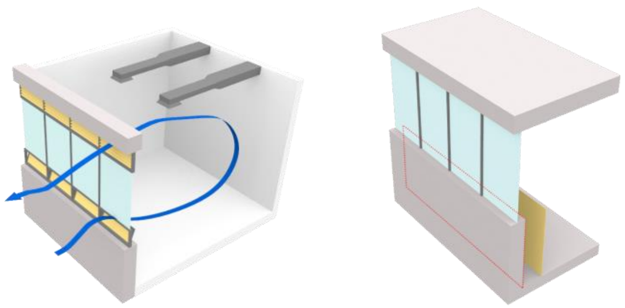
White Surfaces



Application of white surfaces perform better when combined with lower WWR.





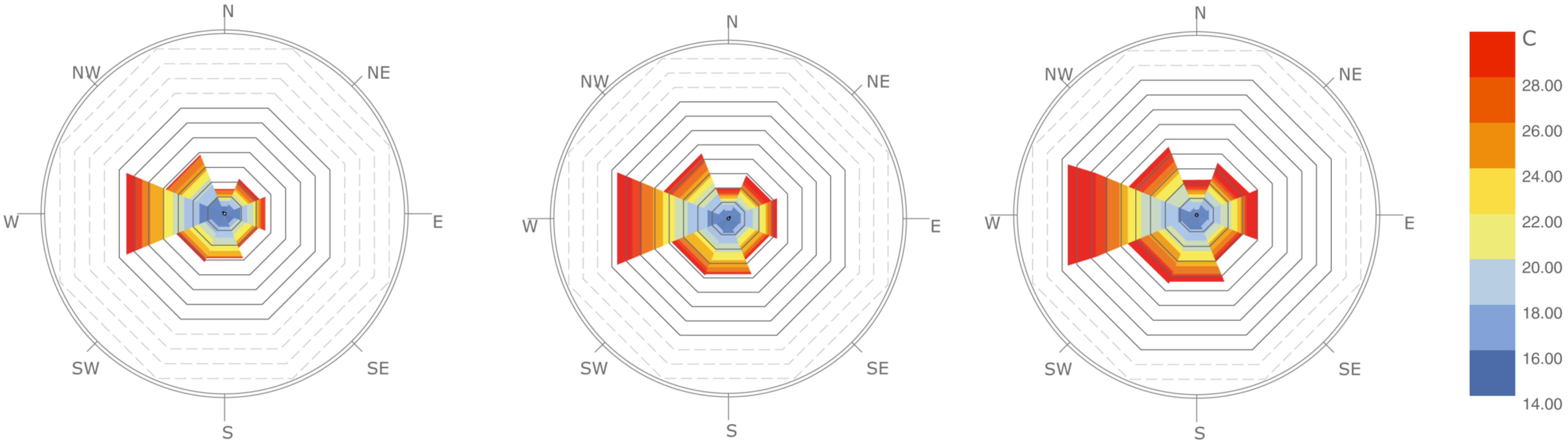


Mixed Mode + PCM Panels

Mixed Mode Ventilation Strategy with PCM panels installed towards the inside of the external wall.

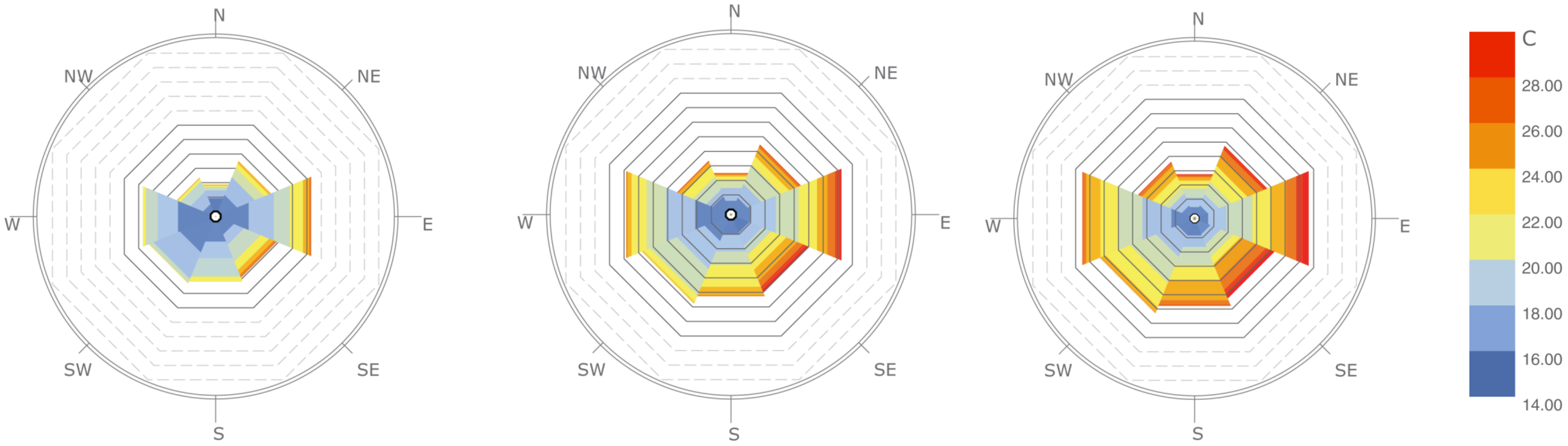
In ***2085***, *the* ***outdoor air temperature*** *is too* ***high*** *to be used for* ***ventilative cooling***

Ladybug Wind Rose Analysis
Period : May-September
Daytime : 9:00 – 17:00
One octagonal polyline : 33 hours

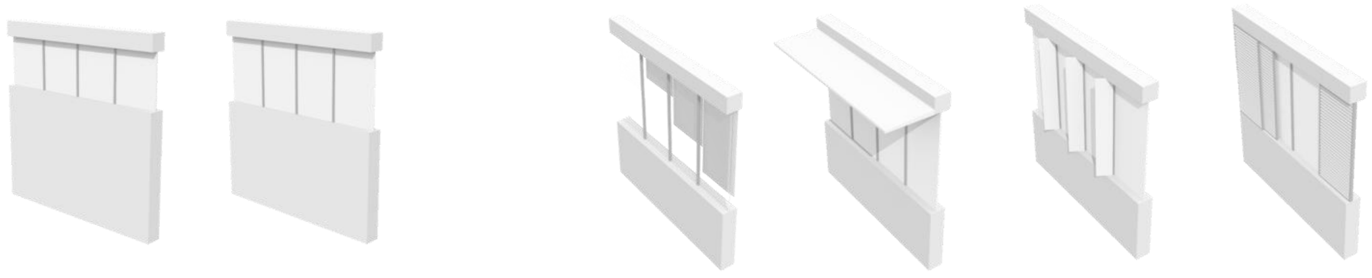


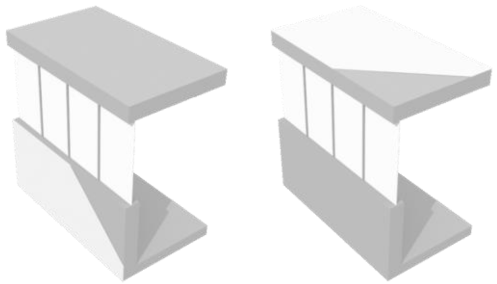
Baseline *2050* *2085*

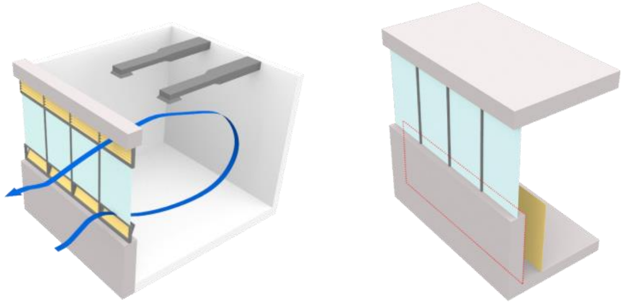
Ladybug Wind Rose Analysis
Period : May-September
Night-time : 22:00 – 6:00
One octagonal polyline : 33 hours



Baseline *2050* *2085*



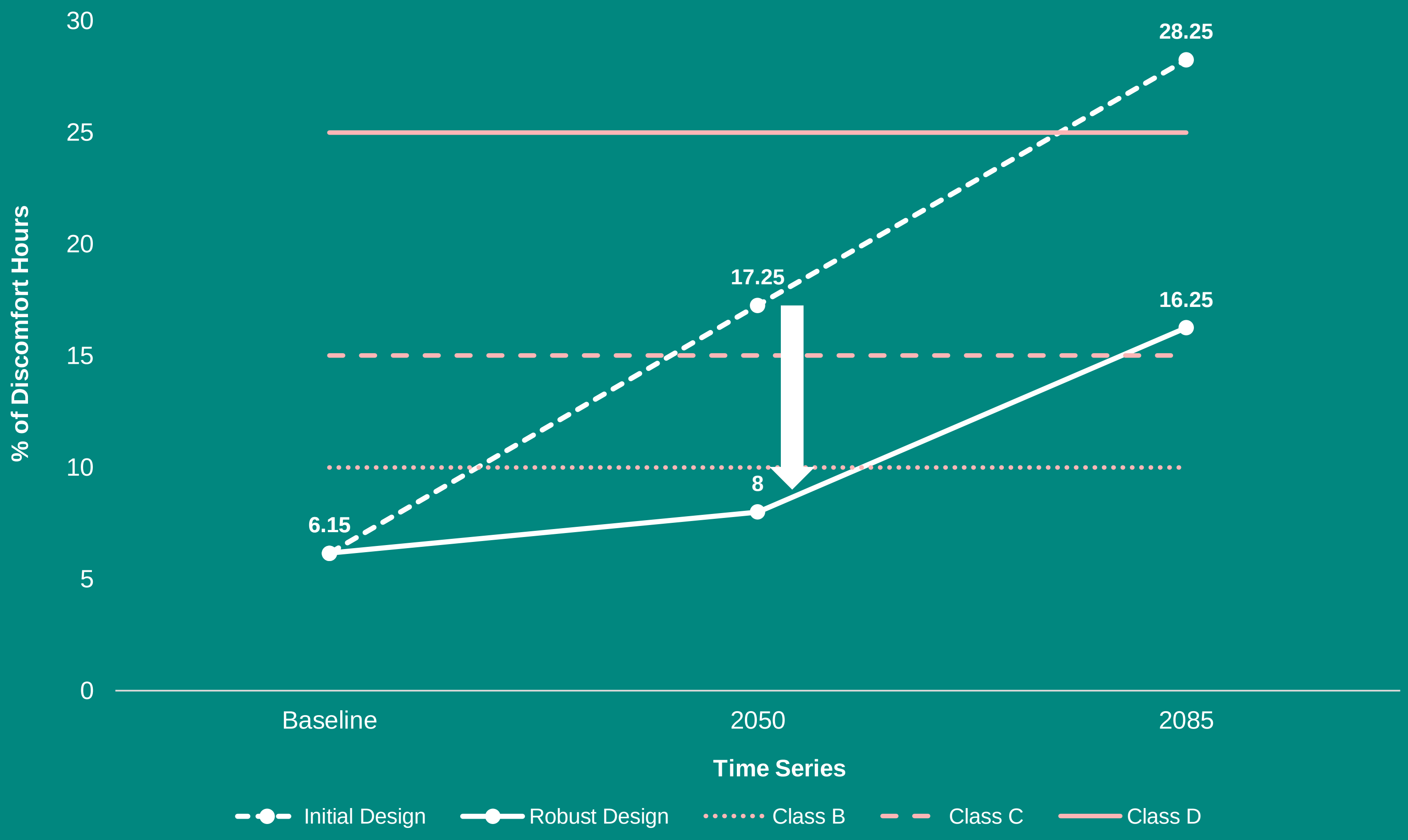




Mixed Mode + PCM Panels

Ventilation has limited application in 2085

Pulse Building



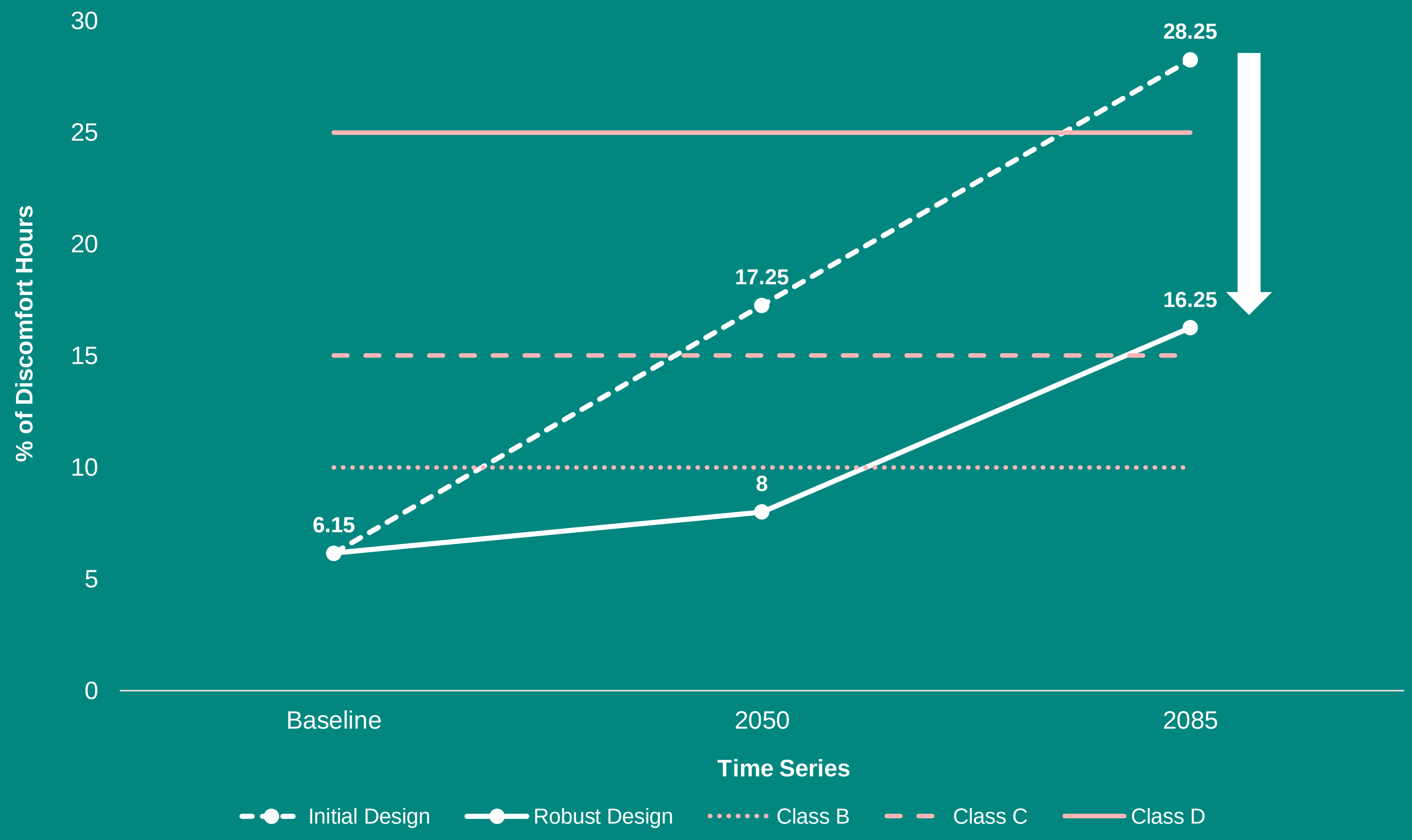
54%

reduction of

discomfort hours in

2050

Pulse Building



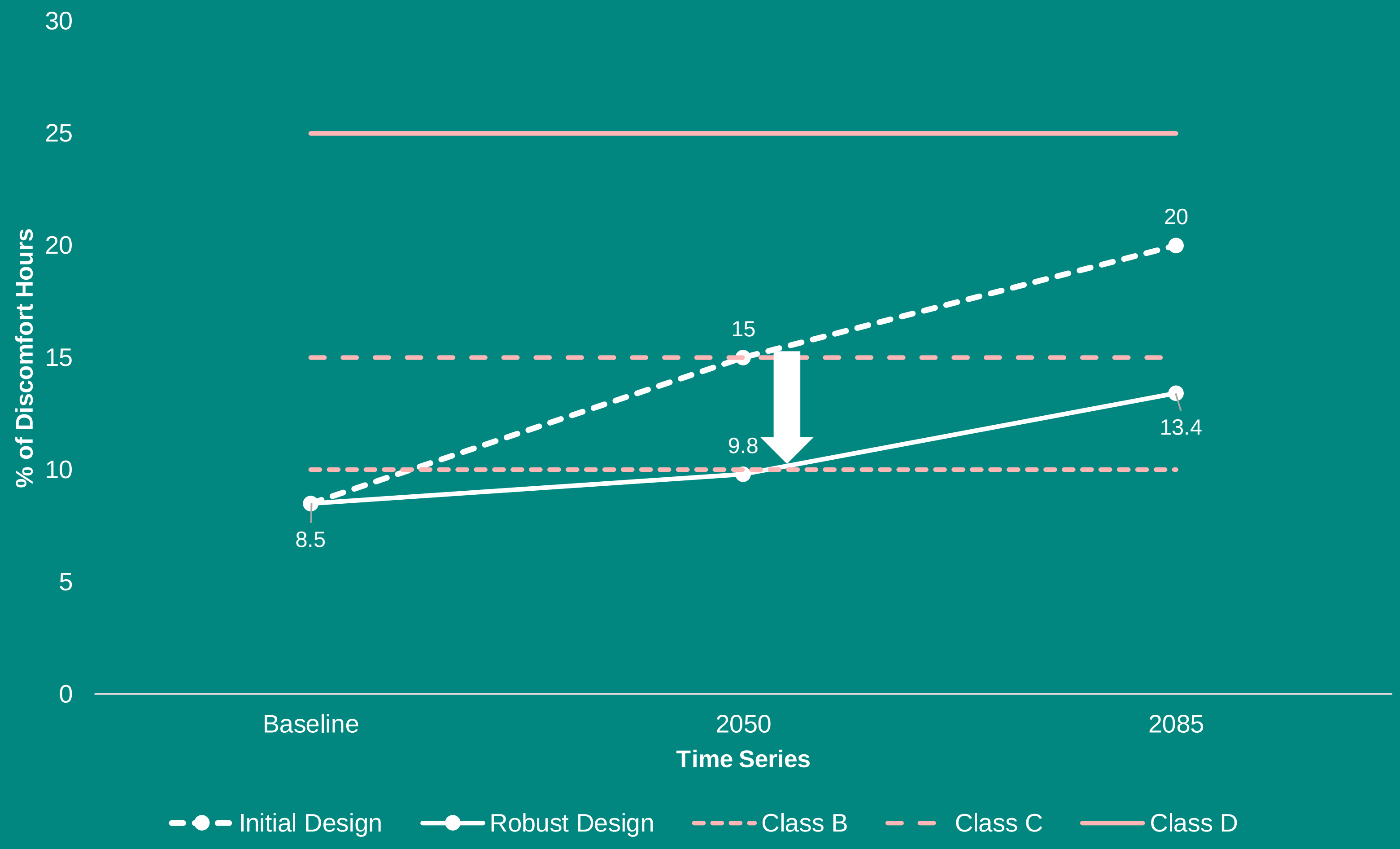
43%

reduction of

discomfort hours in

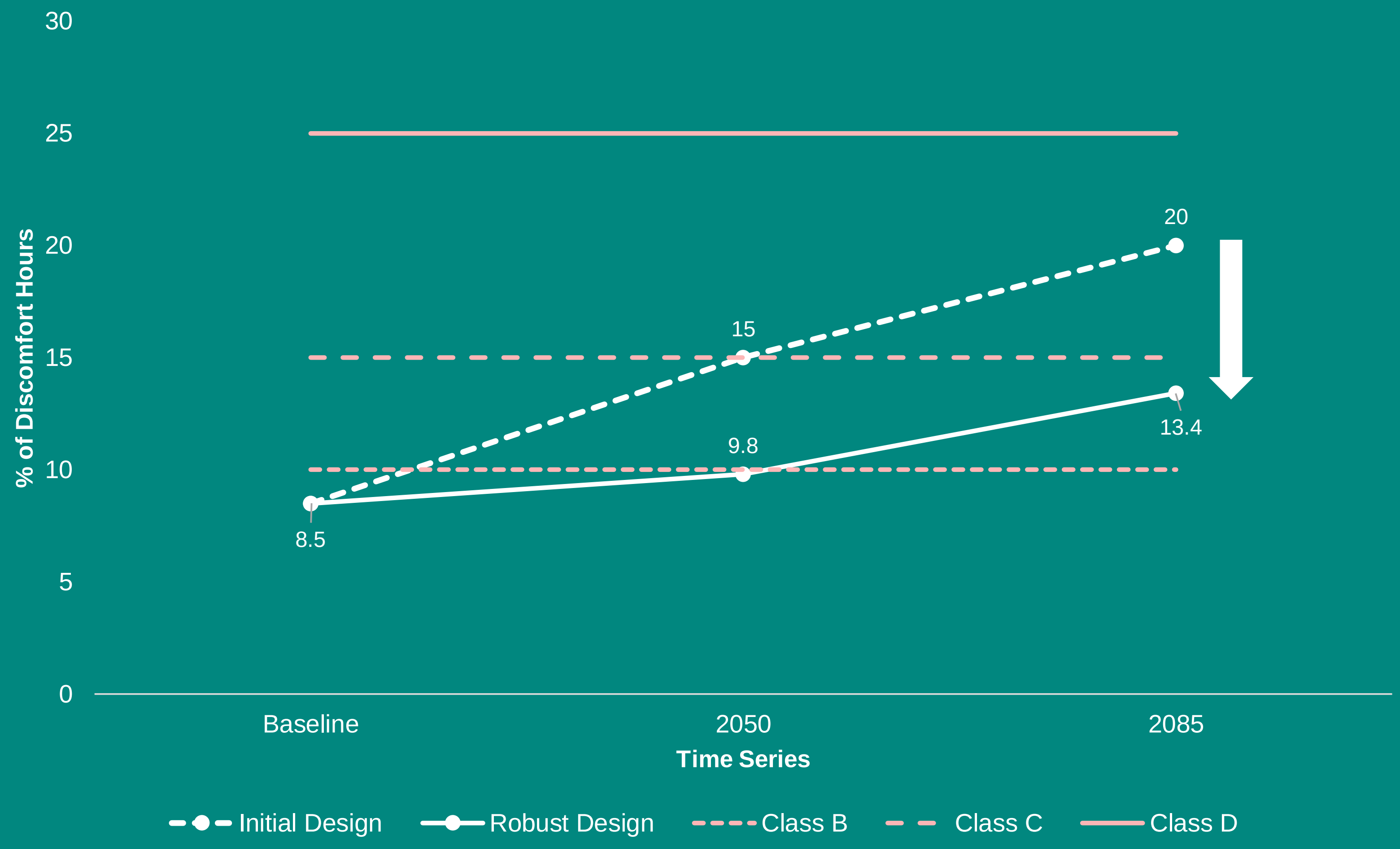
2085

Melanchthon School



35% reduction of discomfort hours in **2050**

Melanchthon School



33%

reduction of

discomfort hours in

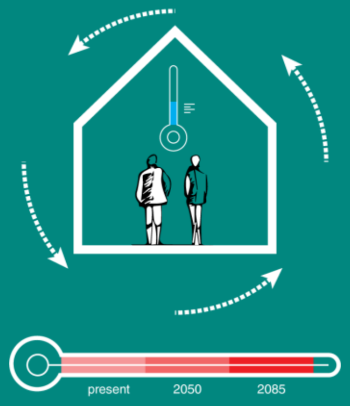
2085

Robustness of a design is a viable method to include the uncertainties of climate change.

Uncertainties of
Climate Change

Early Design
Stage

Robustness
Evaluation



Comfort in building
lifespan

How do we **integrate robustness evaluation** into the **design process**?

Designer’s Tool

Simple

Min. Inputs

Simple GUI

Design Oriented

Iterative

Analysis

D.O.T.T.

Design Oriented Transformative Tool

Project Details

Spatial Details

Dimensional Properties

Glazing Properties

Thermal Insulation

Shading Properties

Ventilation Properties

Internal Loads

8 Sections

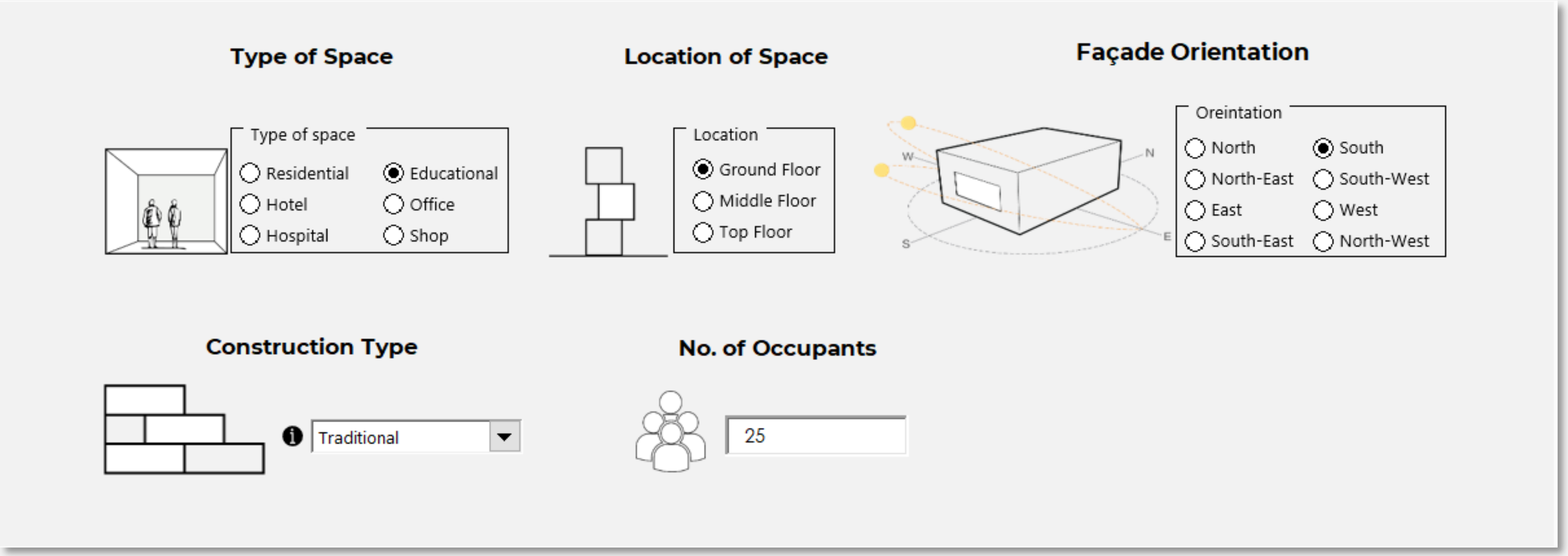
for input parameter

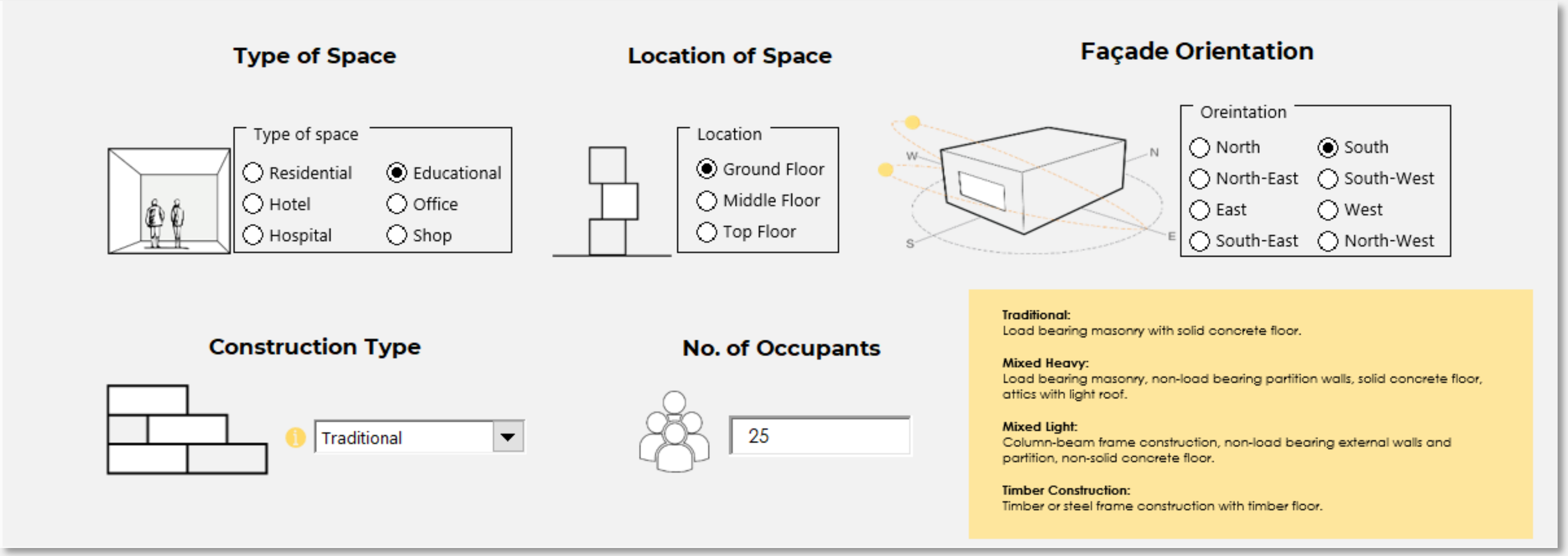
Project Details

Project Name	Melanchthon School, Rotterdam	**Date**	23/06/2020
Room Details	Class 32	**Design Option**	DO1

Project Details

Spatial Details



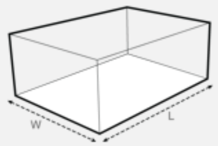


Project Details

Spatial Details

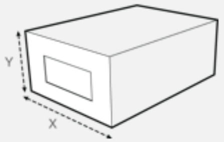
Dimensional Properties

Floor / Wall / Roof Area

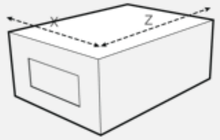


Floor Area [m^2] 53.2

Perimeter [m] 29.2



Wall Area [m^2] 28.5



Roof Area [m^2] 53.2

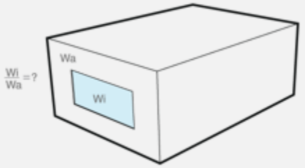
Project Details

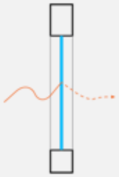
Spatial Details

Dimensional Properties

Glazing Properties

Glazing Properties



Windor-Wall Ratio [-]		Type of Glass	U-Value [W/m²K]	g-Value (ZTA) [-]
0.5		TGU Low E	0.5	0.4

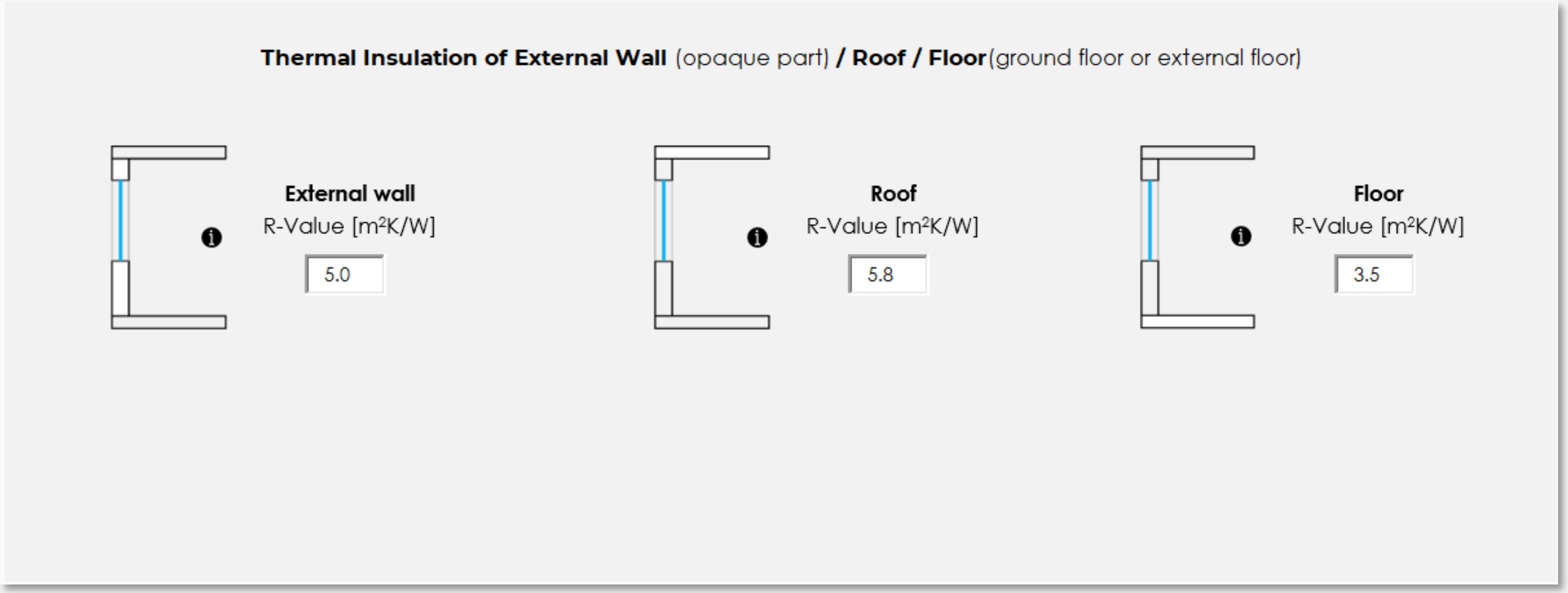
Project Details

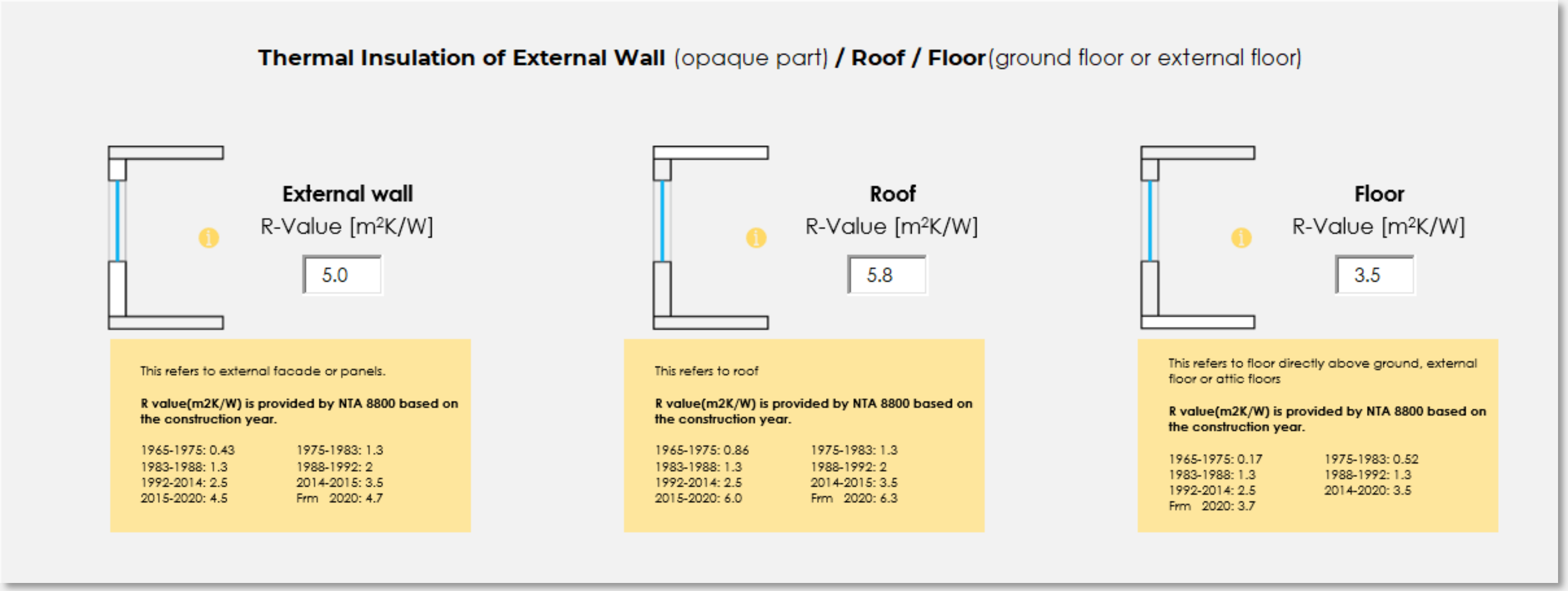
Spatial Details

Dimensional Properties

Glazing Properties

Thermal Insulation





Project Details

Spatial Details

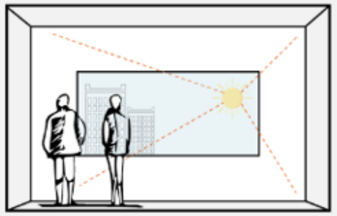
Dimensional Properties

Glazing Properties

Thermal Insulation

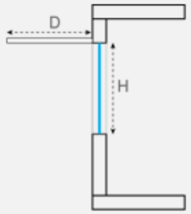
Shading Properties

% of sky blocked by nearby context



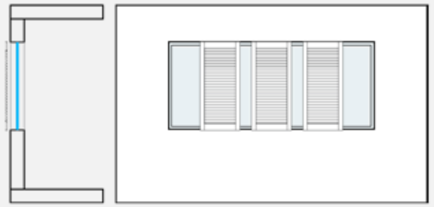
Heavy (>80%)

Overhangs



D/H=0.6

Curtains/Blinds/Shutters



Dark Coloured External Shutter (Openable Windows)

Project Details

Spatial Details

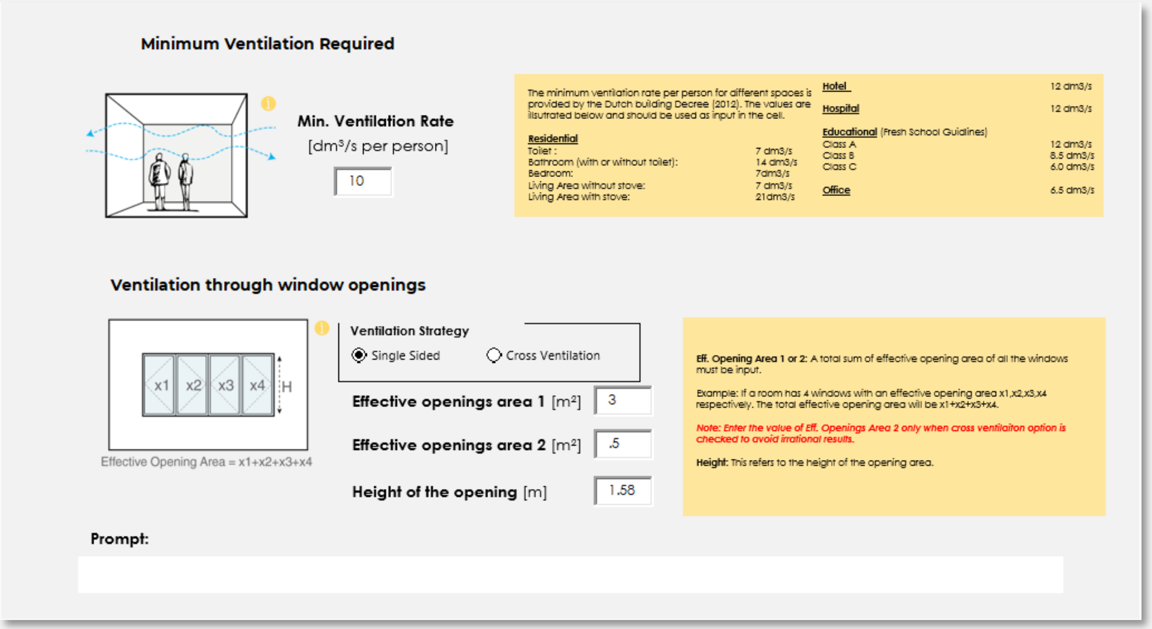
Dimensional Properties

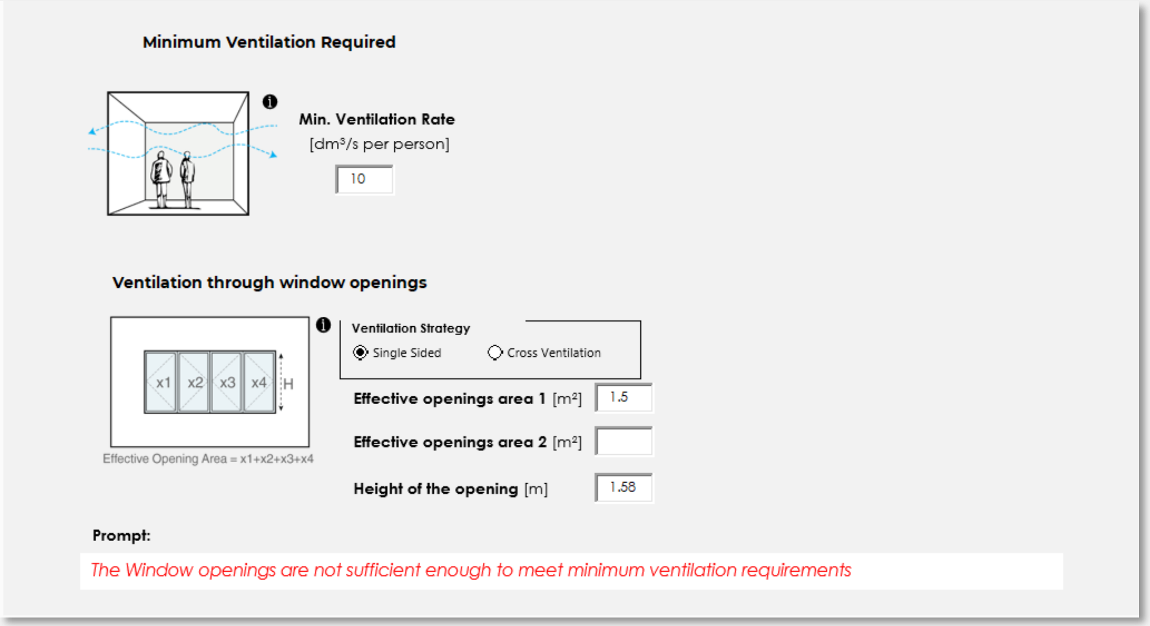
Glazing Properties

Thermal Insulation

Shading Properties

Ventilation Properties





Project Details

Spatial Details

Dimensional Properties

Glazing Properties

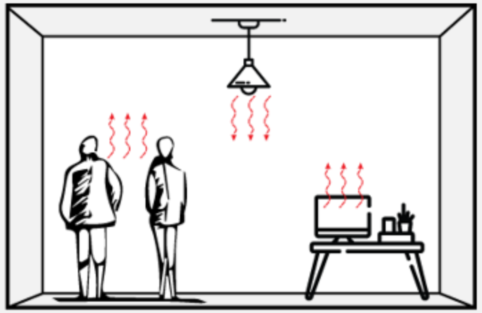
Thermal Insulation

Shading Properties

Ventilation Properties

Internal Loads

Heat generated through occupants, equipment and lighting



Occupant Load

10 [W/m²]

Equipment Load

10 [W/m²]

Lighting Load

10 [W/m²]

Internal heating load generated by occupants per m2 as indicated in NTA 8800 is illsutrated below. These Values can be used as guidance to input the values.

Residential/Hotel: 3 W/m2
Healthcare: 5 W/m2
Education: 10 W/m2
Office: 5 W/m2
Shops: 3 W/m2

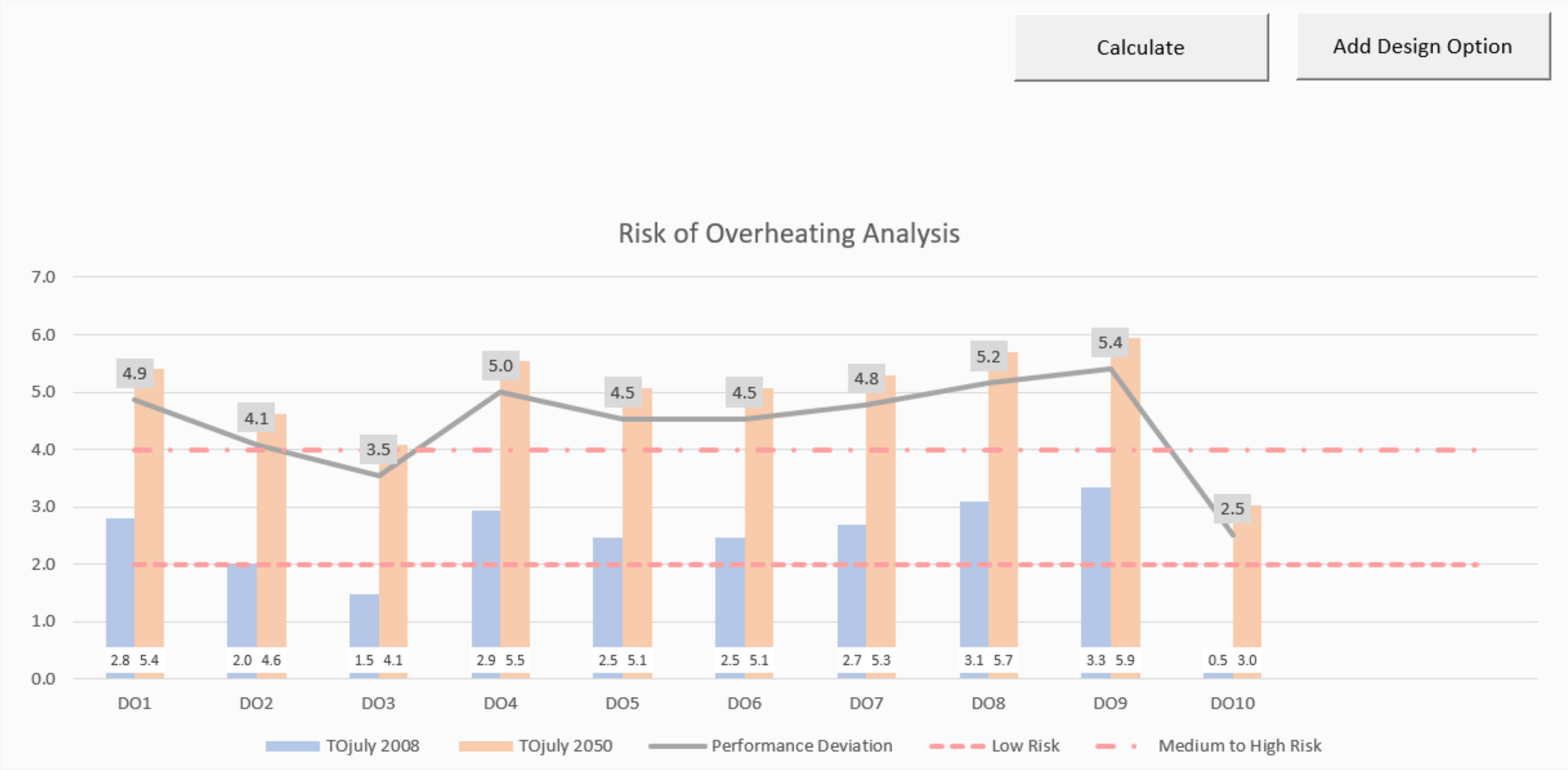
Internal heating load generated by equipments per m2 as indicated in NTA 8800 is illsutrated below. These Values can be used as guidance to input the values.

Residential/Hotel: 2 W/m2
Healthcare: 4 W/m2
Education: 2 W/m2
Office: 4 W/m2
Shops: 3 W/m2

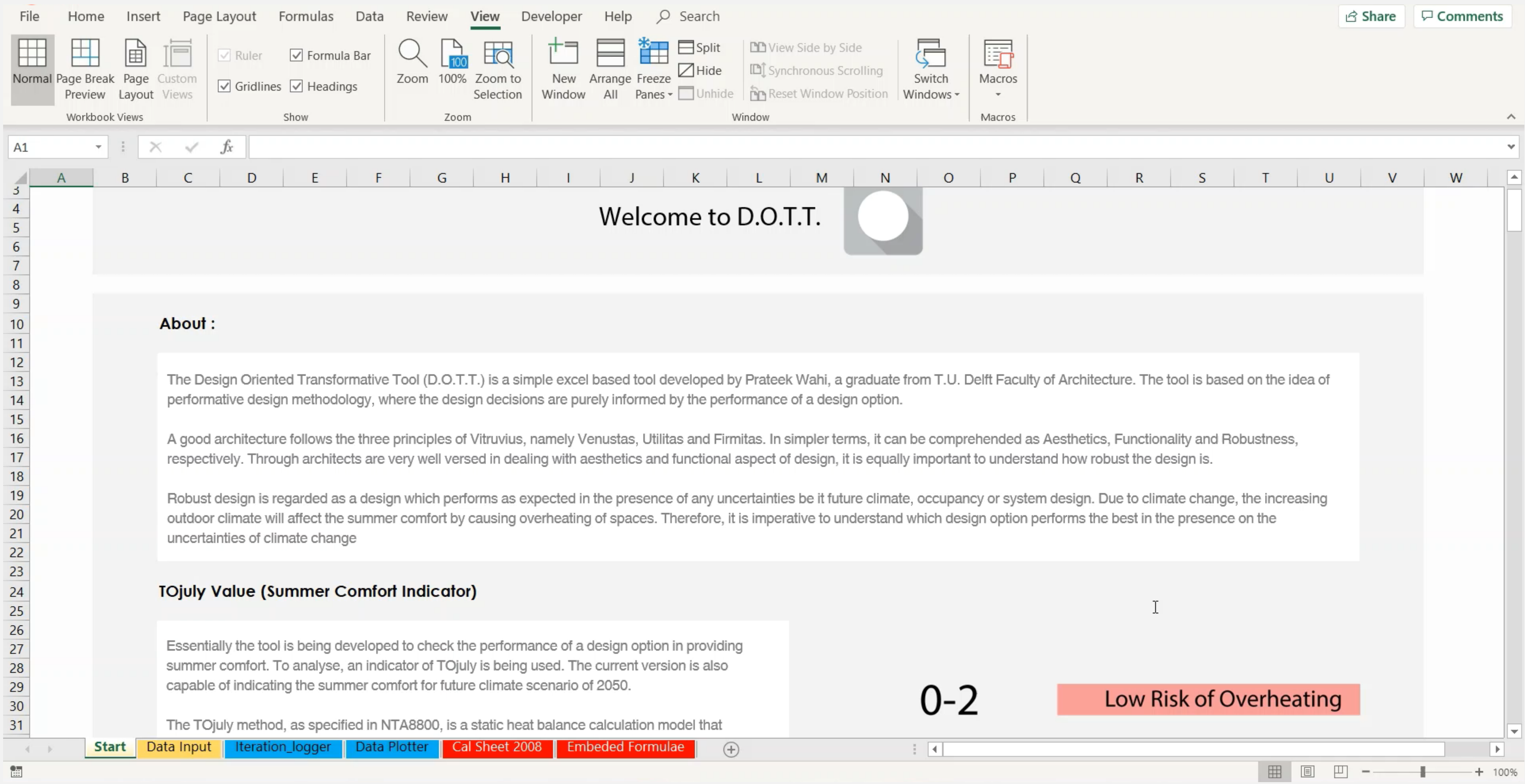
Internal heating load generated by lighting per m2 as indicated in NTA 8800 is illsutrated below. These Values can be used as guidance to input the values.

Residential: 5 W/m2
Education: 10 W/m2
Office: 8-15 W/m2

Analysis



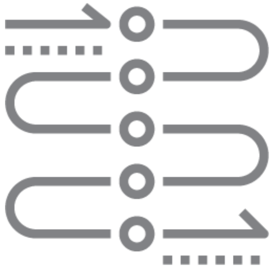
- Design option **DO10** has **lowest TOjuly** values in both climate
- **DO10** has the **least performance deviation** among all the design options.
- Therefore, design option **DO10 is the most robust.**


File Home Insert Page Layout Formulas Data Review View Developer Help Search
Share
Comments
Normal
Page Break Preview
Page Layout
Custom Views
Workbook Views
Ruler
Formula Bar
Gridlines
Headings
Show
Zoom
100%
Zoom to Selection
New Window
Arrange All
Freeze Panes
Split
Hide
Unhide
View Side by Side
Synchronous Scrolling
Reset Window Position
Switch Windows
Window
Macros
A1
Welcome to D.O.T.T.
About :
The Design Oriented Transformative Tool (D.O.T.T.) is a simple excel based tool developed by Prateek Wahi, a graduate from T.U. Delft Faculty of Architecture. The tool is based on the idea of performative design methodology, where the design decisions are purely informed by the performance of a design option.
A good architecture follows the three principles of Vitruvius, namely Venustas, Utilitas and Firmitas. In simpler terms, it can be comprehended as Aesthetics, Functionality and Robustness, respectively. Through architects are very well versed in dealing with aesthetics and functional aspect of design, it is equally important to understand how robust the design is.
Robust design is regarded as a design which performs as expected in the presence of any uncertainties be it future climate, occupancy or system design. Due to climate change, the increasing outdoor climate will affect the summer comfort by causing overheating of spaces. Therefore, it is imperative to understand which design option performs the best in the presence on the uncertainties of climate change
TOjuly Value (Summer Comfort Indicator)
Essentially the tool is being developed to check the performance of a design option in providing summer comfort. To analyse, an indicator of TOjuly is being used. The current version is also capable of indicating the summer comfort for future climate scenario of 2050.
The TOjuly method, as specified in NTA8800, is a static heat balance calculation model that
0-2
Low Risk of Overheating
Start
Data Input
Iteration_logger
Data Plotter
Cal Sheet 2008
Embeded Formulae
100%

Future Development

Analytical

Future Development



Dynamic

3D Modelling Software

Web and Mobile App

Robustness

Summer Comfort

Energy

Circularity

Cost

Climate Change is real and its happening !!!

As Designers we need to peek into the future
for providing comfortable built environment.

Look for out-of-the box and robust solutions.

We need to know the limits of the box before attempting to think outside of that “box”.

Affirmation is prior to Innovation.

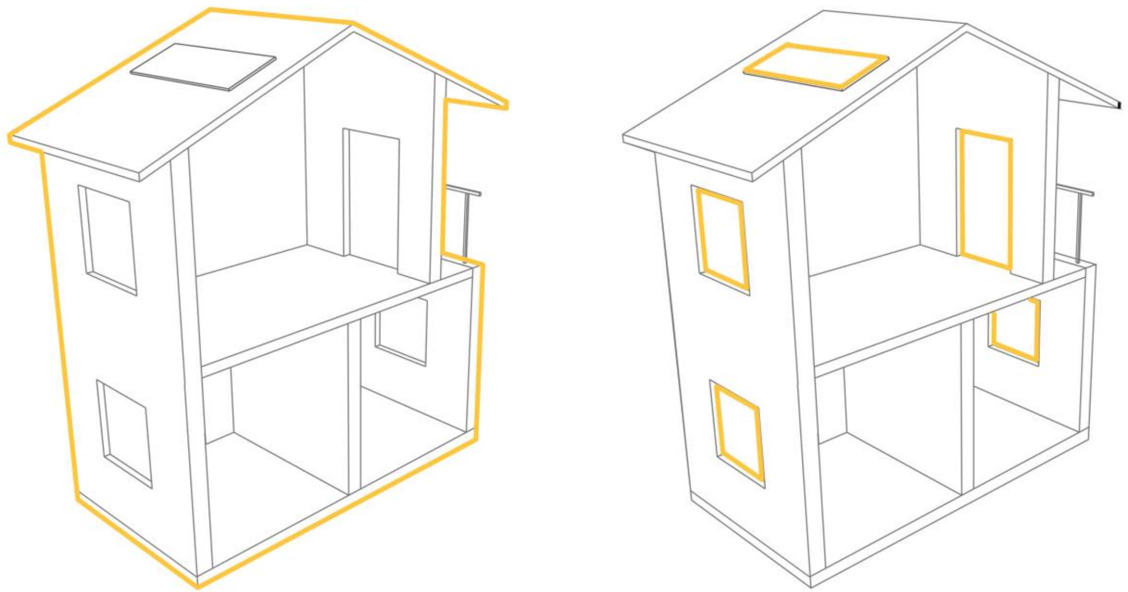
“We shape our buildings thereafter; they shape us” – Winston Churchill.

“We shaped the climate, therefore the climate will shape us.”

Questions ?

Appendix

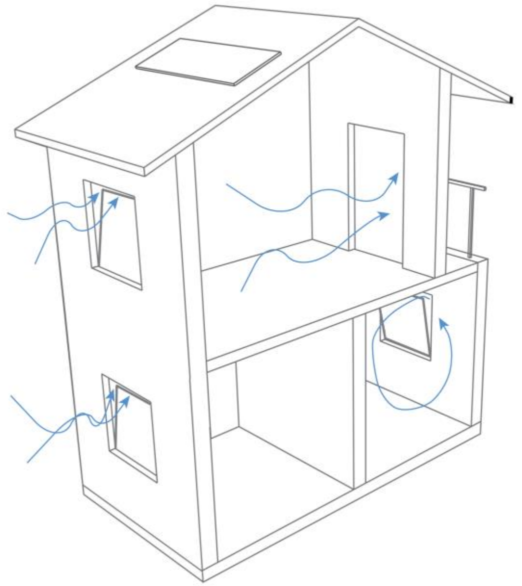
Functional Properties: Thermal Insulation



Components	Insulation Values	
Opaque (R-Value)	**Building Decree,2012**	**NTA 8800, 2021**
Roof	6 m^2.K/W	6.3 m^2.K/W
External Wall	4.5 m^2.K/W	4.7 m^2.K/W
External Floor	3.5 m^2.K/W	3.7 m^2.K/W
Transparent (U-Value)		
Glazing (including frame and glass)	<= 1.65 W/m^2.K	

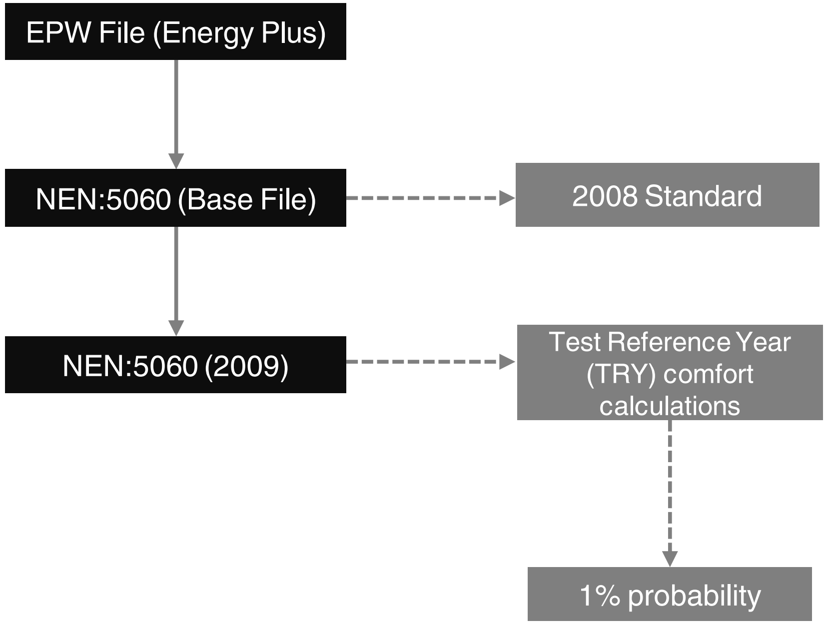
Dutch Building Decree, 2012, NTA 8800, 2019

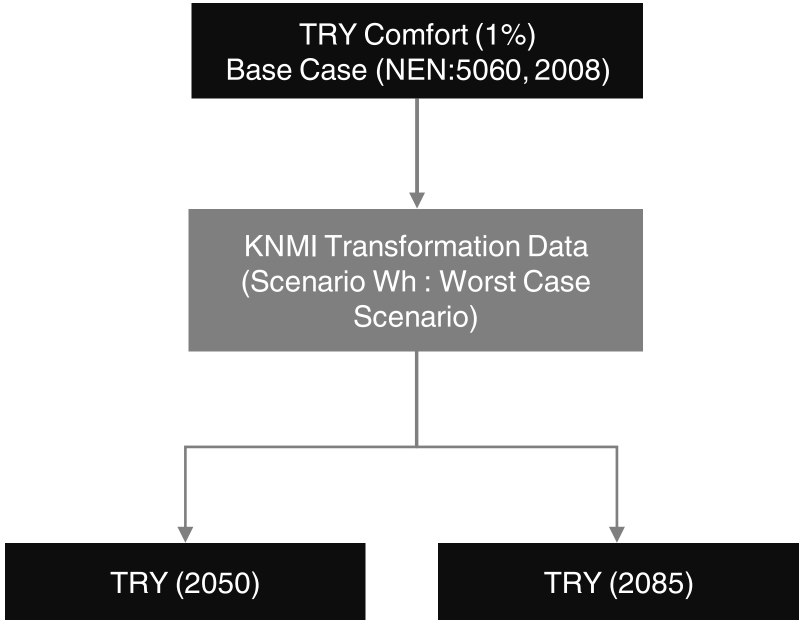
Functional Properties: Ventilation



Educational Buildings	Min Ventilation	
Building Decree,2012		8.5 L/s per person
NTA 8800, 2021		8.5 L/s per person
Fresh School	Class A	12 L/s per person
	Class B	8.5 L/s per person
	Class A	6 L/s per person

Dutch Building Decree, 2012,
Fresh School guidelines, 2015
NTA 8800, 2019





Source : Spoel & Ham, 2012
Bokel, 2019
KNMI,2020

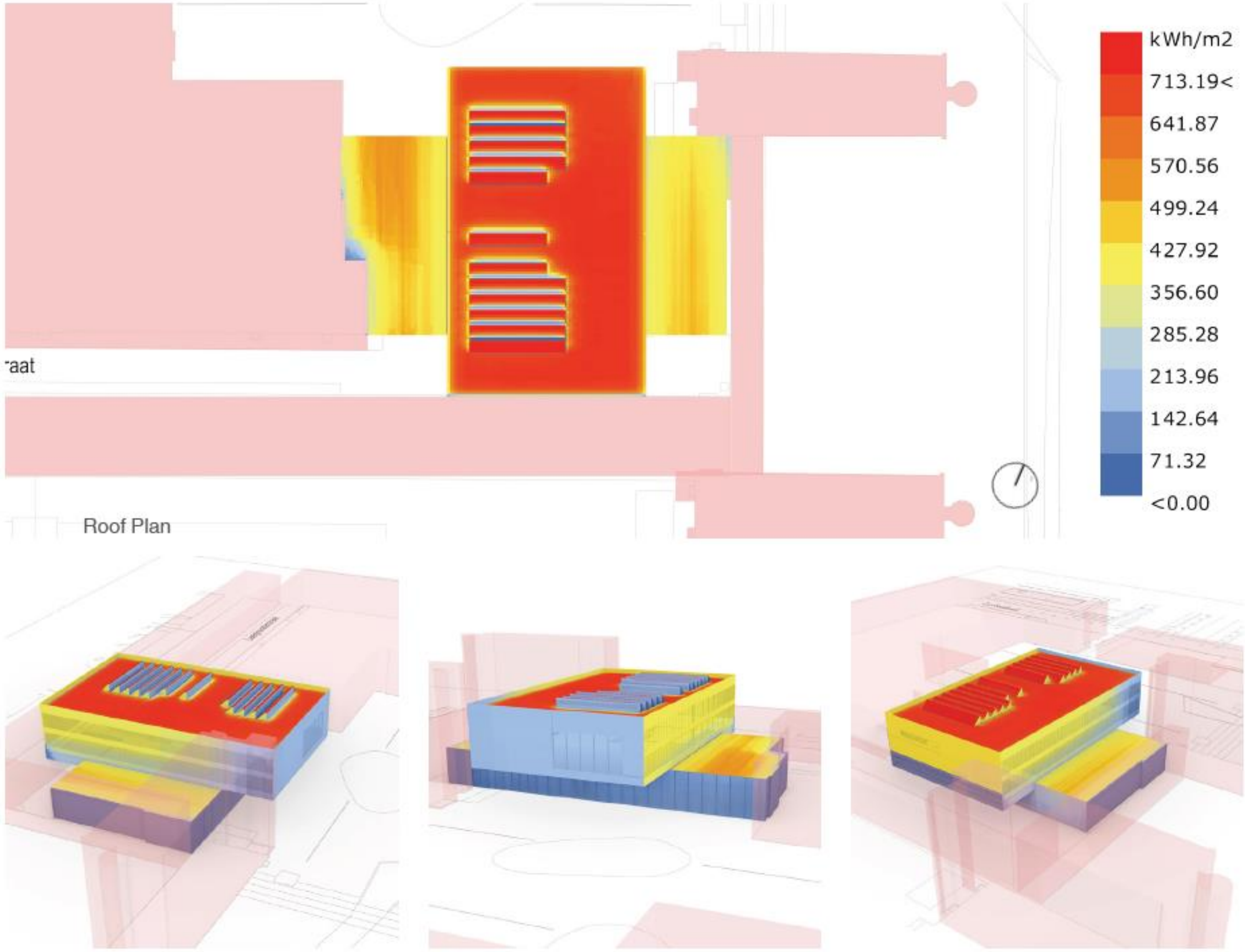
Empirical Studies

Author	Year	Assumed Spaces	Overheating Criteria	Spaces evaluated / Resulted in overheating
Jenkins et al.	2009	• *Teaching Spaces with office type areas which may need air conditioning if necessary* • *Larger communal areas not being used in same frequency*	*Percentage of occupied hours in teaching areas that exceed 28 deg.*	*Teaching spaces in all directions*
Coley et al.	2010	Classrooms	*TM 36*	*Classrooms with south façade and 50% glazing, heavy construction and no infiltration*
Teli et al.	2011	Classrooms	*Survey and aerial photo analysis*	*Identification of classroom clusters which may overheating based on construction, overheating, story and surrounding environment.* *Classrooms with NE and SE orientation with outdoor tarmac surface, bitumen roof, light weight construction, single glazing and lack of wind exposure.*
Kamensky et al.	2014	Classrooms	*Percentage of occupied hours in teaching areas that exceed 28 deg.*	*Classrooms located at south-east façade direction.*
Zinzi et al.	2017	Classrooms	*Percentage above 28 deg.*	*Classrooms at the upper floor to monitor impact of roof, South Facade.*
Irulegi et al.	2017	University Classrooms	*Percentage above 25 deg.*	*Seminar Room facing north west faced on the second floor.*
Lykartsis et al.	2017	Classrooms	*BB 101*	*Classrooms in south direction.*
Heracleous & Michael	2018	Classrooms	*CIBSE*	*Classrooms in all Directions.*

Empirical Studies

Radiation Analysis

Identification of potential spaces which may overheat



North-East
North-West
South-East

Ladybug Solar radiation

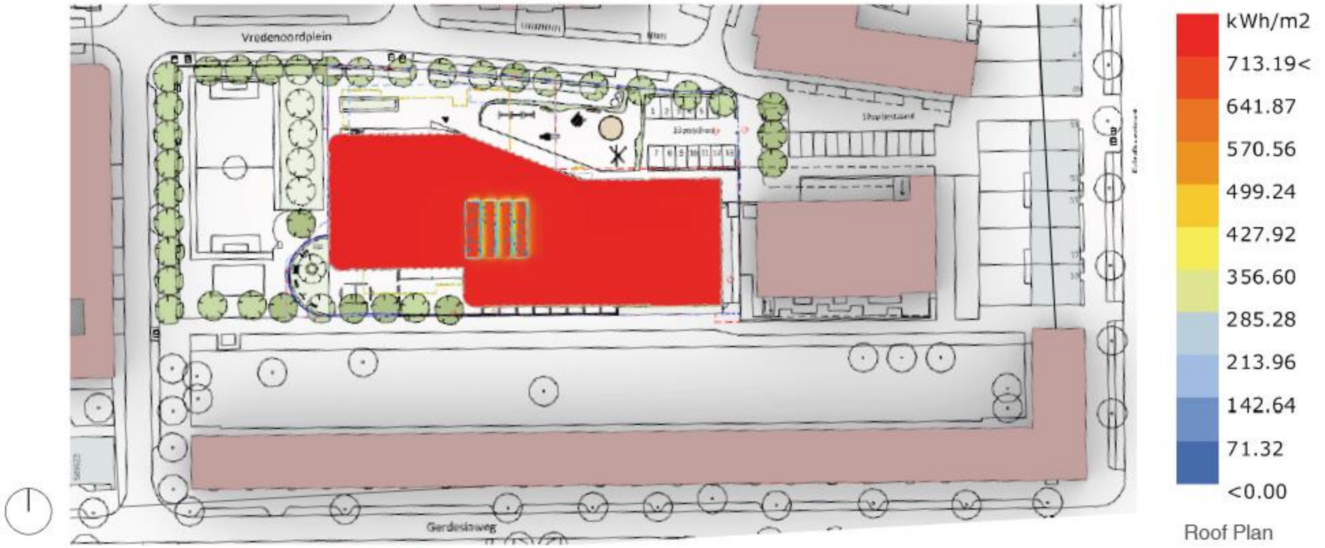
Period : May-September

Climate File : Baseline 2008, 1%

Empirical Studies

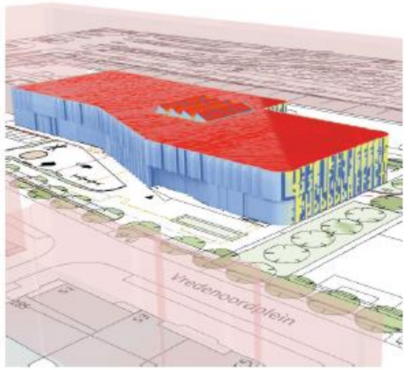
Radiation Analysis

Identification of potential spaces which may overheat



Roof Plan

North-East



North-West

South-East

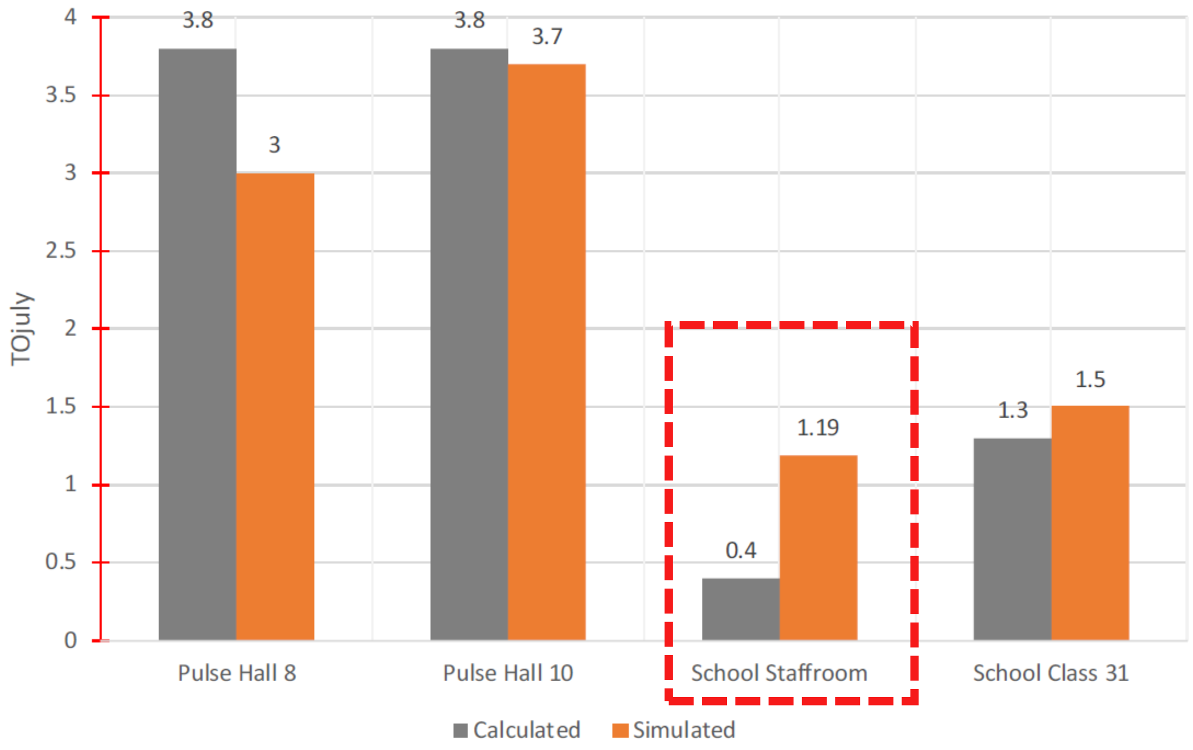
Ladybug Solar radiation

Period : May-September

Climate File : Baseline 2008, 1%

- TOjuly was calculated from dynamic simulation.

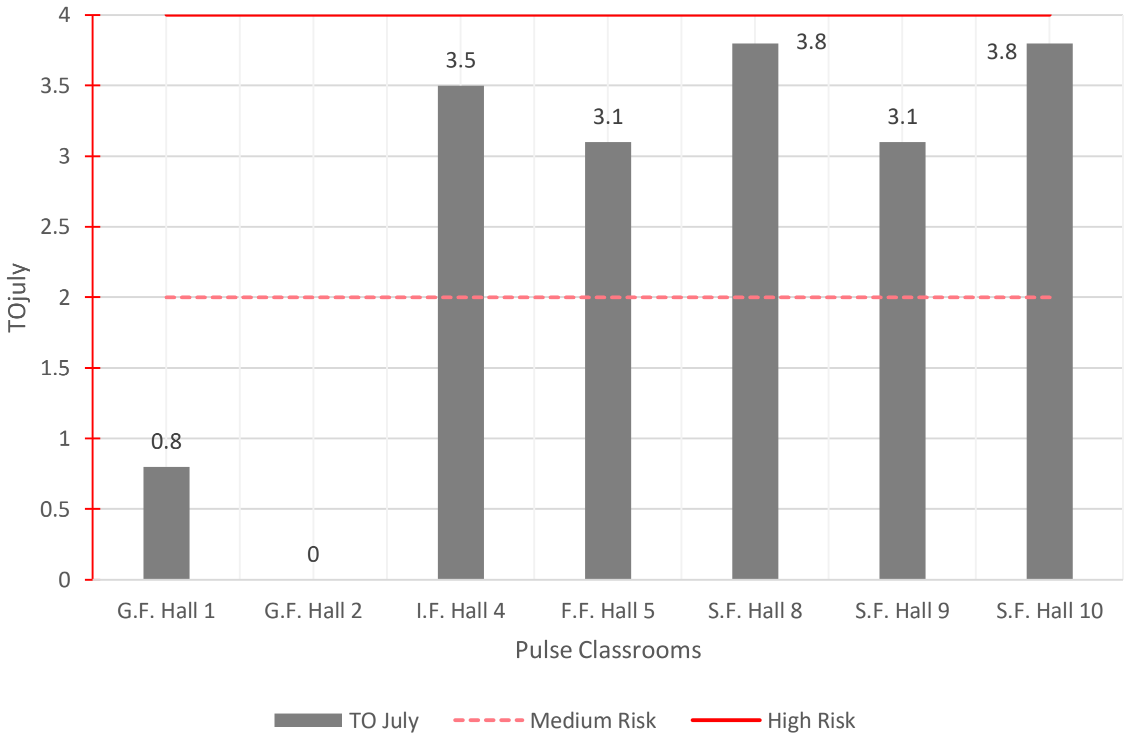
- The **difference** between TOjuly **simulated and simplified method** must be **within 20%.**

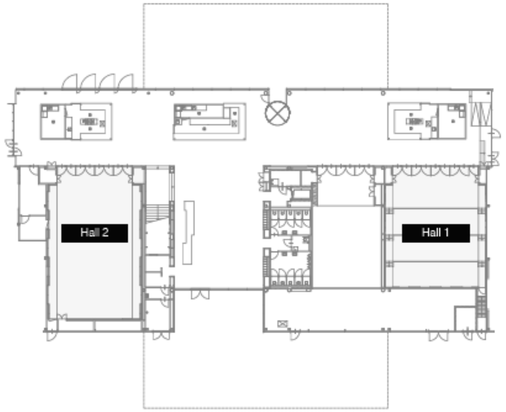


The simplified method can be used for predicting risk for overheating in educational buildings.

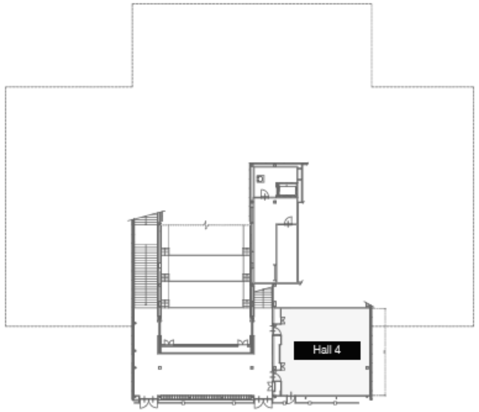
The method cannot be validated for corner spaces.

Staffroom at Melanchthon school will also be considered for dynamic simulations.

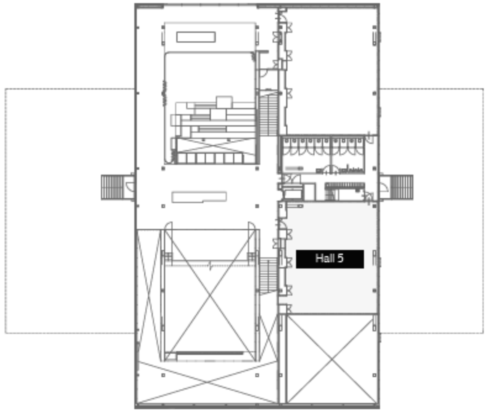




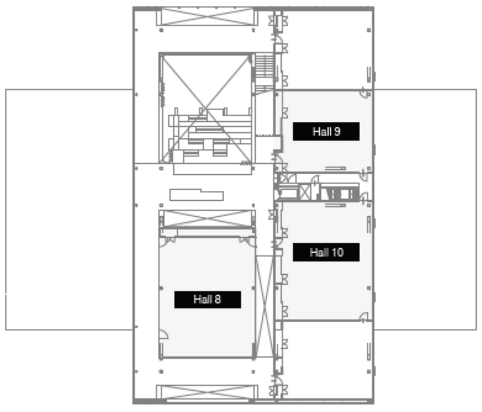
Hall 1 and Hall 2 on Ground Floor



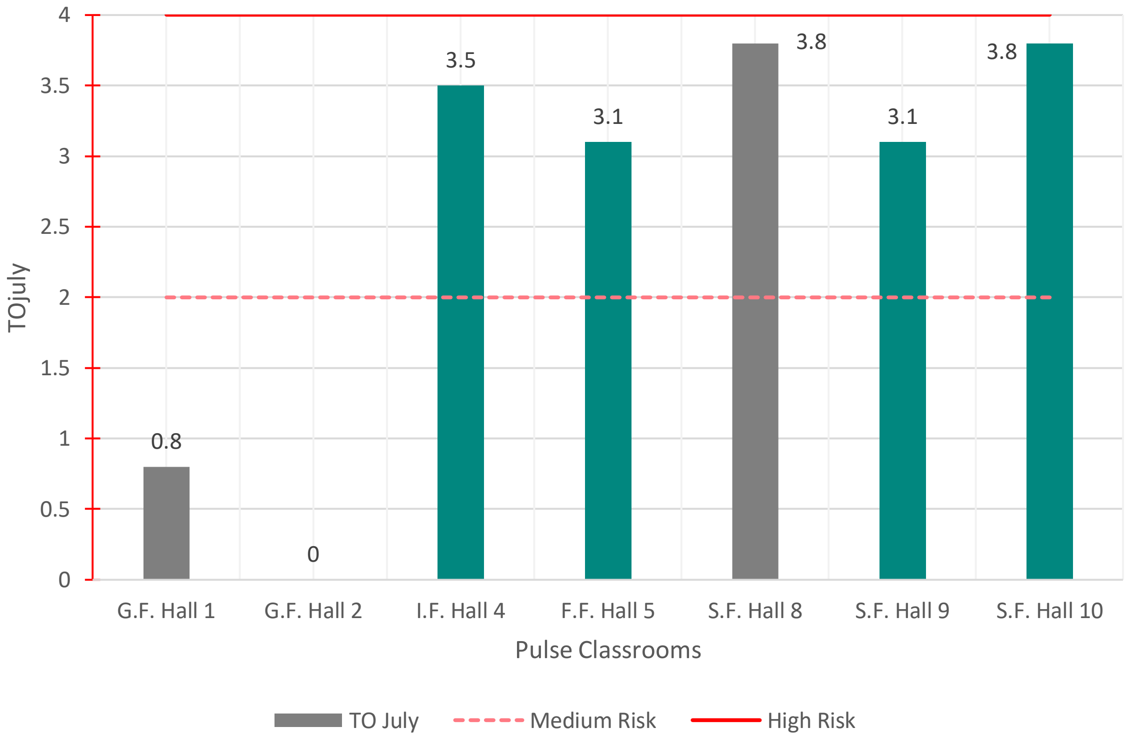
Hall 4 on Intermediate Floor

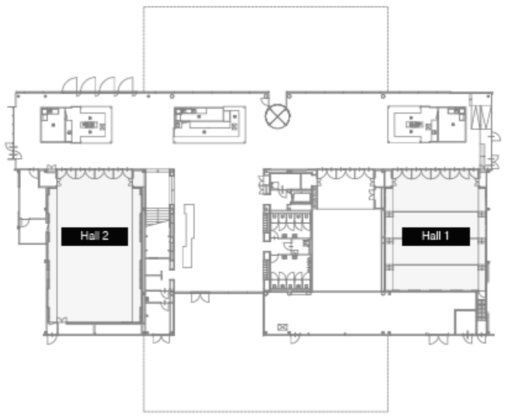


Hall 5 on First Floor

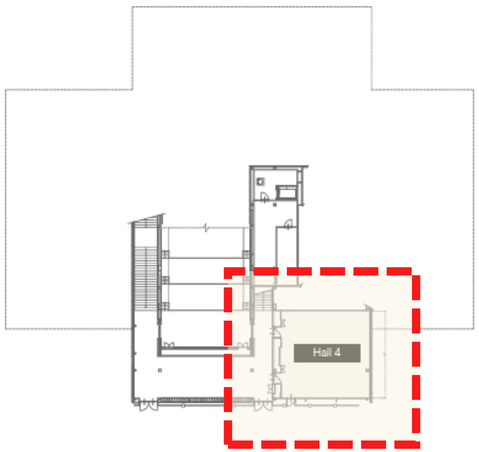


Hall 8,Hall9 and Hall 10 on Second Floor

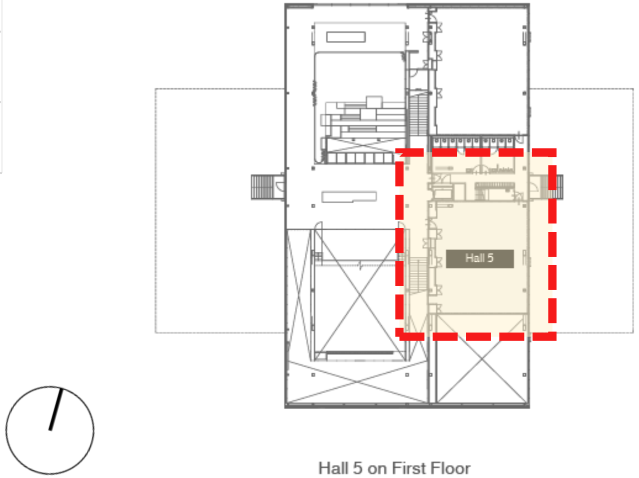




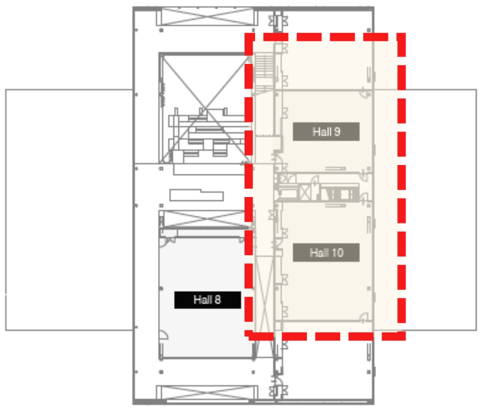
Hall 1 and Hall 2 on Ground Floor



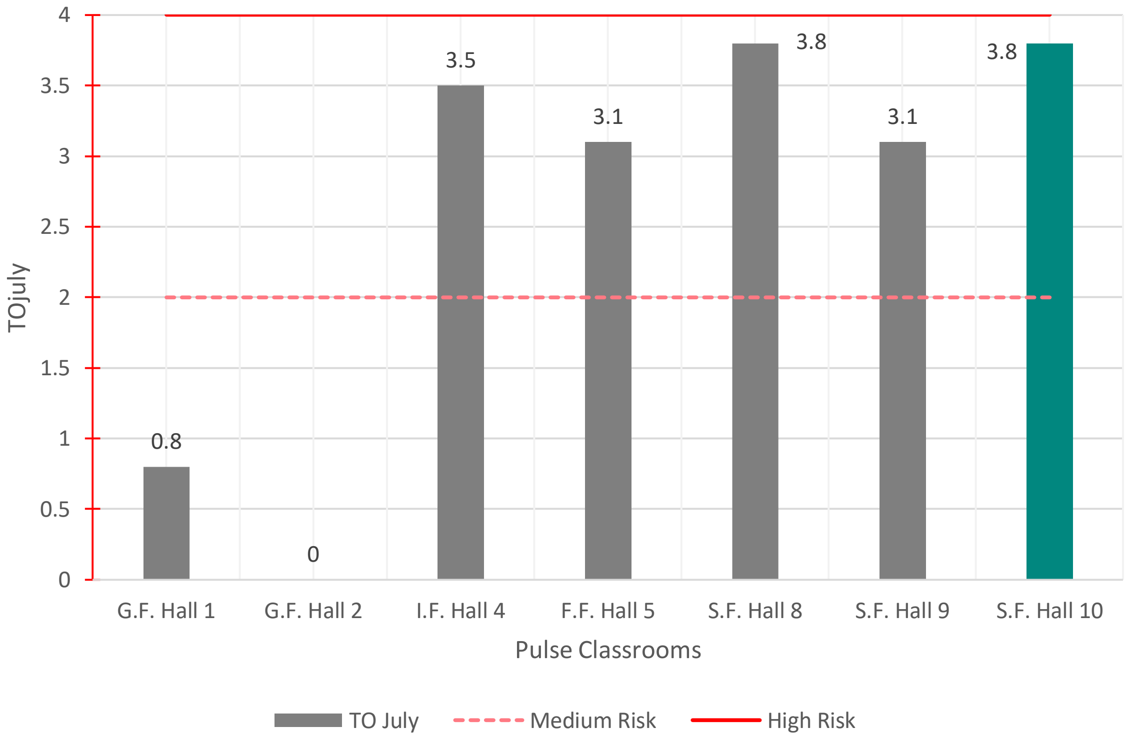
Hall 4 on Intermediate Floor

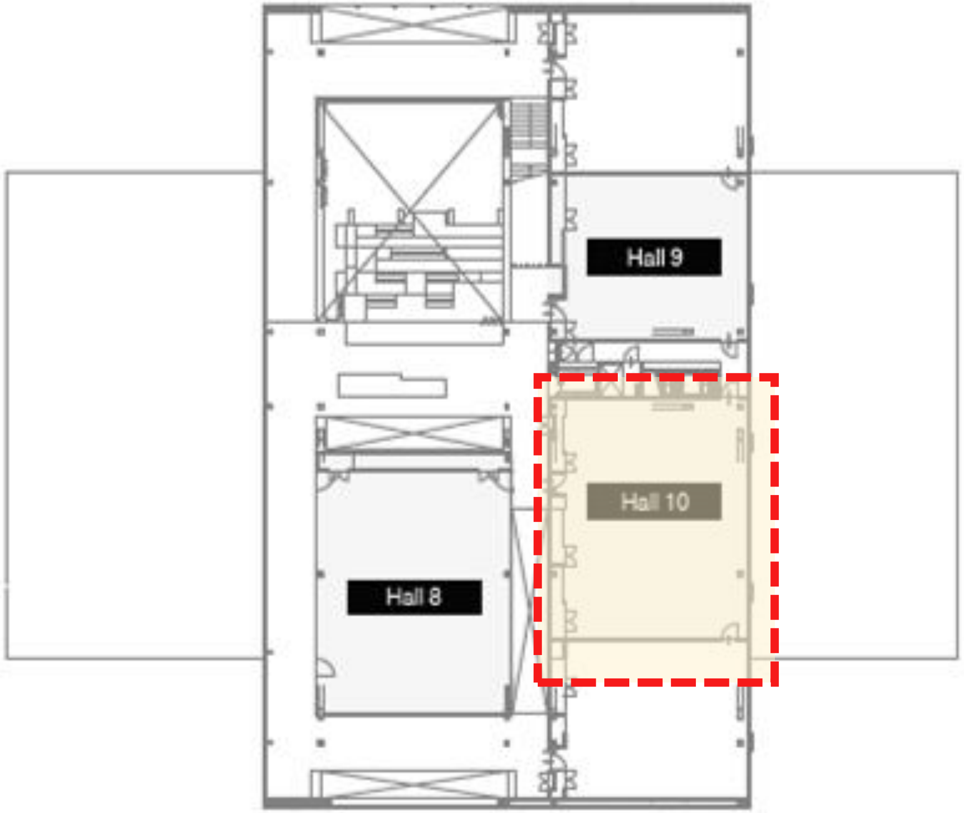


Hall 5 on First Floor

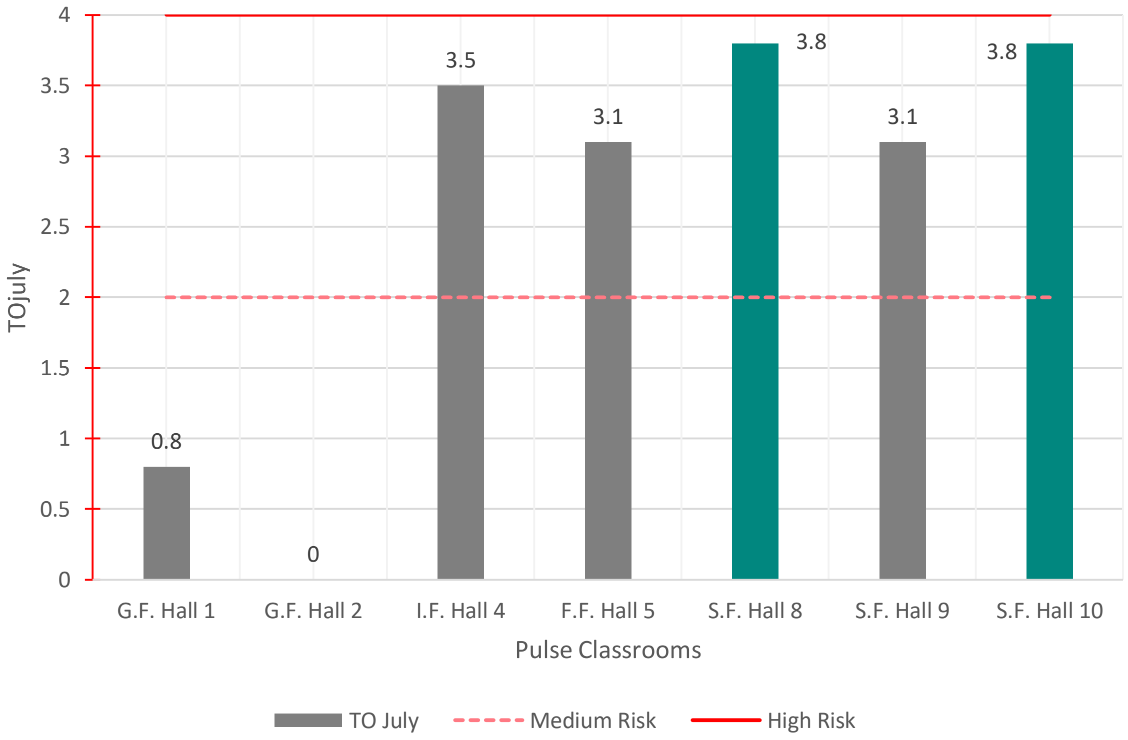


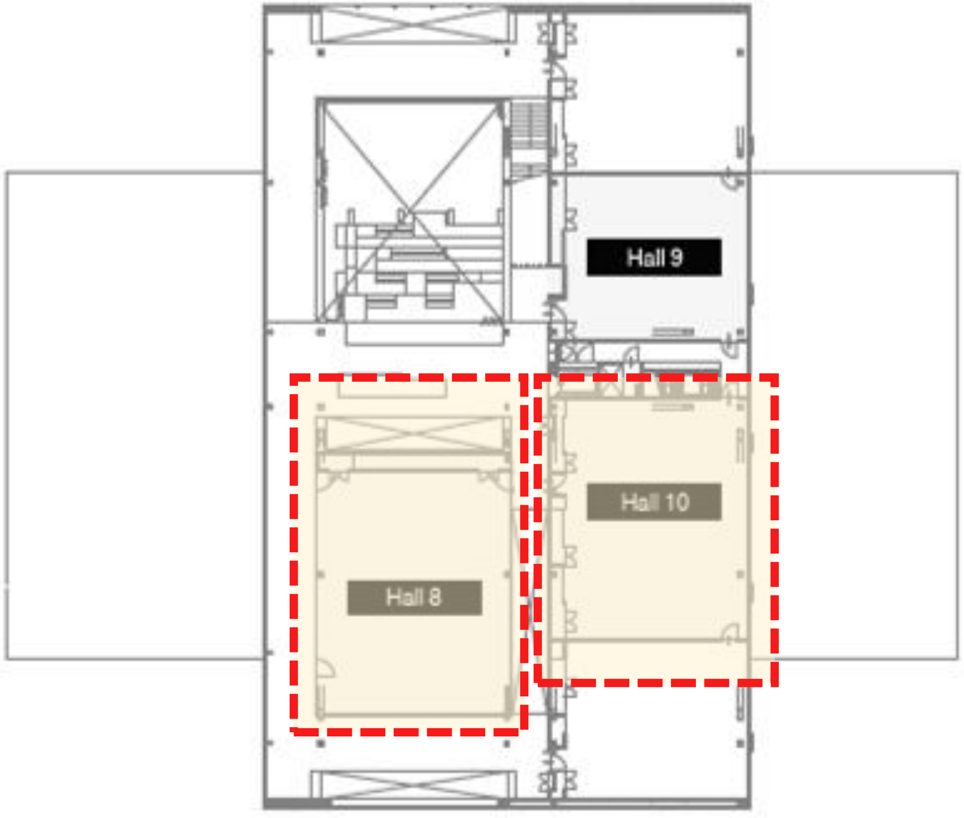
Hall 8,Hall9 and Hall 10 on Second Floor



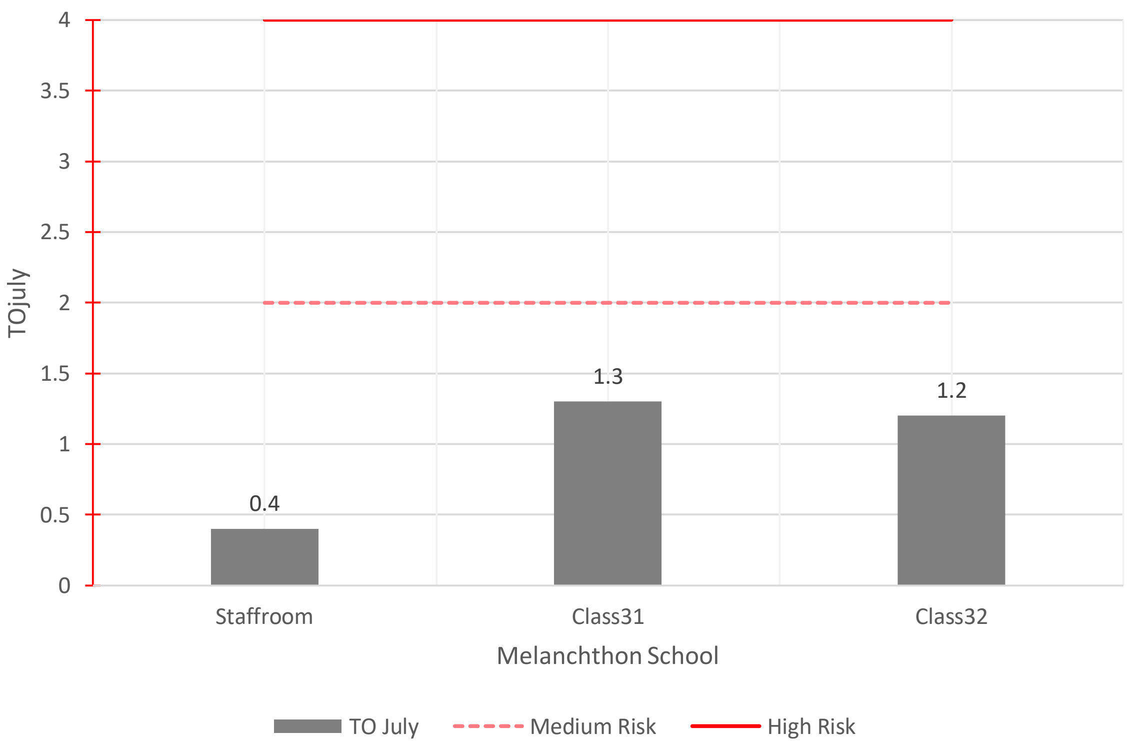


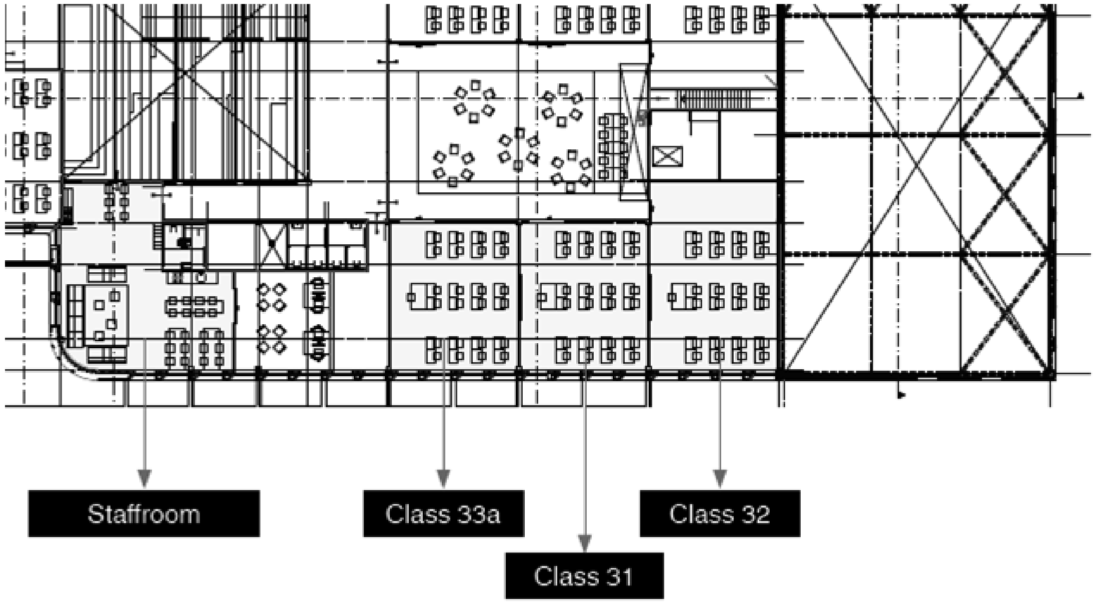
Hall 8,Hall9 and Hall 10 on Second Floor

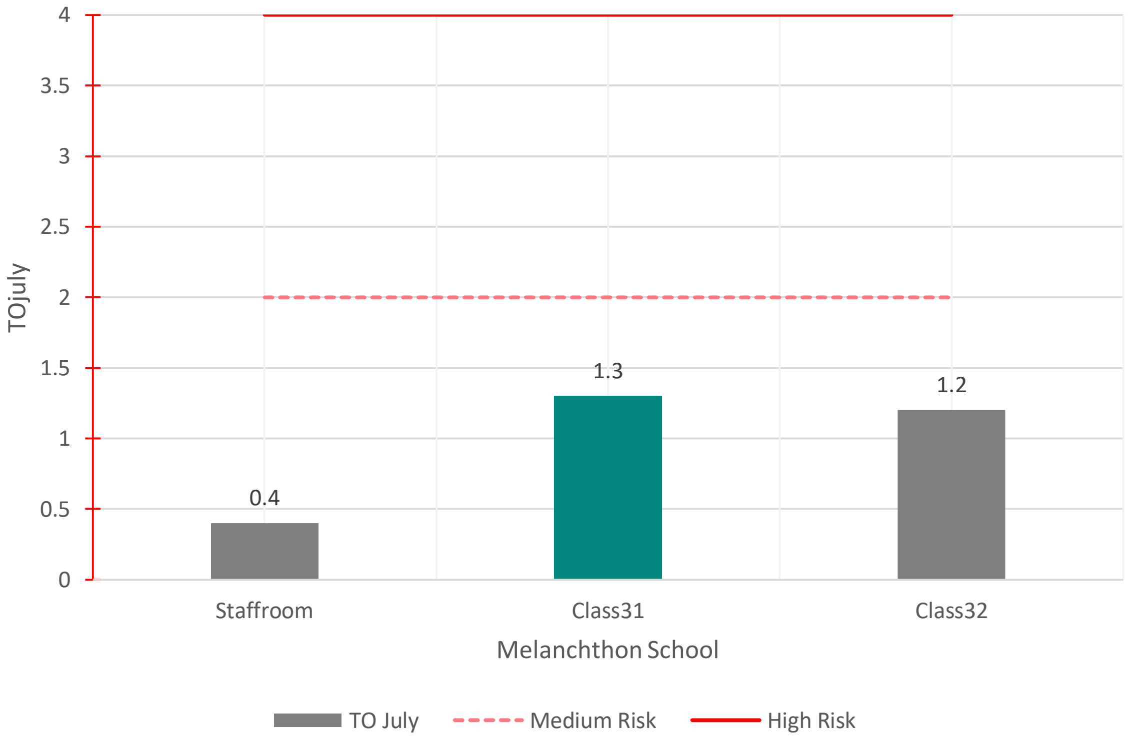




Hall 8,Hall9 and Hall 10 on Second Floor


4
3.5
3
2.5
2
1.5
1
0.5
0
TOjuly
0.4
1.3
1.2
Staffroom
Class31
Class32
Melanchthon School
TO July
Medium Risk
High Risk


Staffroom
Class 33a
Class 32
Class 31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1
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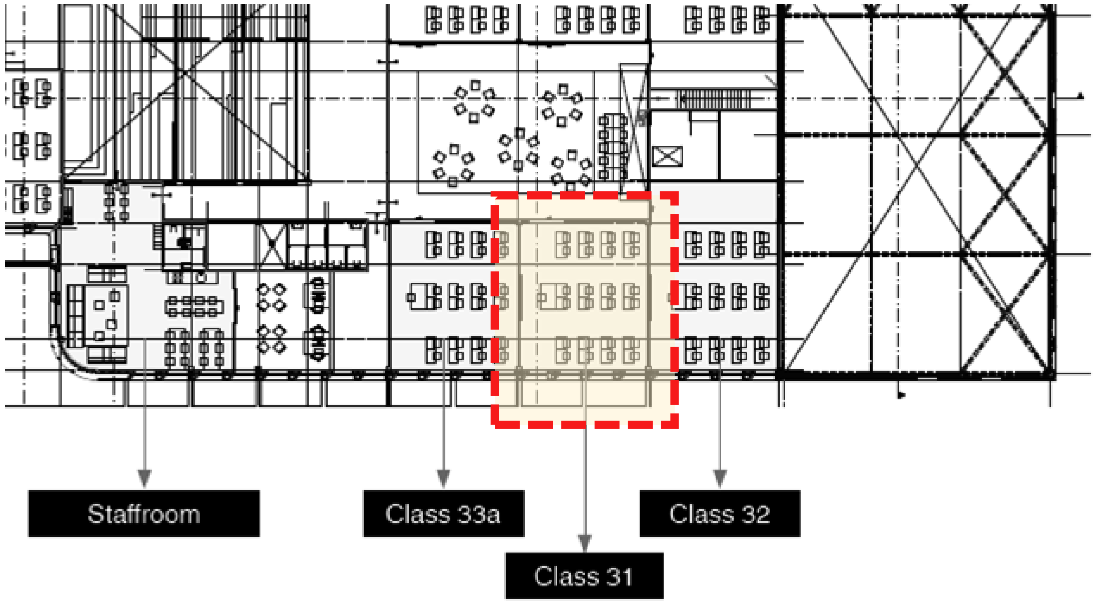
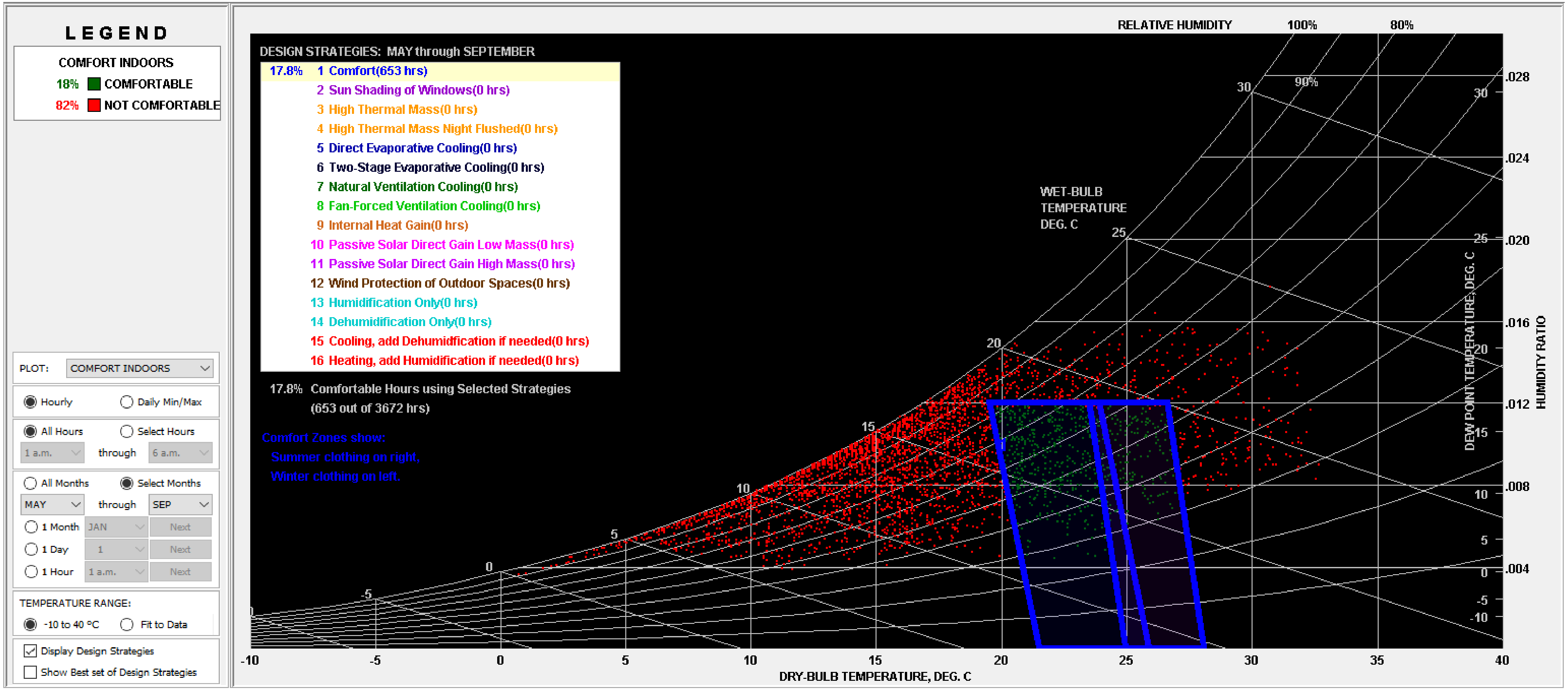
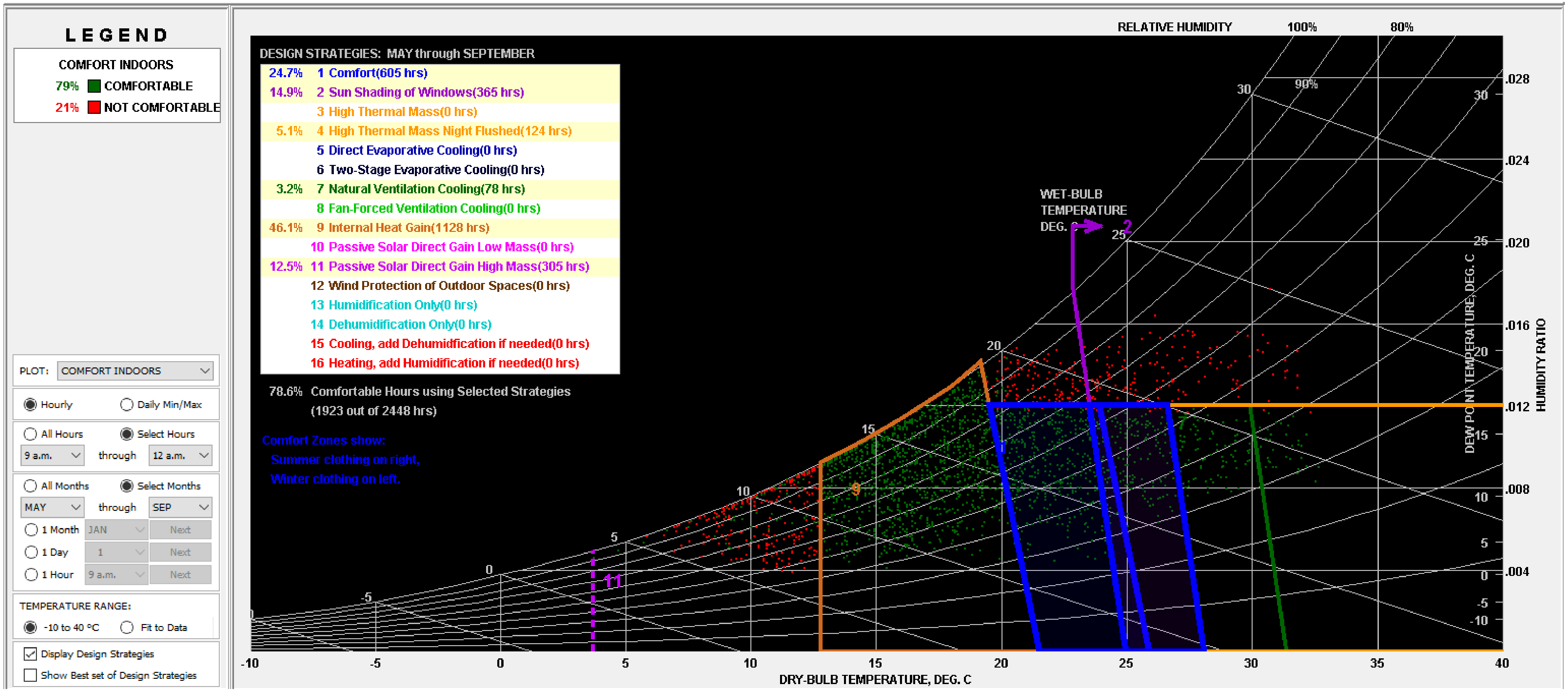
TOjuly
0.4
1.3
1.2
Staffroom
Class31
Class32
Melanchthon School
TO July
Medium Risk
High Risk


Staffroom
Class 33a
Class 32
Class 31

Base line year (NEN 5060:2008 1% Comfort)



Passive Design Strategies



Passive Design Strategies

Present

DESIGN STRATEGIES: MAY through SEPTEMBER

24.7%	1 Comfort(605 hrs)
14.9%	2 Sun Shading of Windows(365 hrs)
	3 High Thermal Mass(0 hrs)
5.1%	4 High Thermal Mass Night Flushed(124 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
3.2%	7 Natural Ventilation Cooling(78 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
46.1%	9 Internal Heat Gain(1128 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
12.5%	11 Passive Solar Direct Gain High Mass(305 hrs)
	12 Wind Protection of Outdoor Spaces(0 hrs)
	13 Humidification Only(0 hrs)
	14 Dehumidification Only(0 hrs)
	15 Cooling, add Dehumidfication if needed(0 hrs)
	16 Heating, add Humidification if needed(0 hrs)

78.6% Comfortable Hours using Selected Strategies (1923 out of 2448 hrs)

2050

DESIGN STRATEGIES: MAY through SEPTEMBER

21.4%	1 Comfort(524 hrs)
22.5%	2 Sun Shading of Windows(551 hrs)
	3 High Thermal Mass(0 hrs)
4.8%	4 High Thermal Mass Night Flushed(117 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
3.3%	7 Natural Ventilation Cooling(80 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
35.7%	9 Internal Heat Gain(874 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
9.2%	11 Passive Solar Direct Gain High Mass(225 hrs)
	12 Wind Protection of Outdoor Spaces(0 hrs)
	13 Humidification Only(0 hrs)
	14 Dehumidification Only(0 hrs)
	15 Cooling, add Dehumidfication if needed(0 hrs)
	16 Heating, add Humidification if needed(0 hrs)

63.9% Comfortable Hours using Selected Strategies (1565 out of 2448 hrs)

2085

DESIGN STRATEGIES: MAY through SEPTEMBER

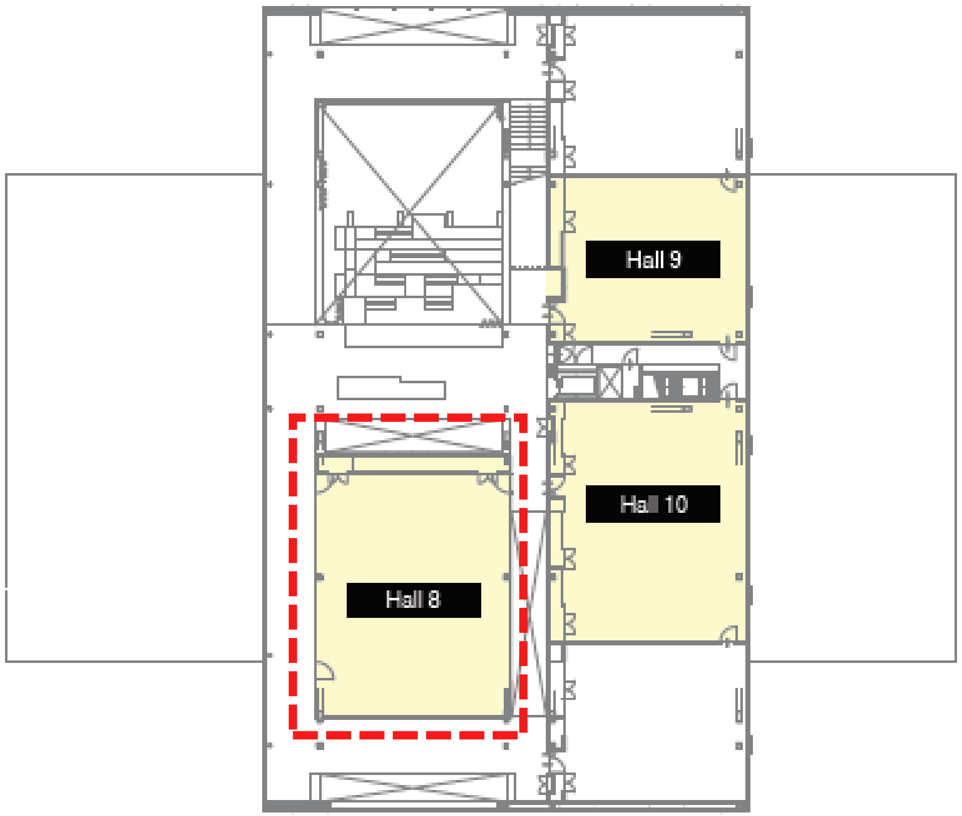
19.4%	1 Comfort(475 hrs)
26.2%	2 Sun Shading of Windows(641 hrs)
	3 High Thermal Mass(0 hrs)
5.3%	4 High Thermal Mass Night Flushed(130 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
3.8%	7 Natural Ventilation Cooling(92 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
28.7%	9 Internal Heat Gain(702 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
7.5%	11 Passive Solar Direct Gain High Mass(183 hrs)
	12 Wind Protection of Outdoor Spaces(0 hrs)
	13 Humidification Only(0 hrs)
	14 Dehumidification Only(0 hrs)
	15 Cooling, add Dehumidfication if needed(0 hrs)
	16 Heating, add Humidification if needed(0 hrs)

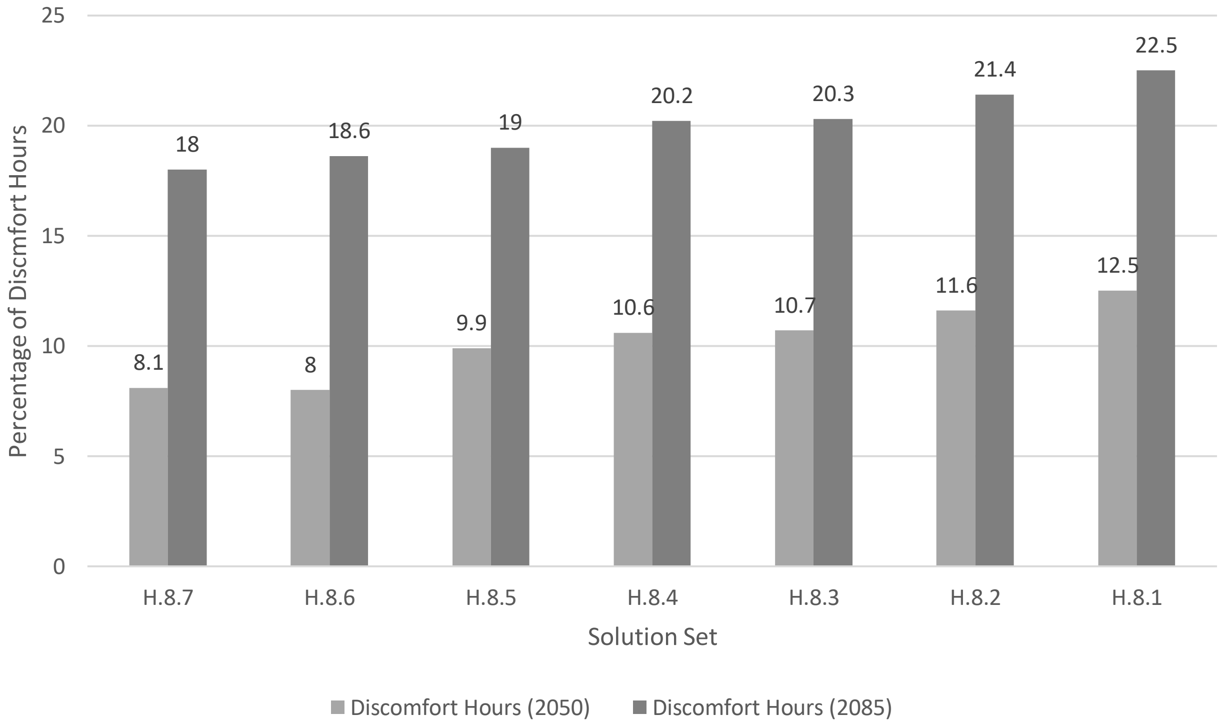
54.8% Comfortable Hours using Selected Strategies (1341 out of 2448 hrs)

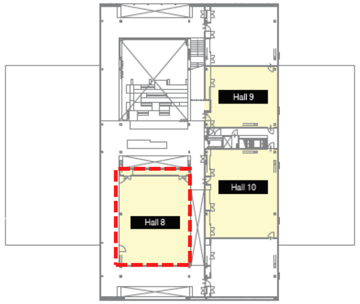
Author	Year	Building Types	Adaptive Strategies
Jenkins et al.	2009	Schools	• *External Shading* • *Passive Cooling* • *Ventilation Strategies*
Lomas et al.	2012	Hospitals	• *Insulations* • *Shading strategies* • *Natural Ventilation Strategies*
Gupta and Gregg	2012	Residences	• *Increased external and internal insulations* • *Cavity Wall Insulations* • *High Albedo Exterior surfaces* • *Exposed Thermal Mass* • *Shading strategies*
Hamdy et al.	2017	Residences	• *Ventilative Cooling* • *Solar Protection*
Shadmanfar et al.	2019	Schools	• *Increasing thermal mass* • *Nigh time cooling*
C Jimenez	2019	Offices	• *Thermal Mass* • *Ventilation Strategies*

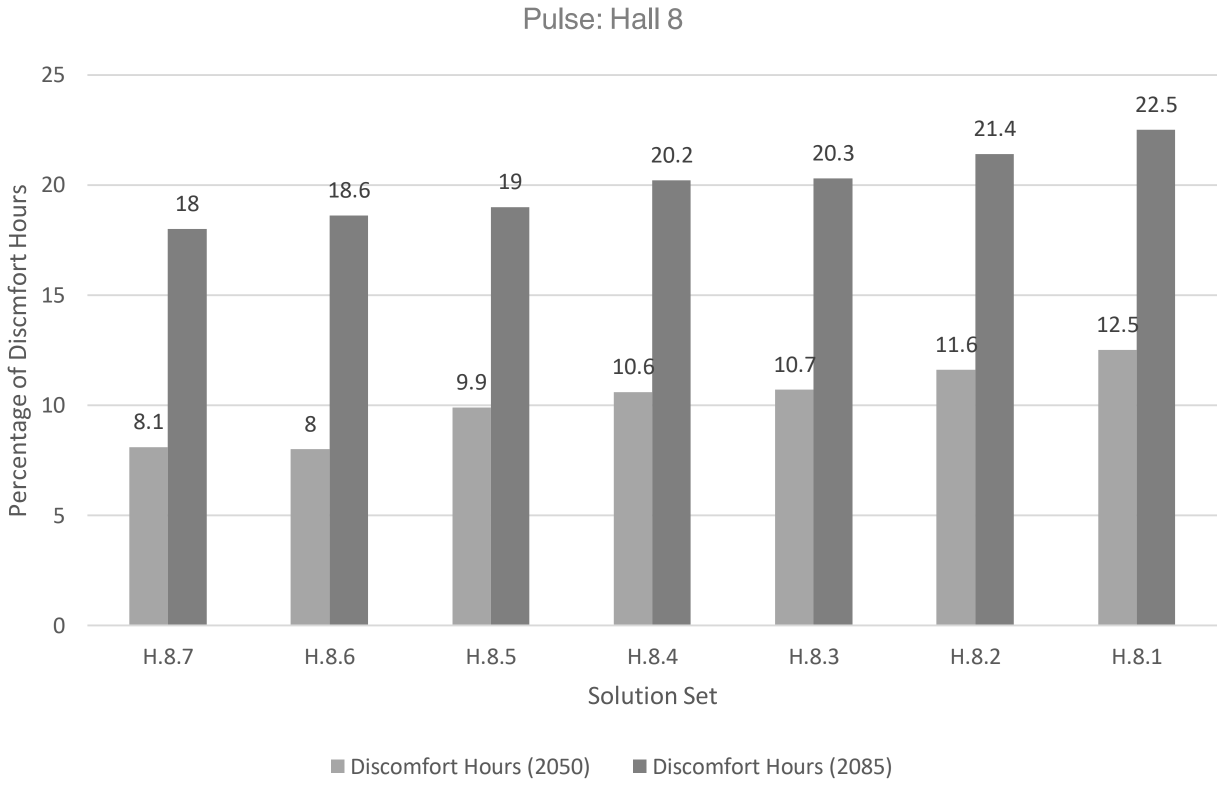
Comparison of adaptive strategies used in different literature studies in temperate climate to reduce overheating . Source: Author

Pulse Hall 8

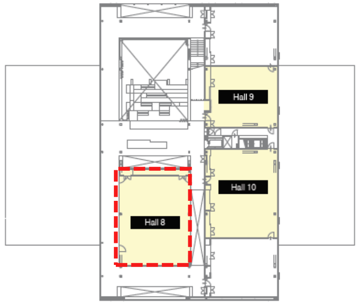

Hall 9
Hall 10
Hall 8


Percentage of Discmfort Hours
Solution Set
H.8.7 H.8.6 H.8.5 H.8.4 H.8.3 H.8.2 H.8.1
8.1 18
8 18.6
9.9 19
10.6 20.2
10.7 20.3
11.6 21.4
12.5 22.5
0 5 10 15 20 25
Discomfort Hours (2050)
Discomfort Hours (2085)

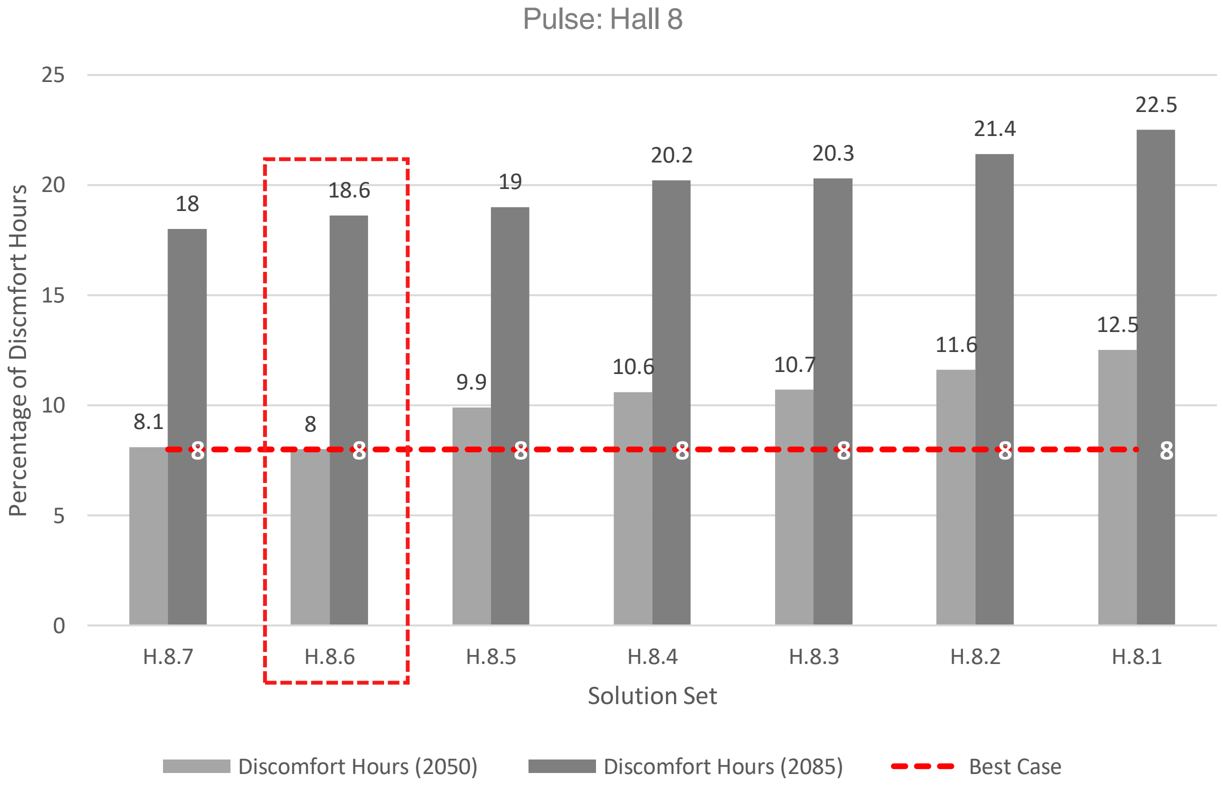


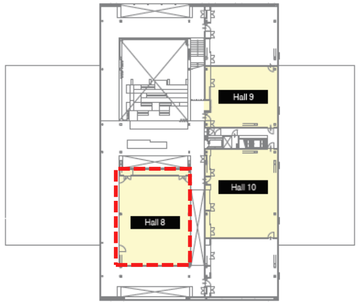


Code	Solution Set	Remarks
H8.1	Reduce U-Value of partition Walls	U-value to 1.65 W/m2K
H8.2.	Reduce U-Value of partition Walls	U-Value to 1 W/m2K
H8. 3.	Reduced U-Value + White Surfaced Roof	WWR 70% from 100%
H8. 4.	Reduced U-Value + White Surfaced Roof+ WWR 70%	R-Value of opaque parts increased 3 m2K/W
H8. 5.	Reduced U-Value + White Surfaced Roof+ WWR 70%	G-value of transparent parts to .4
H8. 6.	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode	Opening skylight windows
H8. 7	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode + PCM Panels	PCM modelled as 80 mm concrete

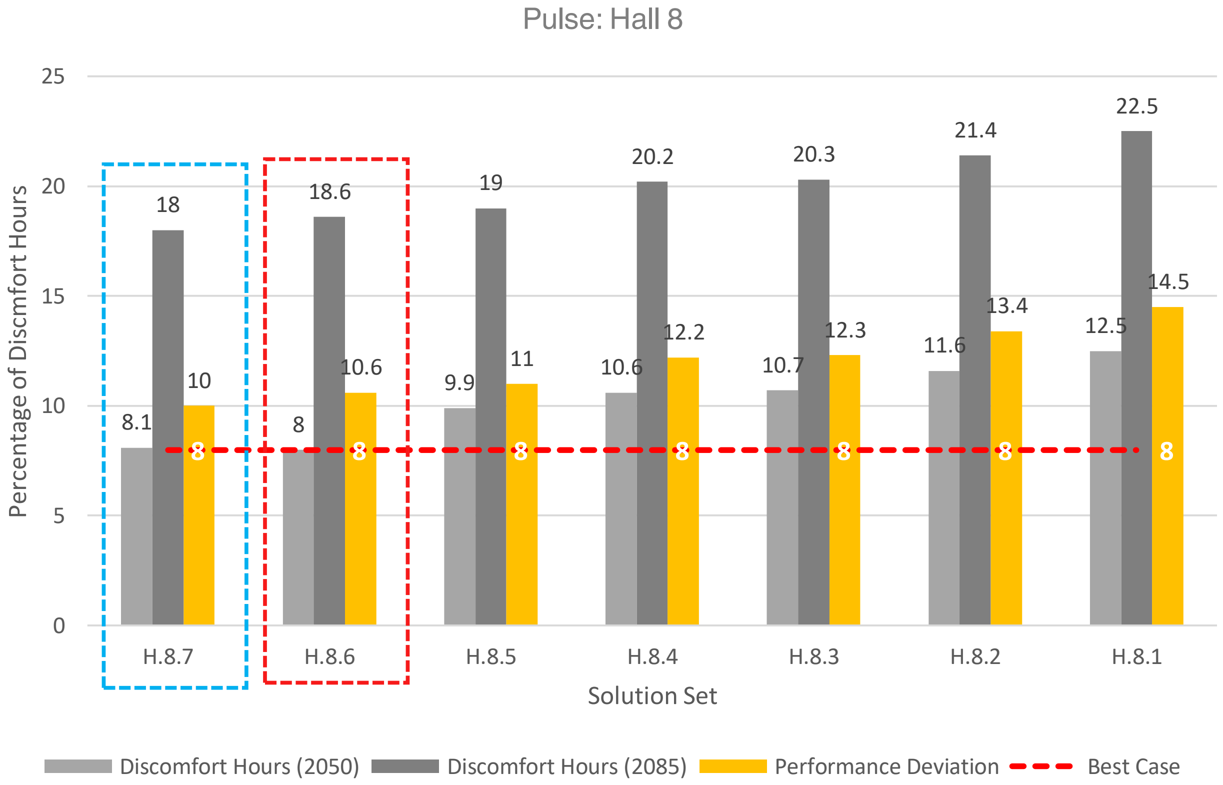


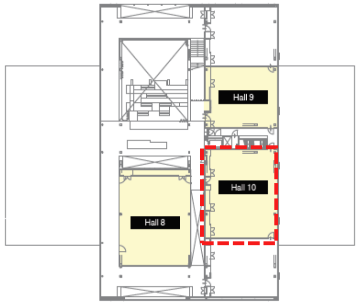
Code	Solution Set	Remarks
H8.1	Reduce U-Value of partition Walls	U-value to 1.65 W/m2K
H8.2.	Reduce U-Value of partition Walls	U-Value to 1 W/m2K
H8. 3.	Reduced U-Value + White Surfaced Roof	WWR 70% from 100%
H8. 4.	Reduced U-Value + White Surfaced Roof+ WWR 70%	R-Value of opaque parts increased 3 m2K/W
H8. 5.	Reduced U-Value + White Surfaced Roof+ WWR 70%	G-value of transparent parts to .4
H8. 6.	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode	Opening skylight windows
H8. 7	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode + PCM Panels	PCM modelled as 80 mm concrete





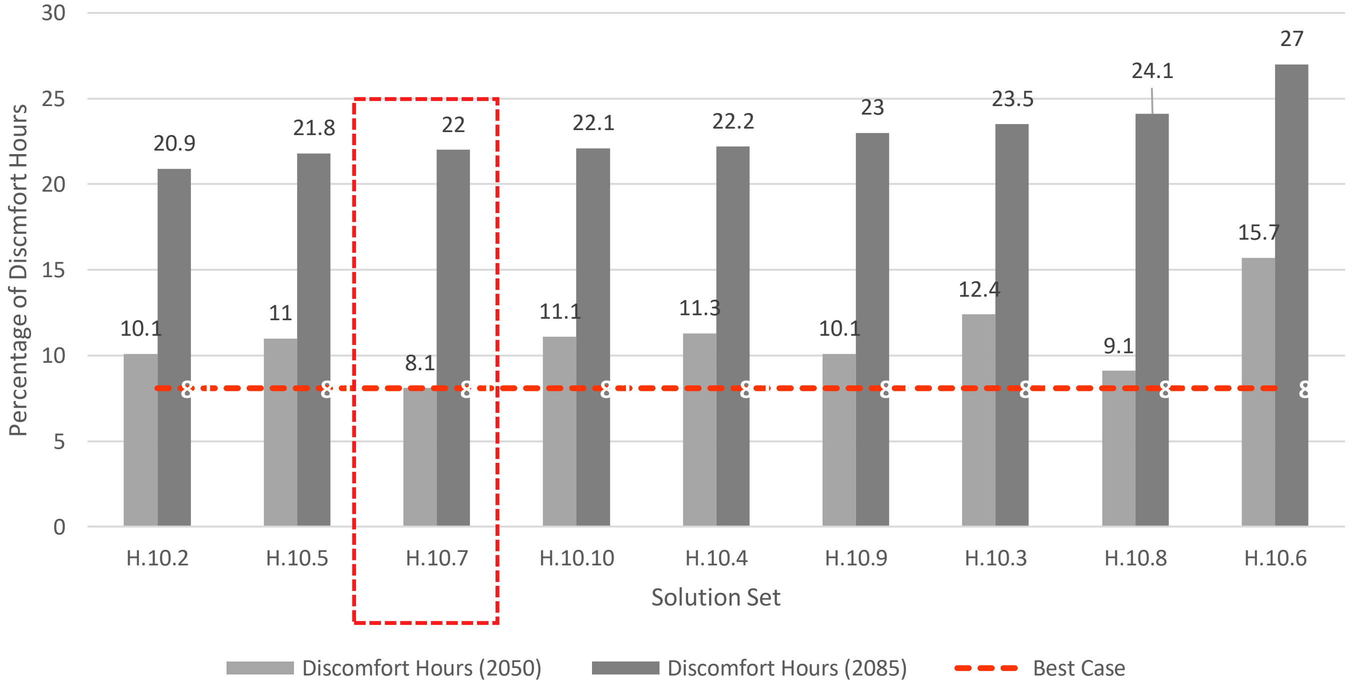
Code	Solution Set	Remarks
H8.1	Reduce U-Value of partition Walls	U-value to 1.65 W/m2K
H8.2.	Reduce U-Value of partition Walls	U-Value to 1 W/m2K
H8. 3.	Reduced U-Value + White Surfaced Roof	WWR 70% from 100%
H8. 4.	Reduced U-Value + White Surfaced Roof+ WWR 70%	R-Value of opaque parts increased 3 m2K/W
H8. 5.	Reduced U-Value + White Surfaced Roof+ WWR 70%	G-value of transparent parts to .4
H8. 6.	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode	Opening skylight windows
H8. 7	Reduced U-Value + White Surfaced Roof+ WWR 70 % +Mixed mode + PCM Panels	PCM modelled as 80 mm concrete

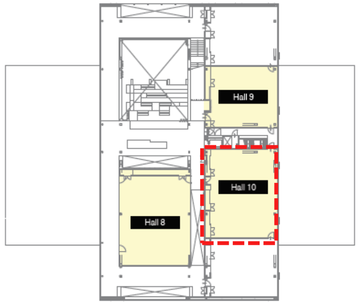




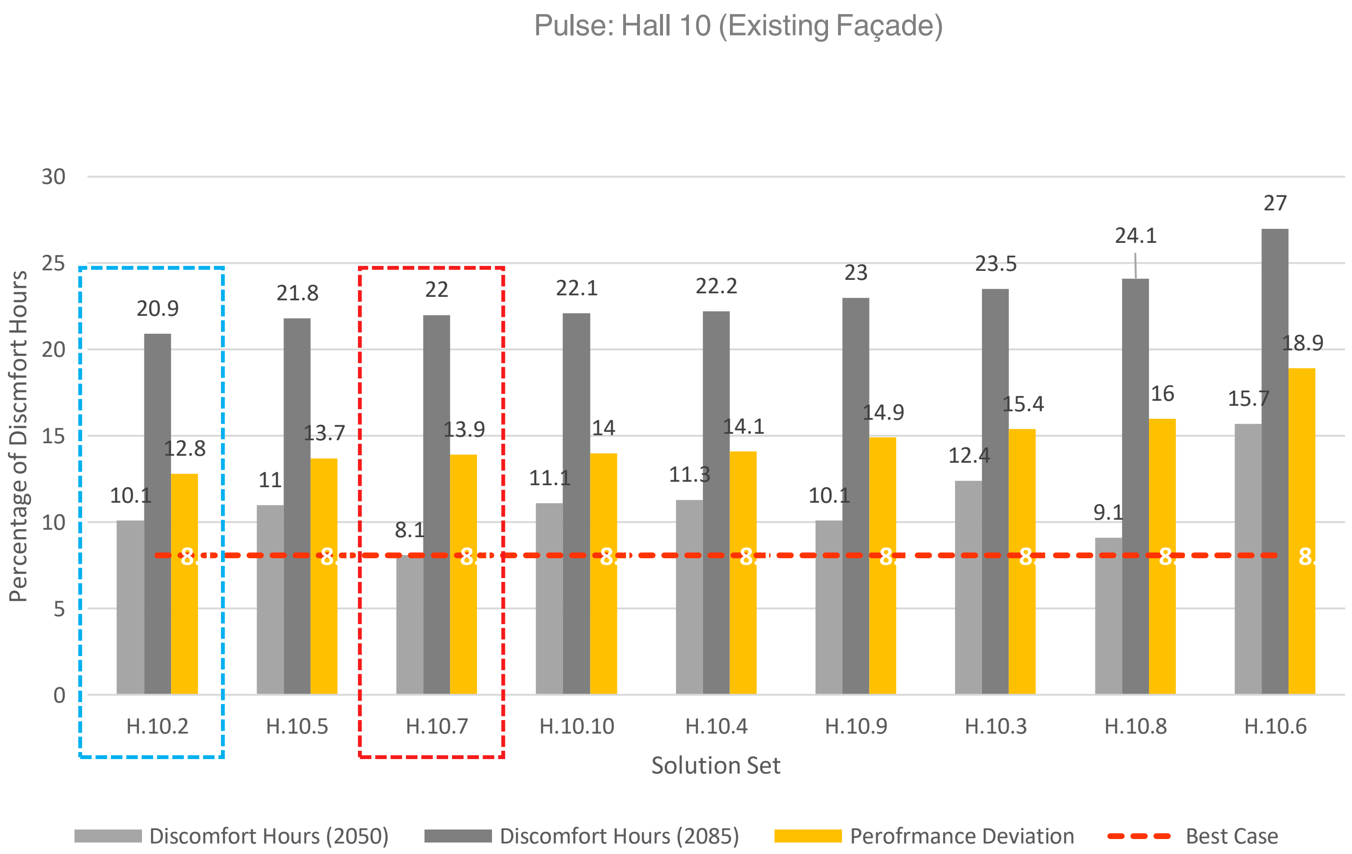
Code	Solution Set	Remarks
H10.1	WWR 75% + White Surfaced roof and Facade	
H10.2	WWR 75% + White Surfaced roof and Façade + External Roller Blinds	
H10.3.	WWR 75% + White Surfaced roof and Facade+ 0.5 m overhang and 0.35 m sidefins.	
H10.4	WWR 75% + White Surfaced roof and Facade+ 1 m overhang and 0.35 m sidefins.	
H10.5	WWR 75% + White Surfaced roof and Facade+ shutters	
H10.6	WWR 75% + White Surfaced roof and Facade+ mixed-mode +PCM Panels	Existing two windows openings with 40% openable area operating through out the day PCM modelled as 80 mm concrete
H10.7	WWR 75% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	
H10.8	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+0.5 m overhang and 0.35 m sidefins.	
H10.9	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+1 m overhang and 0.35 m sidefins.	
H10.10	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+ shutters	

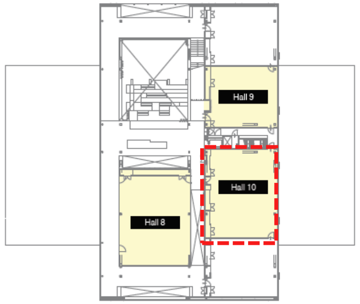
Pulse: Hall 10 (Existing Façade)





Code	Solution Set	Remarks
H10.1	WWR 75% + White Surfaced roof and Facade	
H10.2	WWR 75% + White Surfaced roof and Façade + External Roller Blinds	
H10.3.	WWR 75% + White Surfaced roof and Facade+ 0.5 m overhang and 0.35 m sidefins.	
H10.4	WWR 75% + White Surfaced roof and Facade+ 1 m overhang and 0.35 m sidefins.	
H10.5	WWR 75% + White Surfaced roof and Facade+ shutters	
H10.6	WWR 75% + White Surfaced roof and Facade+ mixed-mode +PCM Panels	Existing two windows openings with 40% openable area operating through out the day PCM modelled as 80 mm concrete
H10.7	WWR 75% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	
H10.8	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+0.5 m overhang and 0.35 m sidefins.	
H10.9	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+1 m overhang and 0.35 m sidefins.	
H10.10	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+ shutters	



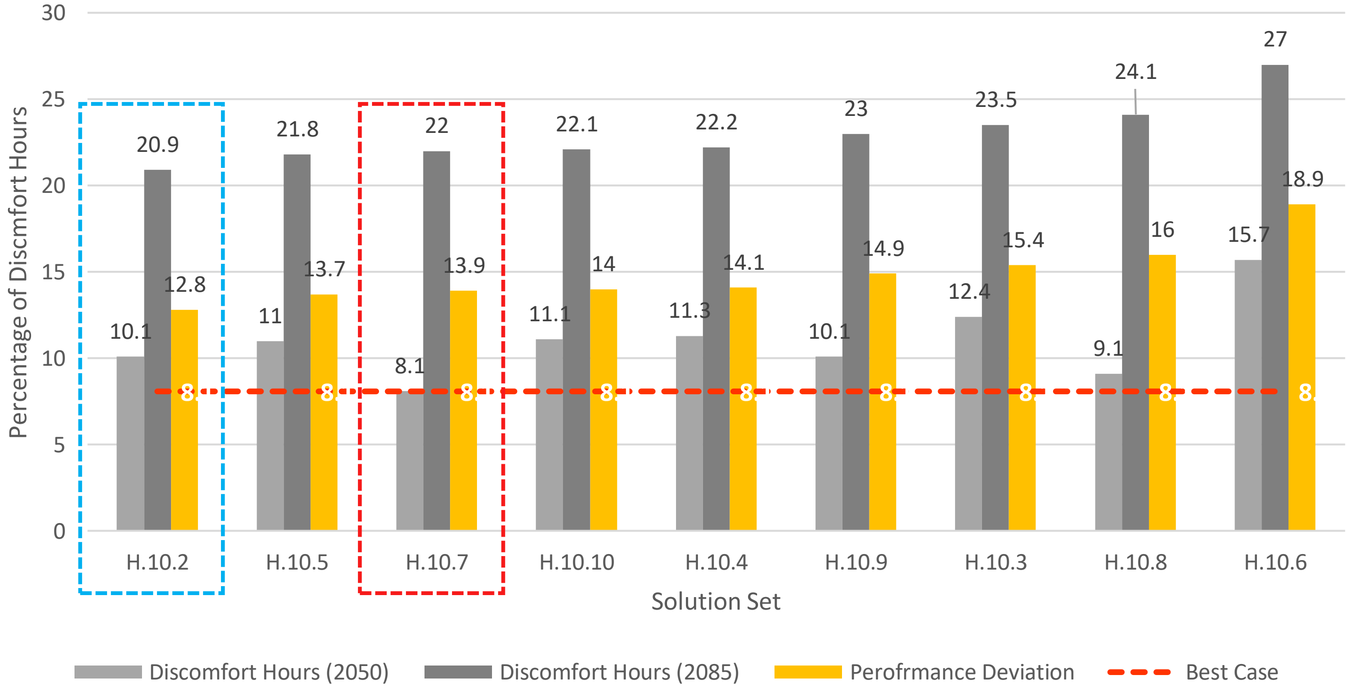


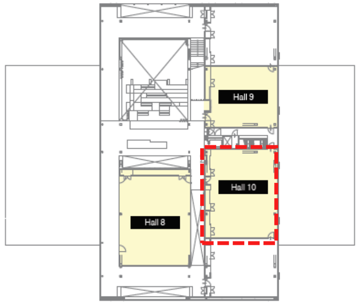
Code	Solution Set	Remarks
H10.2	WWR 75% + White Surfaced roof and Façade + External Roller Blinds	
H10.7	WWR 75% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	

Why does solution H.10.7 has high performance deviation when it is the best performing case ?

Actual performance of the solution must also be considered .

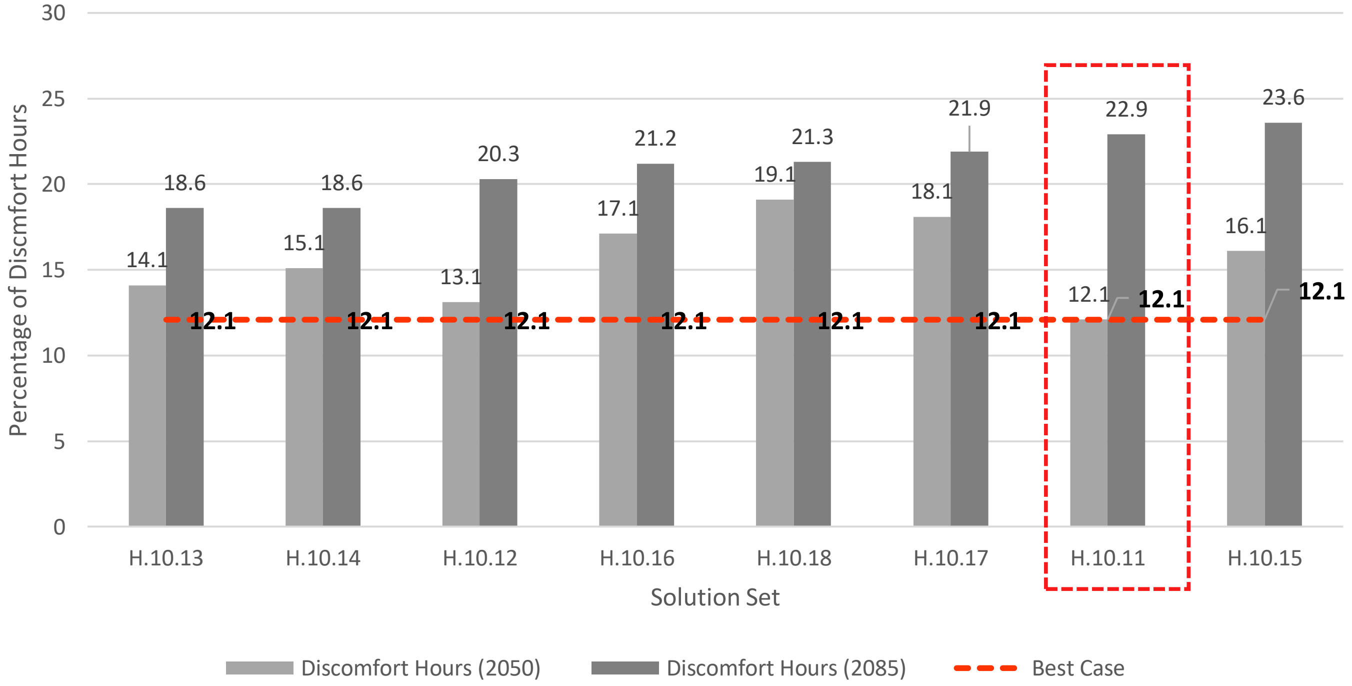
Pulse: Hall 10 (Existing Façade)

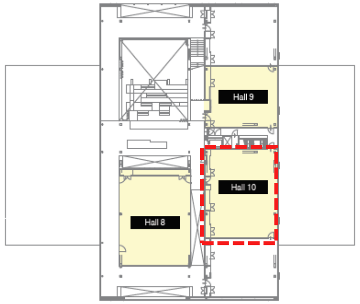




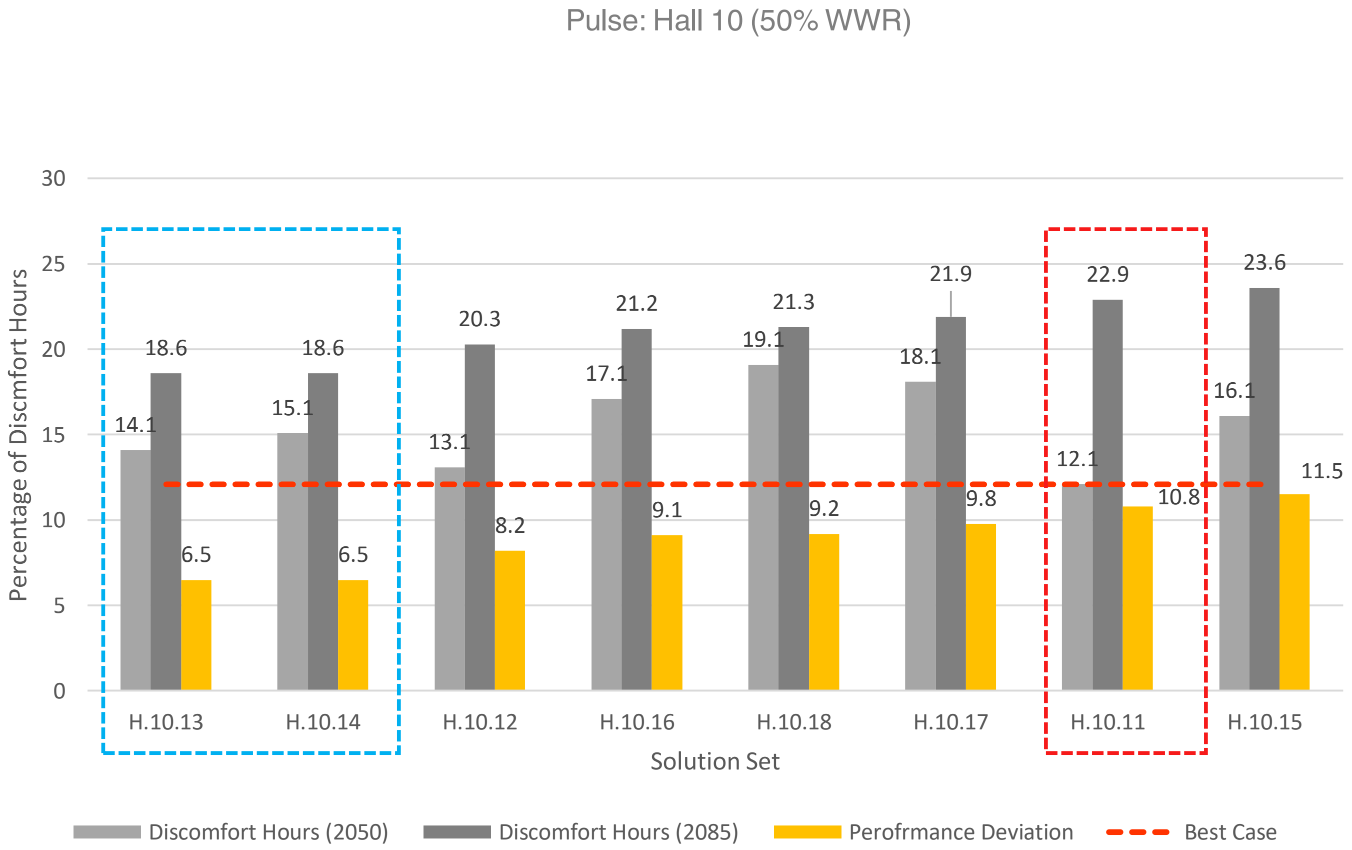
Code	Solution Set	Remarks
H10.11	WWR 50% + White Surfaced roof and Facade	
H10.12	WWR 50% + White Surfaced roof and Façade + External Roller Blinds	
H10.13	WWR 50% + White Surfaced roof and Facade+ 0.5 m overhang and 0.35 m sidefins.	
H10.14	WWR 50% + White Surfaced roof and Facade+ shutters	
H10.15	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels	Existing two windows openings with 40% openable area operating through out the day PCM modelled as 80 mm concrete
H10.16	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	
H10.17	WWR 50% + White Surfaced roof and Facade+ mixed mode +PCM Panels+0.5 m overhang and 0.35 m sidefins.	
H10.18	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+ shutters	

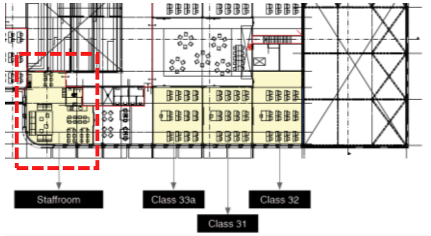
Pulse: Hall 10 (50% WWR)



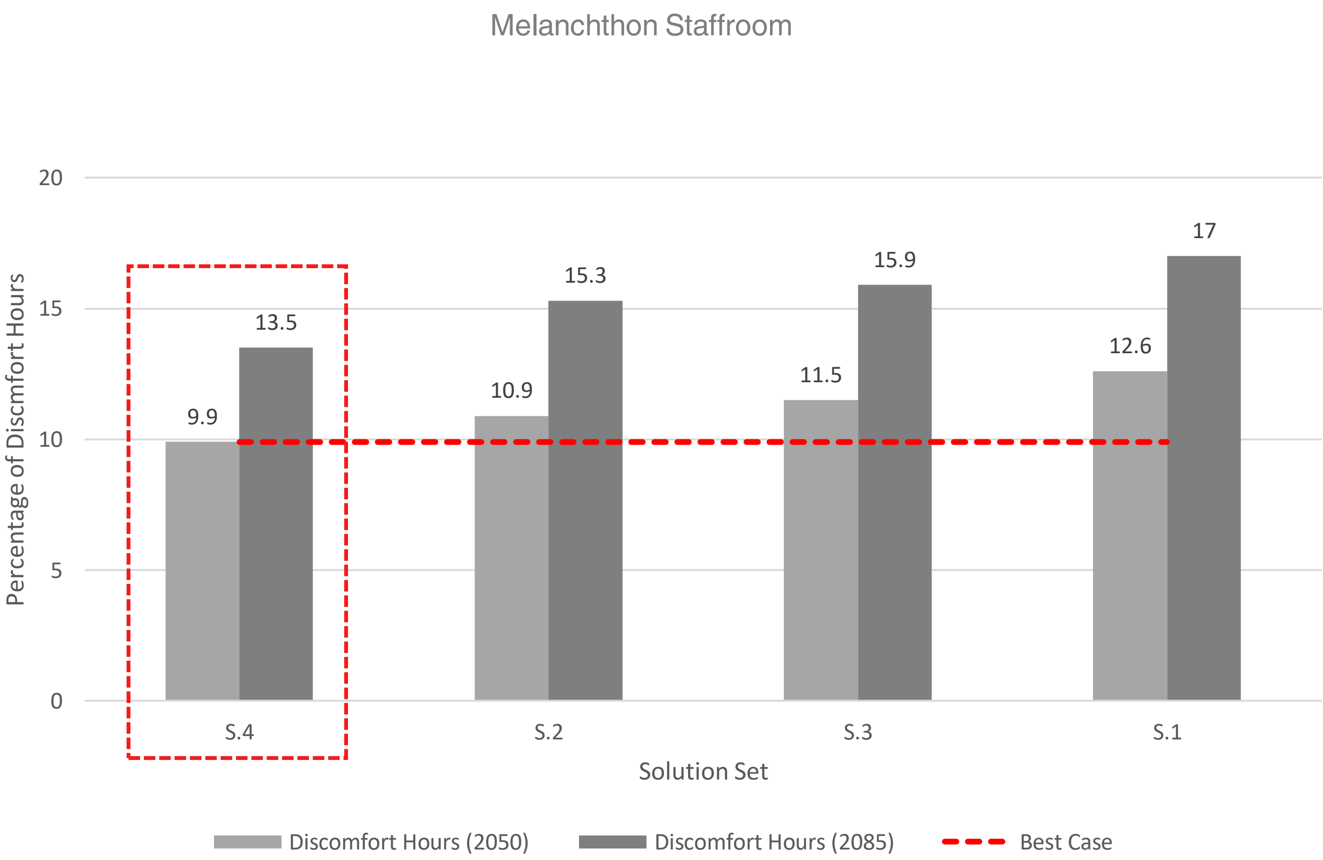


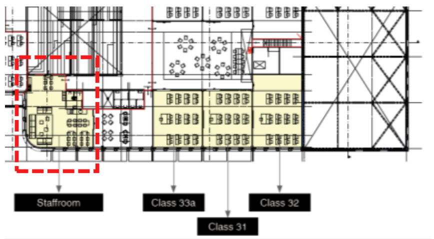
Code	Solution Set	Remarks
H10.11	WWR 50% + White Surfaced roof and Facade	
H10.12	WWR 50% + White Surfaced roof and Façade + External Roller Blinds	
H10.13	WWR 50% + White Surfaced roof and Facade+ 0.5 m overhang and 0.35 m sidefins.	
H10.14	WWR 50% + White Surfaced roof and Facade+ shutters	
H10.15	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels	Existing two windows openings with 40% openable area operating through out the day PCM modelled as 80 mm concrete
H10.16	WWR 50% + White Surfaced roof and Facade+ mixed-mode +PCM Panels+ external blinds	
H10.17	WWR 50% + White Surfaced roof and Facade+ mixed mode +PCM Panels+0.5 m overhang and 0.35 m sidefins.	
H10.18	WWR 75% + White Surfaced roof and Facade+ mixed mode +PCM Panels+ shutters	



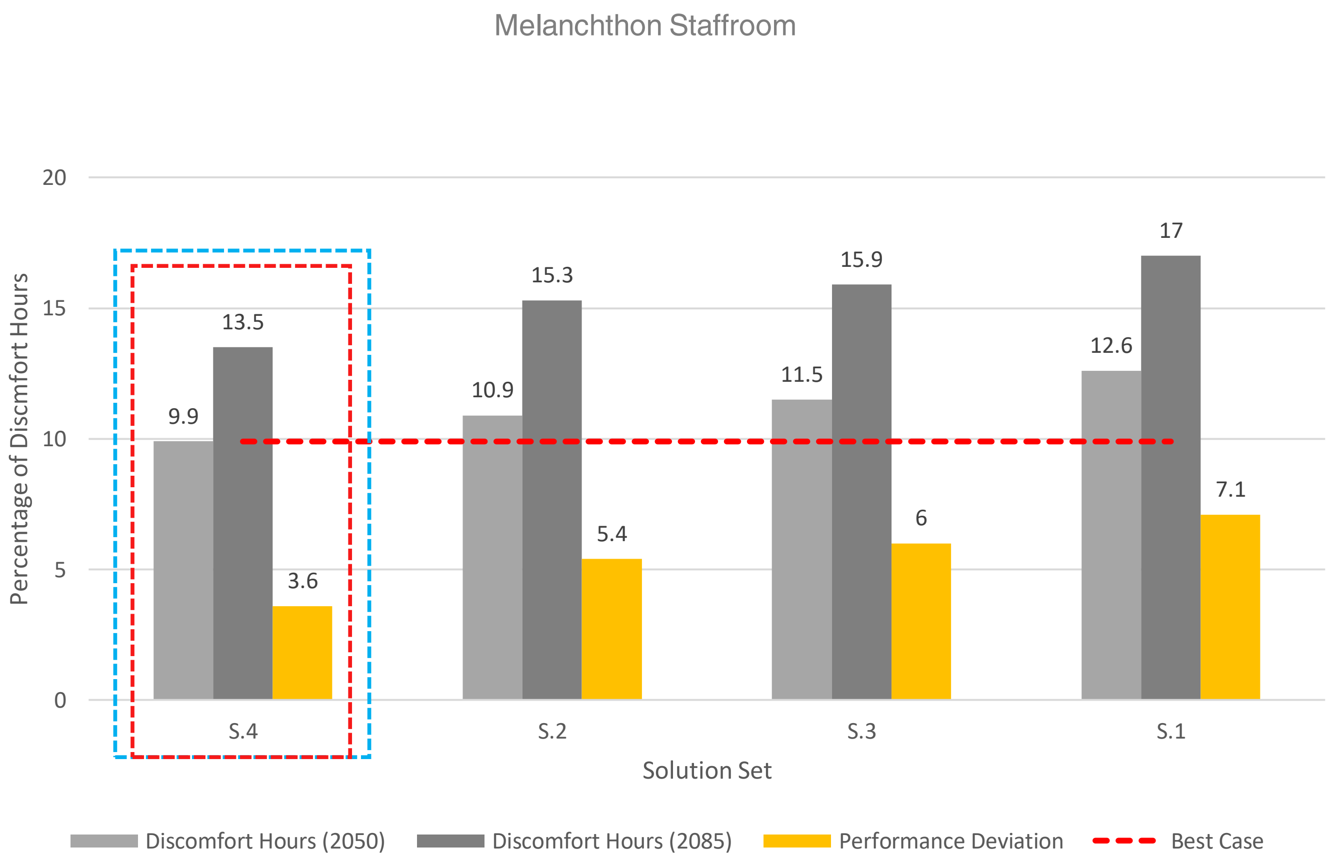


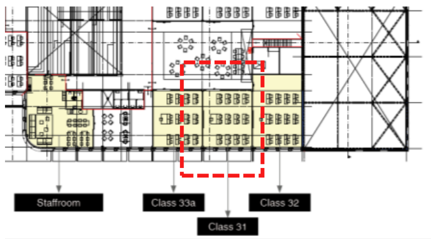
Code	Solution Set	Remarks
S.1	White Surfaced roof and Facade	
S.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
S.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
S.4	White Surfaced roof and Facade+2 m width pergola +PCM Panels	extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete



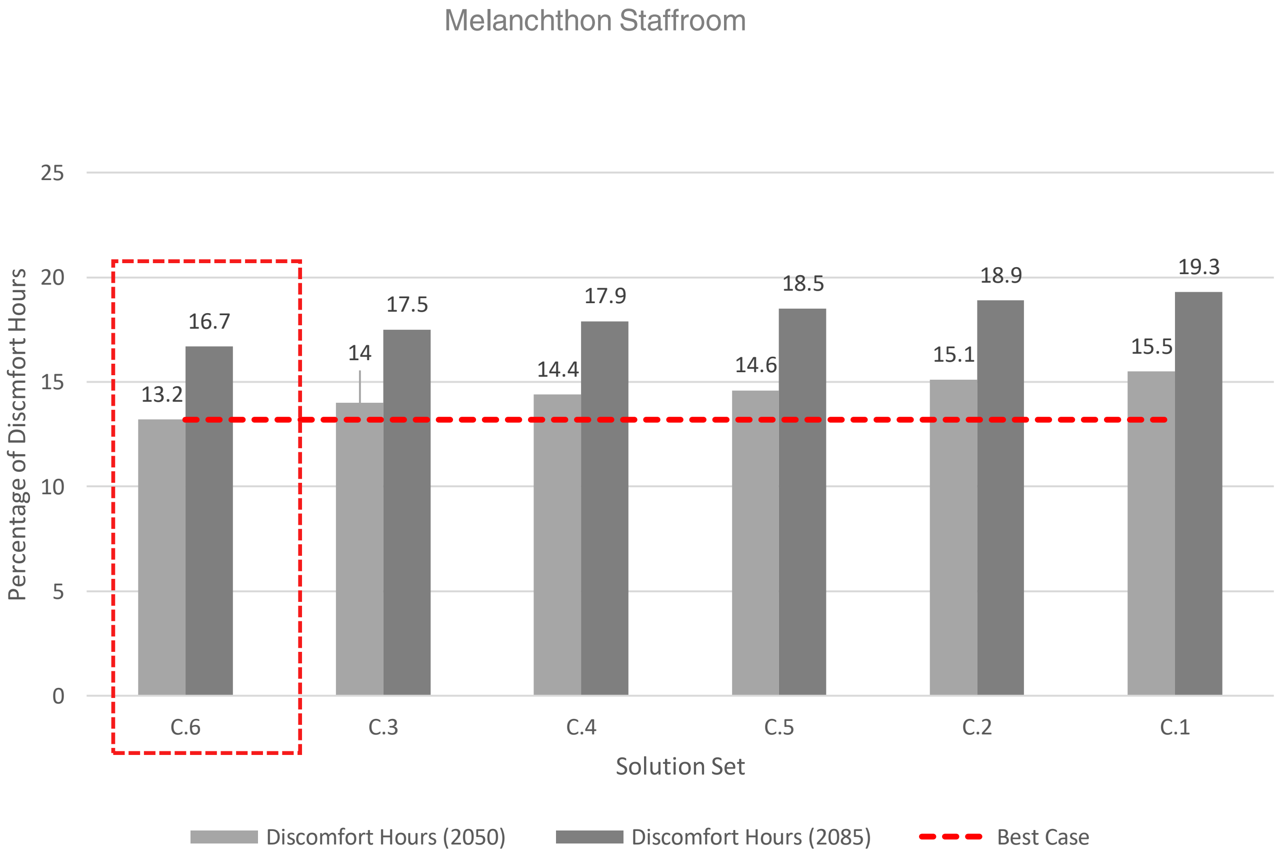


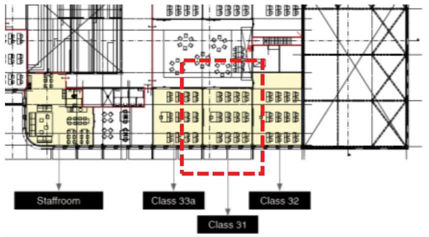
Code	Solution Set	Remarks
S.1	White Surfaced roof and Facade	
S.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
S.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
S.4	White Surfaced roof and Facade+2 m width pergola +PCM Panels	extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete



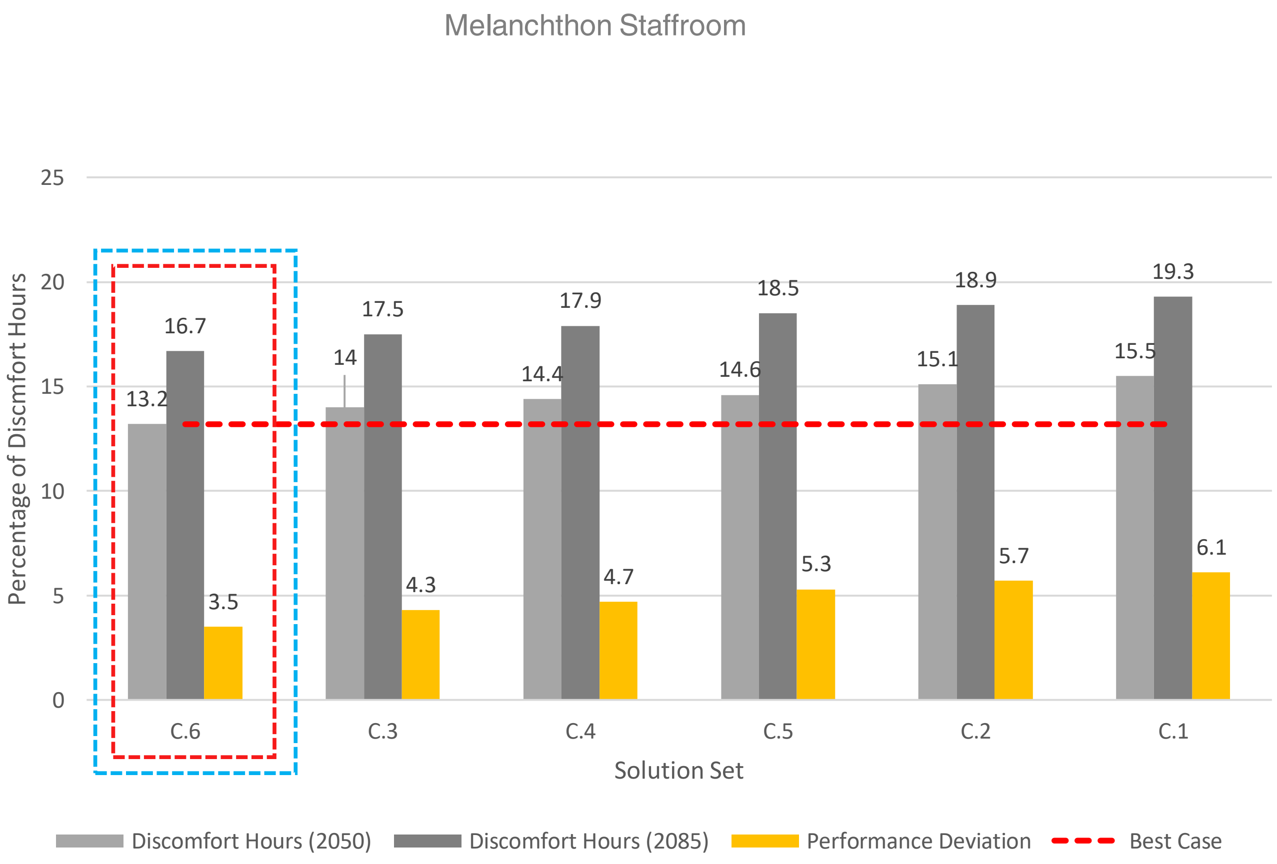


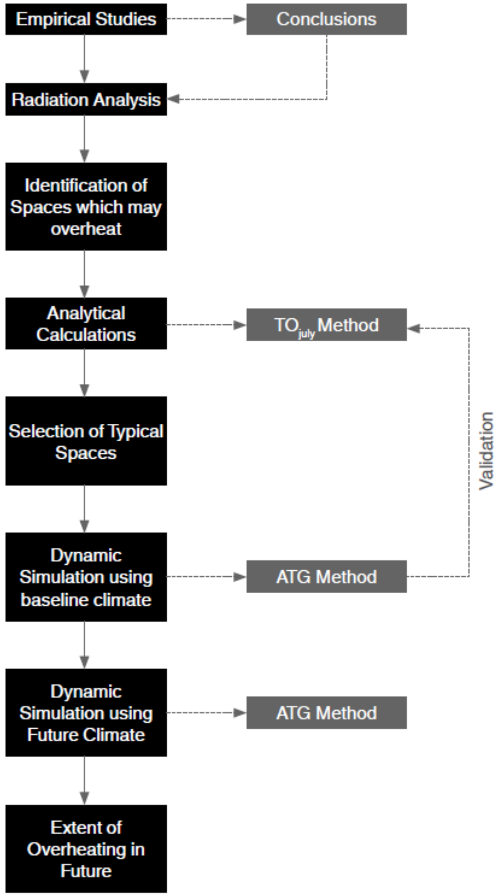
Code	Solution Set	Remarks
C.1	White Surfaced roof and Facade	
C.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
C.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
C.4	White Surfaced roof and Facade +PCM Panels+ WWR 50%	PCM modelled as 80 mm concrete
C.5	White Surfaced roof and Facade +PCM Panels + combination of openings	BMS controlled Ventilator at top with manual opening windows at the bottom PCM modelled as 80 mm concrete
C.6	White Surfaced roof and Facade +PCM Panels+ combination of openings+ 2 m width pergola	BMS controlled Ventilator at top with manual opening windows at the bottom extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete



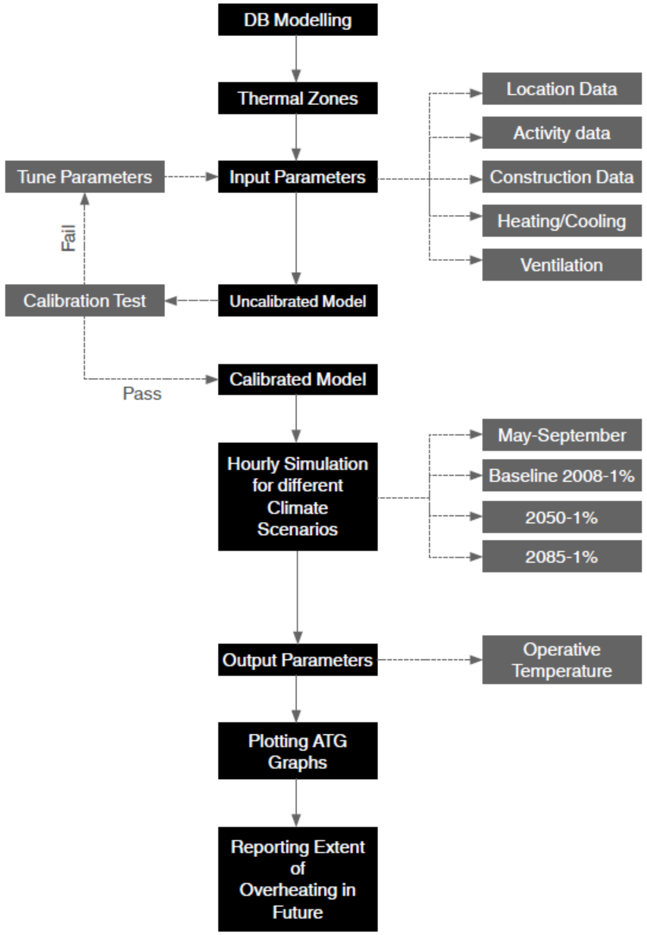


Code	Solution Set	Remarks
C.1	White Surfaced roof and Facade	
C.2	White Surfaced roof and Façade +PCM Panels	Night ventilation already present by summer bypass. PCM modelled as 80 mm concrete
C.3	White Surfaced roof and Facade+2 m width pergola	extension of pergola on ground floor to first floor
C.4	White Surfaced roof and Facade +PCM Panels+ WWR 50%	PCM modelled as 80 mm concrete
C.5	White Surfaced roof and Facade +PCM Panels + combination of openings	BMS controlled Ventilator at top with manual opening windows at the bottom PCM modelled as 80 mm concrete
C.6	White Surfaced roof and Facade +PCM Panels+ combination of openings+ 2 m width pergola	BMS controlled Ventilator at top with manual opening windows at the bottom extension of pergola on ground floor to first floor PCM modelled as 80 mm concrete

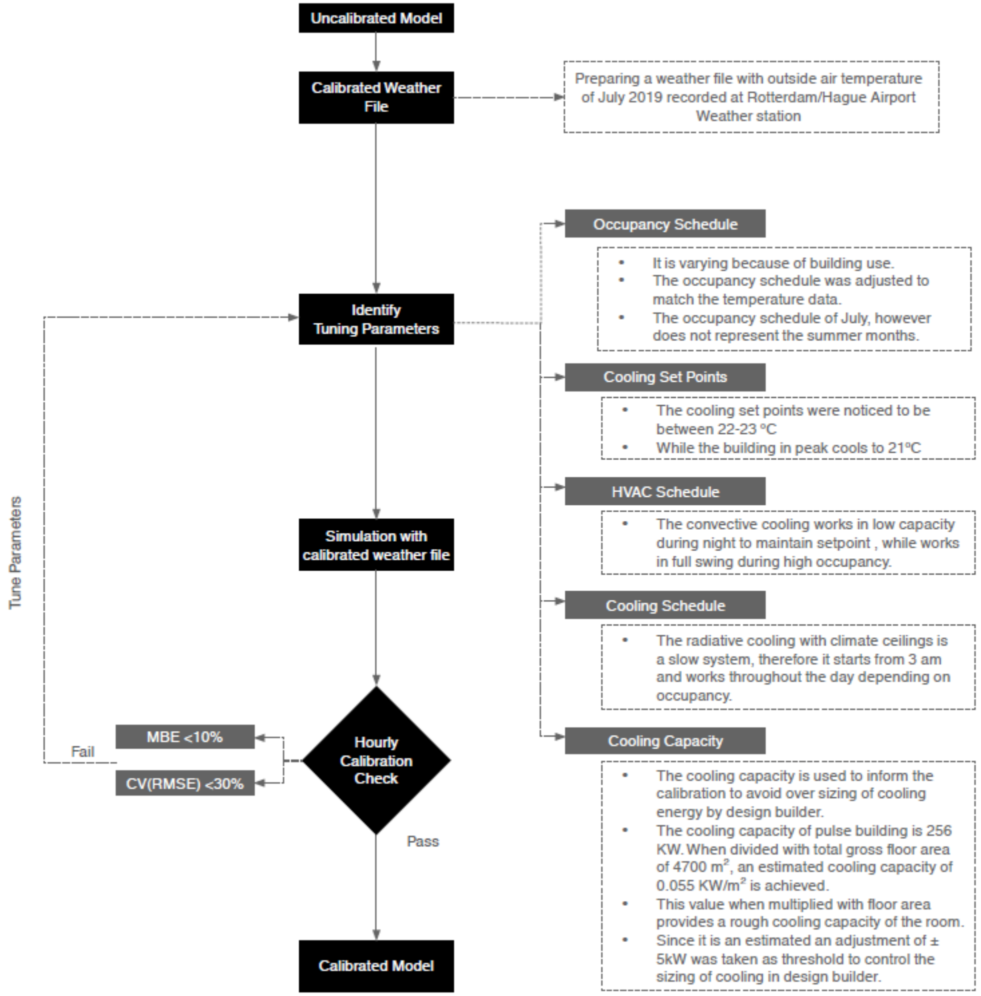




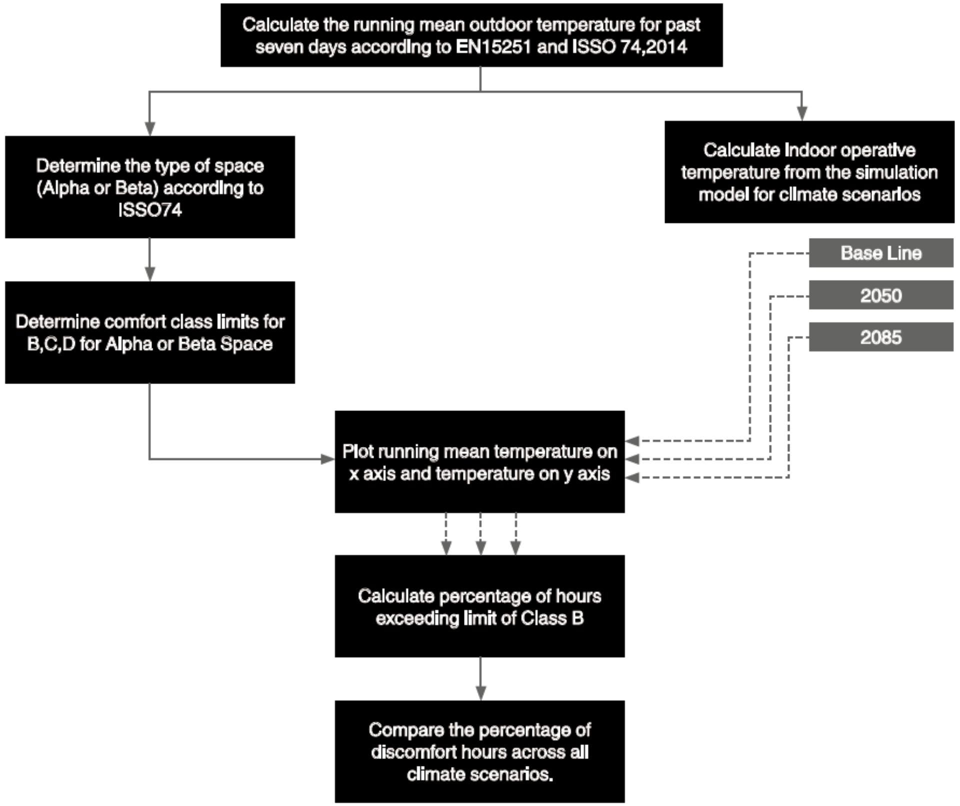
Analytical Calculations



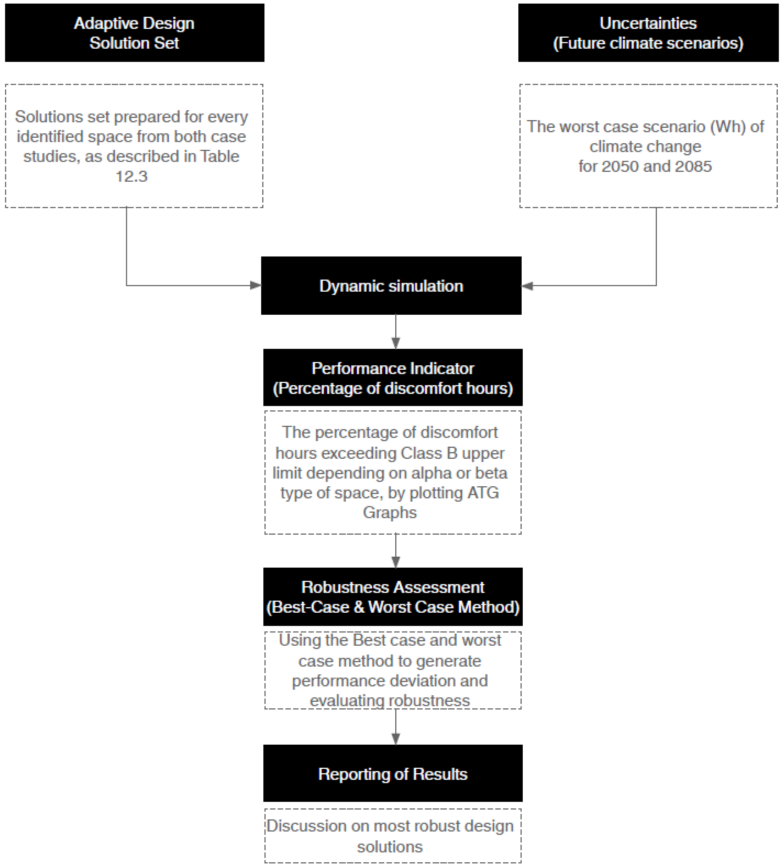
Dynamic Calculations



Dynamic Model Calibration



Plotting ATG Graphs



Robustness Evaluation