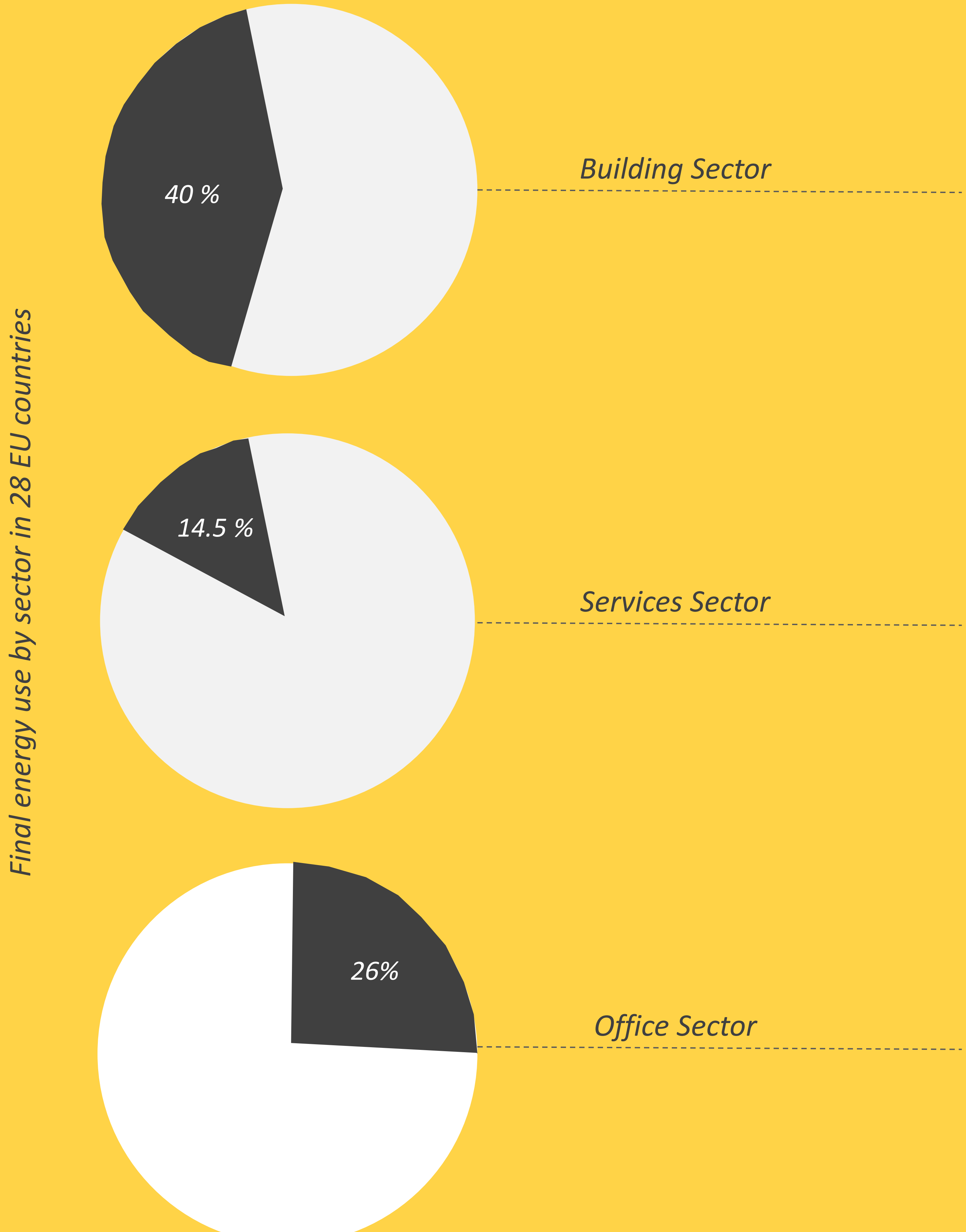
“So, ladies and gentlemen. Let’s act. Let’s act together. And let’s act now! “
-Mark Rutte, Prime Minister of The Netherlands

(Ministerie van Algemene Zaken, 2015)



(Eurostat, 2017)
(National Energy Foundation, 2016)

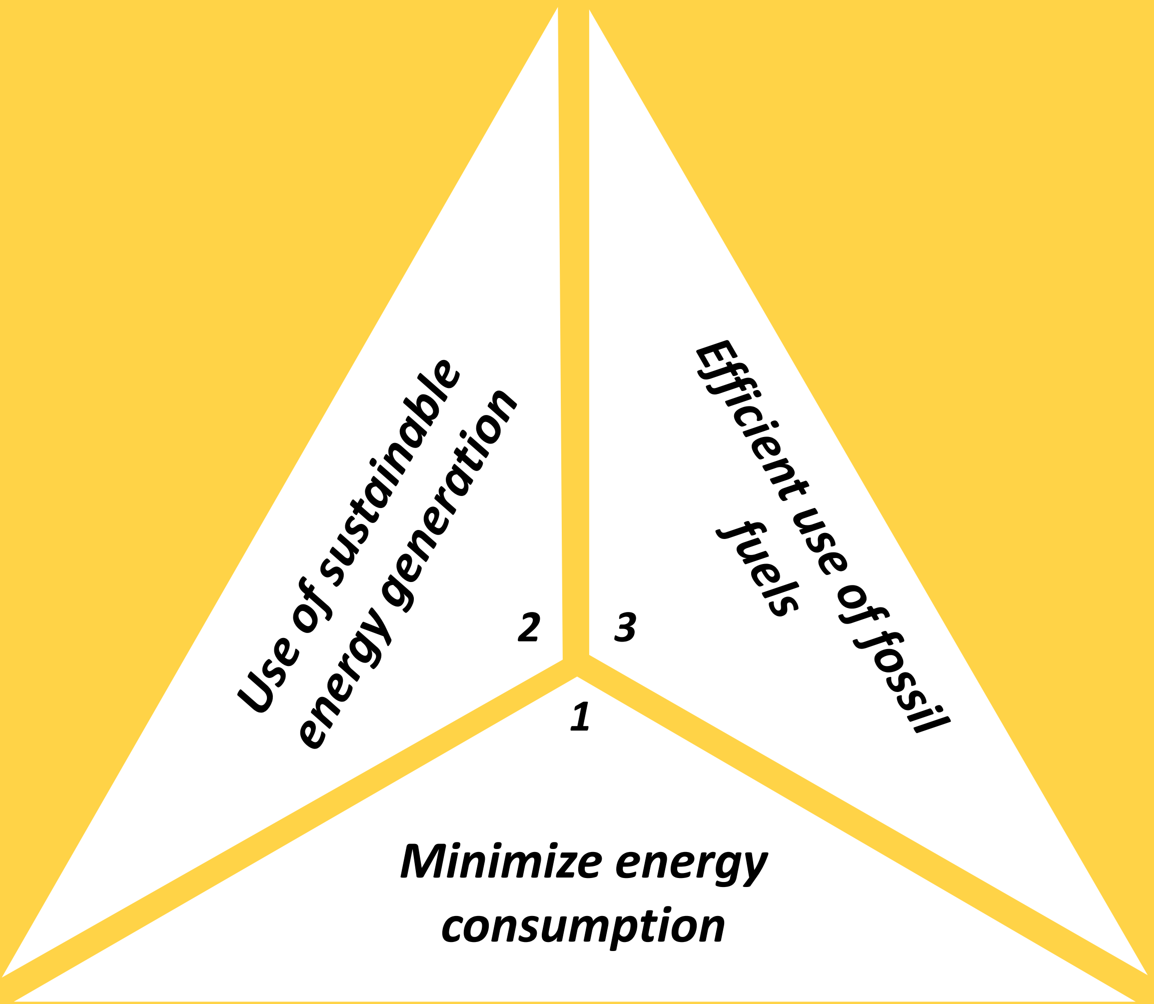
45 %

45% of the offices in The Netherlands are older than **30 years.**

-50 %

Energy renovation can **reduce** the overall energy demand by **50%.**

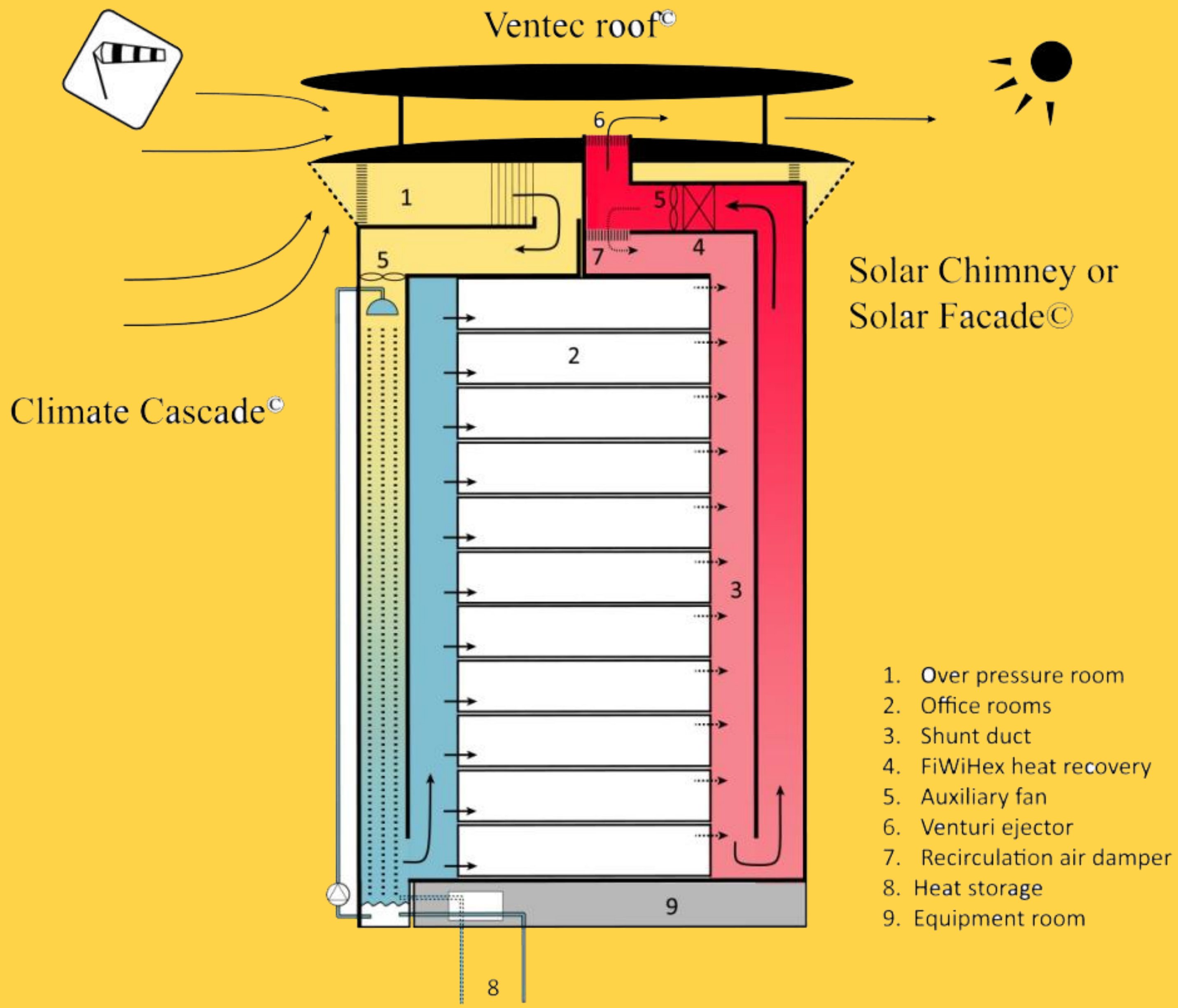
(Vijverberg, 2002)
(Saheb et al., 2015)



Design principle NZEB: Trias Energetica

Only **7.8%** of the total final energy consumption in The Netherlands **use the energy generated from renewable sources**.

(EPBD, 2016)
(European Commission, 2020)



The **Earth, Wind and Fire concept** (EWF) can play a key intervention as it utilizes the environmental energy of **earth mass, wind and sun** to **generate and supply energy**.

(Bronsema, 2013).

Refurbishment of an office building in The Netherlands using the Earth, Wind and Fire system.

P5| Shriya Balakrishnan

1st Mentor: Dr. R.M.J. Bokel (Building Physics and Services)
2nd Mentor: Dr. ing. T. Konstantinou (Building Product Innovation)
Research Advisors: Kitty Huijbers (ABT), Dr. Ben Bronsema & Provinciehuis Utrecht

Research Question | *Literature study* | *Analysis* | *Results* | *Conclusion*

Research Question *Literature study* *Analysis* *Results* *Conclusion*

Research Question   *Literature study*   ***Analysis***   *Results*   *Conclusion*

Research Question

Literature study

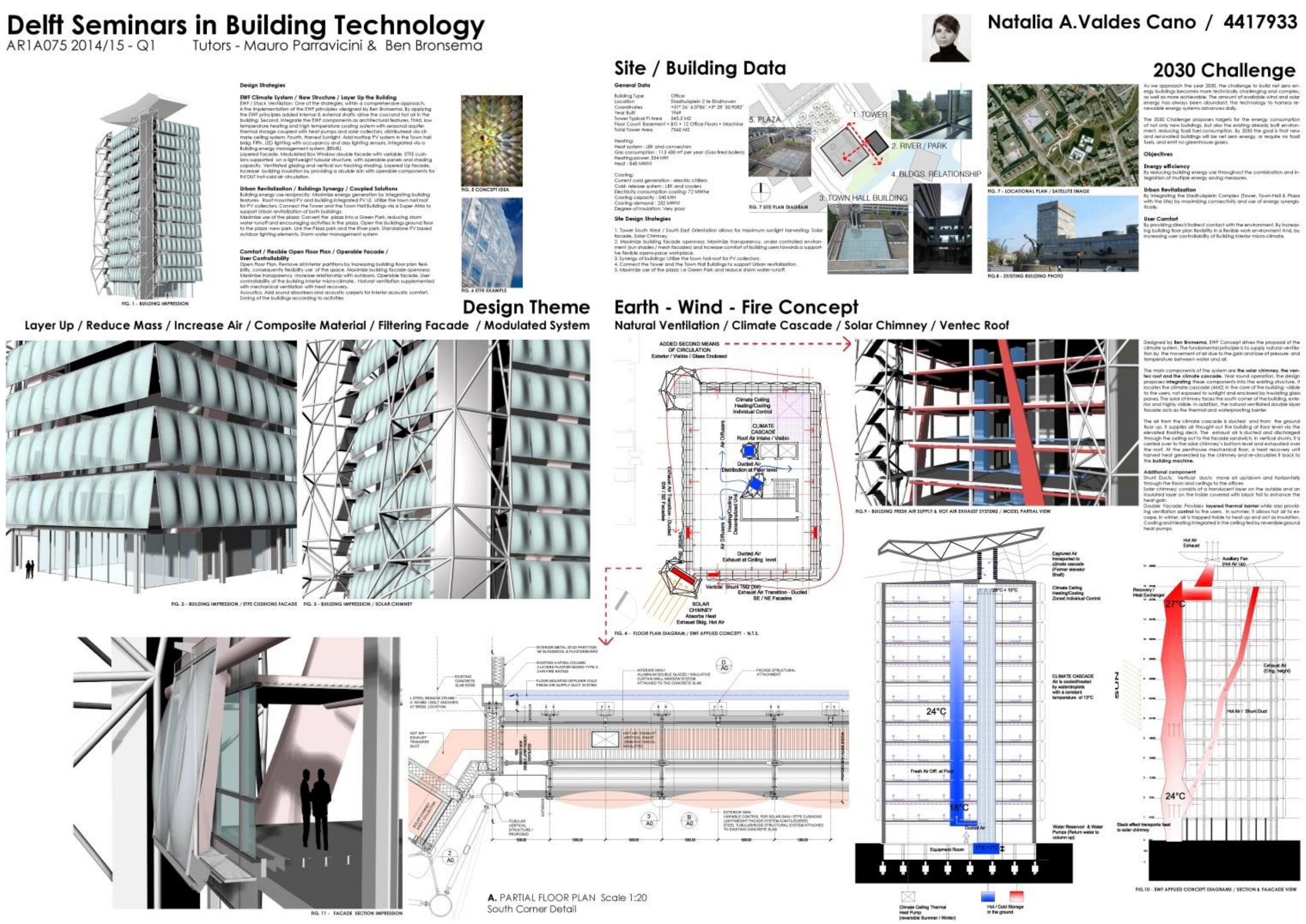
Analysis

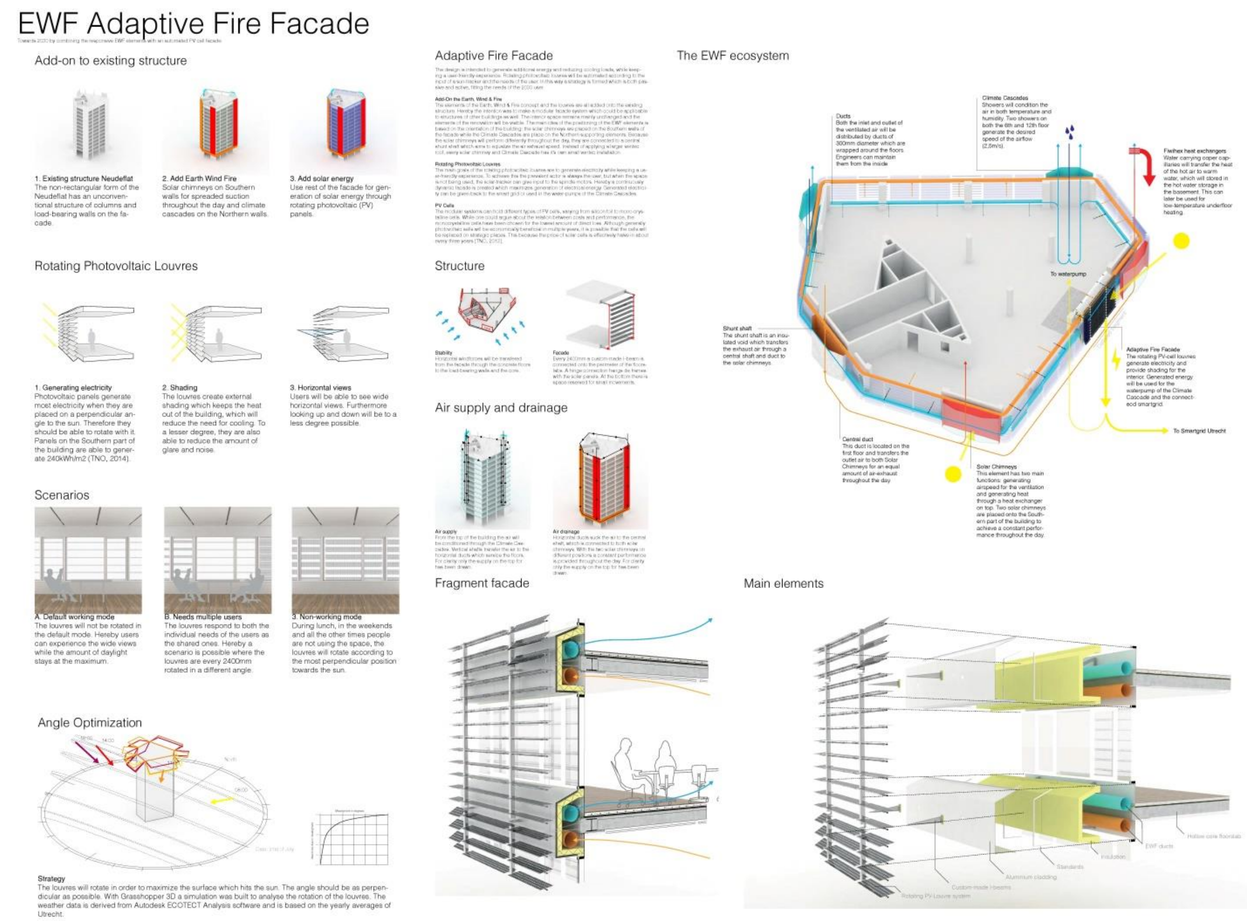
Results

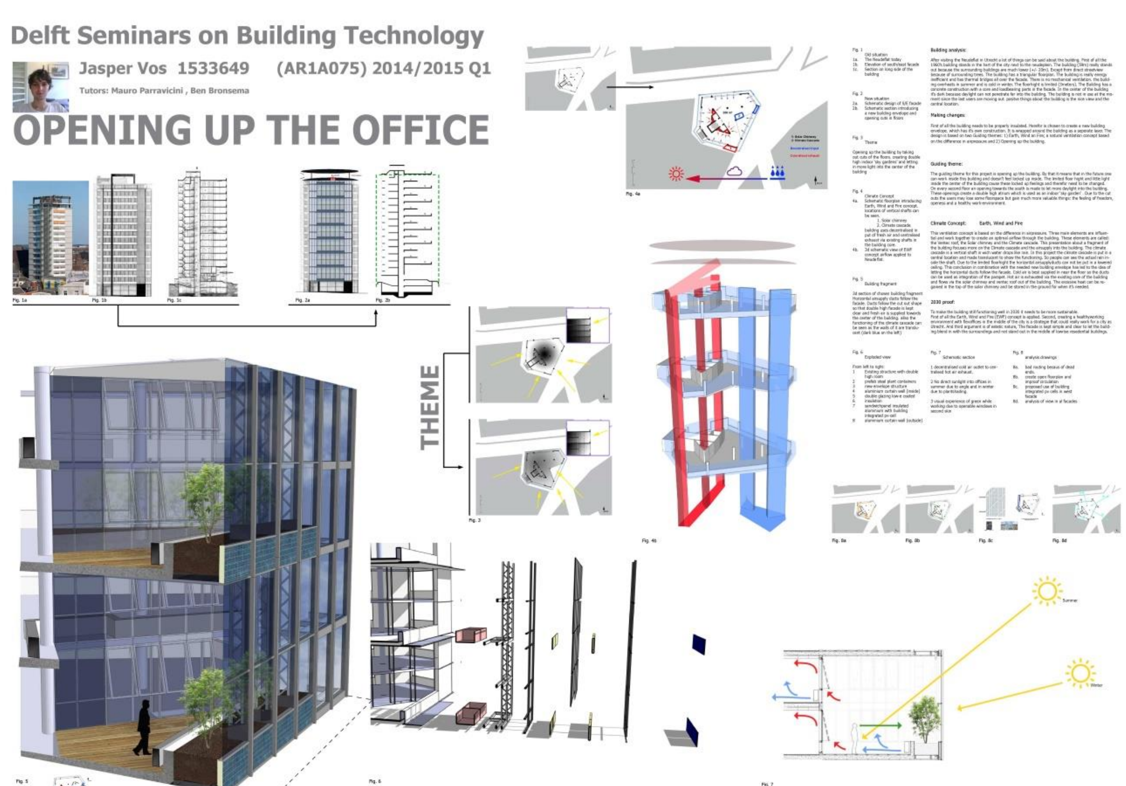
Conclusion

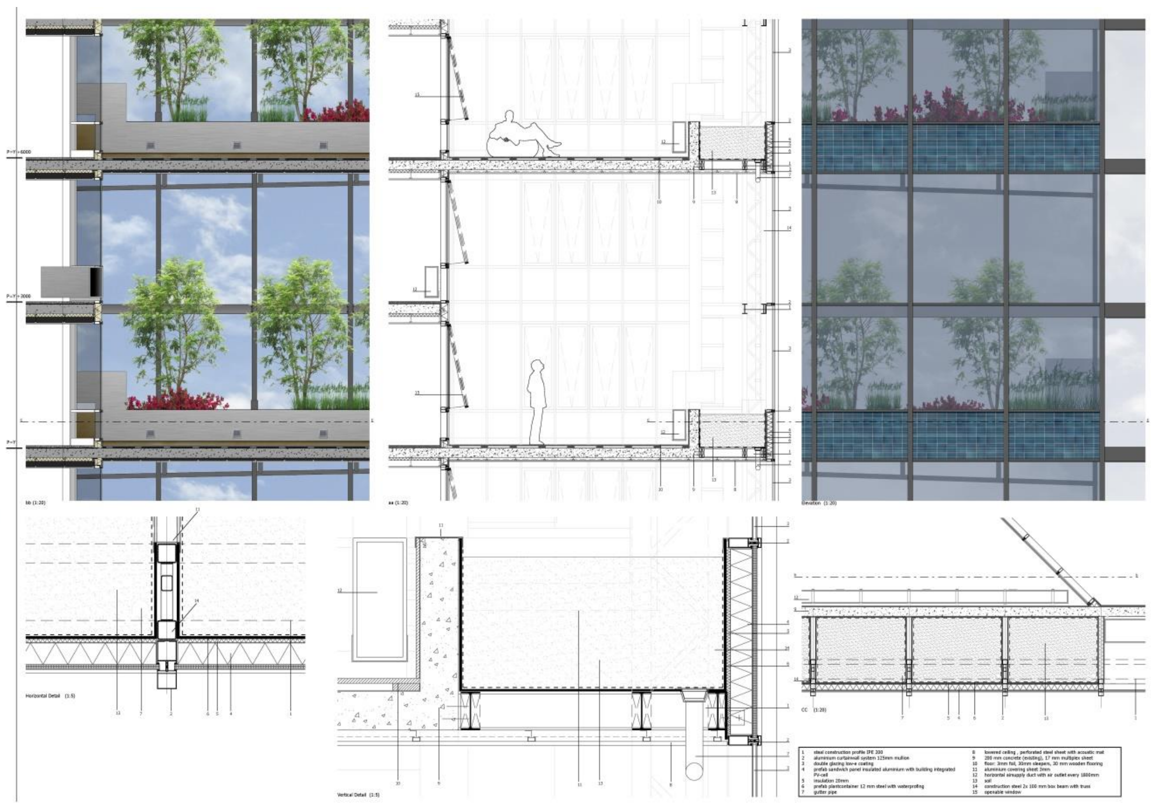
Research Question | *Literature study* | *Analysis* | *Results* | ***Conclusion***

How are the **design strategies,** derived from the **Earth, Wind and Fire system**, implemented in the **refurbishment of an office building** in The Netherlands in order to **improve the energy performance**?









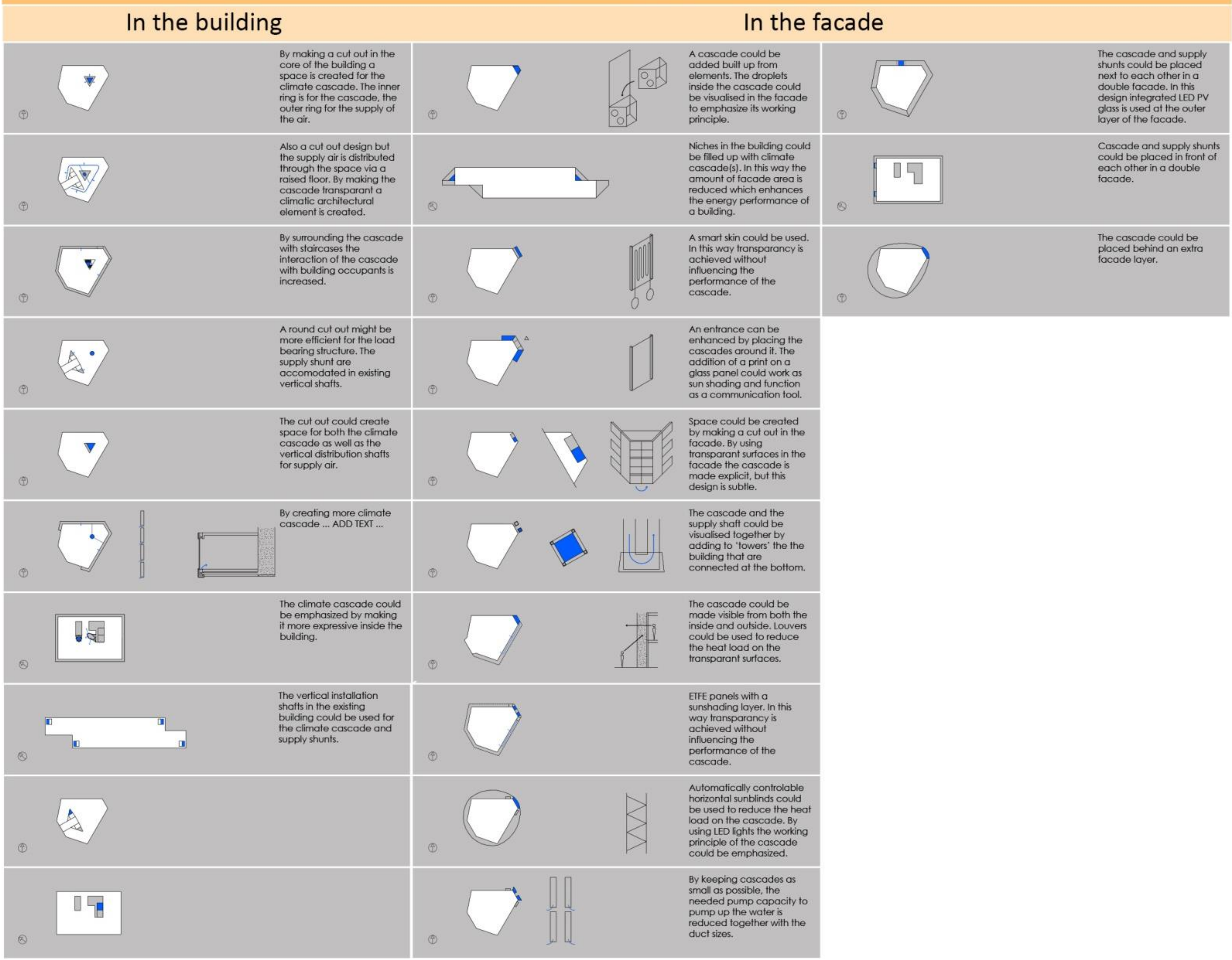
(Brightspace, 2020)

SOLAR CHIMNEY

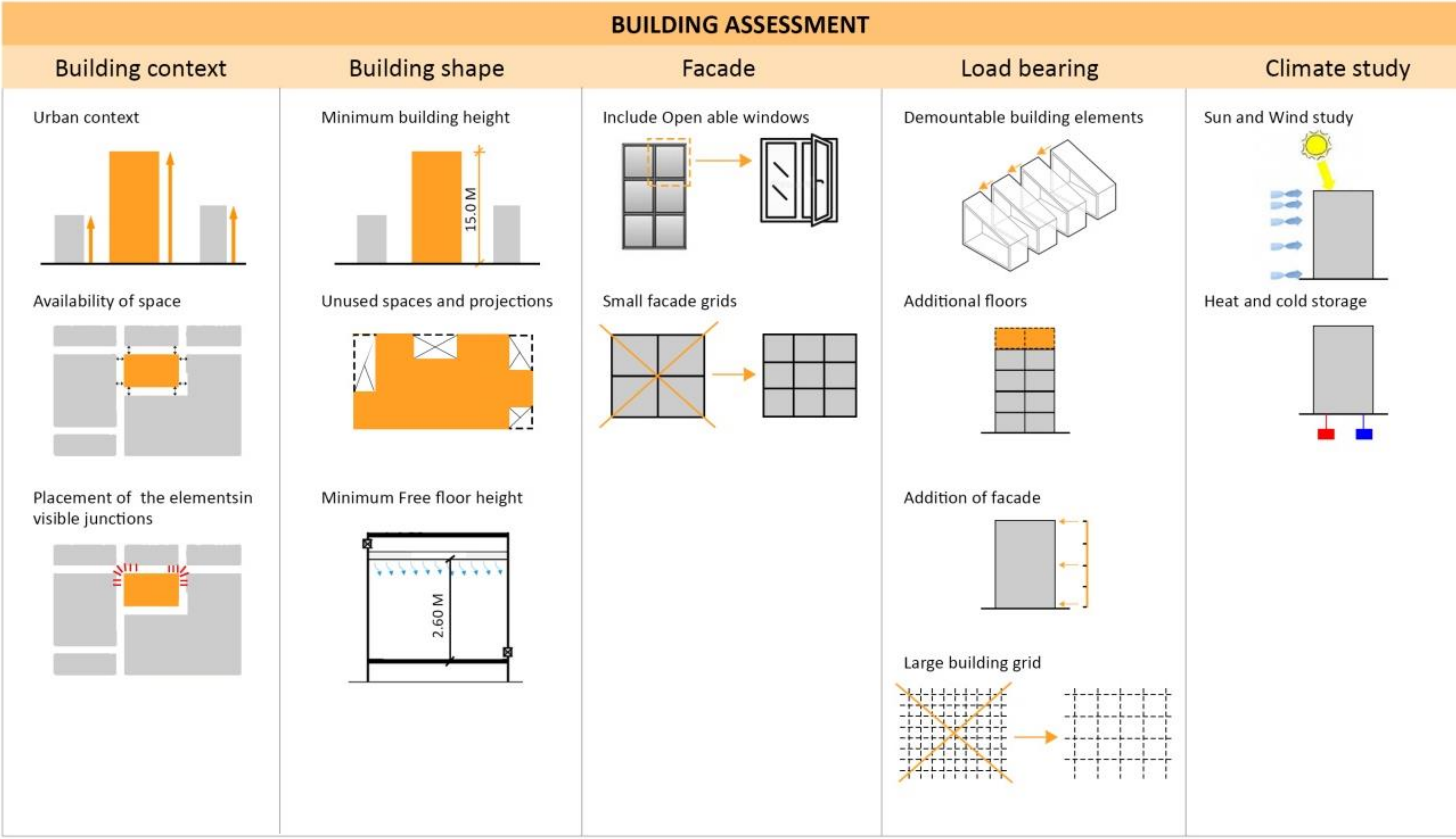
Separate from the building	Connected to the building	In the facade	On the roof
Seperate chimney's could function as sun shading device and to get more daylight into the building.	A chimney could be designed like it bumped into the existing building. By combining it with an atrium the distribution of exhaust air could also be arranged.	The niches in the building shape could be filled up with chimney. This doesn't make them very expressive but is effective from a climatic point of view by reducing the facade area.	By adding a greenhouse on the roof of a building, air could be sucked out of the building due to the overpressure in the greenhouse.
Reuse old material to construct the chimney. Put a small ventec roof on top of the chimney to improve its performance.	An expressive 'proboscis'-like chimney could be added to the building.	The chimney could be expressed a bit in the facade by delecate changes in the shape of an extra facade layer.	
A lot of small chimney's around the building would add character but compromise on its performance.	The chimney's and supply/exhaust shunts could be made expressive/explicit in the shape of an extra facade layer that is wrapped around the building.	The chimney('s) could be hided behind an extra facade layer that is wrapped around the building.	
One large seperate chimney would have a better performance than a lot of small chimney's. Seperation of the building would allow more daylight in the building.	The collection of the exhaust air at the bottom of the building could be made expressive with big shunt channels that circle around the building.	The chimney('s) could be hided behind an extra facade layer that is wrapped around the building.	
	The diagrid structure could be emphasized with a swaying chimney and exhaust shunts in different directions around it.	By creating a solar facade the building shape is kept the same but the building performance is improved.	
Swaying chimney's around the building wouldn't compromise its performance but add more architectural identity. Add heat recovery on top incl. turbine to produce energy.	Seperate facade elements with difference characteristics (depths, material) could be designed for the different EWF elements.	The chimney could be hided in an extra facade layer but delicately emphasized by an orientation of glass facade sheets.	
	A trapezium shaped chimney with integrated exhaust shunt could be should. The shape doesn't necessarily improve it's performance.	Space for the chimney's could be created by making cut outs in the structure if the structure allows this.	
	Whole floor elements could be removed to create an atrium with chimney's that stick out of the building.	Space for the chimney could be created by cutting off a part of a corner of the structure if the structure allows this.	

(Swier, 2019)

CLIMATE CASCADE

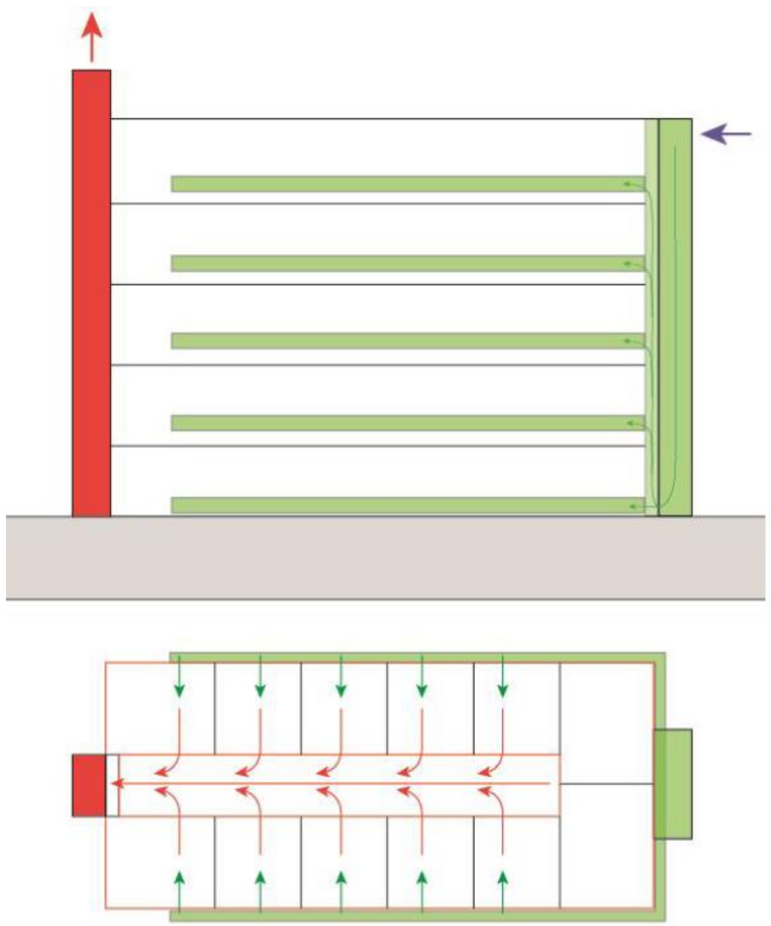


(Swier, 2019)

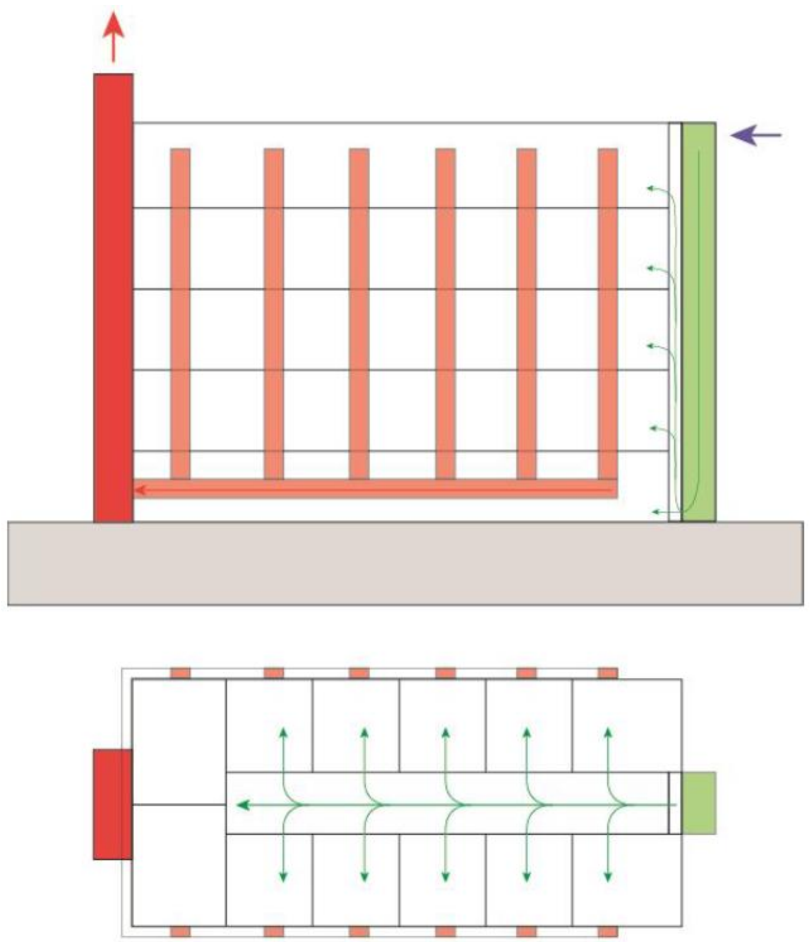

BUILDING ASSESSMENT
Building context
Building shape
Facade
Load bearing
Climate study
Urban context
Minimum building height
15.0 M
Include Open able windows
Demountable building elements
Sun and Wind study
Availability of space
Unused spaces and projections
Small facade grids
Additional floors
Heat and cold storage
Placement of the elementsin visible junctions
Minimum Free floor height
2.60 M
Addition of facade
Large building grid

EWF design strategies : General strategies

- **Shaft**/duct sizes are **bigger** than usual
- **Decentralized supply** and **centralized exhaust** or **centralized supply** and **decentralized exhaust.**



Centralized supply and decentralized exhaust



Decentralized supply and centralized exhaust

(Chaouat, 2015)

Climate cascade

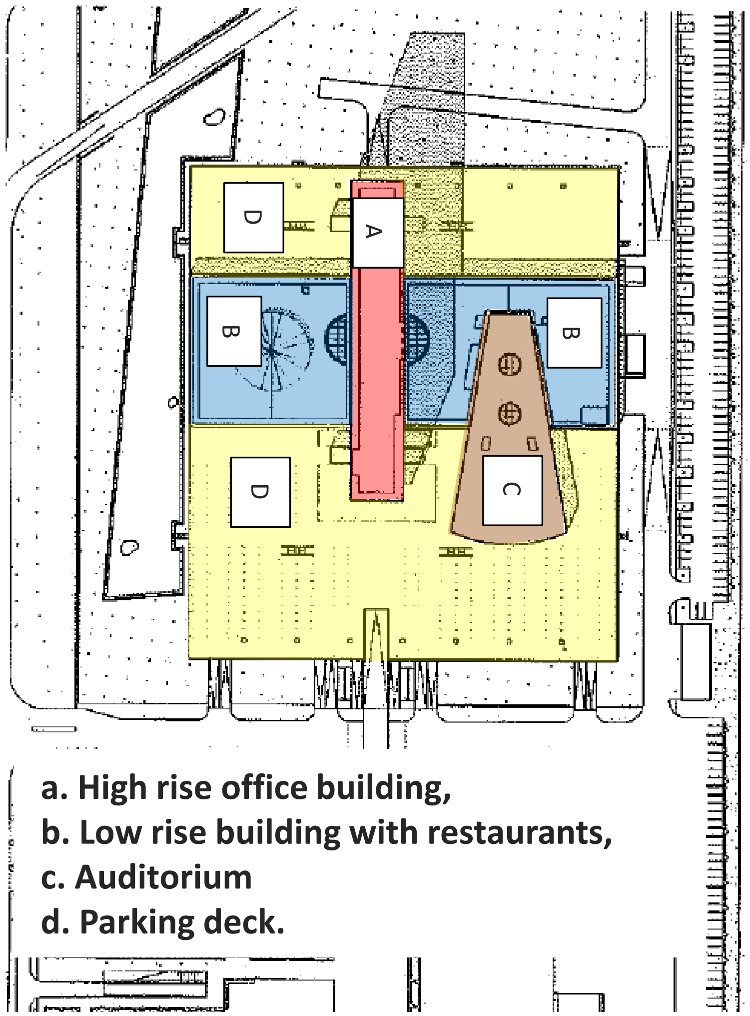
- The **ventilation capacity** of the climate cascade should be **6.5 dm/s/person .**
- Climate cascade should be placed at **every 6th floor or multiple of it** .

Solar Chimney

- Orientation: **South, South west or south east**.
- A **single big solar chimney** gives better results than multiple small chimneys.
- The **depth** should be **min 0.65 m**
- The glass panes should have a **high G-value** and **low U-value** .
- **Solar facades** are a good solution.
- **Building integrated PV** and **solar panels** on the roof can contribute to high energy savings.
- The **heat from the exhaust air** should be **reused and stored.**

Provinciehuis Utrecht , Utrecht (flying holland.nl, n.d.)

Construction period	: 1992-2012
Number of floors	: 18 floors (19^{th} and 20^{th} floors are technical spaces)
Size	: 53953 m^2 GFA/ 29096 m^2 GO
Parking area	: 18270 m^2 GFA
Function	: predominantly office with meeting function
Working hours	: 8:00 am – 8:00 pm (Mon-Fri)
Meeting rooms timings	: 8:00 am to 10:00pm (Mon-Fri)
No. of Occupants	: 1000
Floor height	: 3.5 m



Architectural data

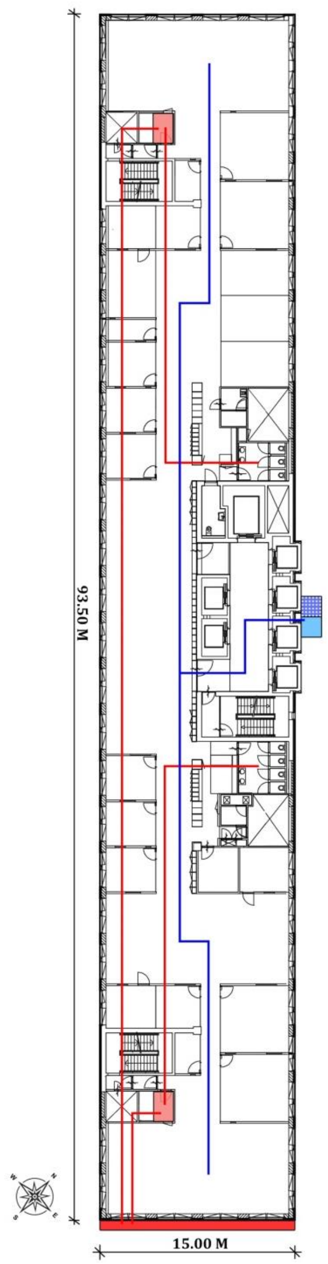
Façade	: Rc= 2.0
Climate window	: U=1.2 W/ m2 K (13cm cavity)
Sun protection inside	: electrically operated intermediate blinds

Technical data

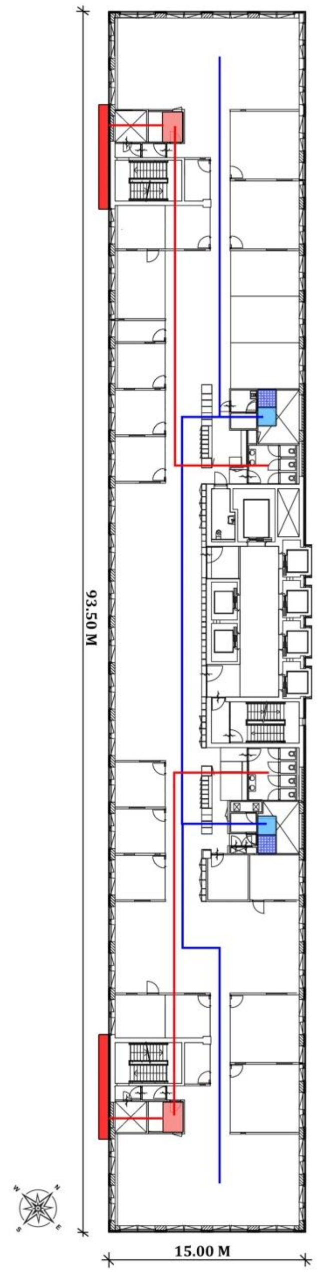
Heat generation	: district heat network Utrecht-Nieuwegein (ŋ= 150%)
Heat distribution	: VAV boxes (transport medium water)
Space heating control	: room thermostats
Cold generation	: air/water compression refrigerators
Cold distribution	: ventilation air (transport medium air with 7°C)
Ventilation	: mechanical exhaust and supply
Domestic Hot Water	: TSA on district heating network and electric boilers
Humidification	: adiabatic humidification
Heat recovery high rise	: heat wheels

4 Design options

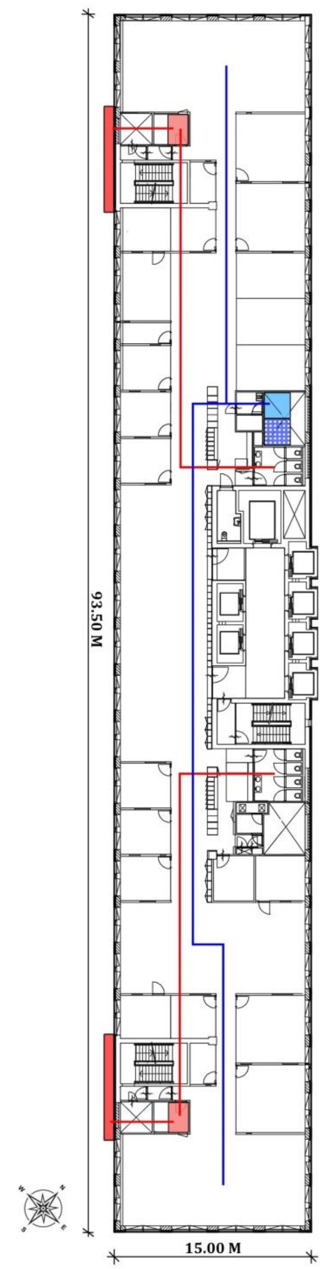
Case 1: 1 Climate Cascade, 1 Solar Chimney



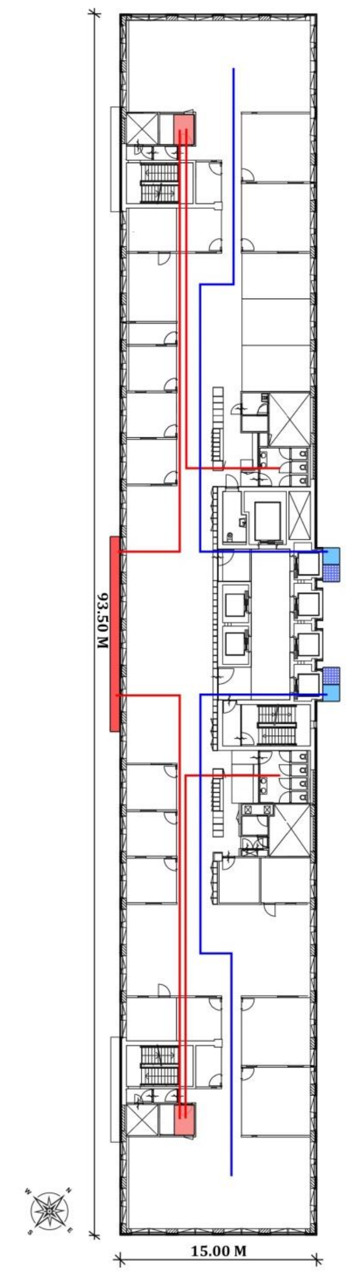
Case 2: 2 Climate Cascade, 2 Solar Chimney



Case 3: 1 Climate Cascade, 2 Solar Chimney

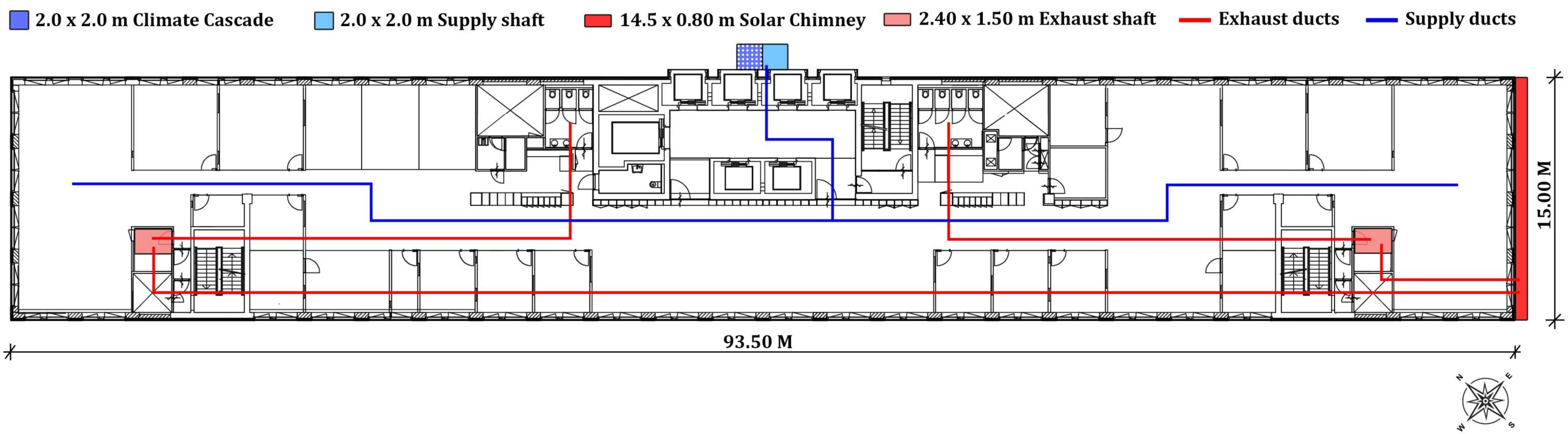


Case 4: 2 Climate Cascade, 1 Solar Chimney

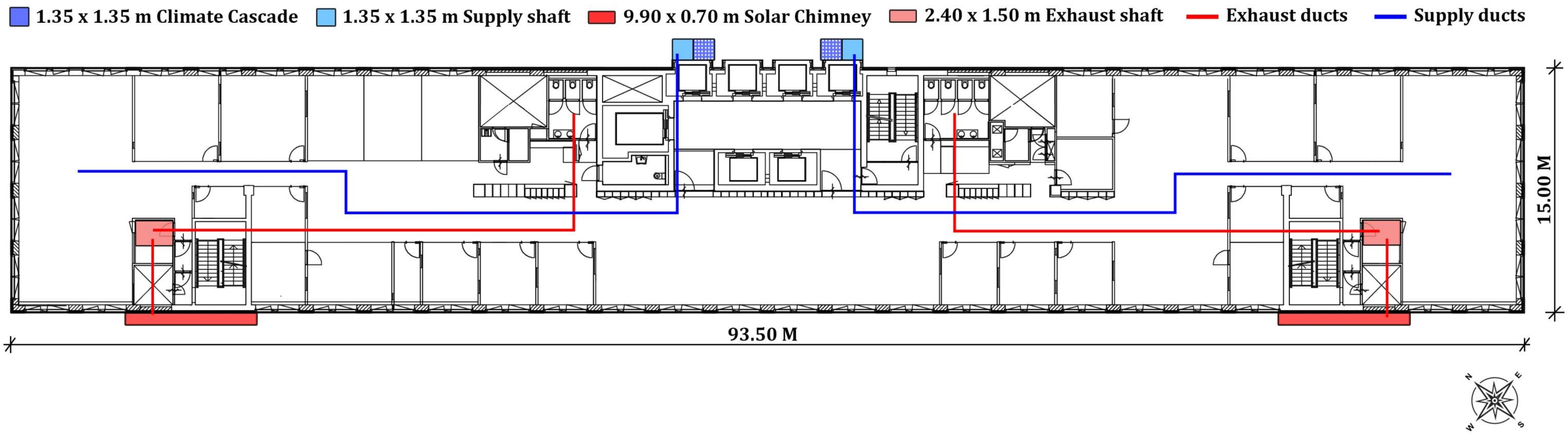


Climate Cascade | Supply shaft | Solar Chimney | Exhaust Exhaust shaft | Exhaust ducts | Supply ducts

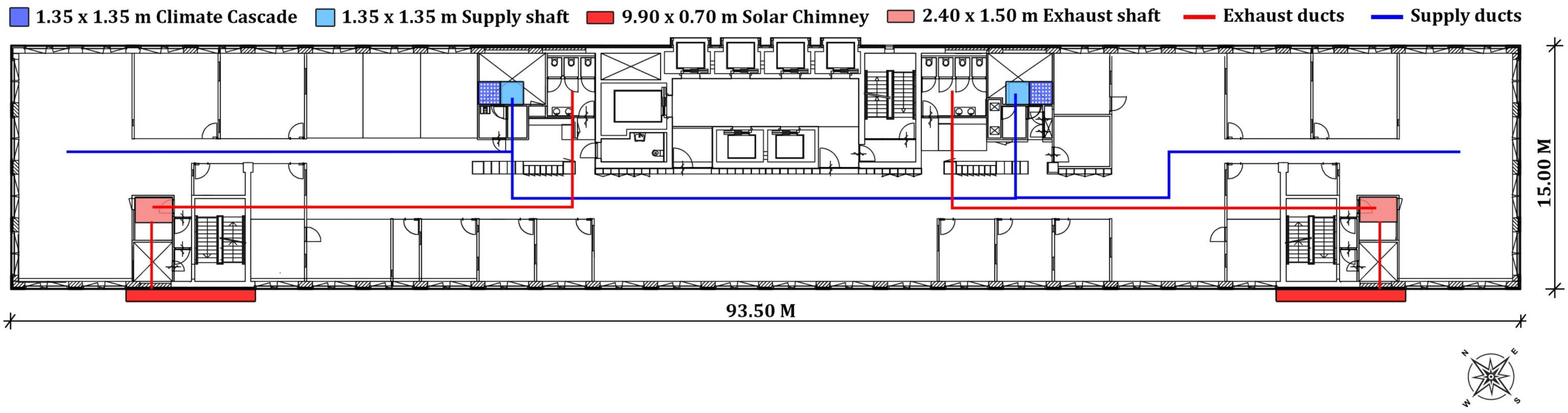
Case 1: 1 Climate Cascade, 1 Solar Chimney
(Decentralized supply, Centralized exhaust)



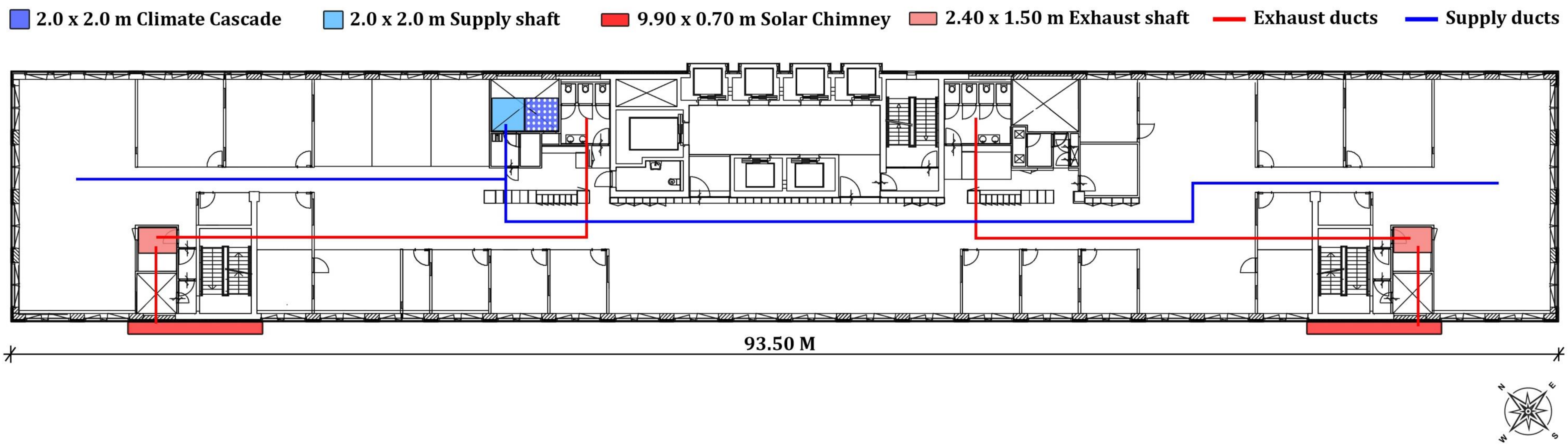
Case 2a: 2 Climate Cascade, 2 Solar Chimney (Decentralized supply, Decentralized exhaust)



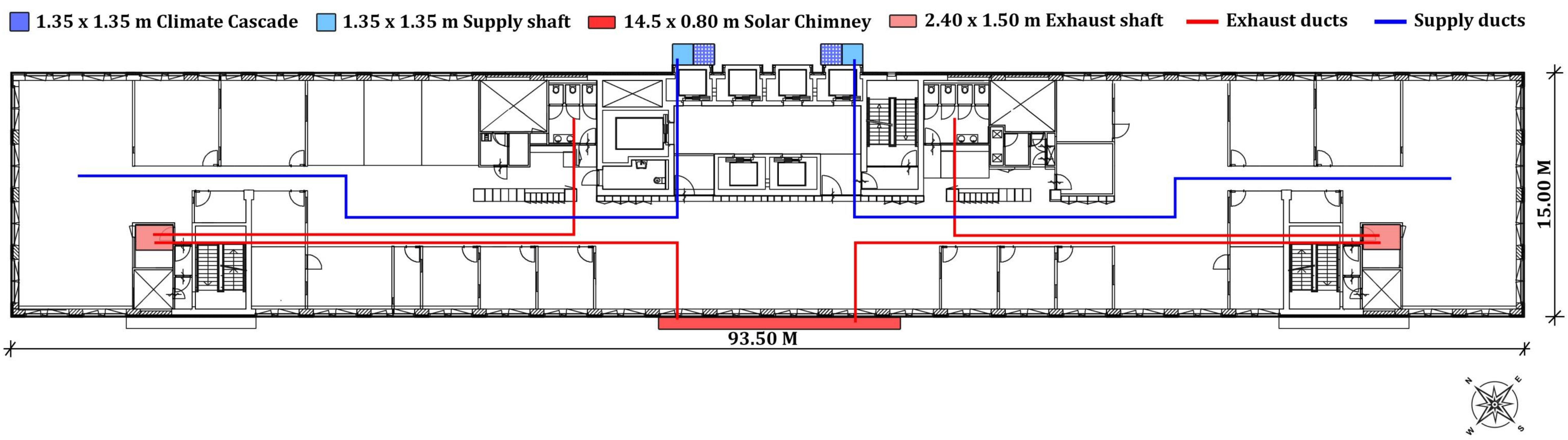
Case 2b: 2 Climate Cascade, 2 Solar Chimney (Decentralized supply, Centralized exhaust)



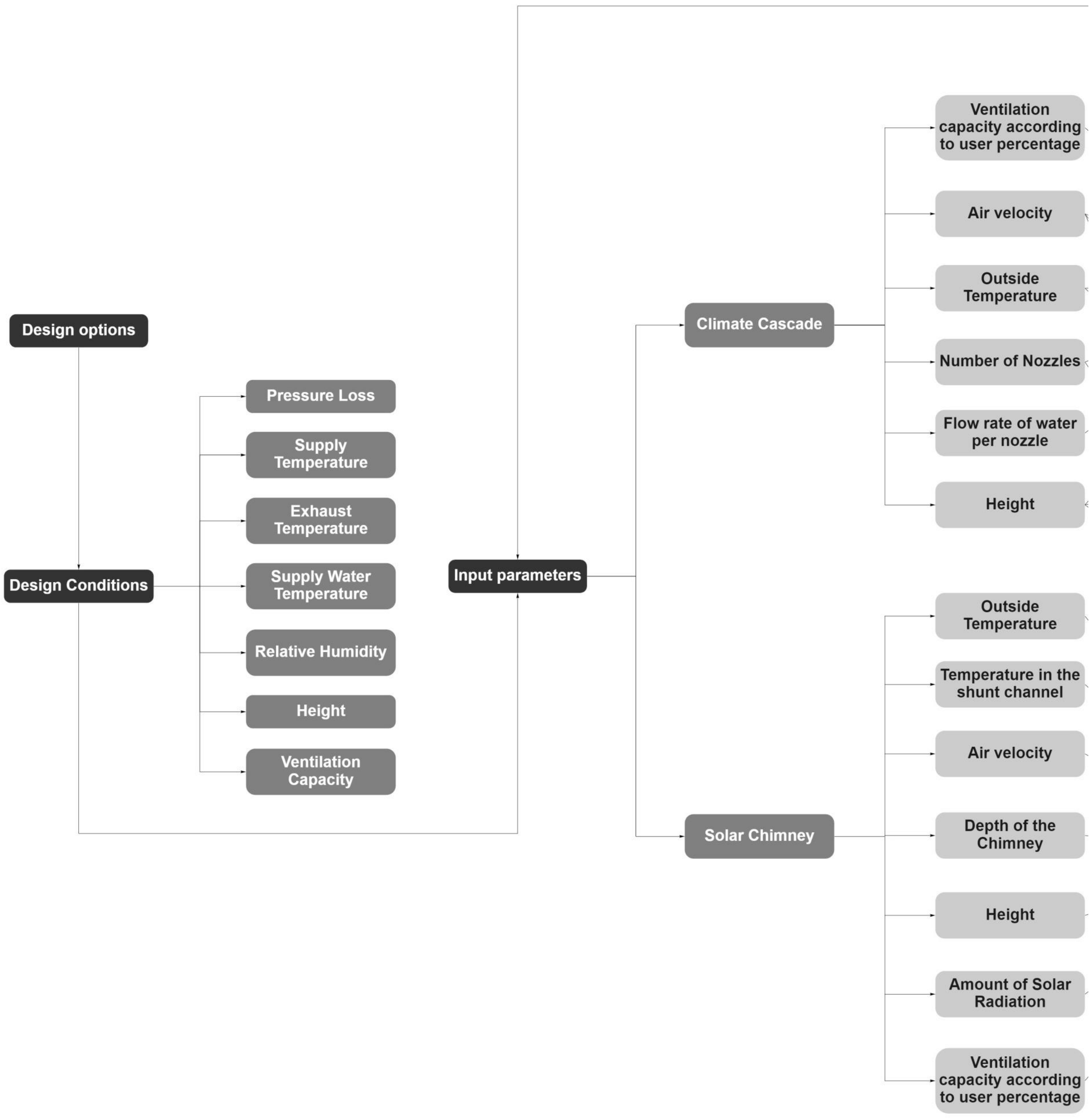
Case 3: 1 Climate Cascade, 2 Solar Chimney (Decentralized supply, Centralized exhaust)

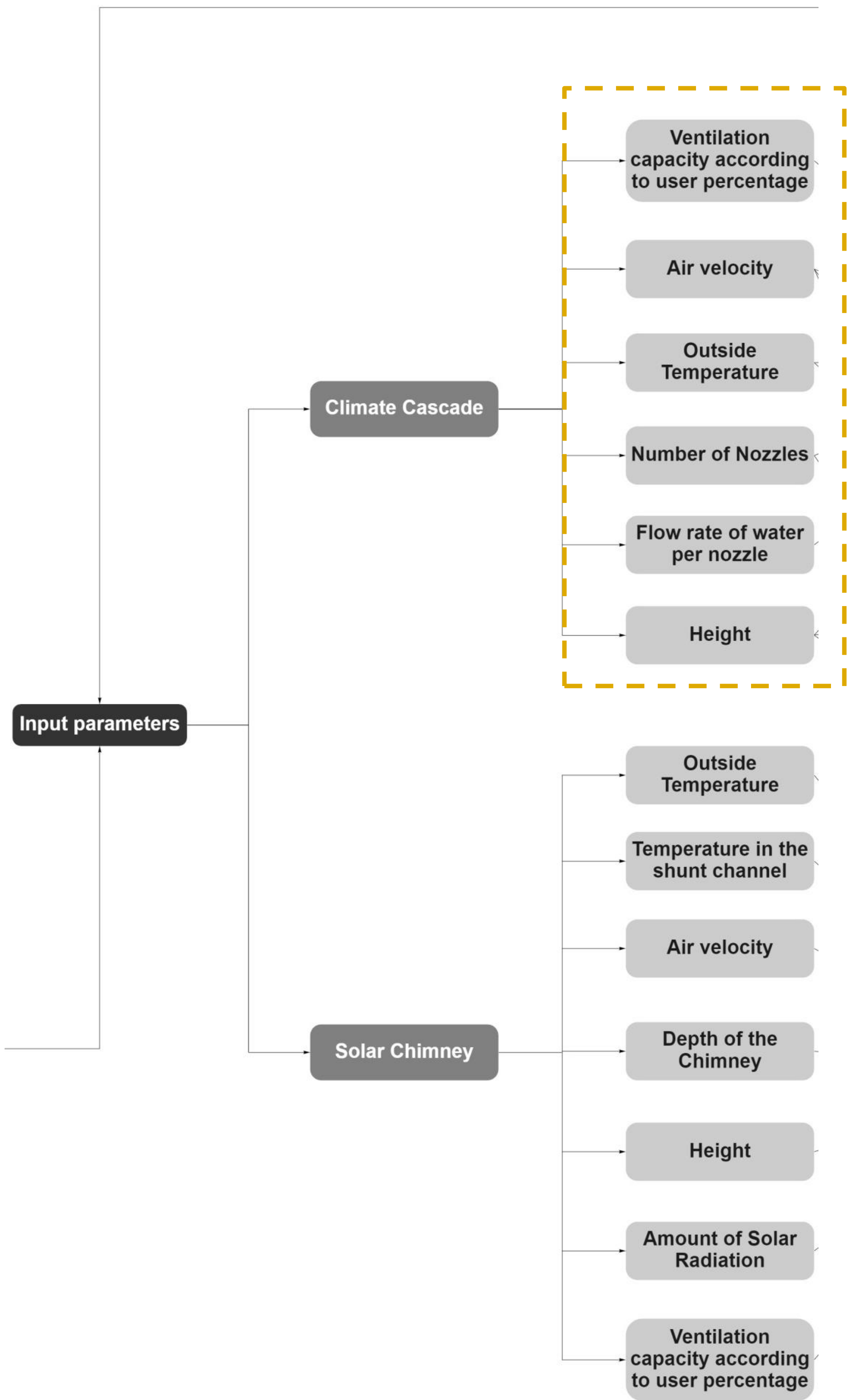


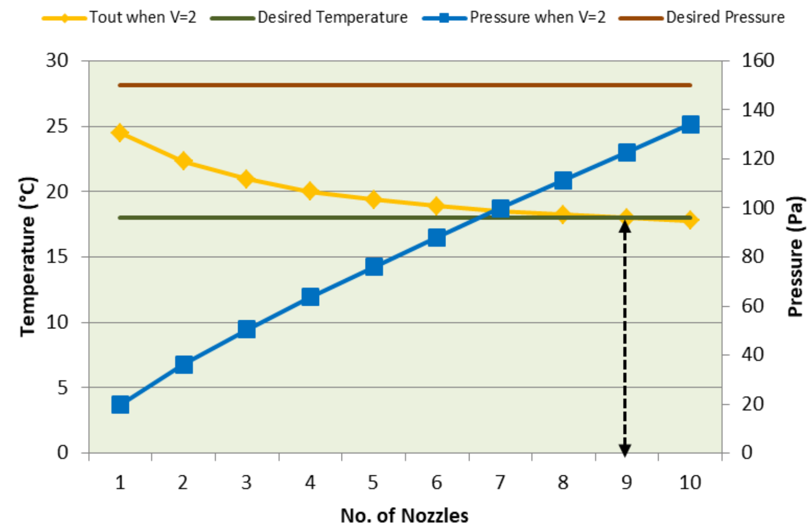
Case 4: 2 Climate Cascade, 1 Solar Chimney
(Decentralized supply, Centralized exhaust)



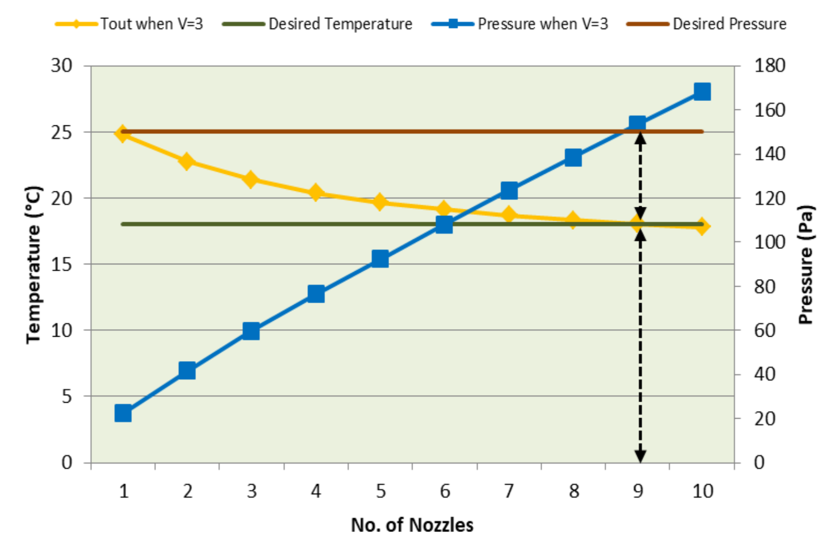
Basic Excel Modeling


Design options
Design Conditions
Pressure Loss
Supply Temperature
Exhaust Temperature
Supply Water Temperature
Relative Humidity
Height
Ventilation Capacity
Input parameters
Climate Cascade
Ventilation capacity according to user percentage
Air velocity
Outside Temperature
Number of Nozzles
Flow rate of water per nozzle
Height
Solar Chimney
Outside Temperature
Temperature in the shunt channel
Air velocity
Depth of the Chimney
Height
Amount of Solar Radiation
Ventilation capacity according to user percentage

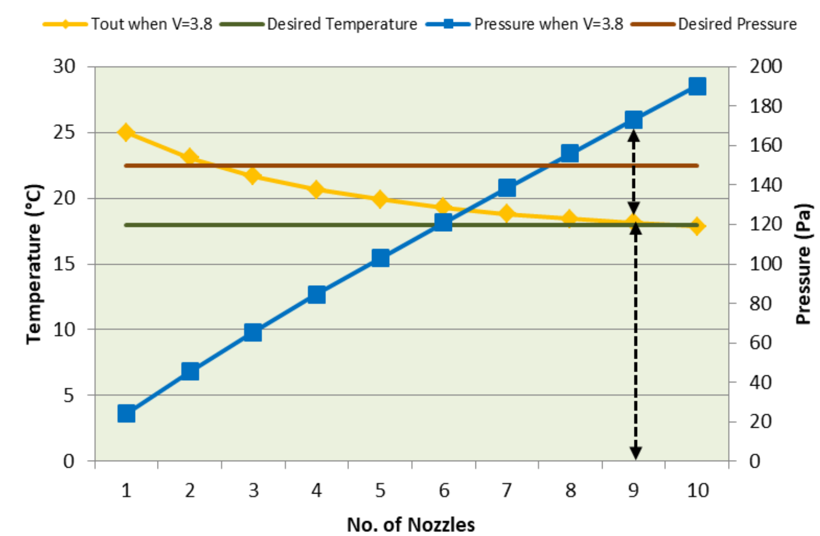




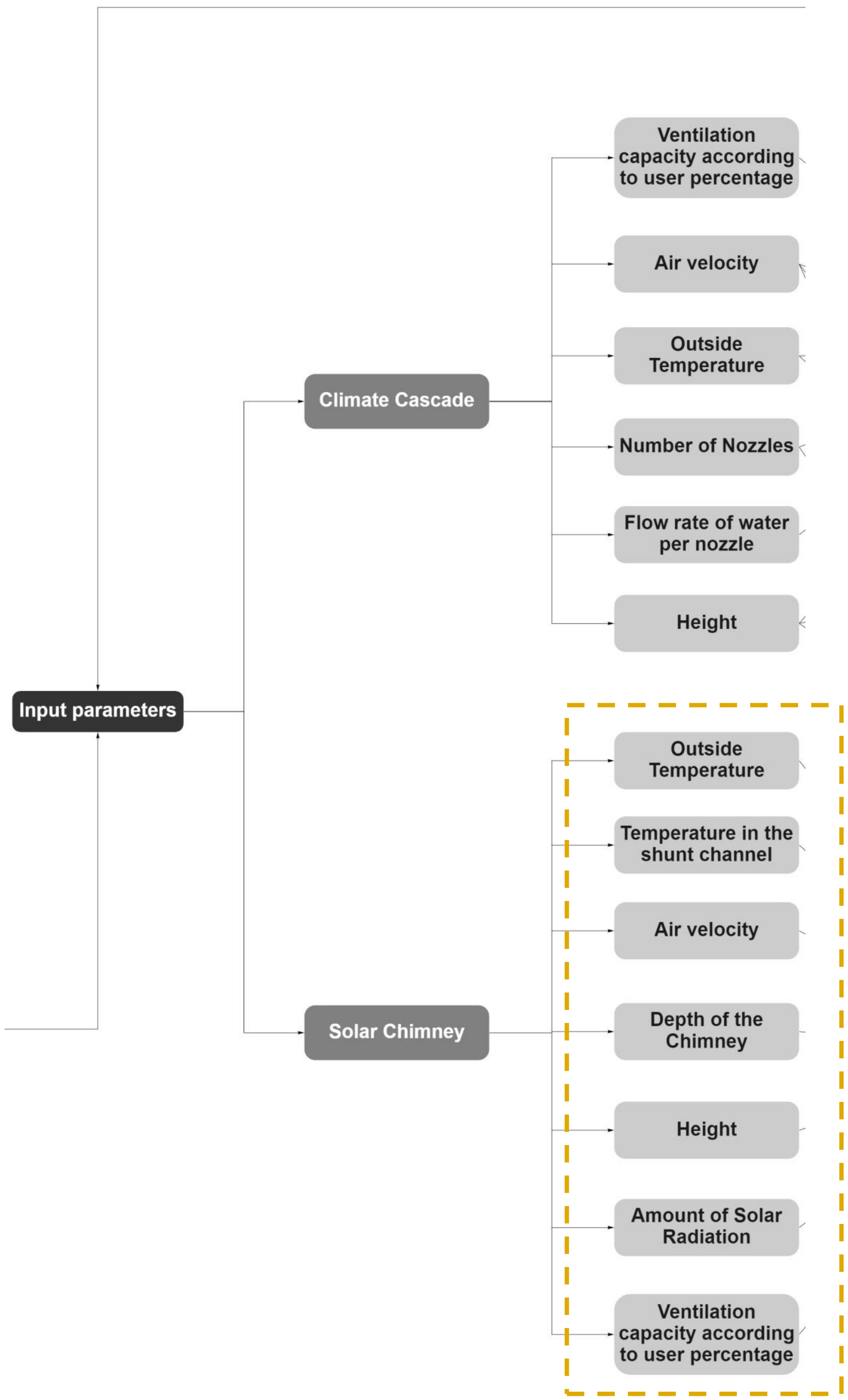
- Air Velocity= 2 m/s
- No. of Nozzles= 9

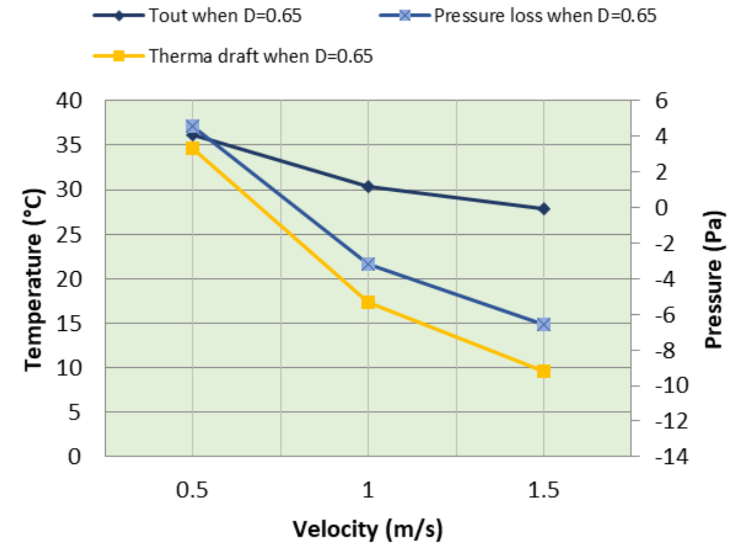


- Air Velocity= 3 m/s
- No. of Nozzles= 9

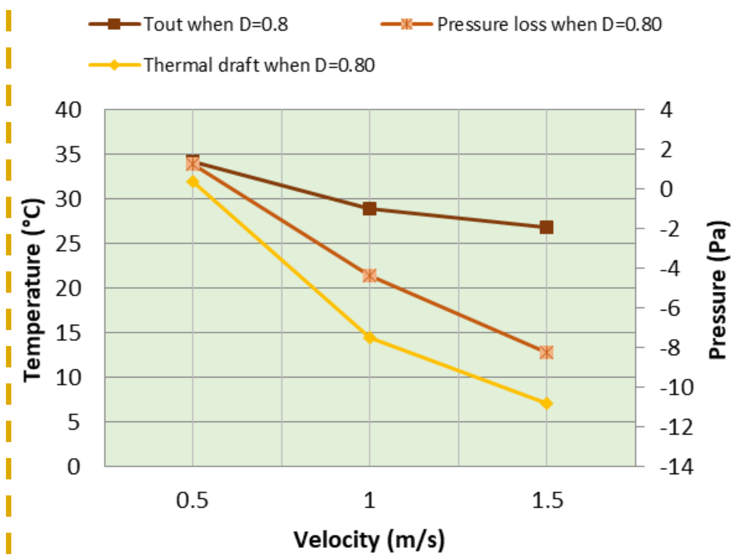


- Air Velocity= 3.8 m/s
- No. of Nozzles= 9

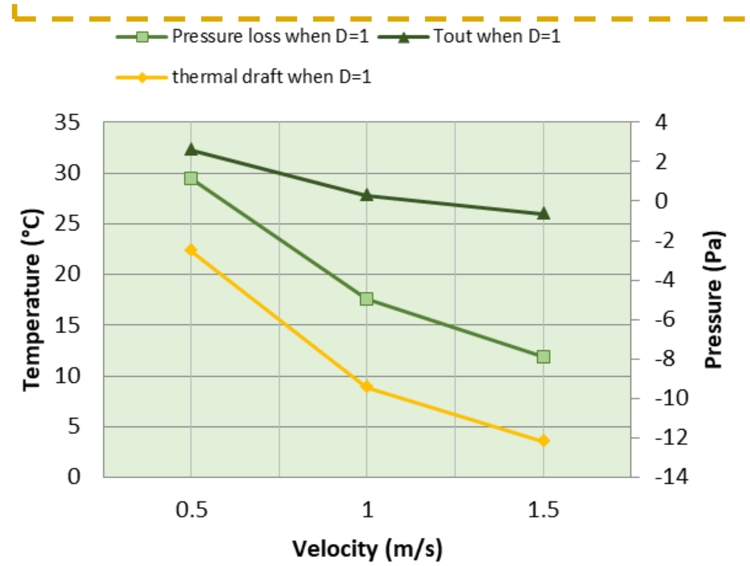




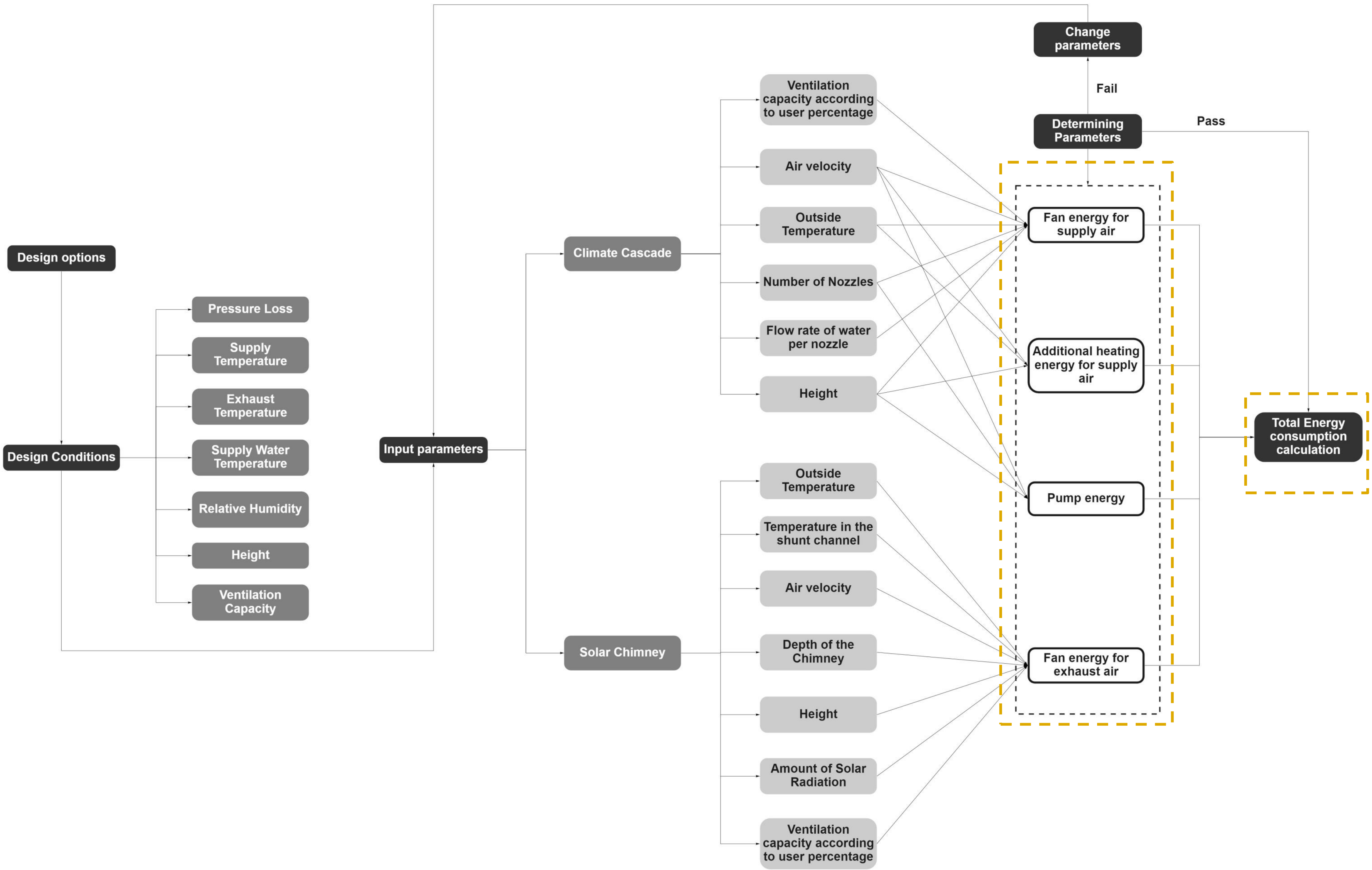
- Depth= 0.65 m
- Air velocity= 0.5 m/s
  1.0 m/s
  1.5 m/s



- Depth= 0.80 m
- Air velocity= 0.5 m/s
  1.0 m/s
  1.5 m/s

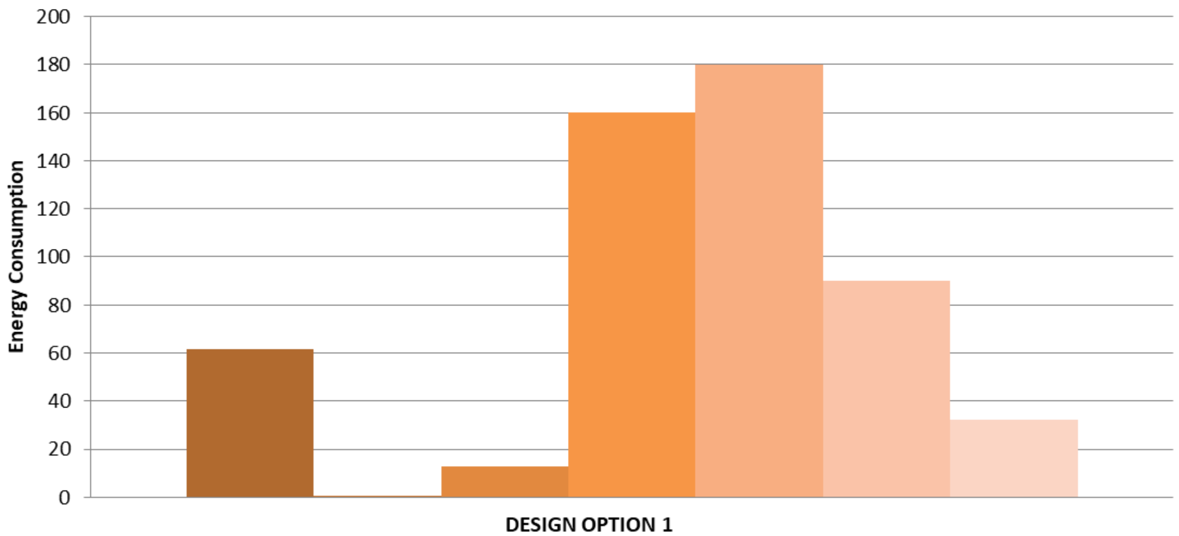


- Depth= 1.0 m
- Air velocity= 0.5 m/s
  1.0 m/s
  1.5 m/s

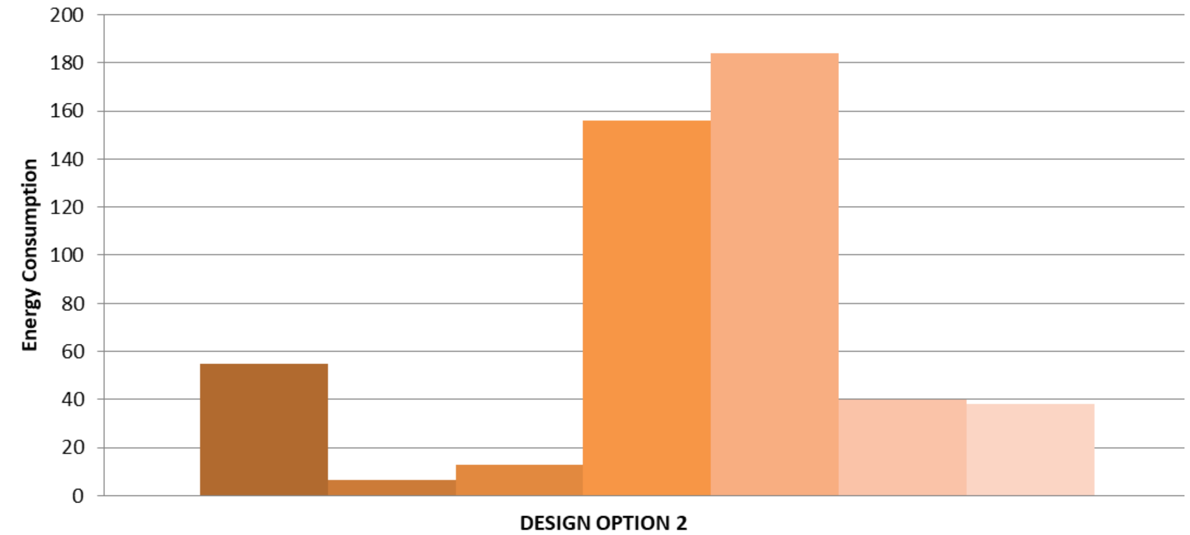

Change parameters
Fail
Pass
Determining Parameters
Design options
Design Conditions
Pressure Loss
Supply Temperature
Exhaust Temperature
Supply Water Temperature
Relative Humidity
Height
Ventilation Capacity
Input parameters
Climate Cascade
Solar Chimney
Ventilation capacity according to user percentage
Air velocity
Outside Temperature
Number of Nozzles
Flow rate of water per nozzle
Height
Outside Temperature
Temperature in the shunt channel
Air velocity
Depth of the Chimney
Height
Amount of Solar Radiation
Ventilation capacity according to user percentage
Fan energy for supply air
Additional heating energy for supply air
Pump energy
Fan energy for exhaust air
Total Energy consumption calculation

CLIMATE CASCADE

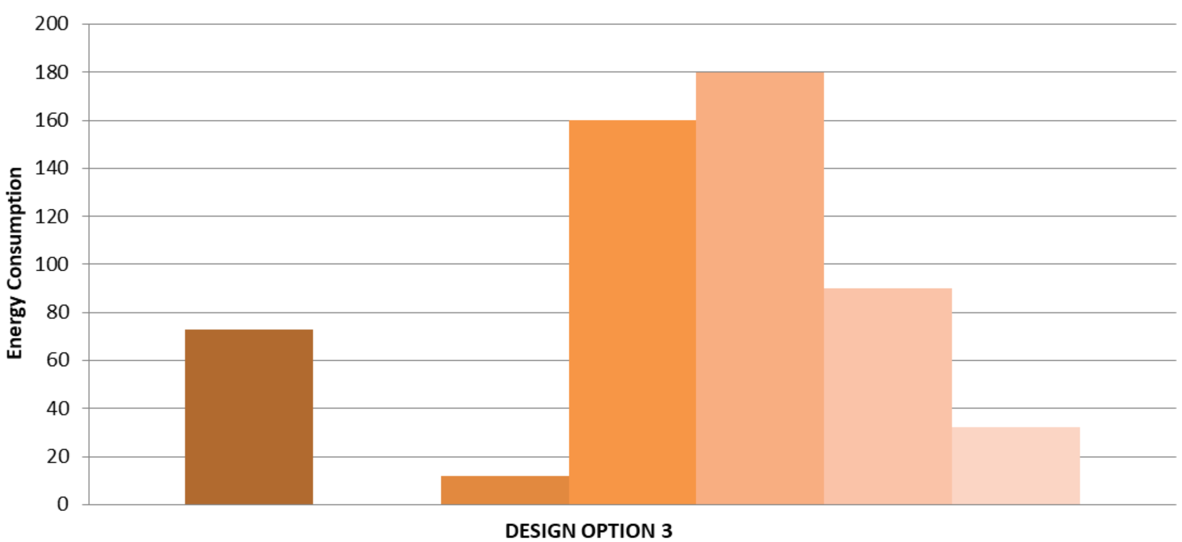
Case 1: 1 Climate Cascade, 1 Solar Chimney



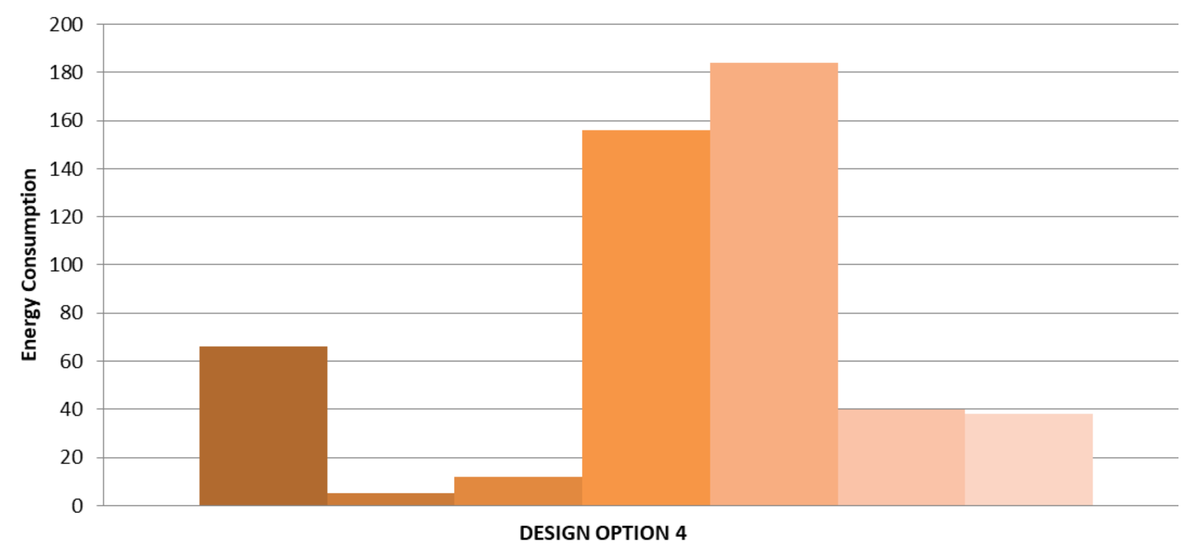
Case 2: 2 Climate Cascade, 2 Solar Chimney



Case 3: 1 Climate Cascade, 2 Solar Chimney



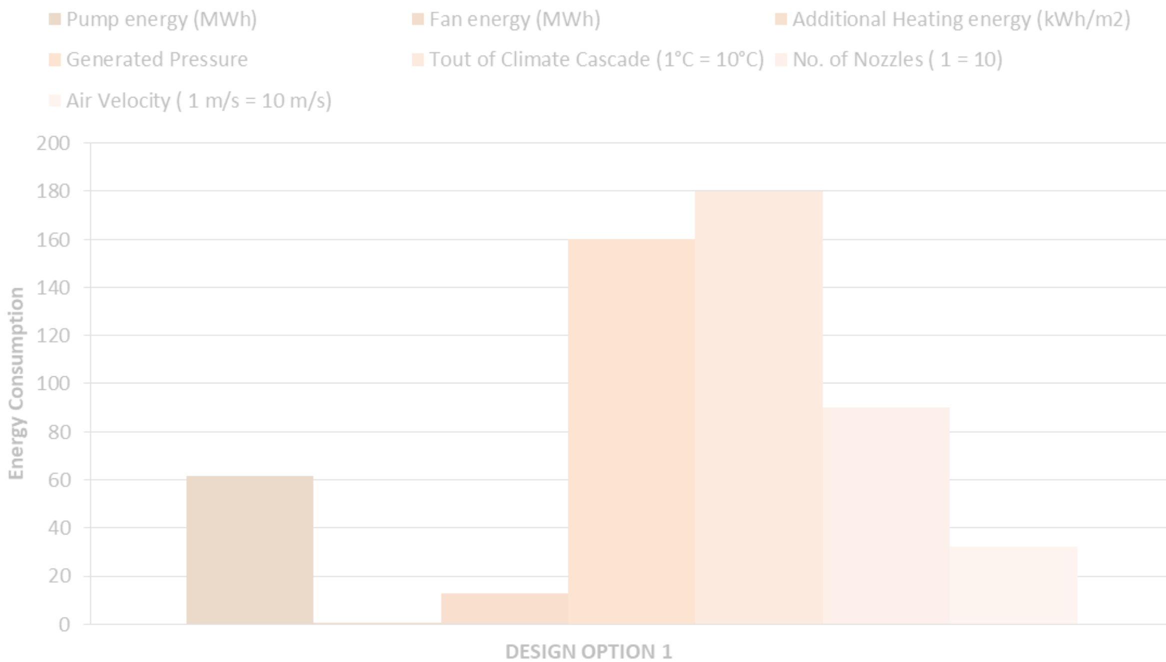
Case 4: 2 Climate Cascade, 1 Solar Chimney



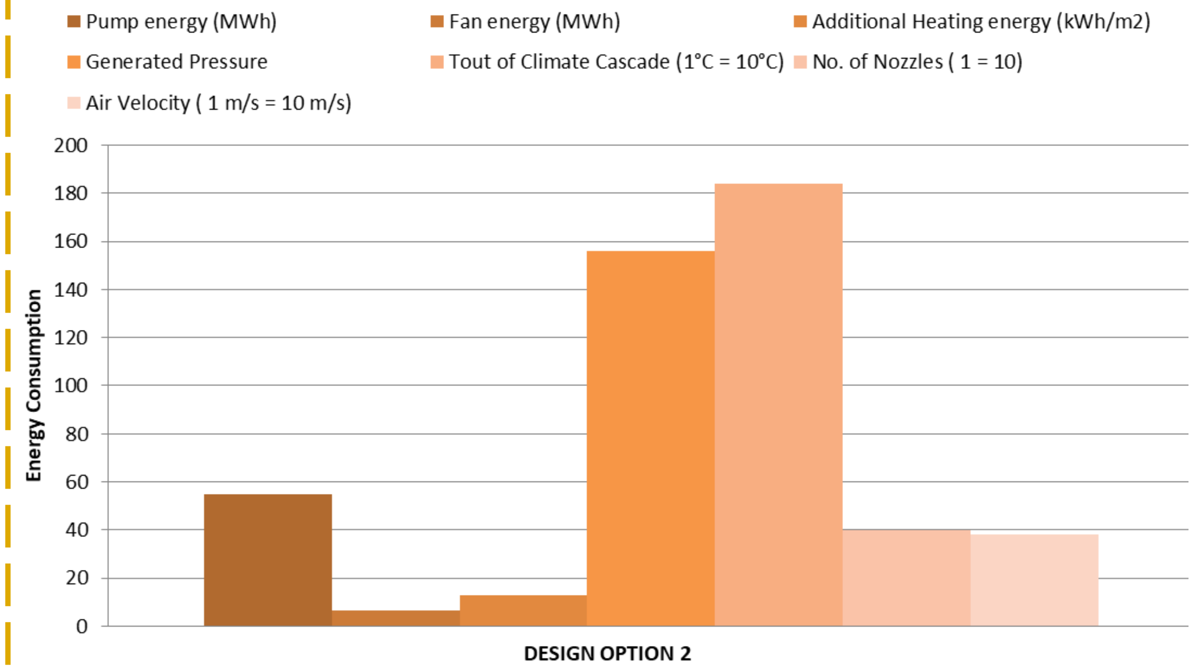
- Pump energy (MWh)
- Fan energy (MWh)
- Additional Heating energy (kWh/m2)
- Air Velocity (1 m/s = 10 m/s)
- Generated Pressure
- Tout of Climate Cascade (1°C = 10°C)
- No. of Nozzles (1 = 10)

CLIMATE CASCADE

Case 1: 1 Climate Cascade, 1 Solar Chimney

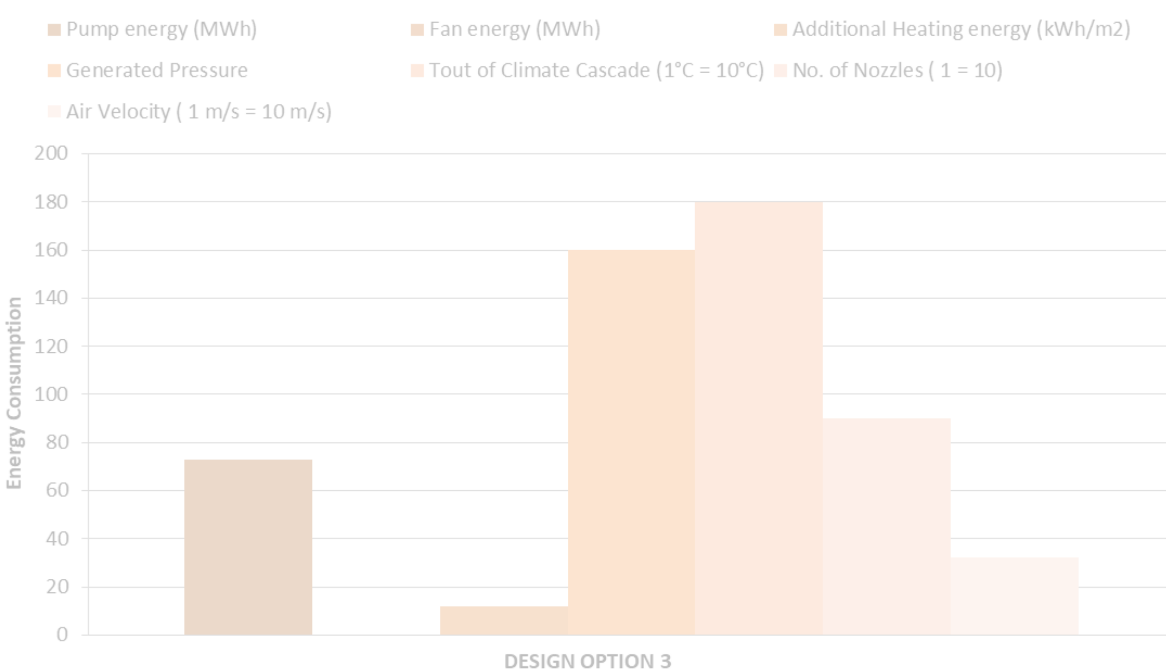


Case 2: 2 Climate Cascade, 2 Solar Chimney

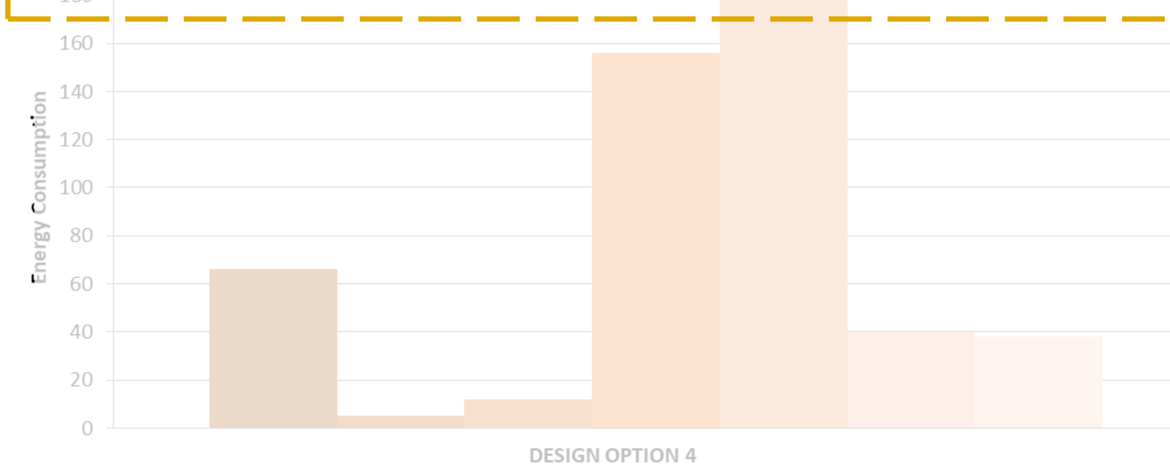


- **Lower pump energy**
- **Minimum fan energy**
- **Reduced Pressure losses via supply ducts**
- **No. of Nozzles= 4**
- **Air velocity= 3.8 m/s**
- **Size= 1.35 x 1.35 m**

Case 3: 1 Climate Cascade, 2 Solar Chimney

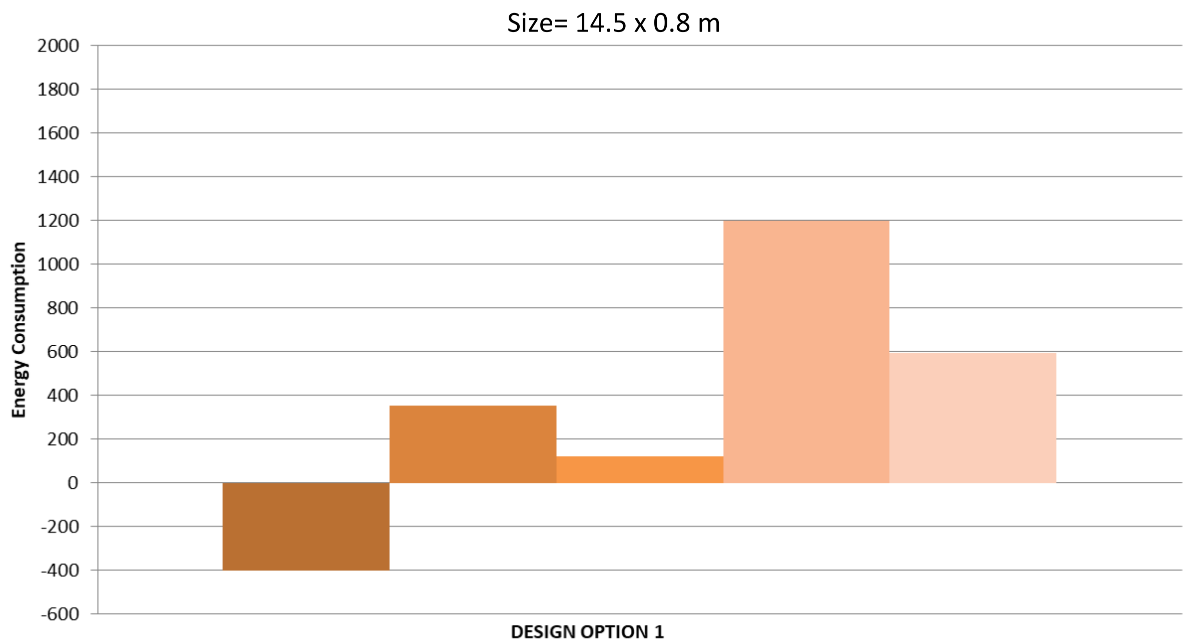


Case 4: 2 Climate Cascade, 1 Solar Chimney

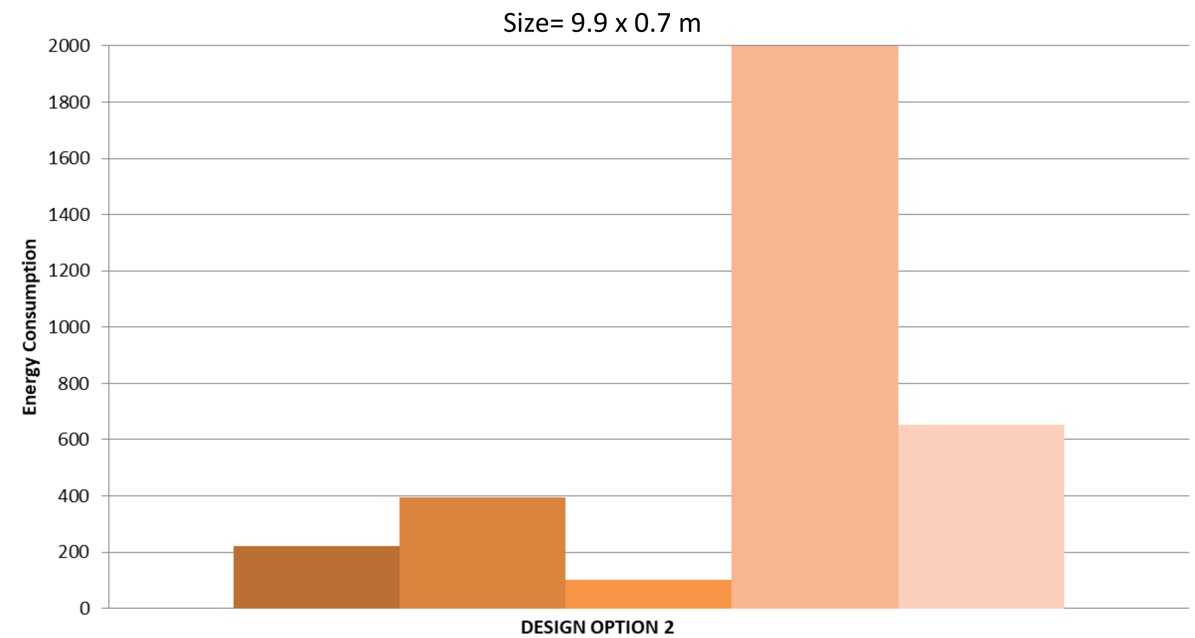


SOLAR CHIMNEY

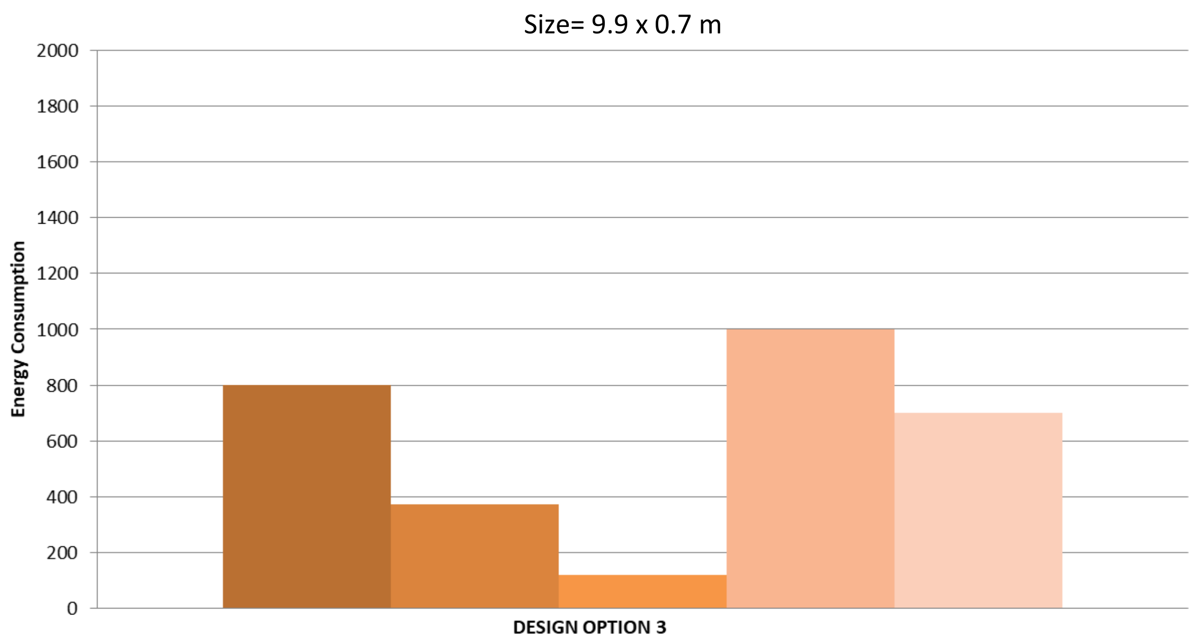
Case 1: 1 Climate Cascade, 1 Solar Chimney



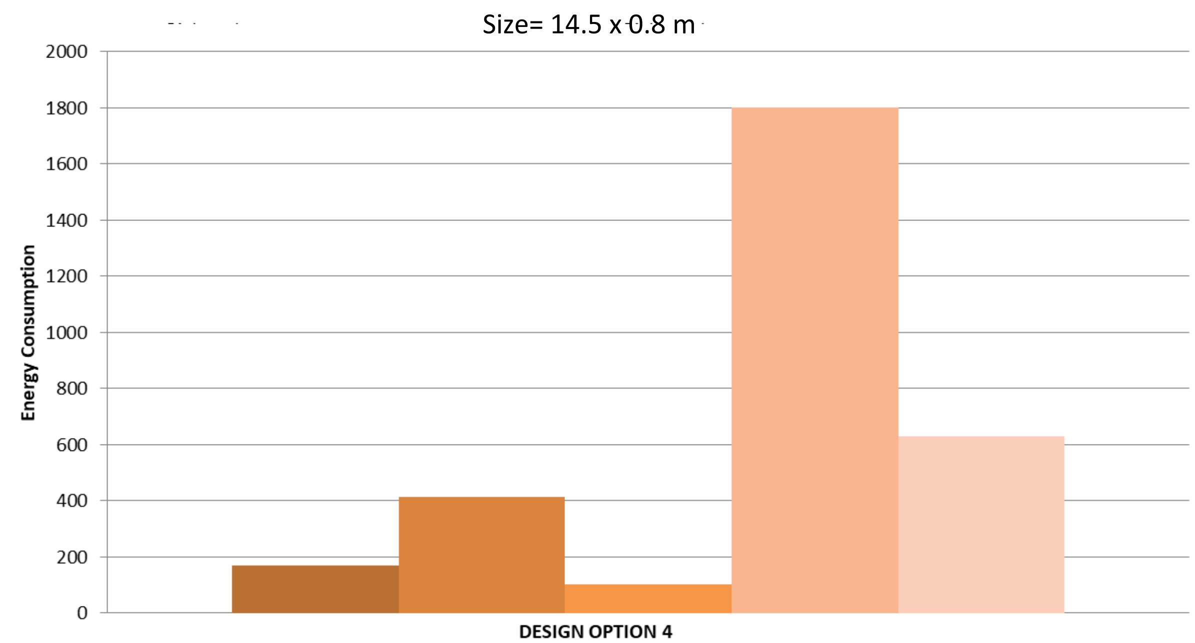
Case 2: 2 Climate Cascade, 2 Solar Chimney



Case 3: 1 Climate Cascade, 2 Solar Chimney



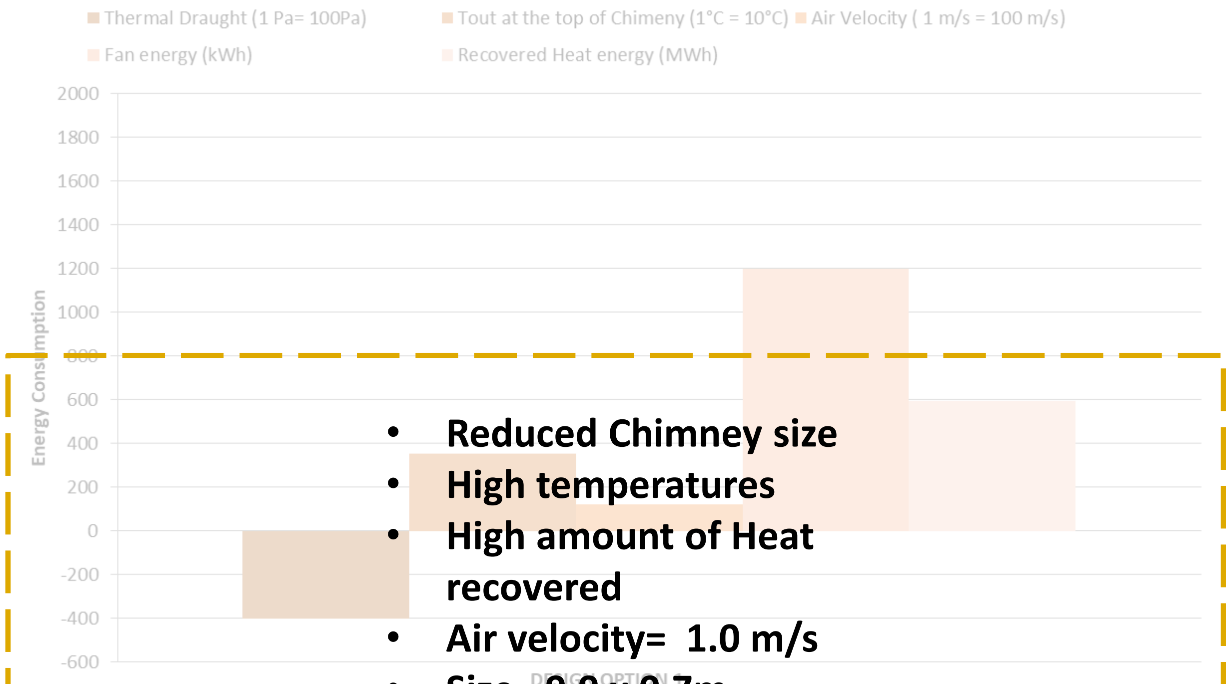
Case 4: 2 Climate Cascade, 1 Solar Chimney



Thermal Draught (1 Pa= 100Pa) | Tout at the top of Chimeny (1°C = 10°C) | Air Velocity (1 m/s = 100 m/s) | Fan energy (kWh) | Recovered Heat energy (MWh)

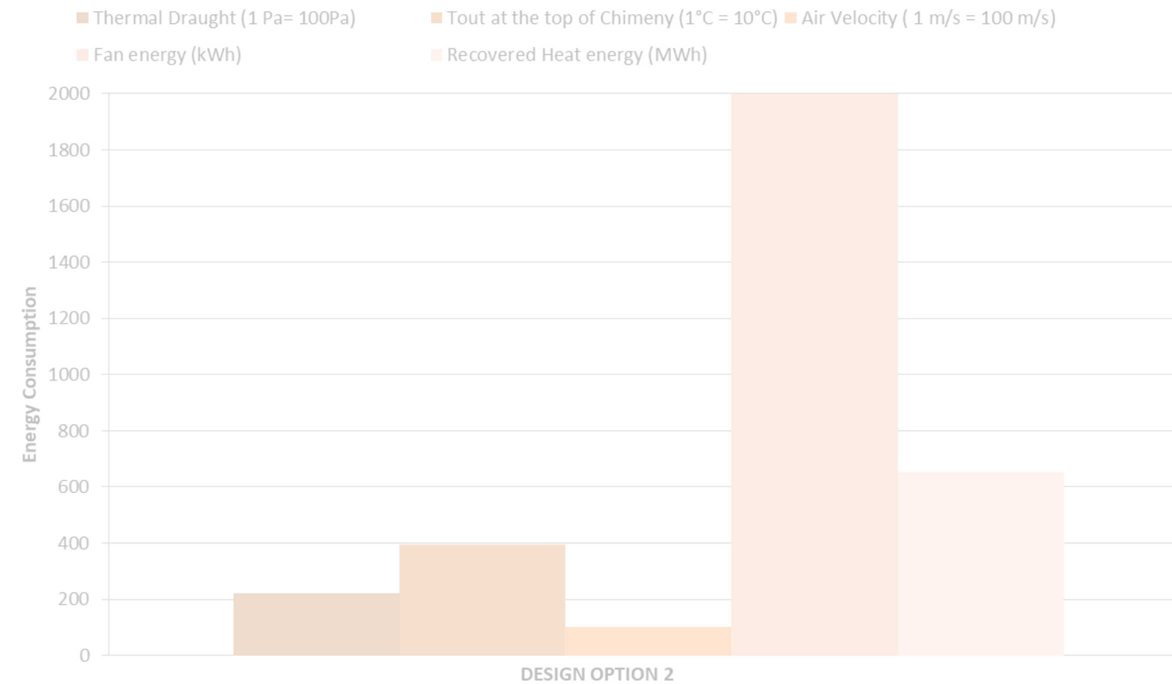
SOLAR CHIMNEY

Case 1: 1 Climate Cascade, 1 Solar Chimney

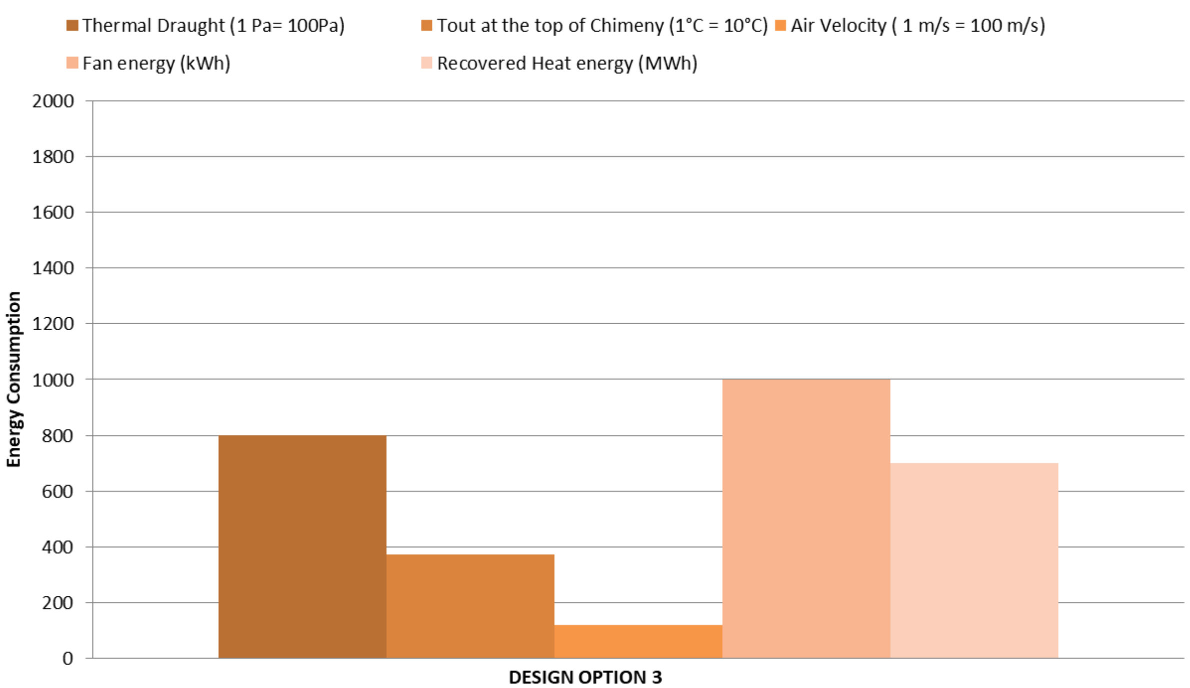


- **Reduced Chimney size**
- **High temperatures**
- **High amount of Heat recovered**
- **Air velocity= 1.0 m/s**
- **Size= 9.9 x 0.7m**

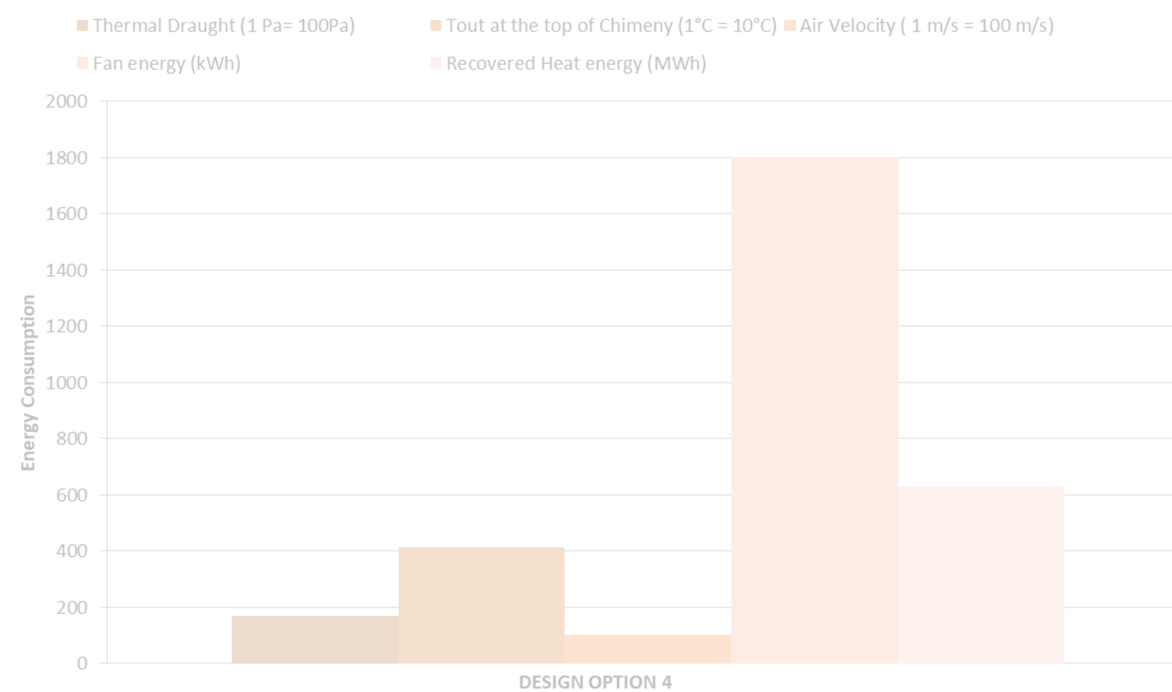
Case 2: 2 Climate Cascade, 2 Solar Chimney



Case 3: 1 Climate Cascade, 2 Solar Chimney

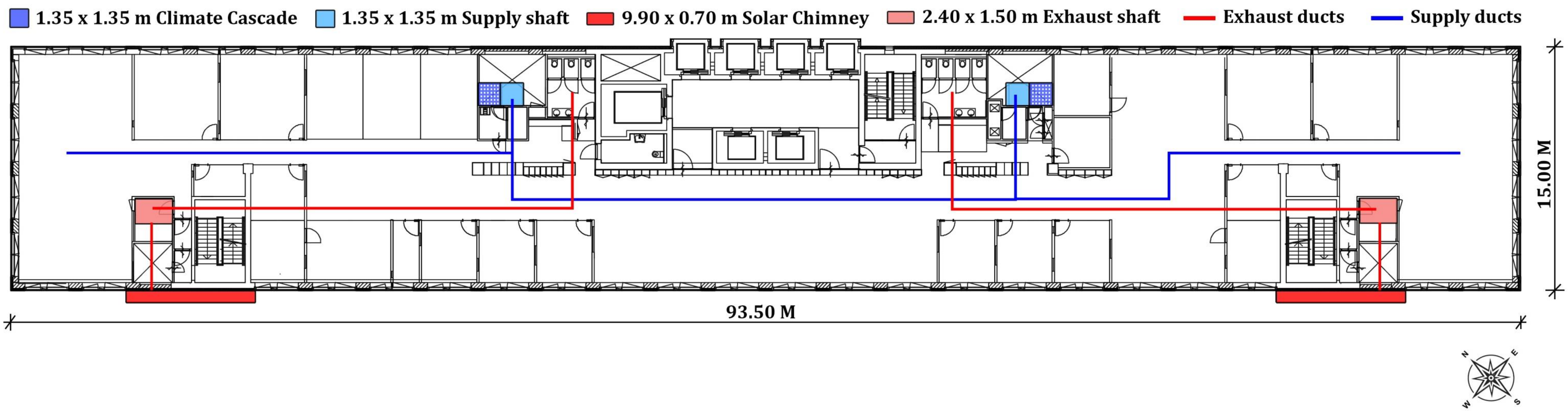


Case 4: 2 Climate Cascade, 1 Solar Chimney

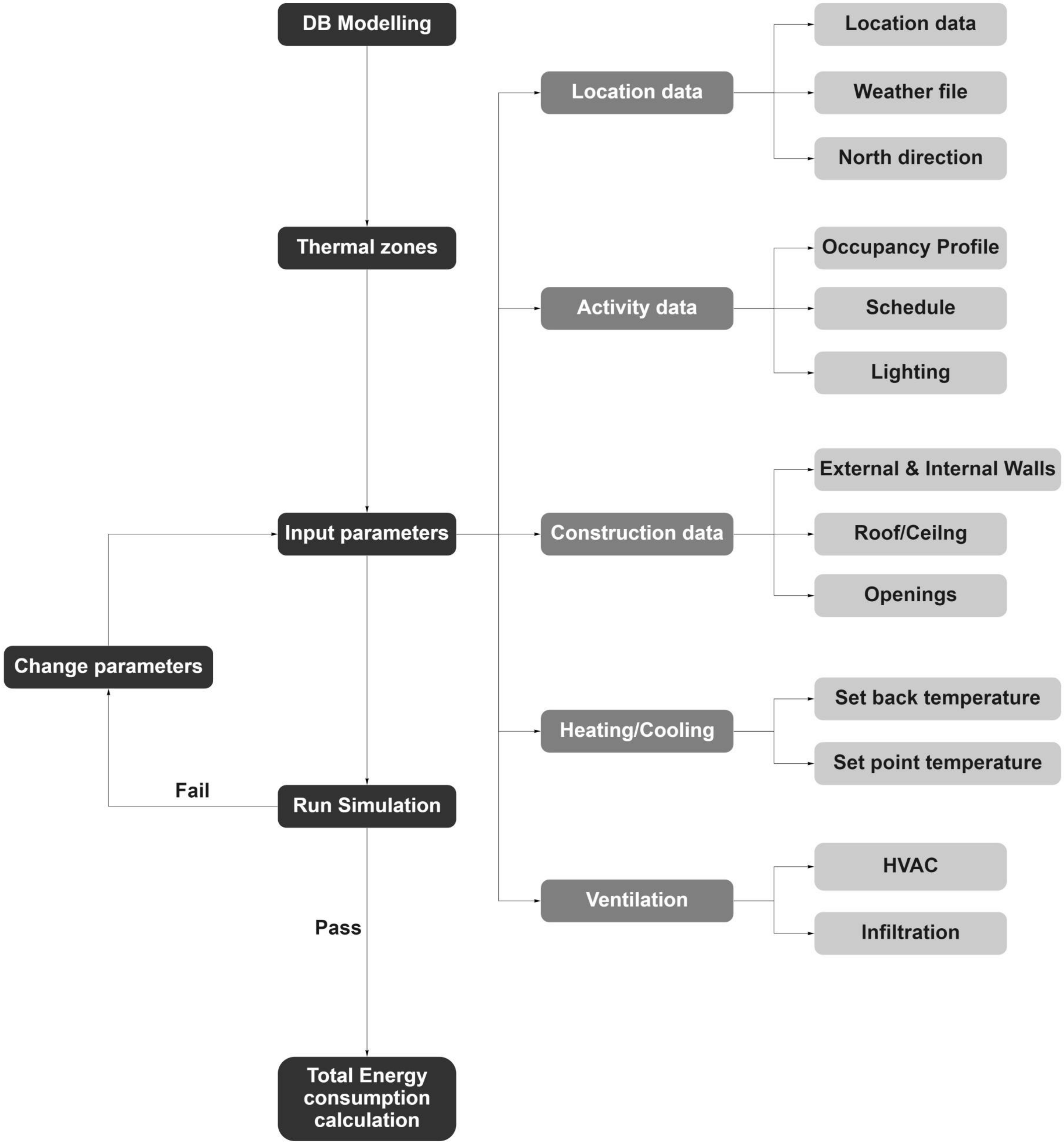


CHOSEN OPTION

Case 2b: 2 Climate Cascade, 2 Solar Chimney
(Decentralized supply, Centralized exhaust)

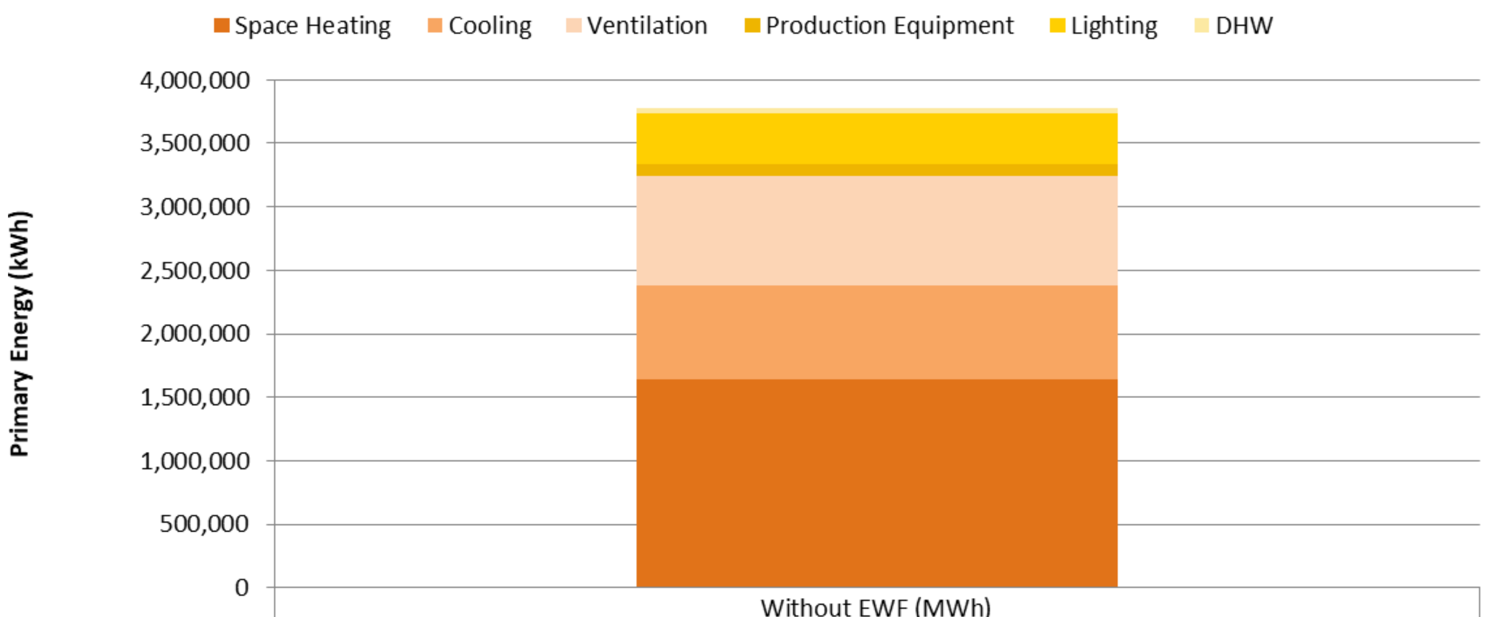


Dynamic Modeling using Design Builder

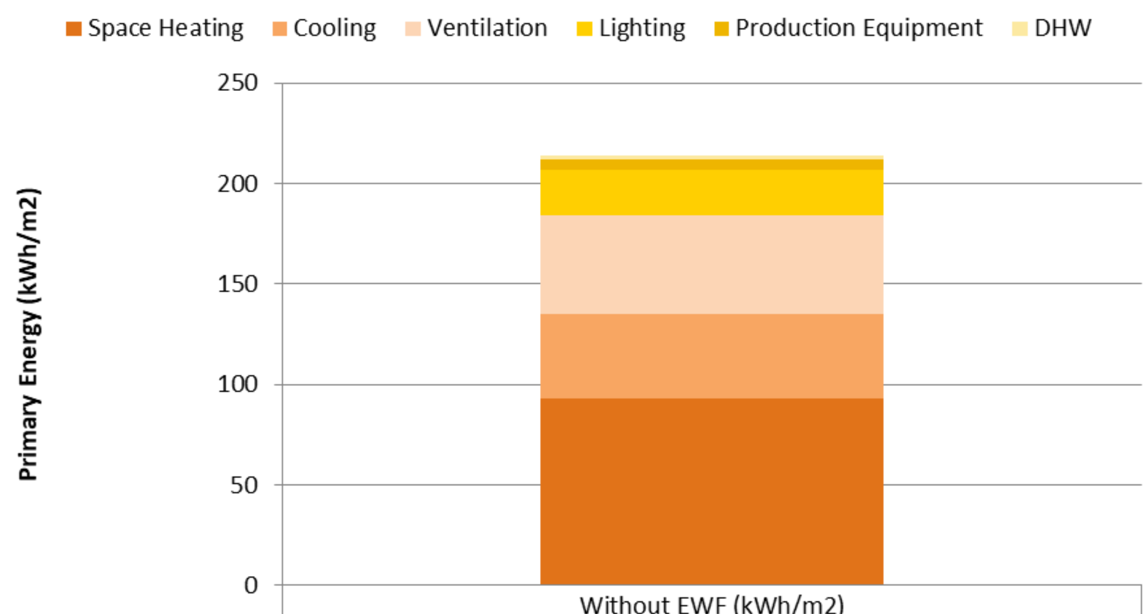

DB Modelling
Thermal zones
Input parameters
Change parameters
Fail
Run Simulation
Pass
Total Energy consumption calculation
Location data
Activity data
Construction data
Heating/Cooling
Ventilation
Location data
Weather file
North direction
Occupancy Profile
Schedule
Lighting
External & Internal Walls
Roof/Ceilng
Openings
Set back temperature
Set point temperature
HVAC
Infiltration

Existing System without EWF

Existing System without EWF



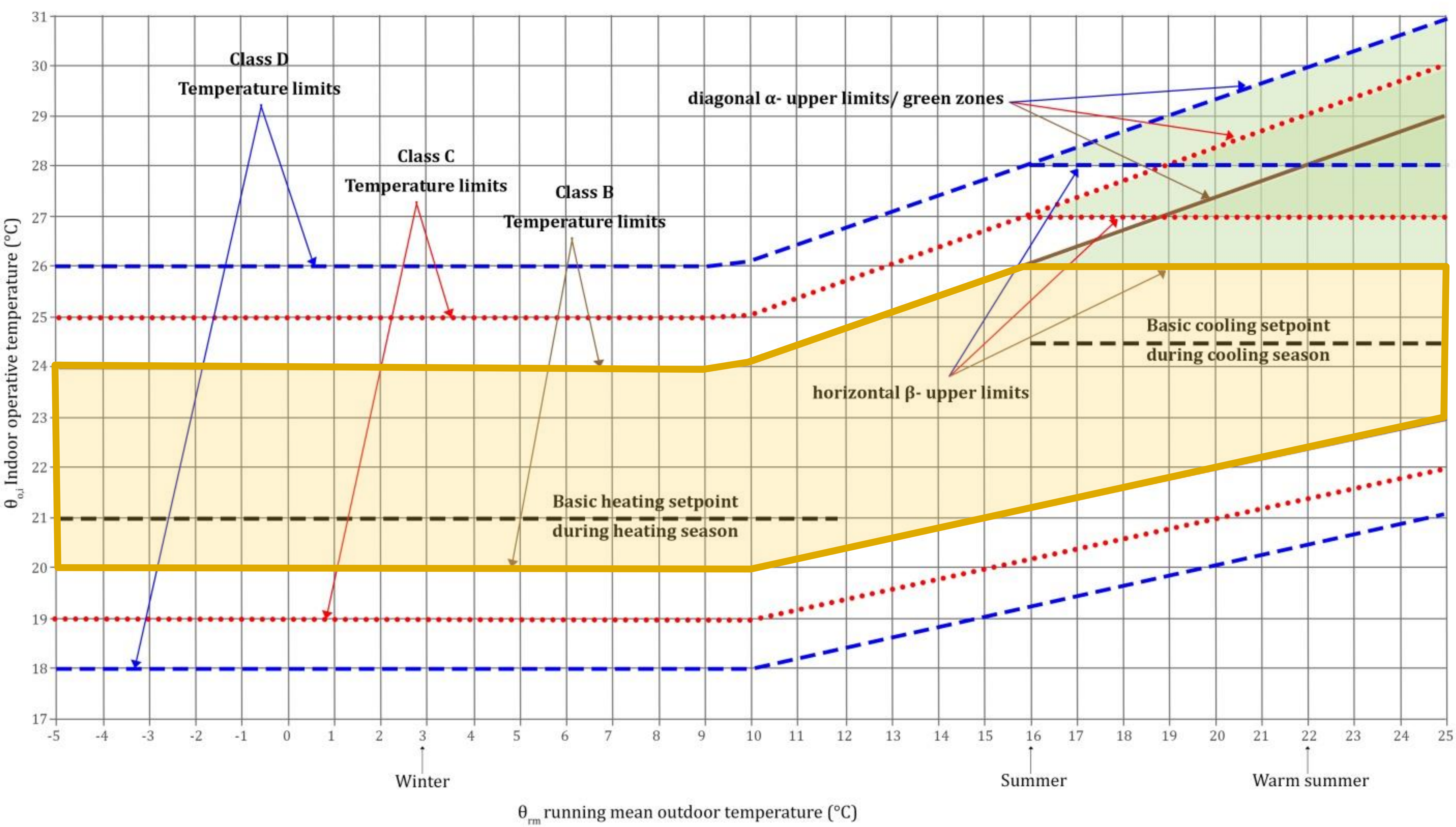
	Without EWF (MWh)
DHW	35,280
Lighting	405,720
Production Equipment	88,200
Ventilation	864,360
Cooling	740,880
Space Heating	1,640,520



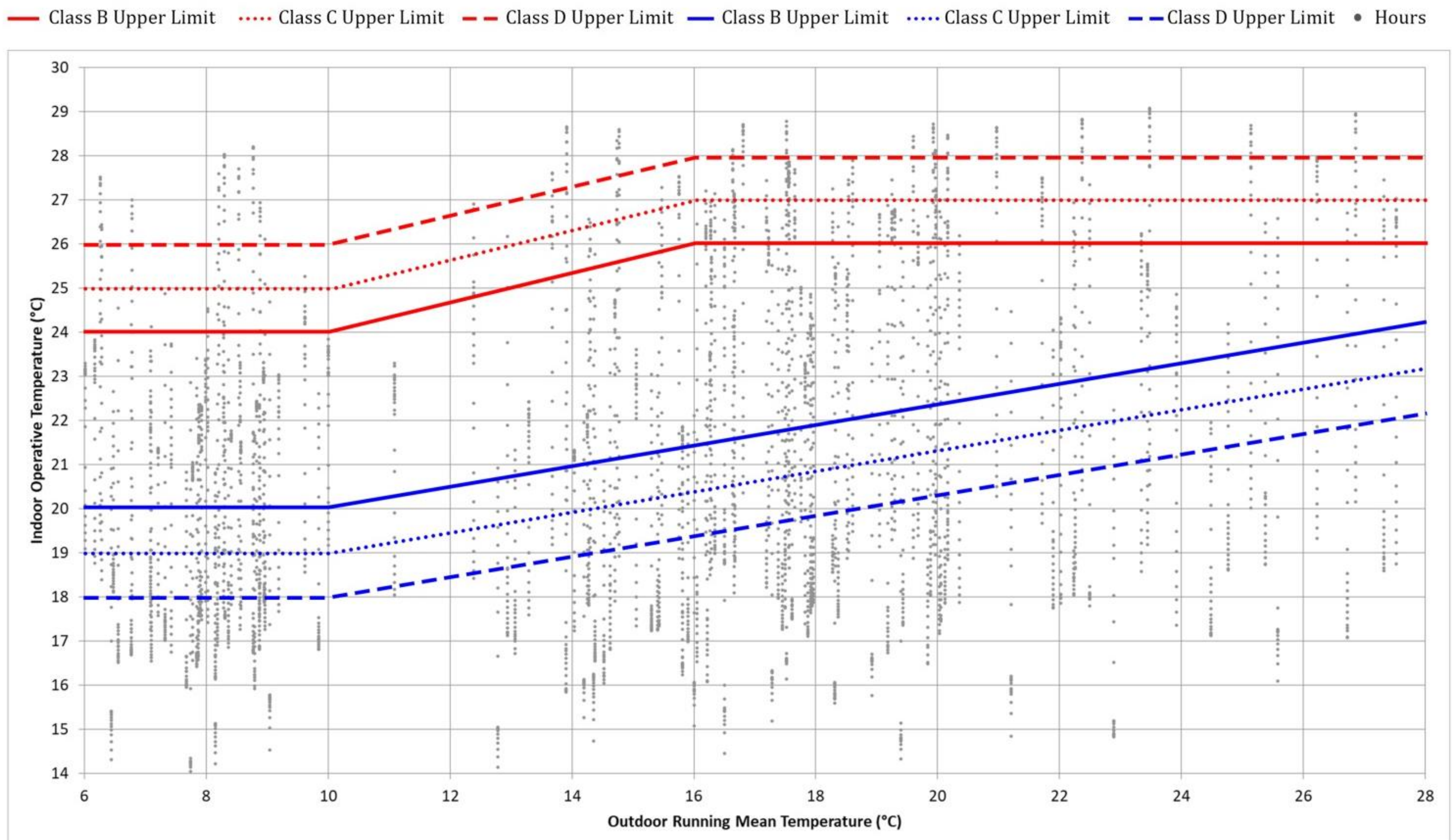
	Without EWF (kWh/m2)
DHW	2
Production Equipment	5
Lighting	23
Ventilation	49
Cooling	42
Space Heating	93

Thermal Comfort

ATG Method for accessing Thermal Comfort

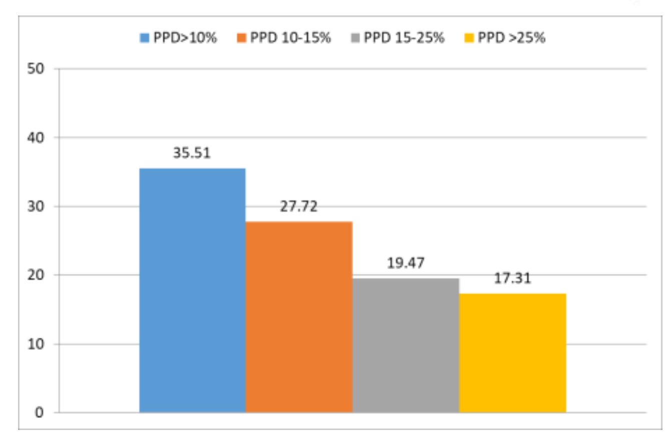


Thermal Comfort assessment of the existing system without EWF



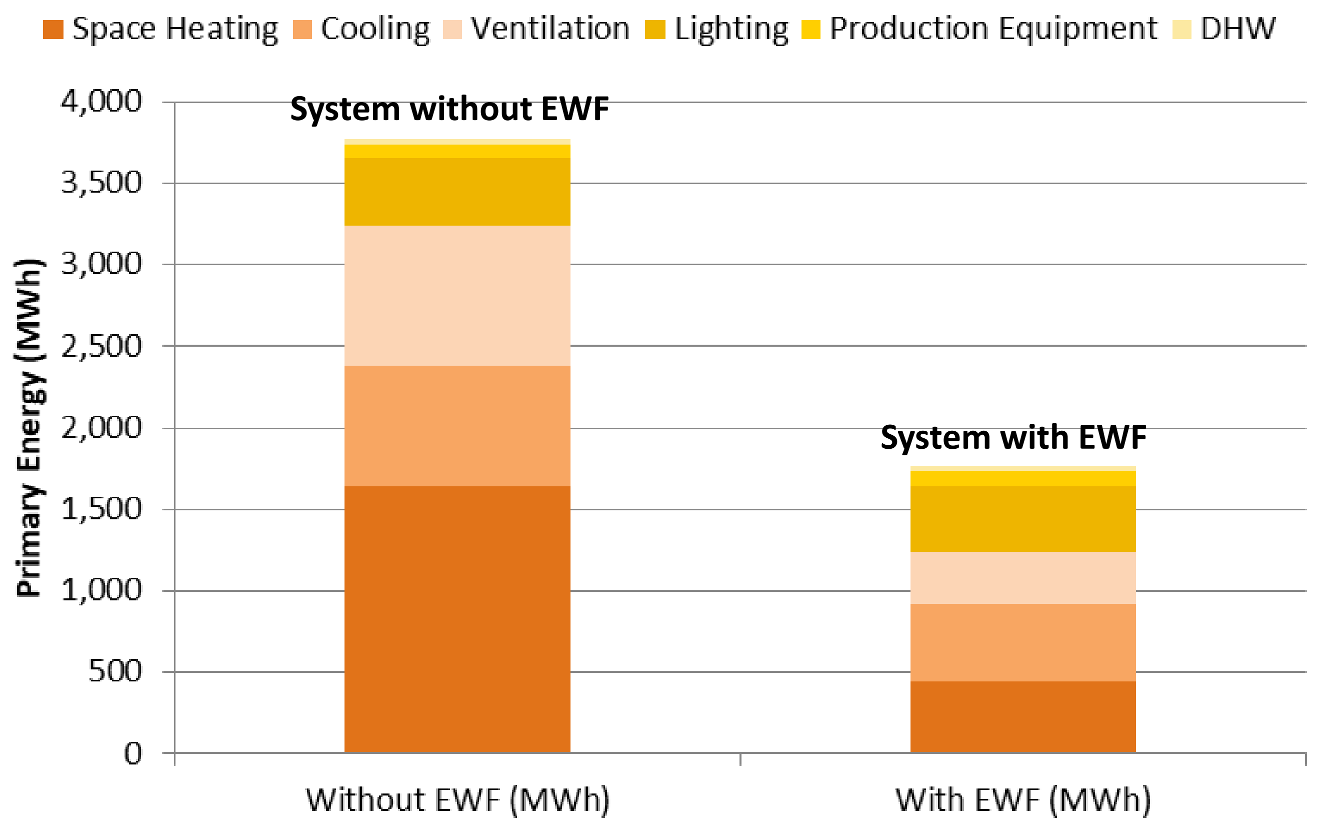
Building	Provinciehuis Utrecht
Space	1 Office floor
Building type	Beta
Temperature type	Operative
Analysis Period	Jan-Sept
Occupied Hours	8049
Thermal Performance	Bad
Class	Class D

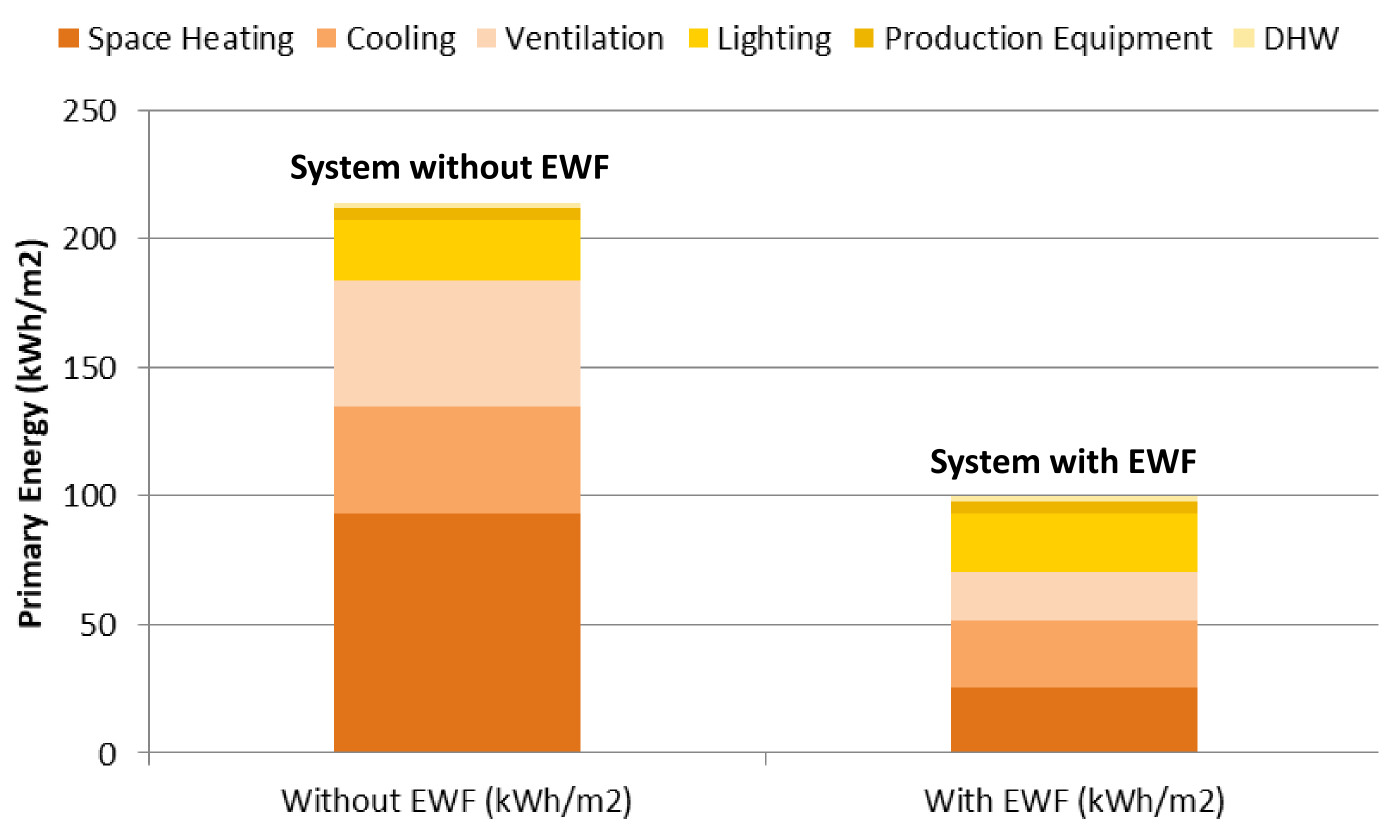
Comfort Bandwidth	No. of Hours	% of Time
Class B	2858	35.51
Class C	2231	27.72
Class D	1567	19.47
Above Class D	1393	17.31



New System with EWF

Comparison between the 2 systems





62% less Ventilation energy

36% less Cooling energy

72% less Heating energy

53% Reduction Overall

EWF System Energy

EWF system energy consumption

	EWF Ventilation Energy without Heat recovery		EWF Ventilation Energy with Heat recovery	
	Primary Energy (kWh/year)	Primary Energy (kWh/m2)	Primary Energy (kWh/year)	Primary Energy (kWh/m2)
Climate Cascade				
Pump energy	54,800	-	25800	
Fan energy	6,700	-	0	
Additional Heating energy	368,000	12.7	196,693	10.2
Solar Chimney				
Fan energy	1800	-	1800	
Total	**431,300**		**224,293**	

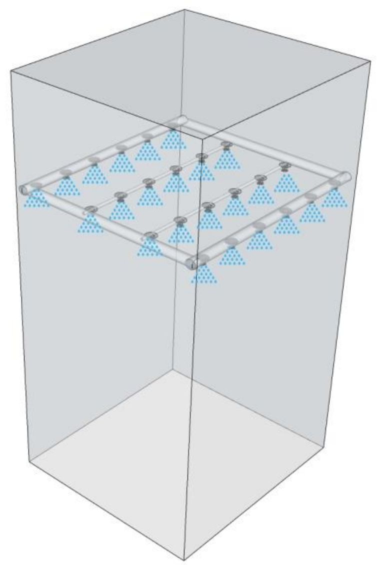
EWF Ventilation Energy		
	Primary Energy (kWh/year)	Primary Energy (kWh/m2)
Climate Cascade		
Pump energy	25800	-
Fan energy	0	-
Additional Heating energy	196,693	12.7
Solar Chimney		
Fan energy (22°C constant Incoming air)	**1800**	-
Fan energy (Varying temperatures according to dynamic simulations)	**2500**	-
Total	**224,993**	

Heat Recovery system

Winter situation

Pre-heats the outdoor air from 2°C to 13°C

Climate Cascade

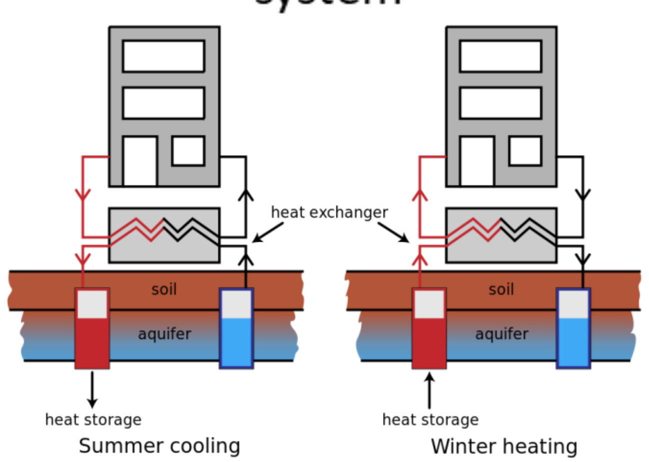


Summer situation

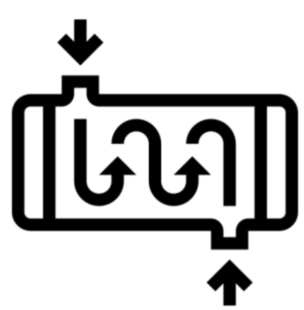
Air-water heat exchanger

Booster heat pump

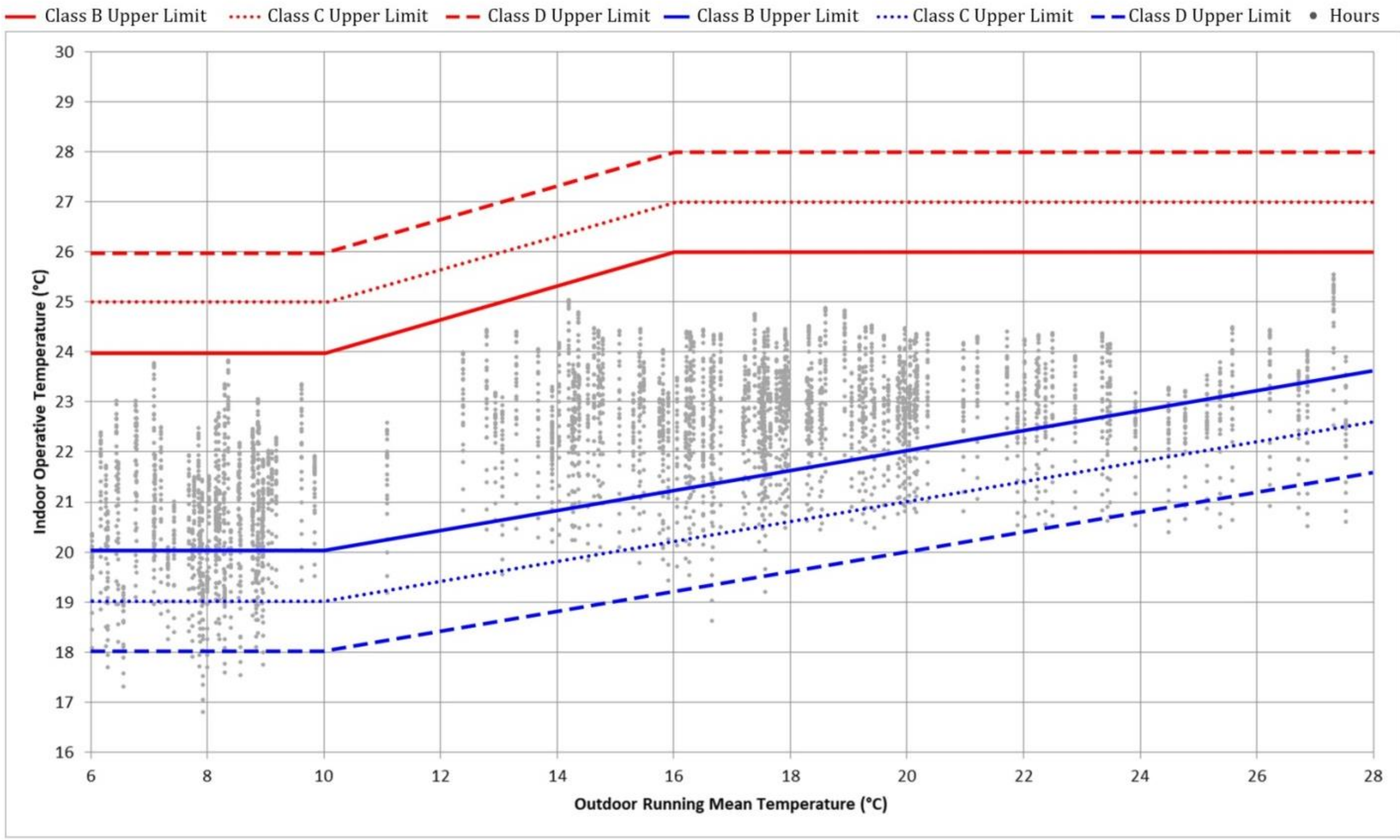
Recharging the ATES system



DHW

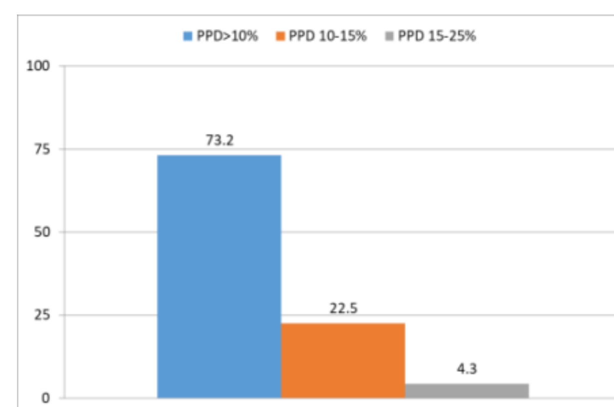


Thermal Comfort assessment of the New system with EWF

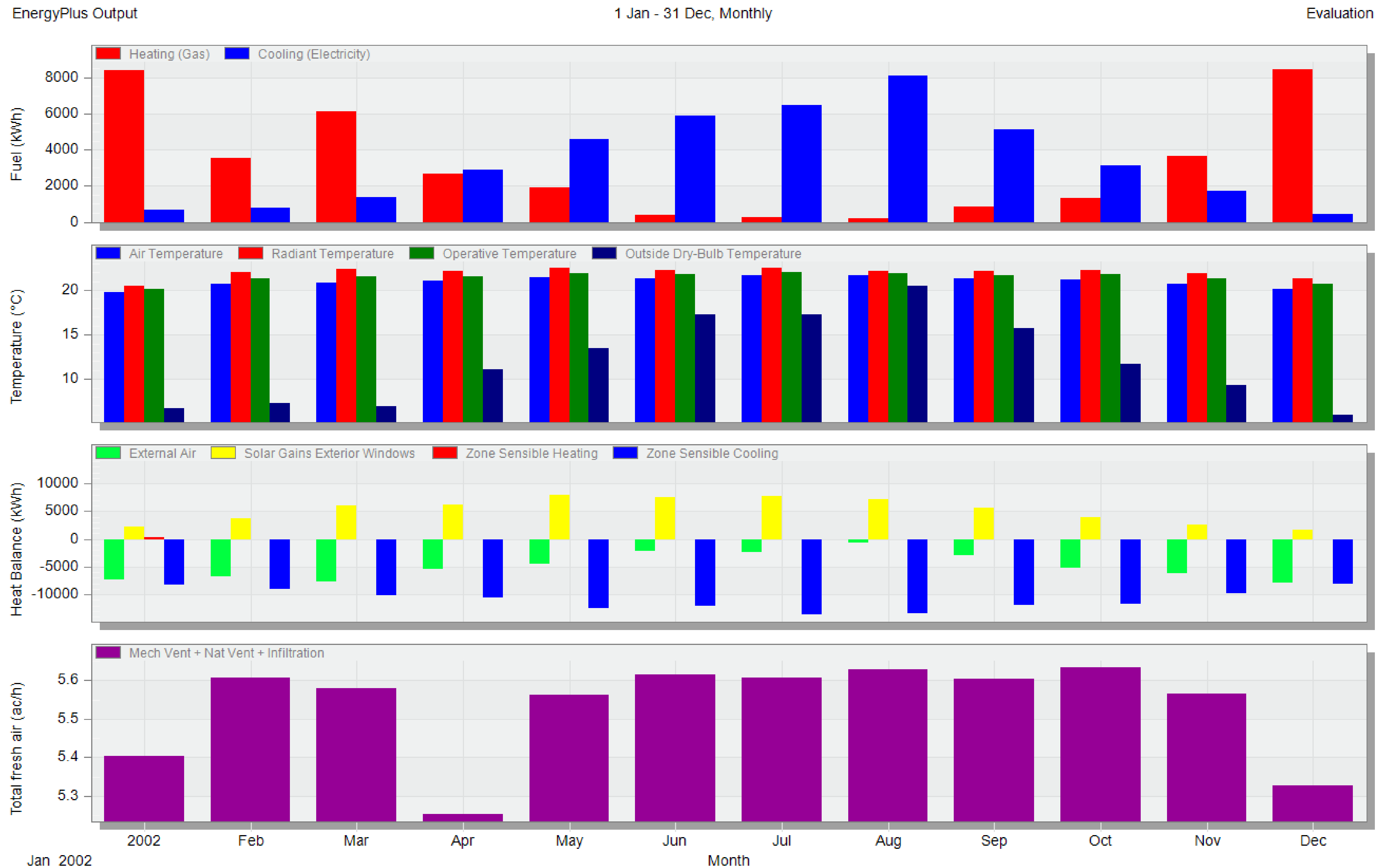


Building	Provinciehuis Utrecht
Space	1 Office floor
Building type	Beta
Temperature type	Operative
Analysis Period	Jan-Sept
Occupied Hours	1367
Thermal Performance	Acceptable
Class	Class C

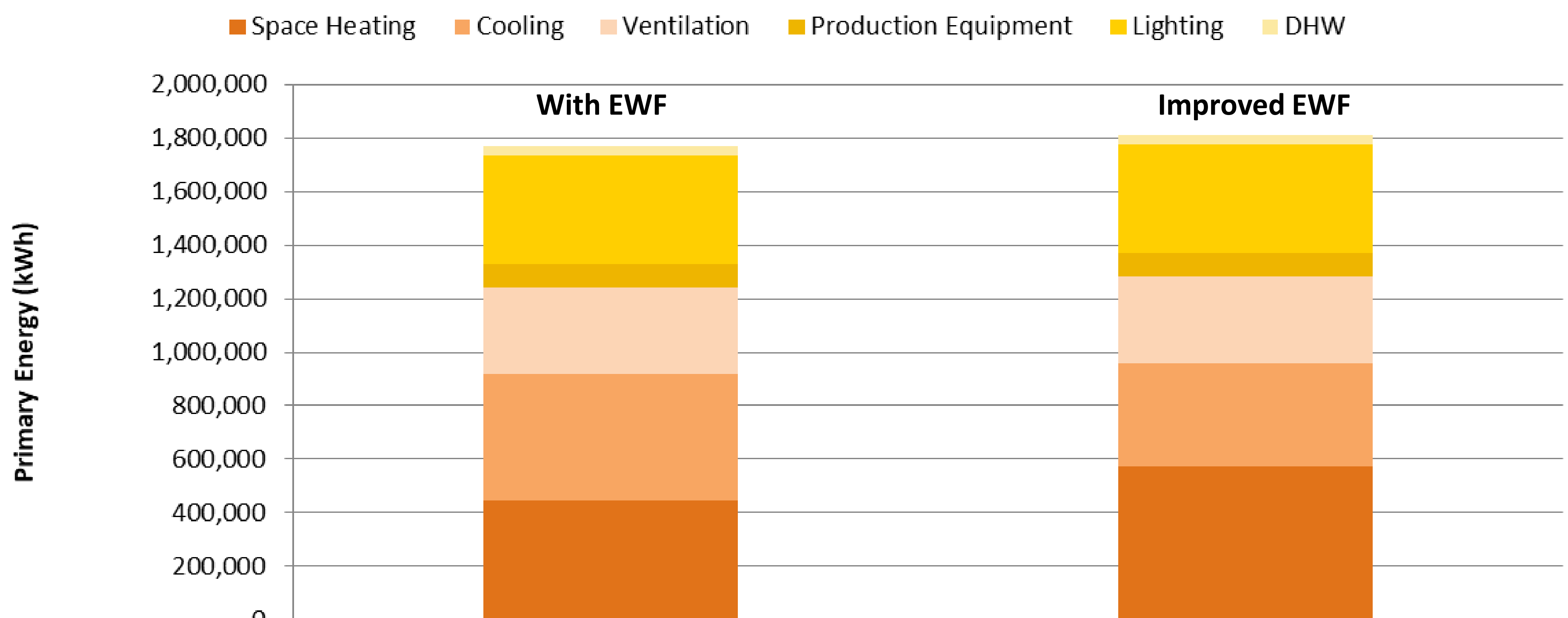
Comfort Bandwidth	No. of Hours	% of Time
Class B	1000	73.1
Class C	308	22.5
Class D	59	4.3



Improved System with EWF



Comparison with EWF and Improved System with EWF



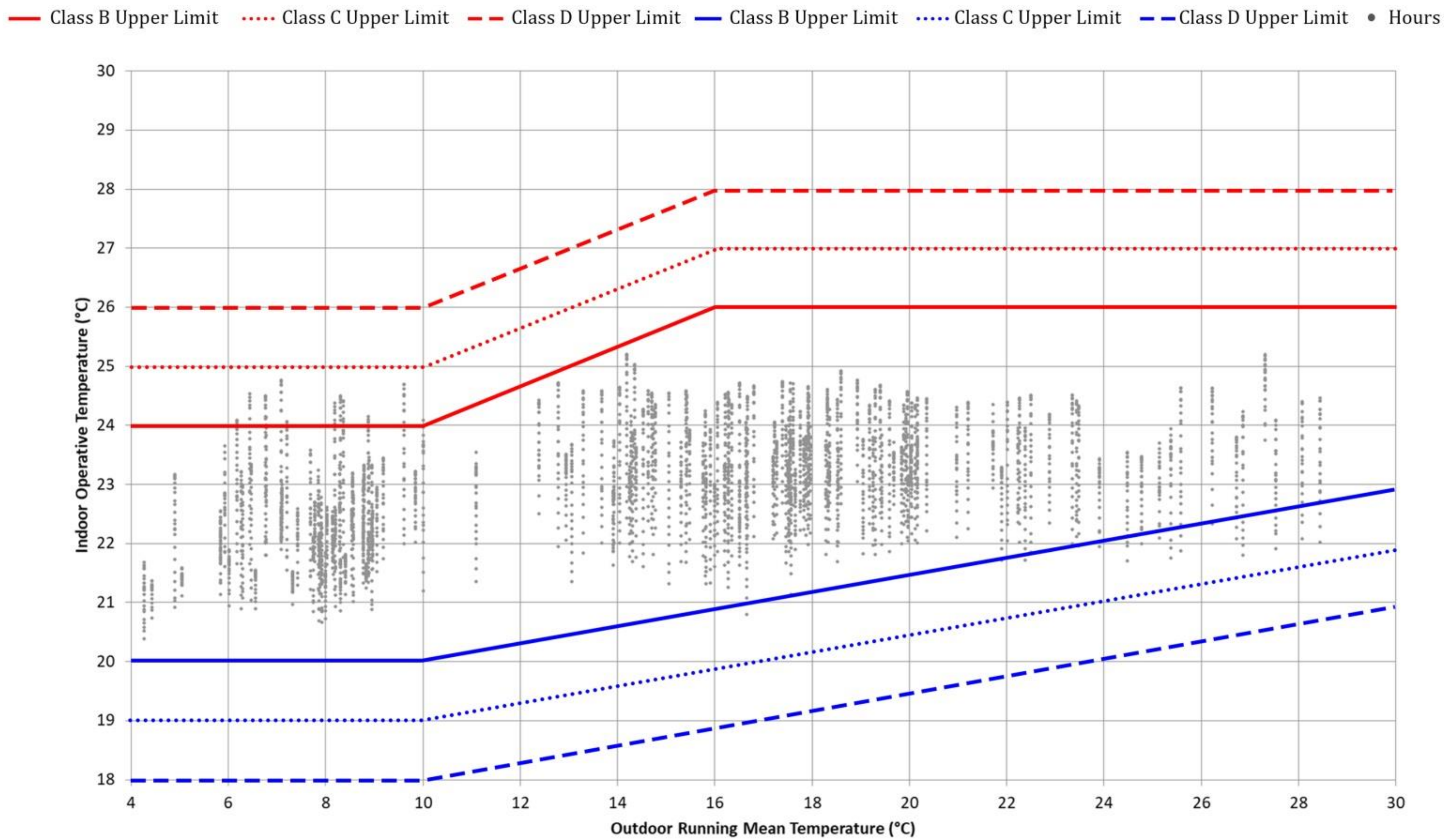
	With EWF(kWh)	Improved EWF (kWh)
DHW	35,280	35,280
Lighting	405,720	405,720
Production Equipment	88,200	88,200
Ventilation	322,400	323,100
Cooling	469,404	385,290
Space Heating	447,660	574,524

22% more Heating energy

18% less Cooling energy

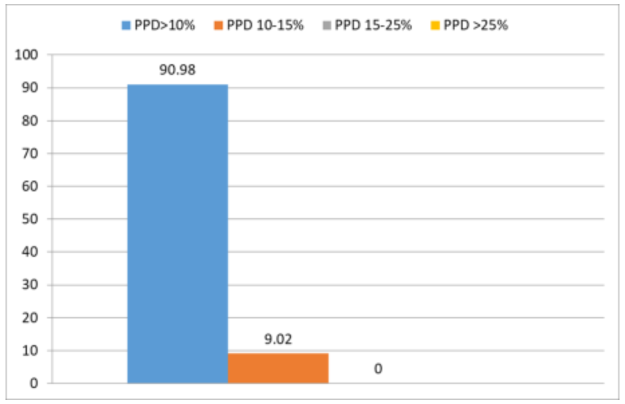
2% Increase overall

Thermal Comfort assessment of the Improved System with EWF



Building	Provinciehuis Utrecht
Space	1 Office floor
Building type	Beta
Temperature type	Operative
Analysis Period	Jan-Sept
Occupied Hours	255
Thermal Performance	Good
Class	Class B

Comfort Bandwidth	No. of Hours	% of Time
Class B	232	90.98
Class C	23	9.02
Class D	0	0



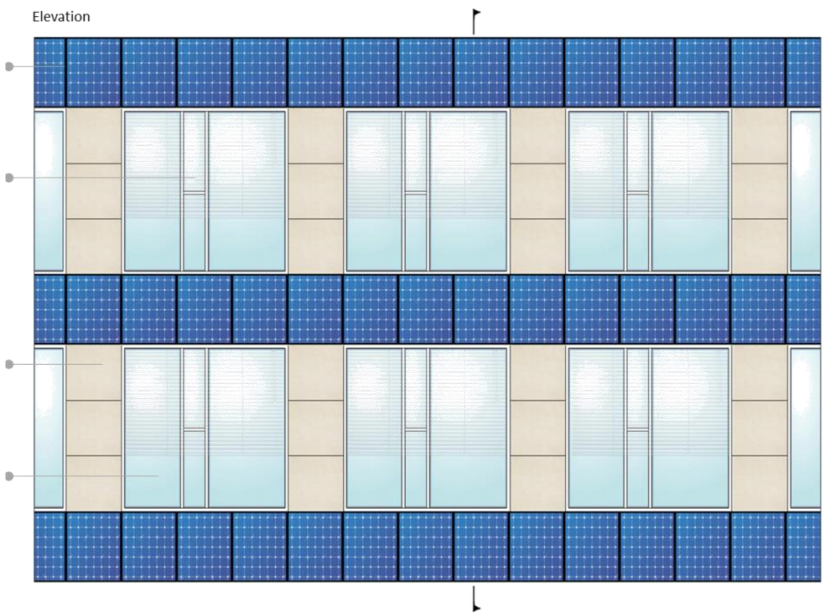
EWF system is an efficient way to reduce the energy consumption.

EWF system has better thermal comfort than the existing system.

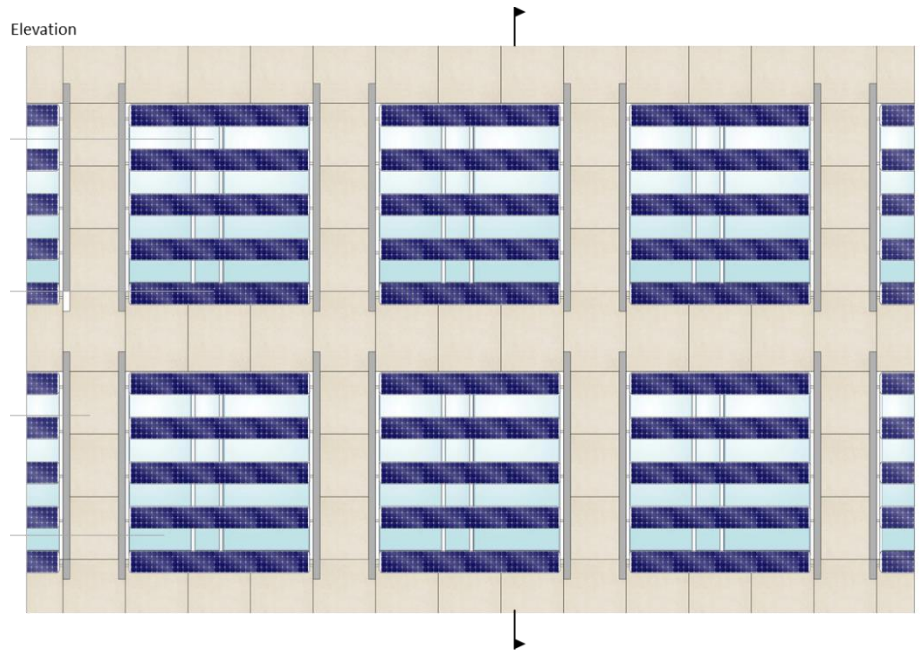
With further improvements, the building achieves maximum thermal comfort.

3 Façade Options

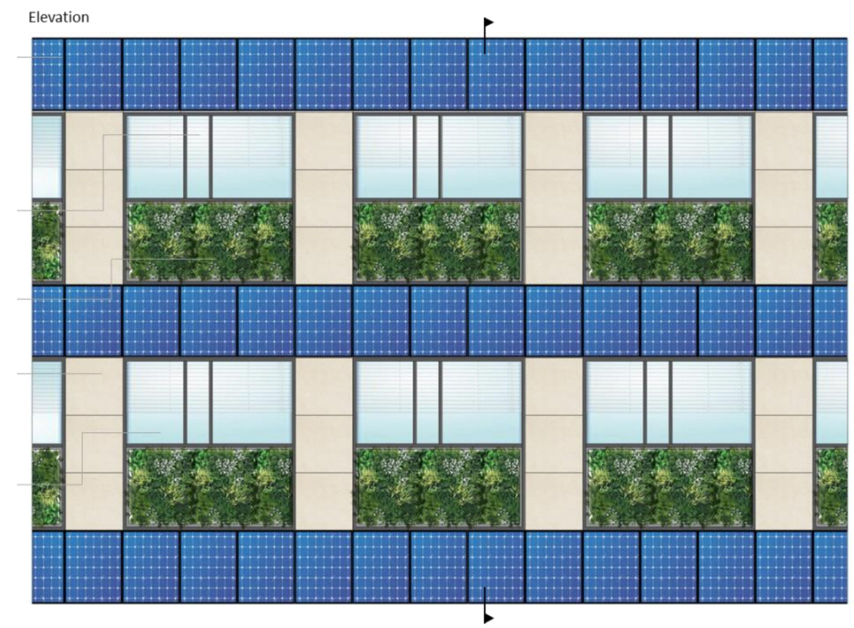
FAÇADE OPTION 1:
Building Integrated Photovoltaic



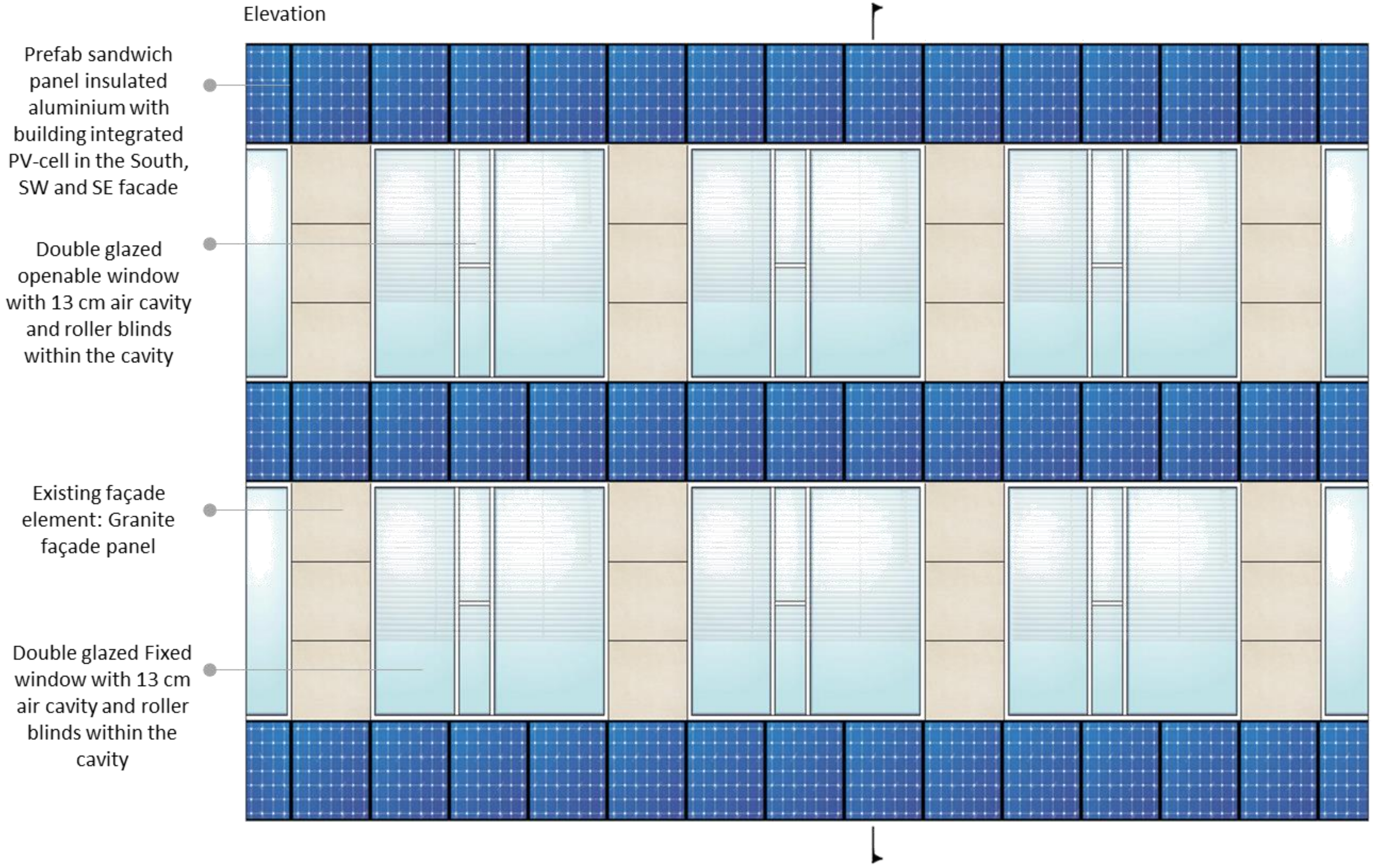
FAÇADE OPTION 2:
Sun-shading with PV

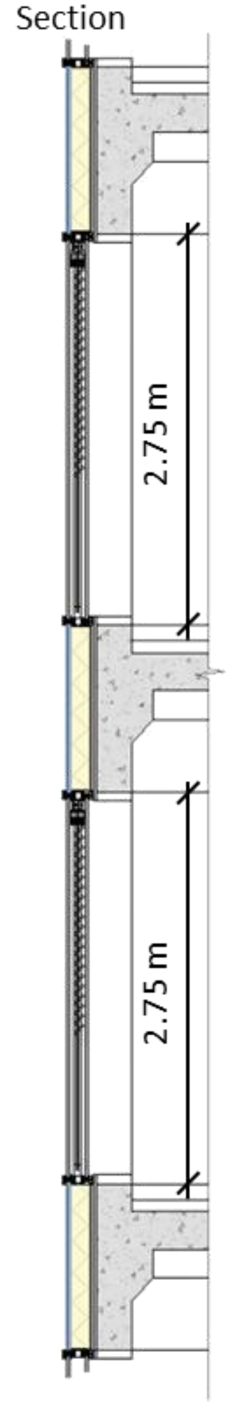


FAÇADE OPTION 3:
Living Wall system with BIPV



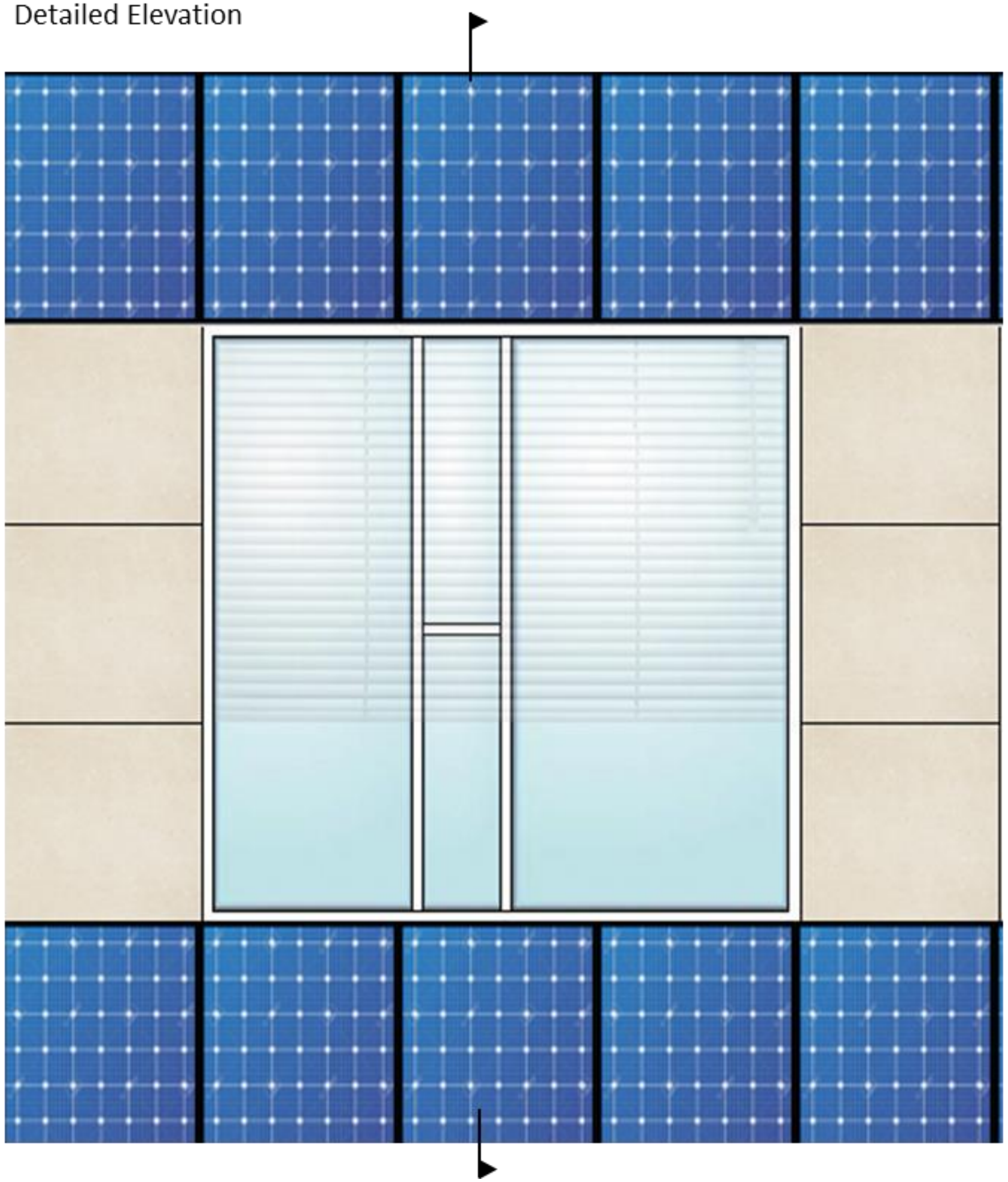
FAÇADE OPTION 1: Building Integrated Photovoltaic



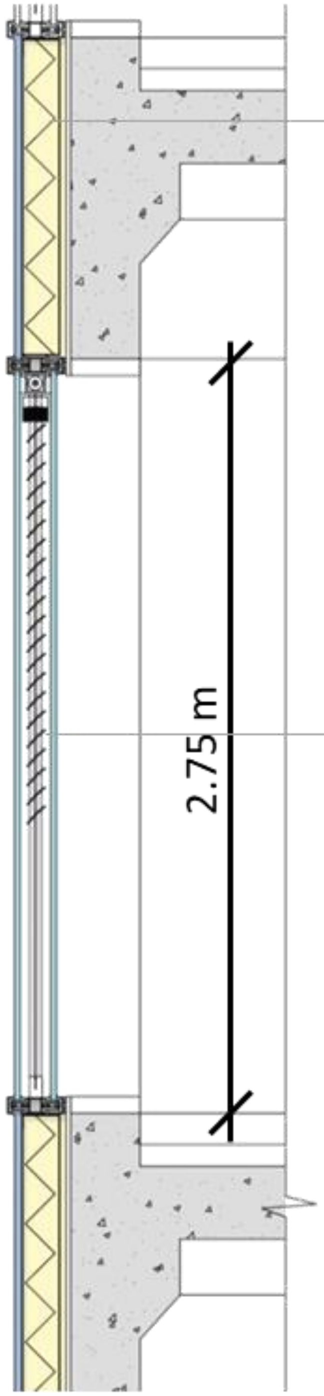


FAÇADE OPTION 1: Building Integrated Photovoltaic

Detailed Elevation

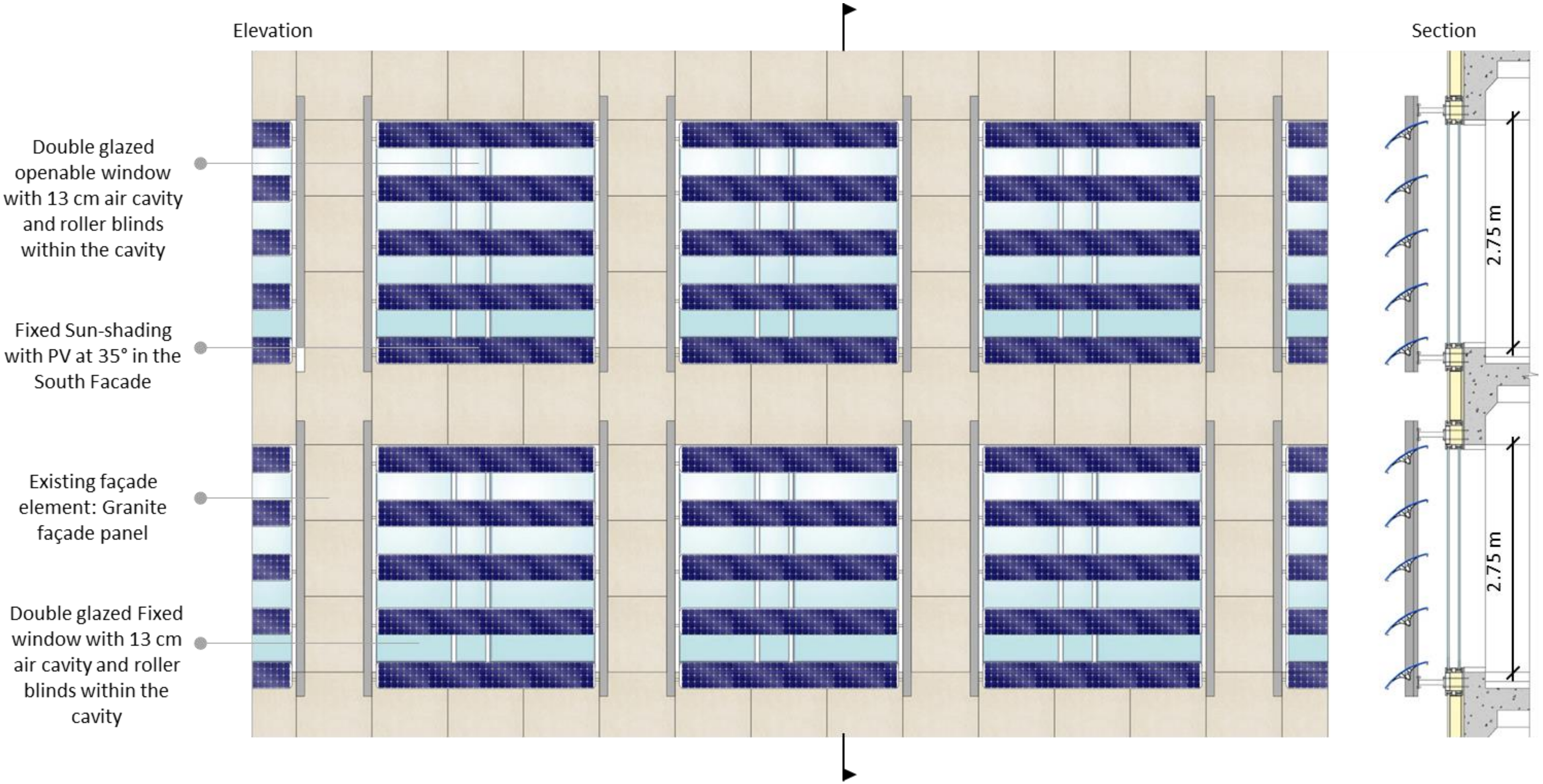


Detailed section



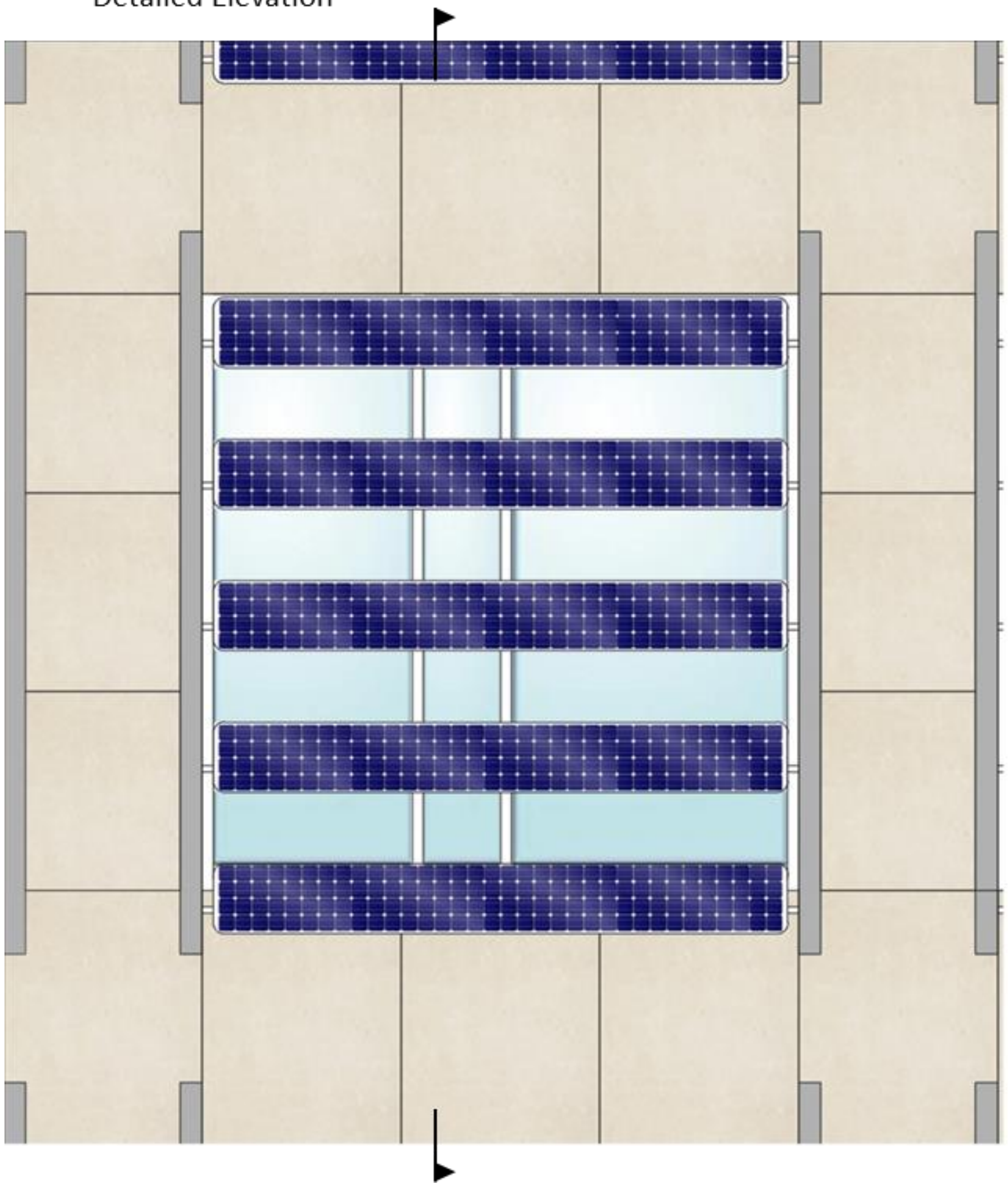
- Prefab sandwich panel insulated Aluminium with building integrated PV-cell
- Double glazed Fixed window with 130 mm air cavity and roller blinds within the cavity

FAÇADE OPTION 2: Sun-shading with PV

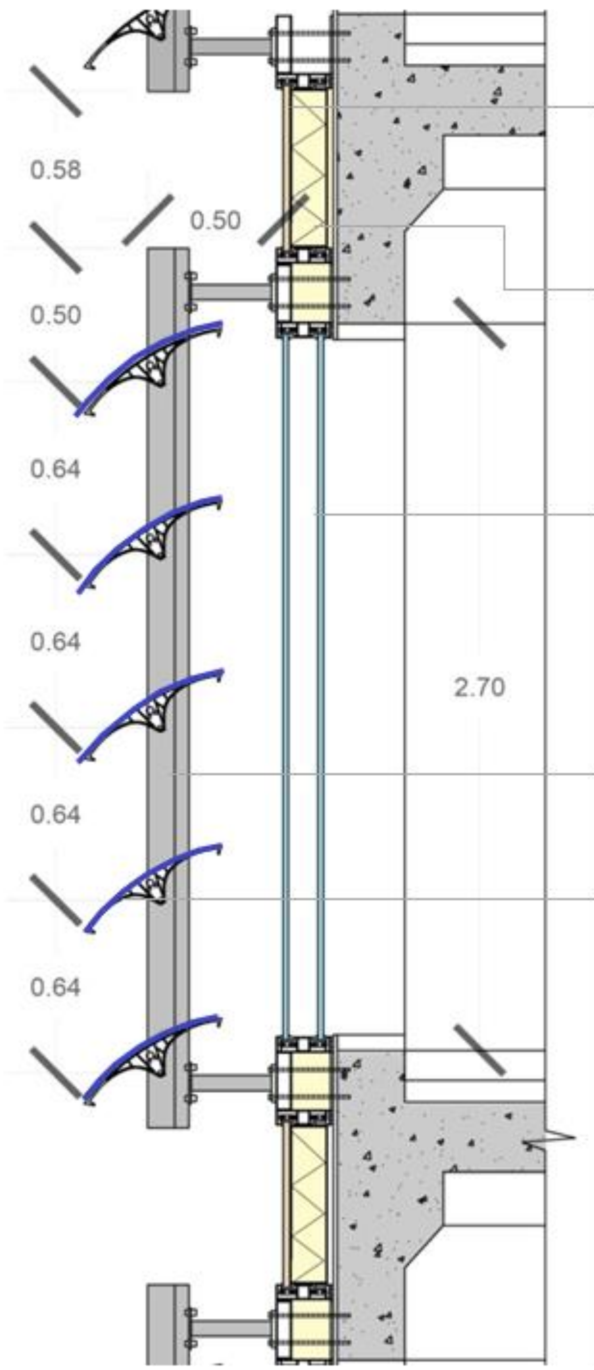


FAÇADE OPTION 2: Sun-shading with PV

Detailed Elevation



Detailed Section



FAÇADE OPTION 3: Living Wall system with BIPV

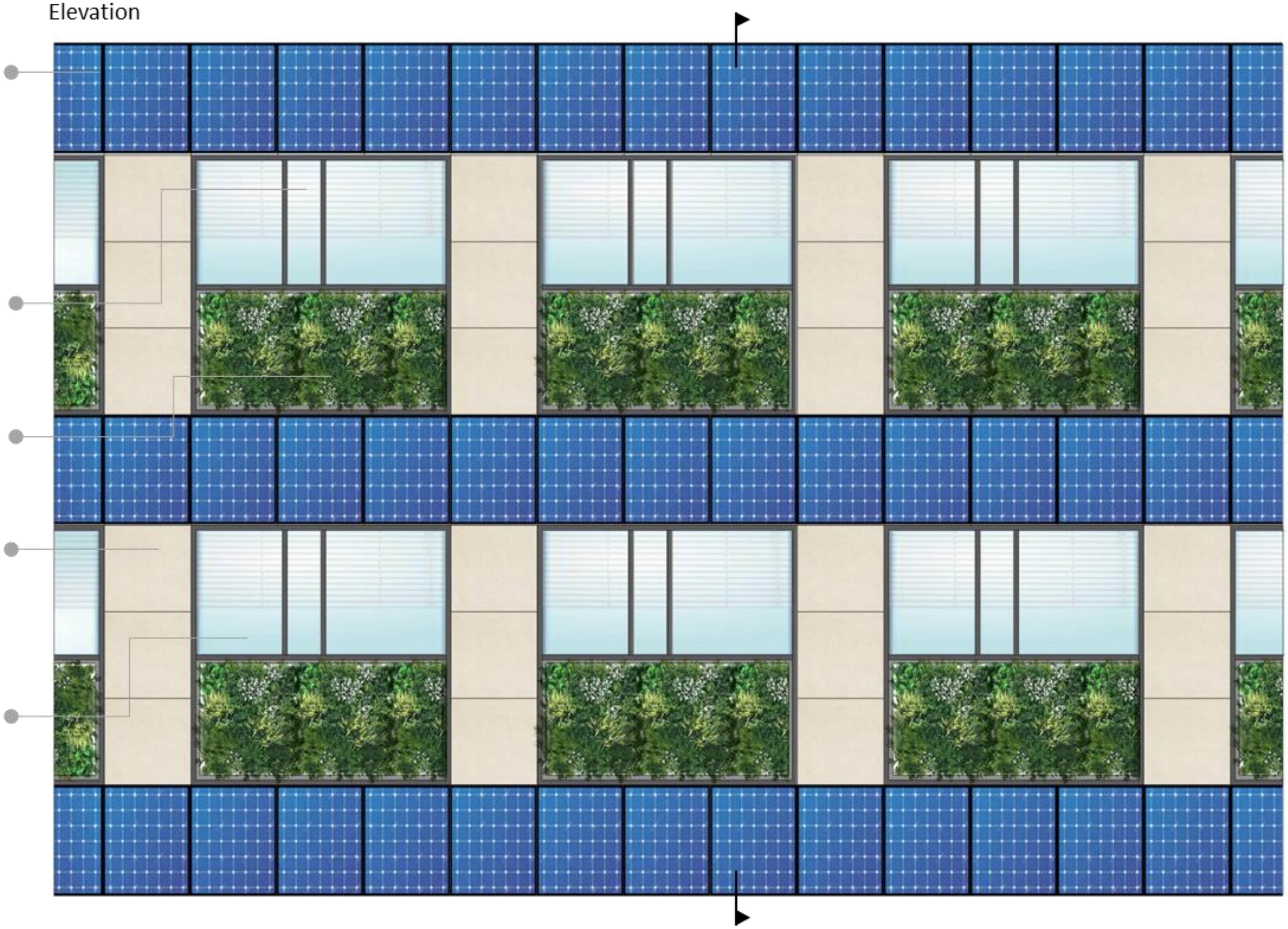
Prefab sandwich panel insulated aluminium with building integrated PV-cell in the South, SW and SE facade

Double glazed openable window with 13 cm air cavity and roller blinds within the cavity

Living Wall system in S,SW & SE

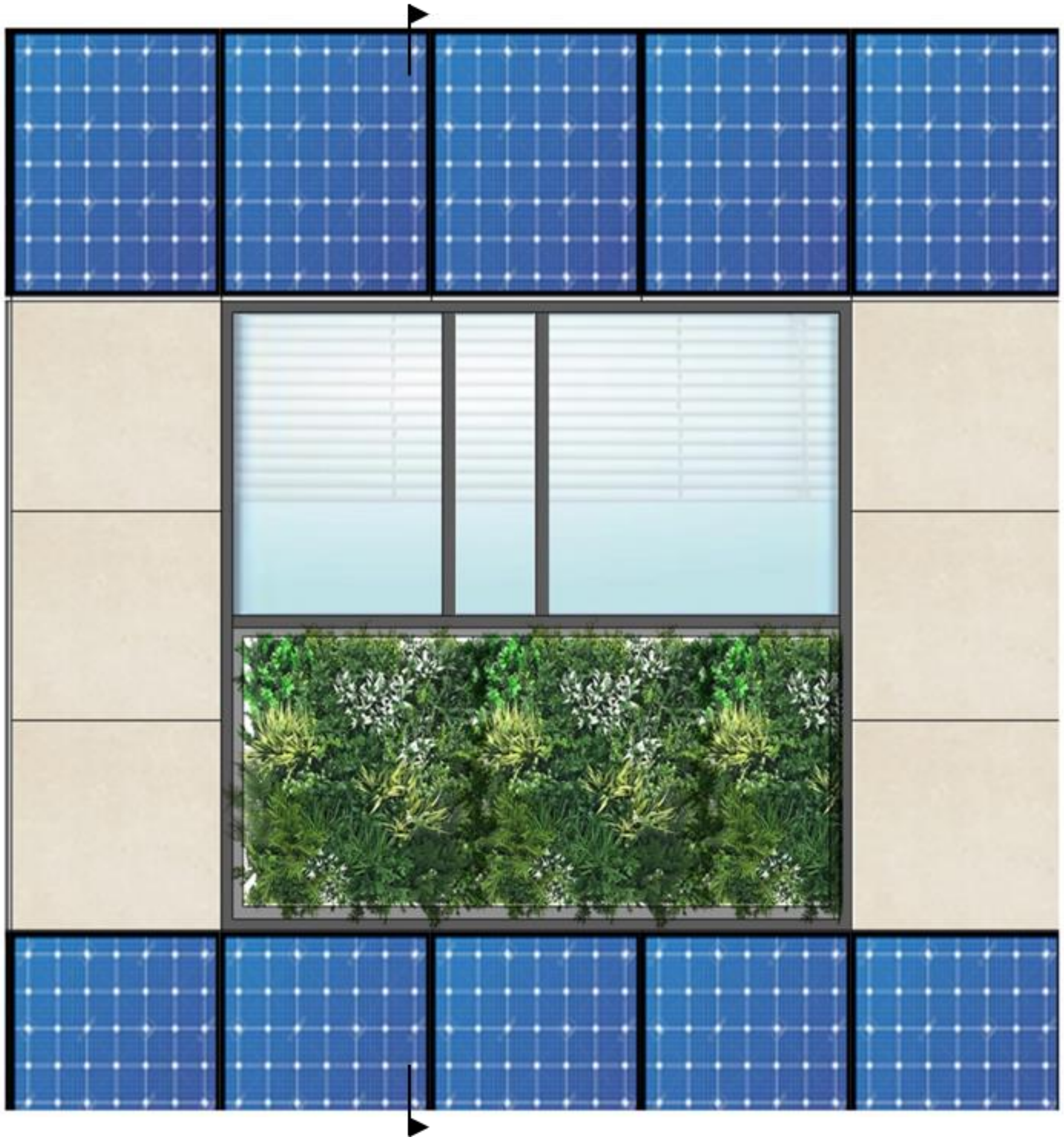
Existing façade element: Granite façade panel

Double glazed Fixed window with 13 cm air cavity and roller blinds within the cavity

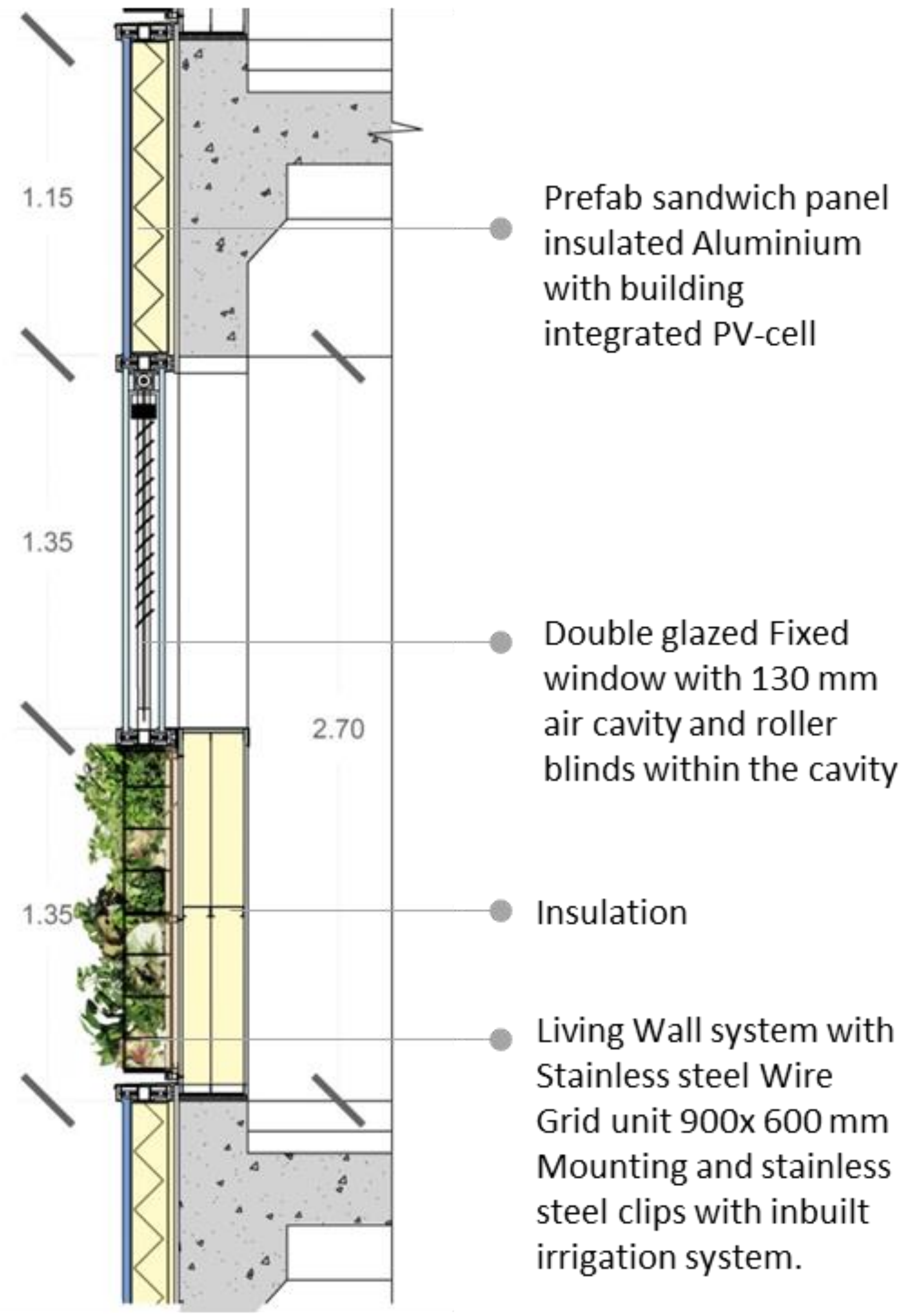


FAÇADE OPTION 3: Living Wall system with BIPV

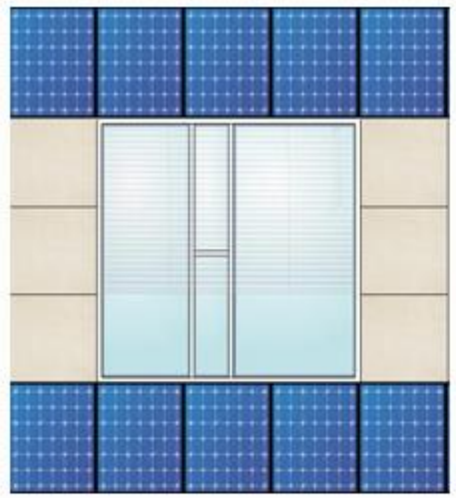
Detailed Elevation



Detailed Section

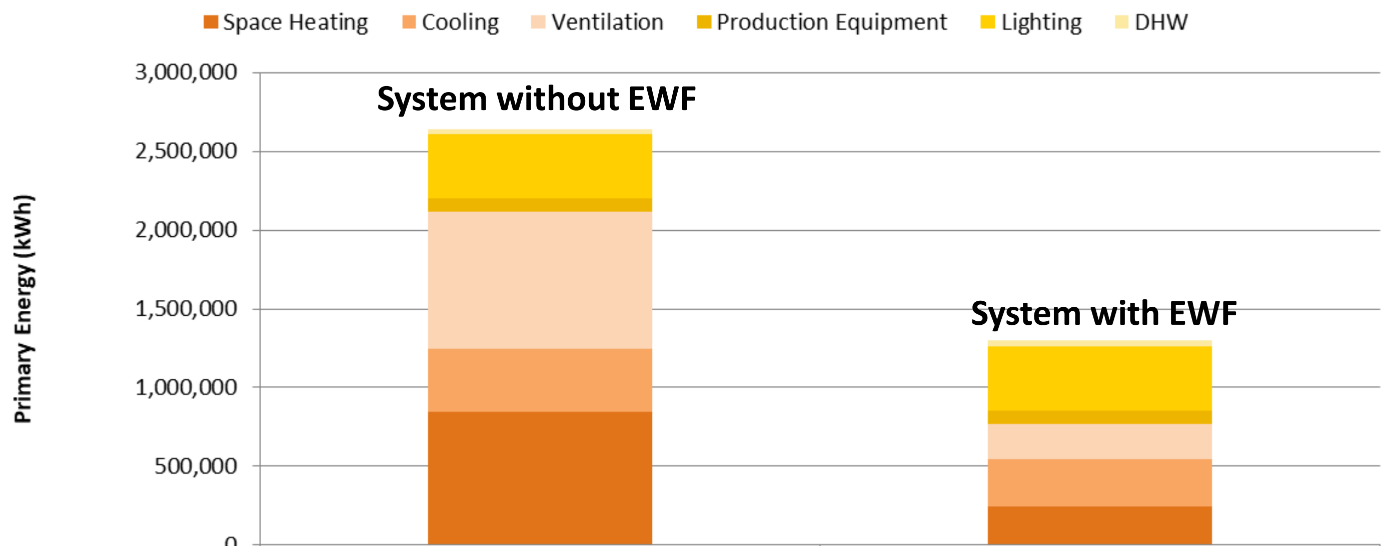


Comparison of 3 façade options

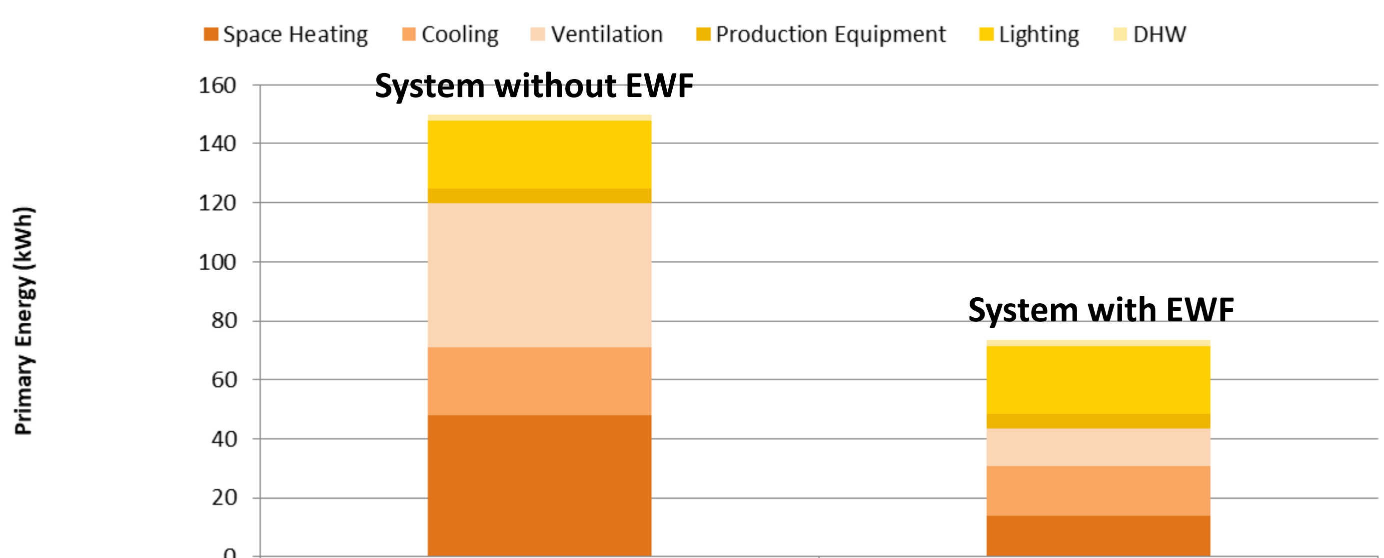
Changed parameters	Façade option 1: BIPV	Façade option 2: Sun-shading with PV	Façade option 3: Living Wall System with BIPV
			
R-value	4.2 m^2K/W	No change	5.9 m^2K/W
% Reduction in solar gain from windows	No change	50%	84%
PV yield	224 MWh/year	150 MWh/year	224 MWh/year
% Reduction in the total energy consumption of the building	12%	13%	19%

EWF system with refurbished façade and GSHP

Comparison between the 2 systems



	Without EWF with GSHP (kWh)	With EWF and GSHP (kWh)
DHW	35,280	35,280
Lighting	405,720	405,720
Production Equipment	88,200	88,200
Ventilation	864,360	224,993
Cooling	403,200	296,190
Space Heating	846,000	247,644



	Without EWF with GSHP (kWh/m2)	With EWF and GSHP (kWh/m2)
DHW	2	2
Lighting	23	23
Production Equipment	5	5
Ventilation	49	13
Cooling	23	17
Space Heating	48	14

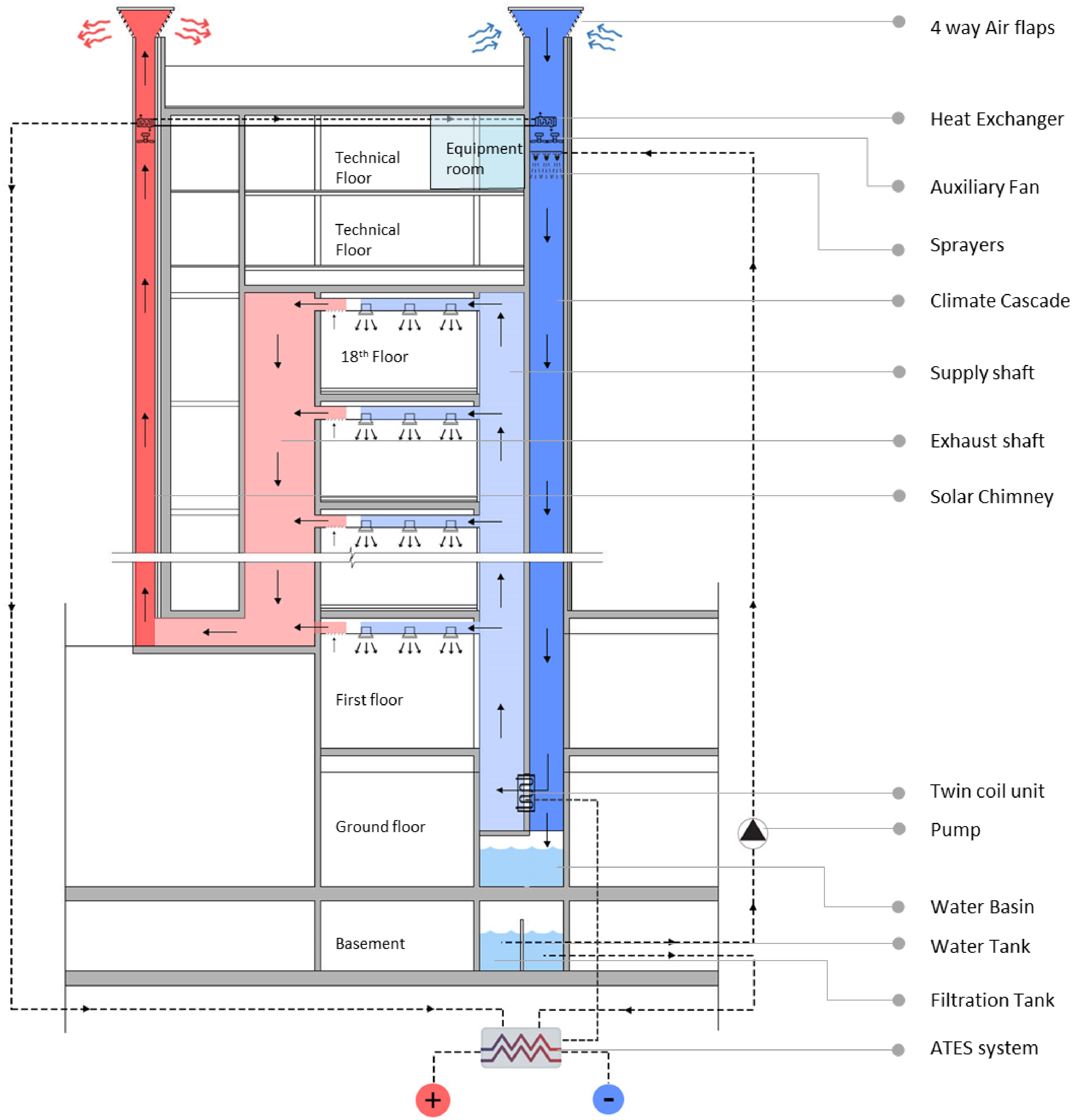
74% less Ventilation energy

26.5% less Cooling energy

70% less Heating energy

50% Reduction Overall

Final Design

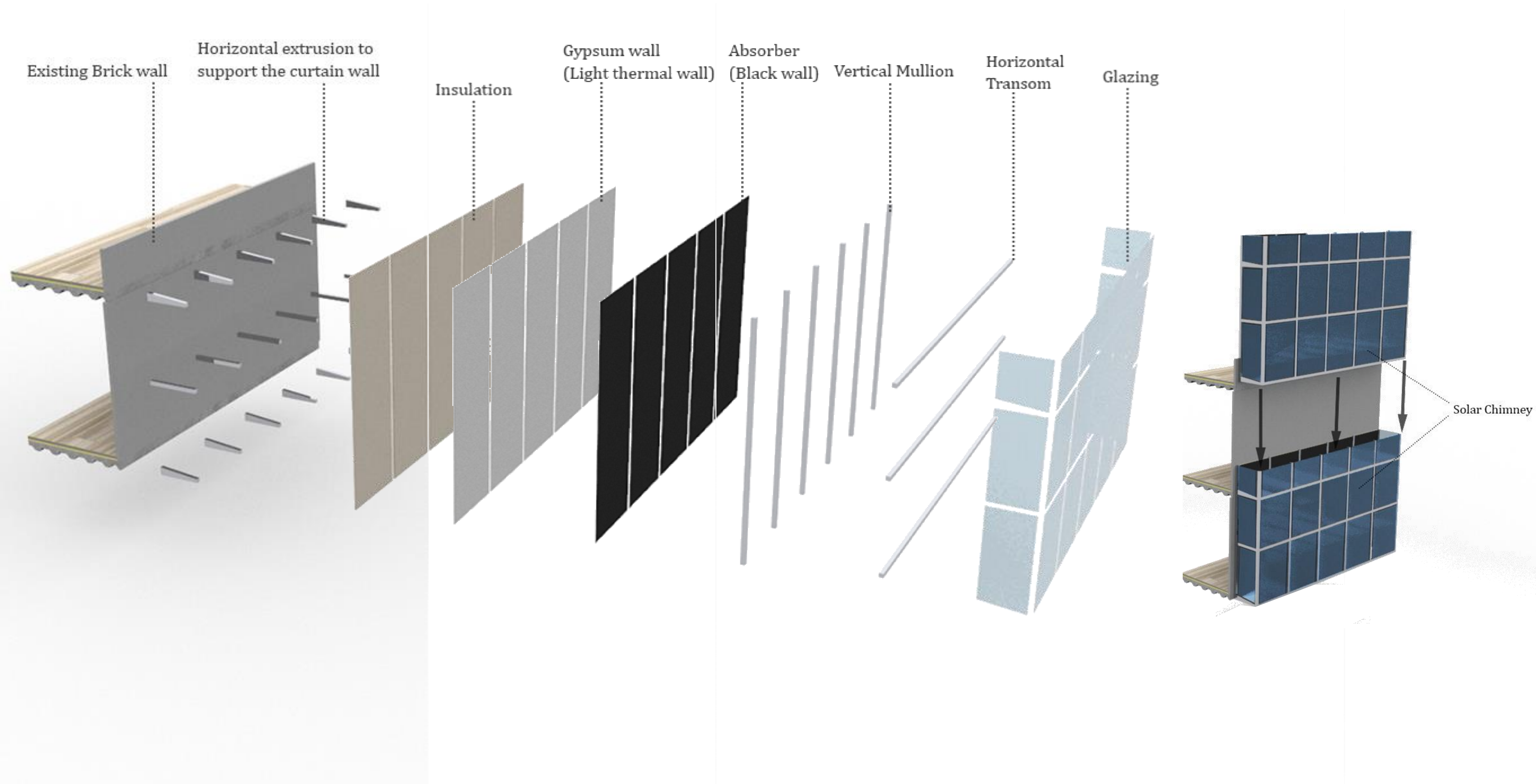

Technical Floor
Equipment room
Technical Floor
18th Floor
First floor
Ground floor
Basement
4 way Air flaps
Heat Exchanger
Auxiliary Fan
Sprayers
Climate Cascade
Supply shaft
Exhaust shaft
Solar Chimney
Twin coil unit
Pump
Water Basin
Water Tank
Filtration Tank
ATES system
+
-


Before


After
PROVINCIE UTRECHT


PROVINCIE UTRECHT

Assembly Sequence of Solar Chimney



BENG Regulations

BENG CALCULATIONS						
Annual amount of energy used for the energy function: Scenario 1						
	COP	**Non-Primary energy (kWh)**	**PEF**	**Primary Energy (kWh)**	**Auxiliary energy Non-Primary energy (kWh)**	**Auxiliary energy Primary energy (kWh)**
Heating	5.4	82,284 kWh	1.45	119,311 kWh	36,425	52,816
Cooling	10	0 kWh	1.45	0 kWh	29,619 kWh	42,947 kWh
DHW	3	0 kWh	1.45	0 kWh	11,760 kWh	17,052 kWh
Fans & Pumps	-	28,300 kWh	1.45	41,035 kWh	0 kWh	0 kWh
Lighting	-	405,720 kWh	1.45	588,294	0 kWh	0 kWh
Total				748,640		112,815

Annual Primary Energy consumption	
Primary energy use including auxiliary energy	861,455
Energy generated by PV	224,076
Annual Primary Energy consumption ($E_{tot\ primary}$)	**637,379**

Annual amount of Renewable Energy	
Heating ($E_{ren.\ heating}$)	362,053
Cooling ($E_{ren\ cooling}$)	266,571
PV ($E_{ren\ pv}$)	224,076
Total amount of Renewable Energy ($E_{tot\ ren}$)	**852,700**

Surface	
Total Useable Floor Area (UFA)	17,640
Surface area of Envelope (SAE)	18445
Ratio	1.04

Heating and cooling Energy (Fossil + renewable energy)		
Heating (Pre heating included) ($E_{heating}$)	444,337 kWh	25.2
Cooling (Pre cooling included) (E_{coolng})	492,883 kWh	28

Energy Performance				
BENG 1	**<90 kWh/m2**	**($E_{heating}$)+(E_{coolng})**	**53.2 kWh/m2**	Satisfied
BENG 2	**<40 kWh/m2**	**($E_{tot\ primary}$)/ UFA**	**36.13 kWh/m2**	Satisfied
BENG 3	**>30%**	**($E_{tot\ ren}$)/ ($E_{tot\ ren}$ + $E_{tot\ primary}$)**	**57.2%**	Satisfied

BENG CALCULATIONS						
Annual amount of energy used for the energy function: Scenario 2						
	COP	**Non-Primary energy (kWh)**	**PEF**	**Primary Energy (kWh)**	**Auxiliary energy Non-Primary energy (kWh)**	**Auxiliary energy Primary energy (kWh)**
Heating	5.4	135,064 kWh	1.45	195,842 kWh	59,879 kWh	86,824 kWh
Cooling	10	0 kWh	1.45	0 kWh	48,430 kWh	70,223 kWh
DHW	3	0 kWh	1.45	0 kWh	19,333 kWh	28,032 kWh
Fans & Pumps	-	46,524 kWh	1.45	67,459 kWh	0 kWh	0 kWh
Lighting	-	667,000 kWh	1.45	967,150	0 kWh	0 kWh
Total				1,230,451		185,079
Annual Primary Energy consumption						
Primary energy use including auxiliary energy				1,415,530		
Energy generated by PV				224,076		
Annual Primary Energy consumption ($E_{tot\ primary}$)				**1,191,454**		
Annual amount of Renewable Energy						
Heating ($E_{ren.\ heating}$)				594,186		
Cooling ($E_{ren\ cooling}$)				435,870		
PV ($E_{ren\ pv}$)				224,076		
Total amount of Renewable Energy ($E_{tot\ ren}$)				**1,254,132**		

Surface		
Total Useable Floor Area (UFA)	29000	
Surface area of Envelope (SAE)	21075	
Ratio	0.72	
Heating and cooling Energy (Fossil + renewable energy)		
Heating (Pre heating included) ($E_{heating}$)	729,350 kWh	25.2
Cooling (Pre cooling included) (E_{coolng})	807,650 kWh	28

Energy Performance				
BENG 1	**<90 kWh/m2**	**($E_{heating}$)+(E_{coolng})**	**53.2 kWh/m2**	**Satisfied**
BENG 2	**<40 kWh/m2**	**($E_{tot\ primary}$)/ UFA**	**41.0 kWh/m2**	**Not Satisfied**
BENG 3	**>30%**	**($E_{tot\ ren}$)/ ($E_{tot\ ren}$ + $E_{tot\ primary}$)**	**51.2%**	**Satisfied**

BENG CALCULATIONS						
Annual amount of energy used for the energy function: Scenario 3						
	COP	**Non-Primary energy (kWh)**	**PEF**	**Primary Energy (kWh)**	**Auxiliary energy Non-Primary energy (kWh)**	**Auxiliary energy Primary energy (kWh)**
Heating	5.4	135,064 kWh	1.45	195,842 kWh	59,879 kWh	86,824 kWh
Cooling	10	0 kWh	1.45	0 kWh	48,430 kWh	70,223 kWh
DHW	3	0 kWh	1.45	0 kWh	19,333 kWh	28,032 kWh
Fans & Pumps	-	46,524 kWh	1.45	67,459 kWh	0 kWh	0 kWh
Lighting	-	667,000 kWh	1.45	967,150	0 kWh	0 kWh
Total				1,230,451		185,079

Annual Primary Energy consumption	
Primary energy use including auxiliary energy	1,415,530
Energy generated by PV	326,097
Annual Primary Energy consumption ($E_{tot\ primary}$)	**1,089,433**
Annual amount of Renewable Energy	
Heating ($E_{ren.\ heating}$)	594,186
Cooling ($E_{ren\ cooling}$)	435,870
PV ($E_{ren\ pv}$)	326,097
Total amount of Renewable Energy ($E_{tot\ ren}$)	**1,356,153**

Surface	
Total Useable Floor Area (UFA)	29000
Surface area of Envelope (SAE)	21075
Ratio	0.72

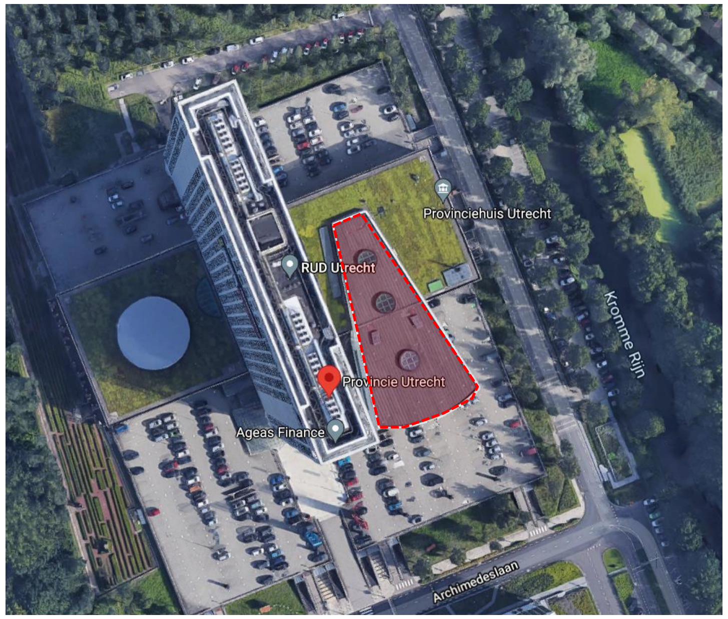
Heating and cooling Energy (Fossil + renewable energy)		
Heating (Pre heating included) ($E_{heating}$)	729,350 kWh	25.2
Cooling (Pre cooling included) (E_{coolng})	807,650 kWh	28

Energy Performance				
BENG 1	**<90 kWh/m2**	**($E_{heating}$)+(E_{coolng})**	**53.2 kWh/m2**	**Satisfied**
BENG 2	**<40 kWh/m2**	**($E_{tot\ primary}$)/ UFA**	**37.56 kWh/m2**	**Satisfied**
BENG 3	**>30%**	**($E_{tot\ ren}$)/ ($E_{tot\ ren}$ + $E_{tot\ primary}$)**	**51.2%**	**Satisfied**

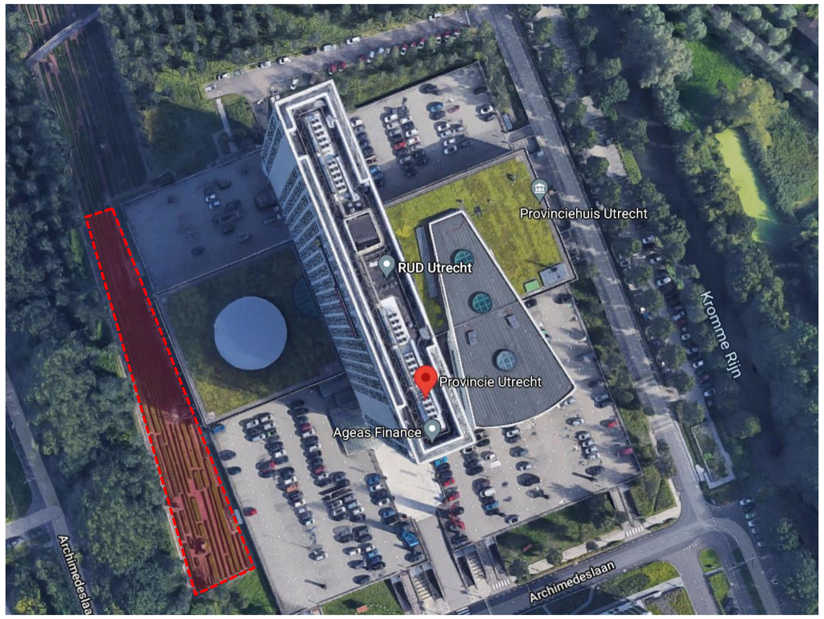
Paris Proof Agreement

PARIS PROOF	
Annual Primary Energy consumption	
1,089,433 kWh	
Total amount of Renewable Energy	
PV on SW,SE & S facade	326,097 kWh
Required PV energy	**763,336 kWh**

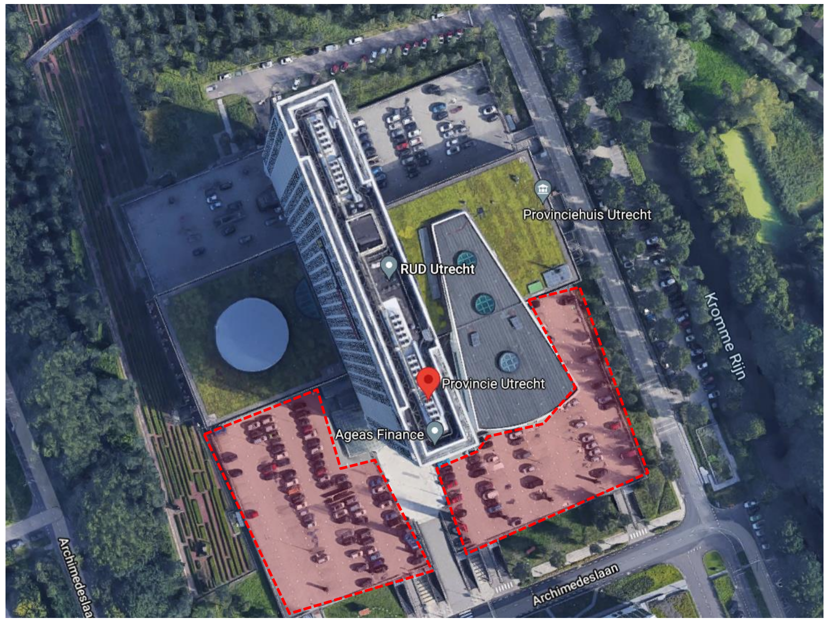
Proposed locations to install PV



PV panels on the Statenzaal roof



PV panels in the Garden on the SW



PV panels on the parking deck

PARIS PROOF	
Annual Primary Energy consumption	
1,089,433 kWh	
Total amount of Renewable Energy	
PV on SW,SE & S facade	326,097 kWh
PV on the roof of the Statenzaal	185,923 kWh
PV panels in the garden (orientation SW)	228,978 kWh
PV on the parking deck	468,450 kWh
	1,209,448 kWh

*The **primary energy** can be **completely provided** by the **PV panels** and **energy neutrality is achieved** on the basis of **zero on the meter concept.***

RECAP

*How are the **design strategies** derived from the **Earth, Wind and Fire system**, implemented in the **refurbishment of an office building** in the Netherlands in order to **improve the energy performance**?*

Basic Excel Model

EWF system can be implemented

- ***No. of EWF elements***
- ***Building design and required pressure***

Dynamic Design Builder Model

EWF system also reduces the energy consumption and improves thermal comfort

- ***53 % energy reduction***
- ***Class B thermal comfort***

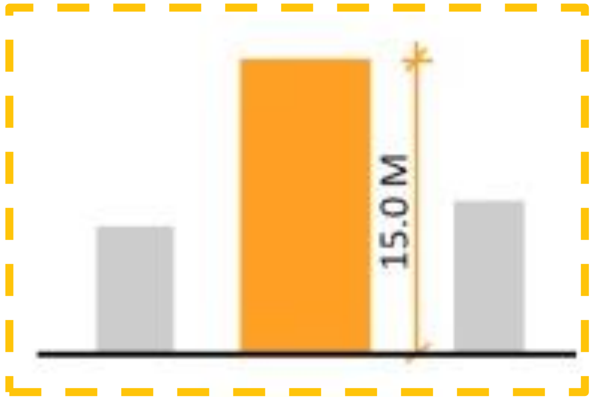
Façade Refurbishment

EWF system with refurbished façade further reduces the energy consumption significantly

- ***Further energy reduction by 19%***
- ***50% energy reduction with GSHP***

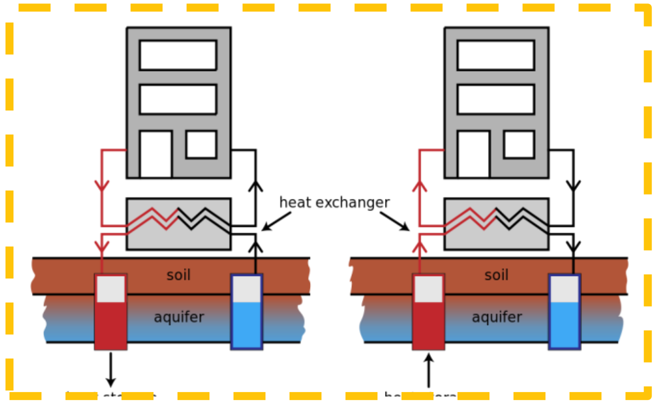
***EWF system** is an **efficient** way to **reduce the energy consumption** of the **Provinciehuis** Utrecht building while also **complying** with all the **BENG regulations** along with **achieving energy neutrality** on the basis of zero on the meter concept.*

In order to implement the EWF system for other buildings, the most influential design strategies to be considered are:

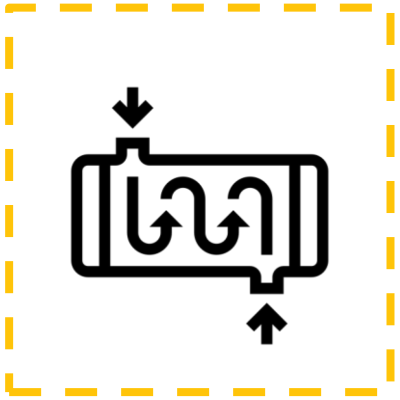


Building Height

Façade Refurbishment

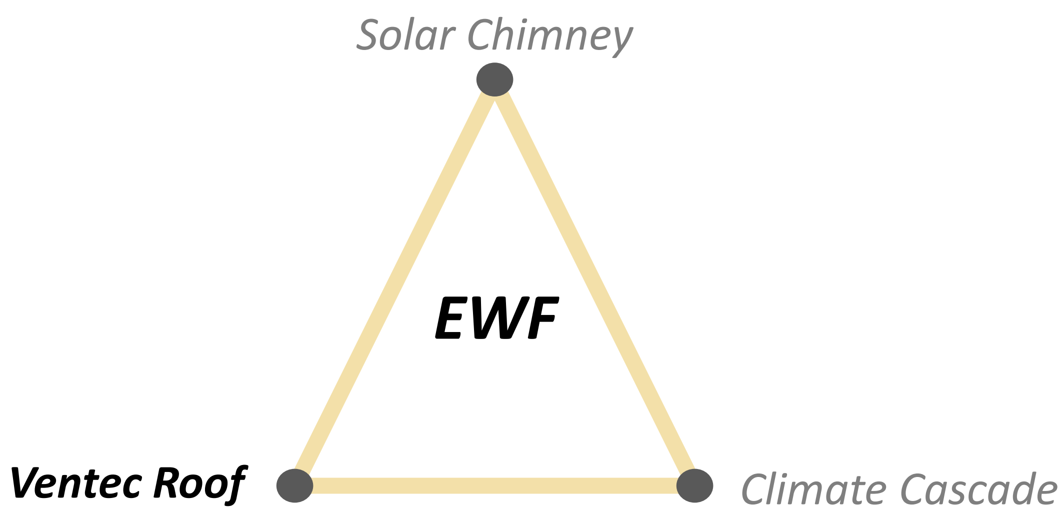


Heat and Cold storage

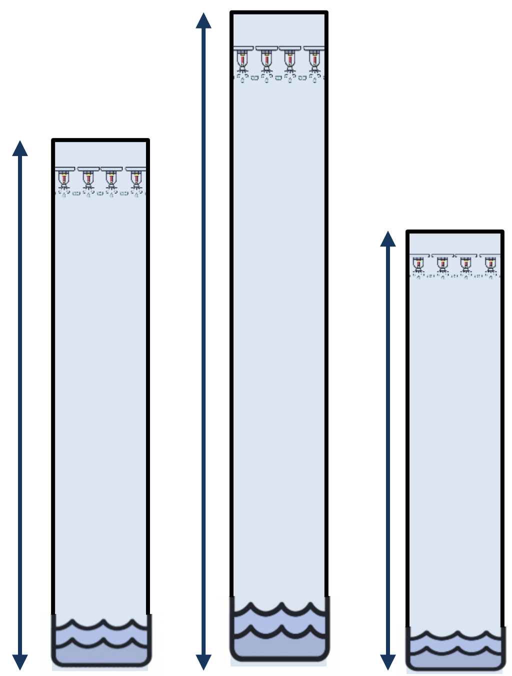


Heat Recovery system

Further Recommendations



Study the effect of Ventec Roof



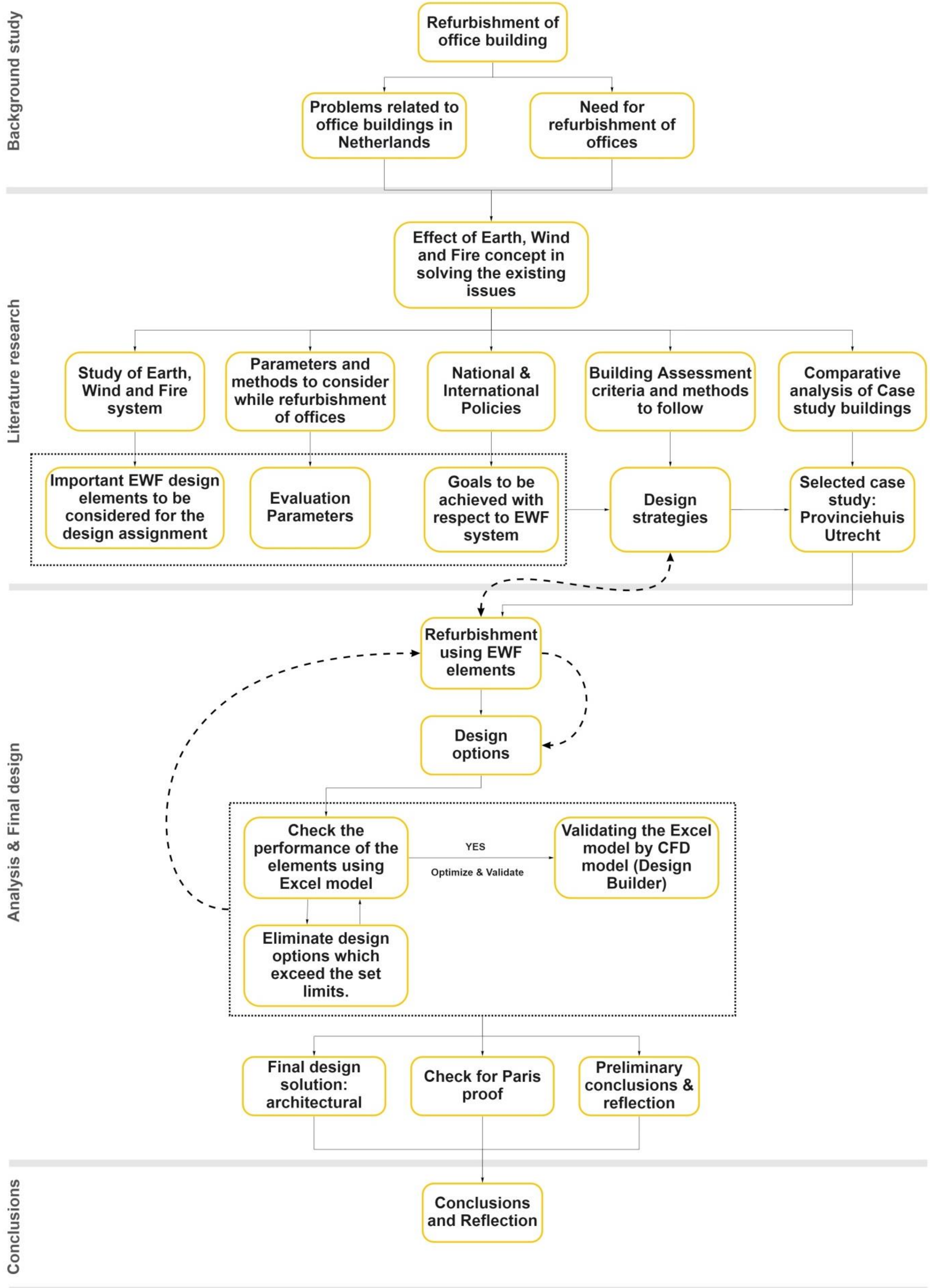
Varying Heights of Climate Cascade

Designer's tool

Thank You!

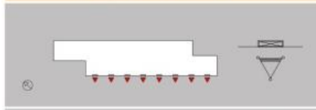
Appendix

Methodology

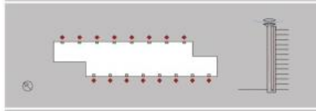


SOLAR CHIMNEY

Separate from the building

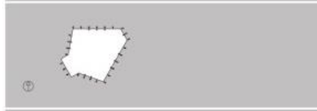


Seperate chimney's could function as sun shading device and to get more daylight into the building.

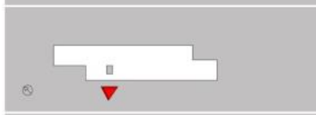


Reuse old material to construct the chimney.

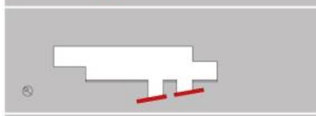
Put a small ventec roof on top of the chimney to improve its performance.

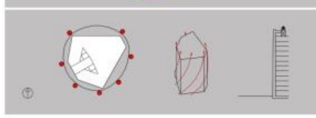


A lot of small chimney's around the building would add character but compromise on its performance.



One large seperate chimney would have a better performance than a lot of small chimney's. Seperation of the building would allow more daylight in the building.

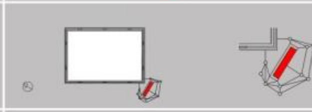




Swaying chimney's around the building wouldn't compromise its performance but add more architectural identity. Add heat recovery on top incl. turbine to produce energy.

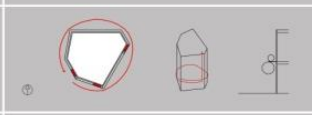
Connected to the building

A chimney could be designed like it bumped into the existing building. By combining it with an atrium the distribution of exhaust air could also be arranged.

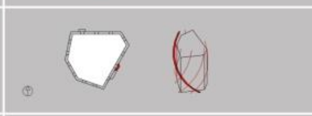


An expressive 'proboscis'-like chimney could be added to the building.

The chimney's and supply/exhaust shunts could be made expressive/explicit in the shape of an extra facade layer that is wrapped around the building.

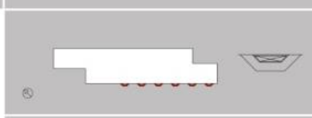


The collection of the exhaust air at the bottom of the building could be made expressive with big shunt channels that circle around the building.

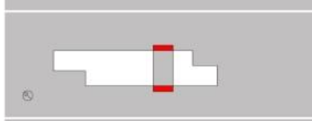


The diagrid structure could be emphasized with a swaying chimney and exhaust shunts in different directions around it.

Seperate facade elements with difference characteristics (depths, material) could be designed for the different EWF elements.



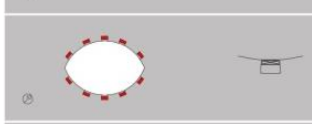
A trapezium shaped chimney with integrated exhaust shunt could be should. The shape doesn't necessarily improve it's performance.



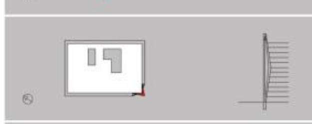
Whole floor elements could be removed to create an atrium with chimney's that stick out of the building.

Chromatic painting that fades due to temperature differences could be used to emphasize the working principle of the solar chimney.

A whole EWF unit could be connected to the building to control the natural airconditioning in the building.

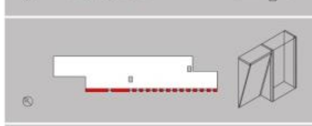


Repetative positioning of the chimney's could be used to give the building shape more character.

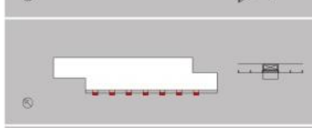


When the chimney is positioned in the corner of a building with a double facade de chimney could be emphazised by it's shape.

The level off expression in the facade could depend on the orientation of the facade. By doing so the building could get more connected with its surroudings.



The facade elements could be placed at an angle and so the chimney's with their straight vertical appearance are emphasized.



The chimney's could be 'pressed' outside to increase solar gains and to create space for exhaust shunts.

In a diagrid structure the diagonal space between the load bearing structure could be filled up with chimney's.

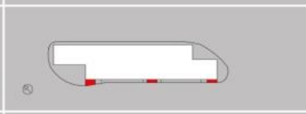
The temperature rise of the air could emphasized with LED lights that are intergrated in the chimney.

Information about the performance of the chimney could be displayed on the glass of the chimney's.

In the facade

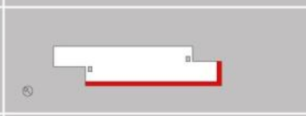
The niches in the building shape could be filled up with chimney. This doesn't make them very expressive but is effective from a climatic point of view by reducing the facade area.

The chimney could be expressed a bit in the facade by delecate changes in the shape of an extra facade layer.

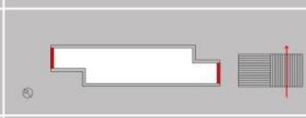


The chimney('s) could be hided behind an extra facade layer that is wrapped around the building.

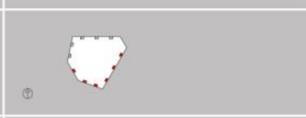
The chimney('s) could be hided behind an extra facade layer that is wrapped around the building.



By creating a solar facade the building shape is kept the same but the building performance is improved.



The chimney could be hided in an extra facade layer but delicately emphasized by an orientation of glass facade sheets.



Space for the chimney's could be created by making cut outs in the structure if the structure allows this.

Space for the chimney could be created by cutting off a part of a corner of the structure if the structure allows this.

On the roof

By adding a greenhouse on the roof of a building, air could be sucked out of the building due to the overpressure in the greenhouse.

CLIMATE CASCADE

In the building

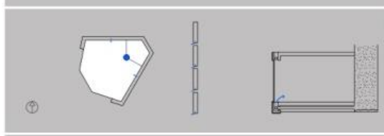

By making a cut out in the core of the building a space is created for the climate cascade. The inner ring is for the cascade, the outer ring for the supply of the air.

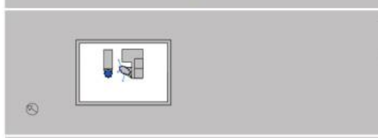

Also a cut out design but the supply air is distributed through the space via a raised floor. By making the cascade transparant a climatic architectural element is created.

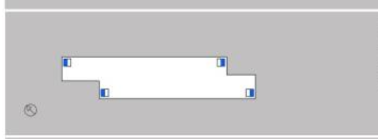

By surrounding the cascade with staircases the interaction of the cascade with building occupants is increased.

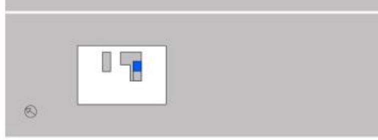

A round cut out might be more efficient for the load bearing structure. The supply shunt are accomodated in existing vertical shafts.


The cut out could create space for both the climate cascade as well as the vertical distribution shafts for supply air.


By creating more climate cascade ... ADD TEXT ...

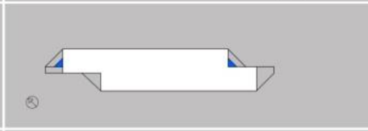

The climate cascade could be emphasized by making it more expressive inside the building.

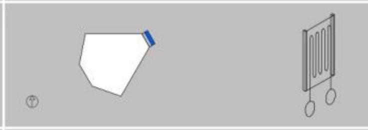

The vertical installation shafts in the existing building could be used for the climate cascade and supply shunts.

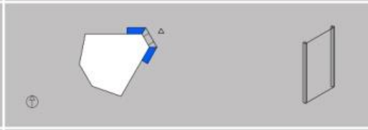


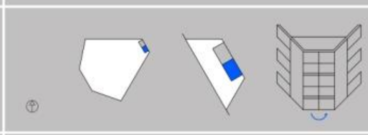
In the facade

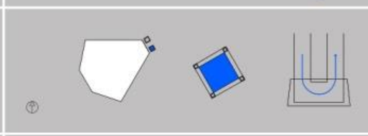

A cascade could be added built up from elements. The droplets inside the cascade could be visualised in the facade to emphasize its working principle.

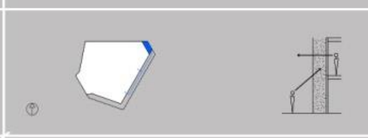

Niches in the building could be filled up with climate cascade(s). In this way the amount of facade area is reduced which enhances the energy performance of a building.

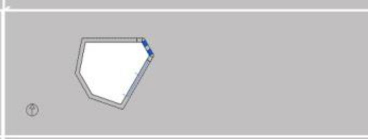

A smart skin could be used. In this way transparency is achieved without influencing the performance of the cascade.

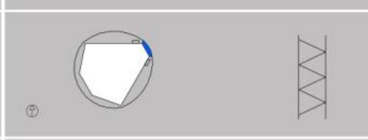

An entrance can be enhanced by placing the cascades around it. The addition of a print on a glass panel could work as sun shading and function as a communication tool.

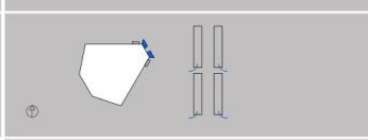

Space could be created by making a cut out in the facade. By using transparant surfaces in the facade the cascade is made explicit, but this design is subtle.

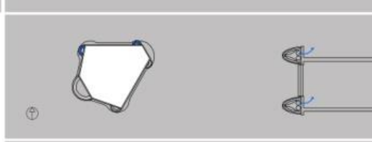

The cascade and the supply shaft could be visualised together by adding to 'towers' the the building that are connected at the bottom.


The cascade could be made visible from both the inside and outside. Louvers could be used to reduce the heat load on the transparant surfaces.

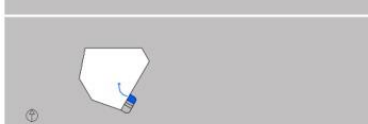

ETFE panels with a sunshading layer. In this way transparancy is achieved without influencing the performance of the cascade.

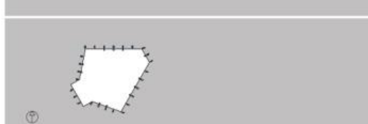

Automatically controlable horizontal sunblinds could be used to reduce the heat load on the cascade. By using LED lights the working principle of the cascade could be emphasized.

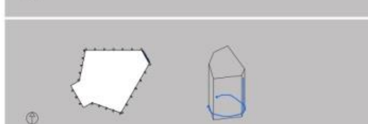

By keeping cascades as small as possible, the needed pump capacity to pump up the water is reduced together with the duct sizes.

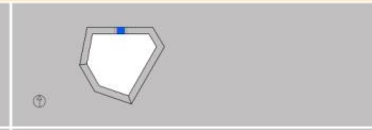

The cascades and ducts could be smoothly visualised by adding a layer around the ducts and EWF elements that changes the shape of a building.

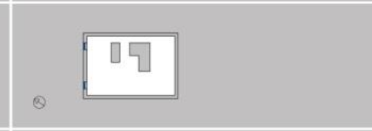

The supply and exhaust ducts could be placed on the facade. This could be useful when the free floor height is limited.

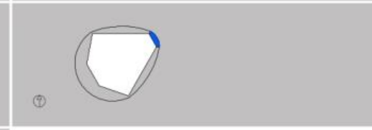

A whole EWF unit could be connected to the building to control the natural airconditioning in the building.


Small cascades seprate from the building with vertical supply shunts could be created. By the reducing the size of the cascade the performance is improved.


In this design a lot of small cascades and supply shunts are placed on the facade. In this way a verticality in the architectural design is achieved.


The cascade and supply shunts could be placed next to each other in a double facade. In this design integrated LED PV glass is used at the outer layer of the facade.


Cascade and supply shunts could be placed in front of each other in a double facade.


The cascade could be placed behind an extra facade layer.

Comparative analysis of case study buildings

Provinciehuis Utrecht , Utrecht
(flying holland.nl, n.d.)

Van Unnikgebouw, Utrecht
(Pepijntje, 2008)

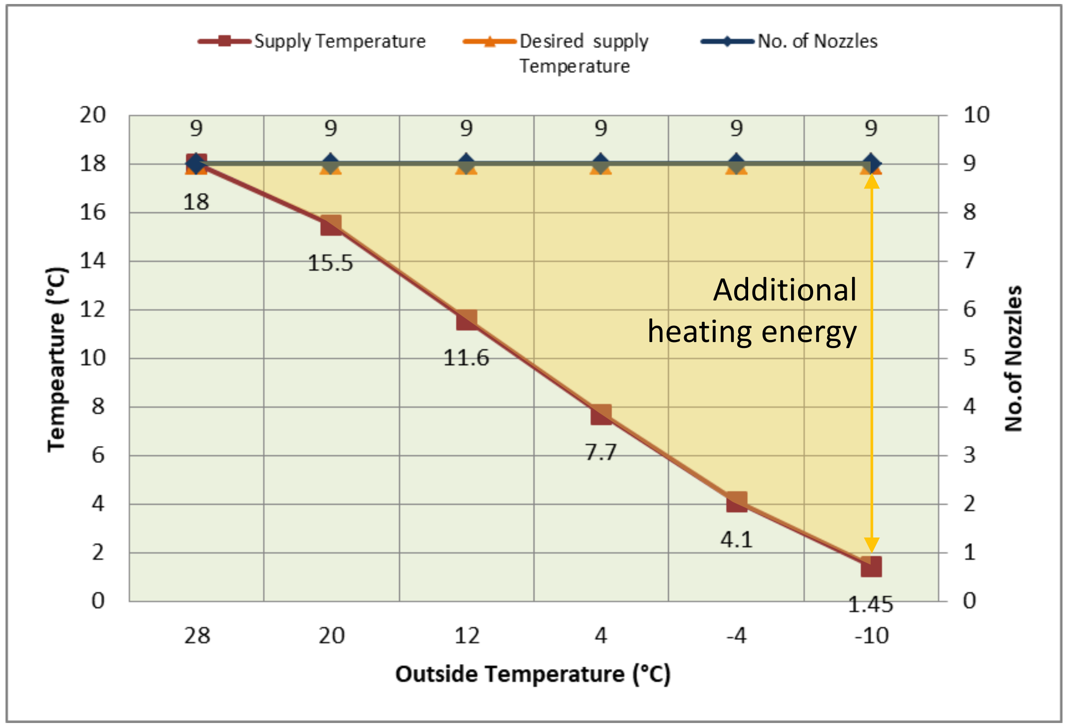
BUILDING	PROVINCIEHUIS UTRECHT	WILLEM C. VAN UNNIKGEBOUW
Typology	Office Building ✓	Education and Office building ✗
Higher than surrounding building	✓	✓
Building height	85m	75.5m
	✓	✓
Possibility to strip down the façade completely	✓	✗
Open able windows in the façade	-	✗
Load bearing façade system	-	✗
Easy disassembly	✗	✓
Poured pipes in the floor	✗	✗
Large column grid	✓	✓
Structural system can withstand additional façade loads	✗	✓
Possibility of cold and heat storage	✓	✓

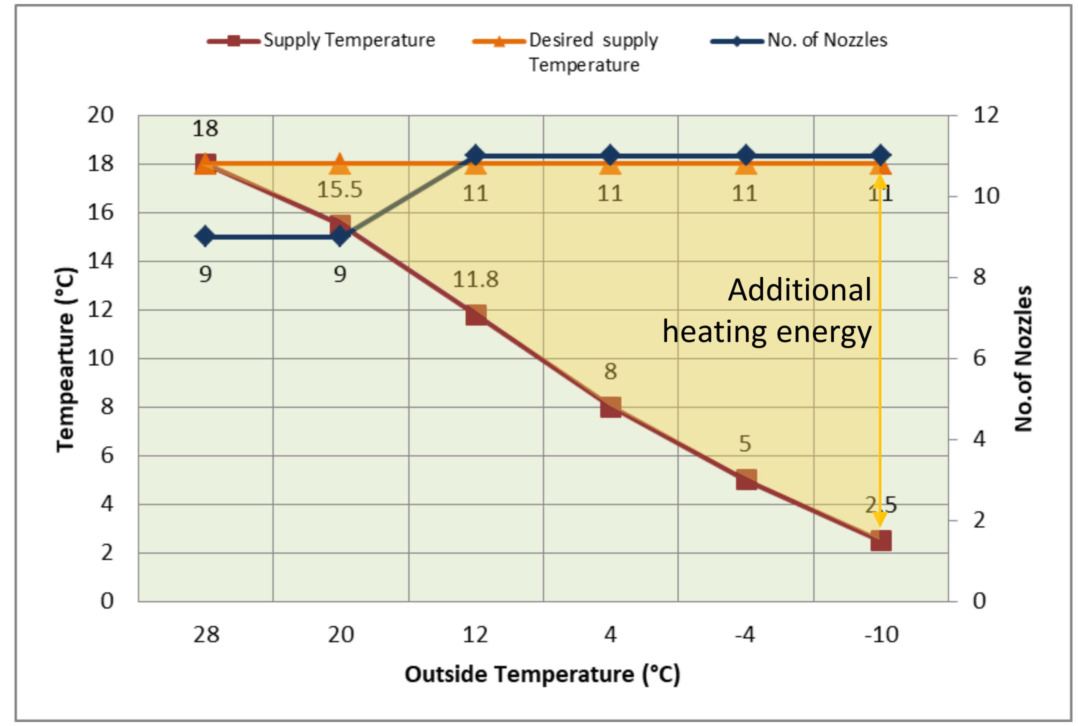
BENG Regulations

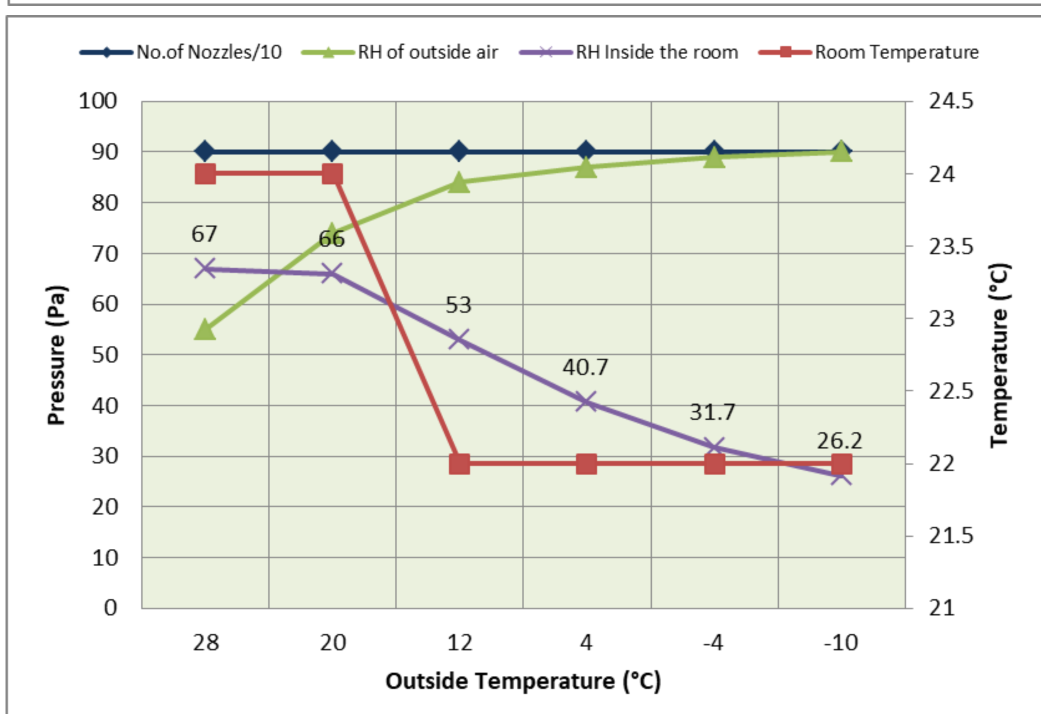
	BENG 1 Energy requirement [kWh/m2.yr]	**BENG 2 Primary fossil energy consumption [kWh/m2.yr]**	**BENG 3 share renewable energy [%]**
2015 - NEN 7120	≤ 50	≤ 25	≥50
2018 - NTA 8800	$A_{ls}/A_g \leq 2{,}2$ ->90 $A_{ls}/A_g > 2{,}2$ ->90 + 50 * (A_{ls}/A_g -2,2)	50	≥30
2019 - NTA 8800	$A_{ls}/A_g \leq 1{,}8$ BENG 1 ≤ 90 $A_{ls}/A_g > 1{,}8$ BENG 1 ≤ 90 + 30 * (A_{ls}/A_g -1,8)	≤ 40	≥30

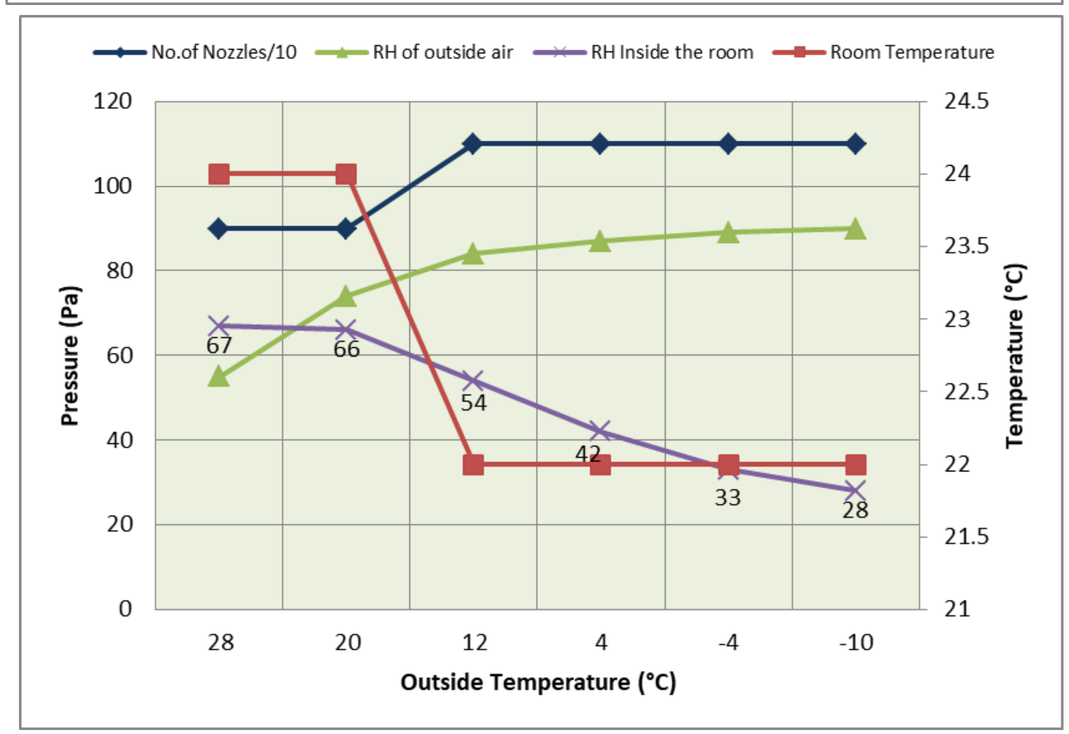
CLIMATE CASCADE: Single Cascade

CASE 1= 1 Climate Cascade & 1 Solar Chimney	CASE 3= 1 Climate Cascade & 2 Solar Chimneys



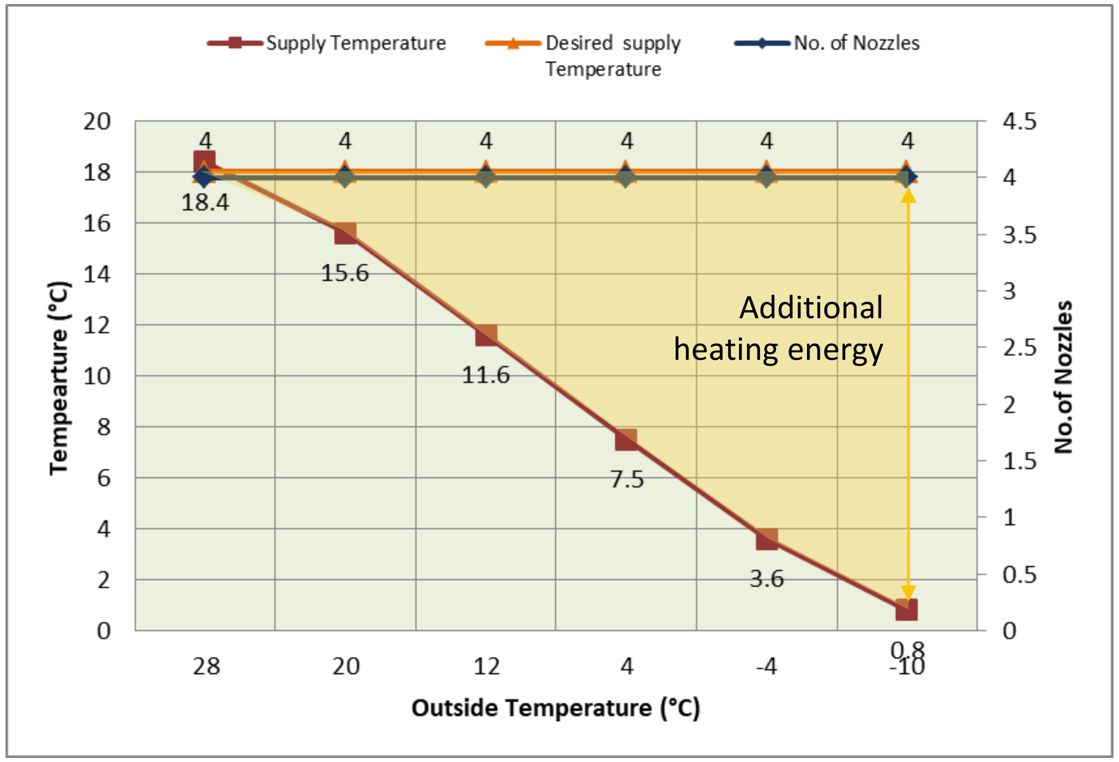


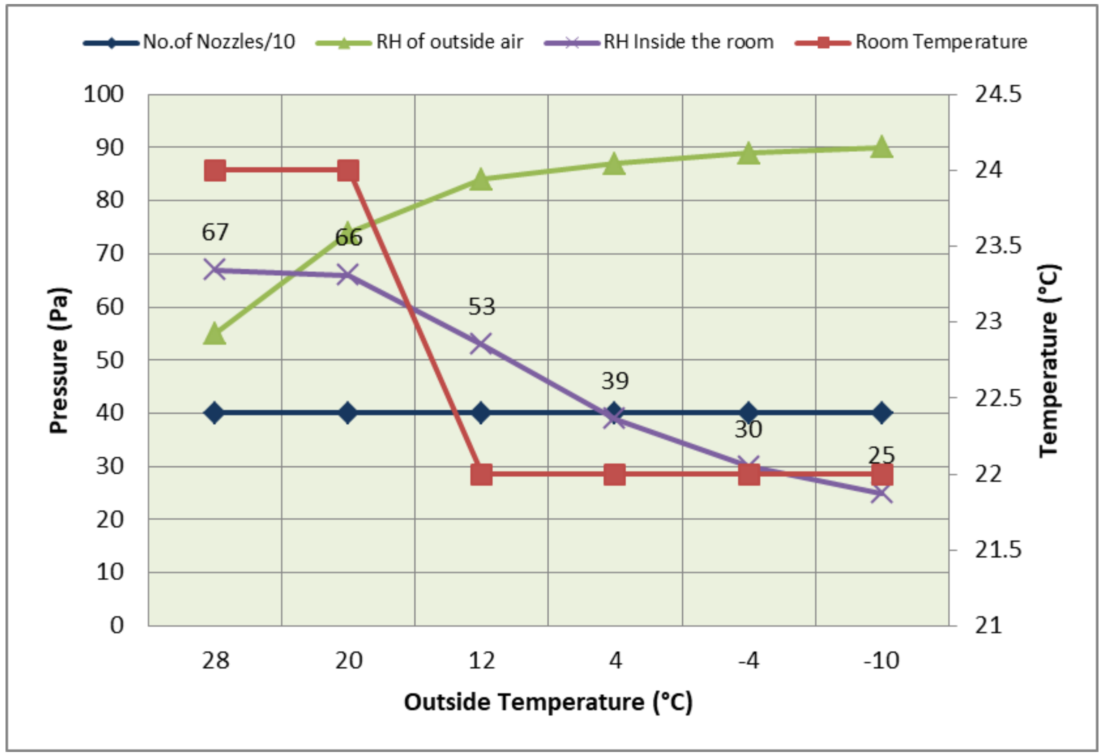




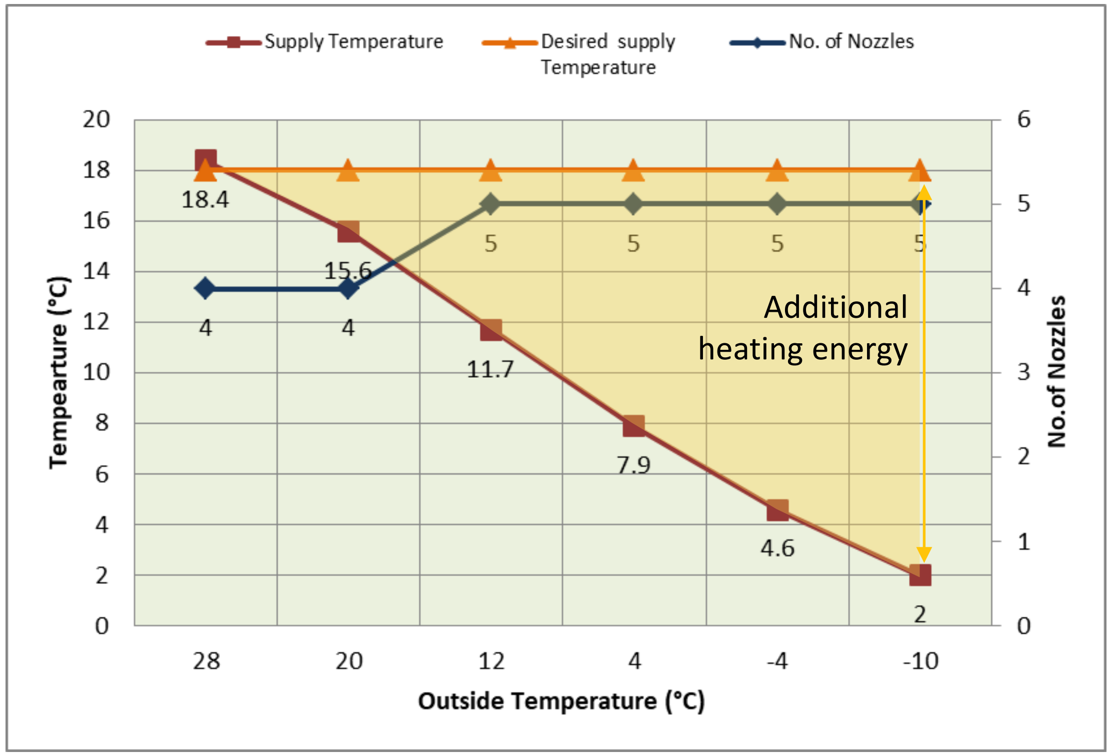
CLIMATE CASCADE: Double Cascade

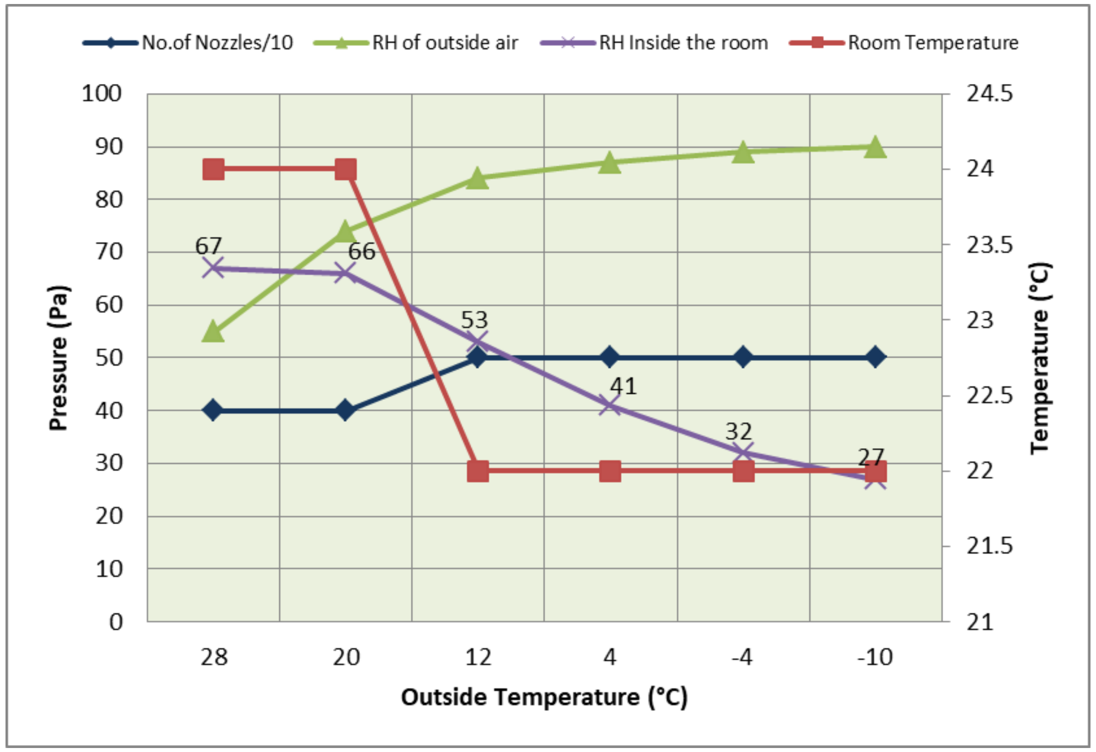
CASE 2= 2 Climate Cascades & 2 Solar Chimneys





CASE 4= 2 Climate Cascades & 1 Solar Chimney





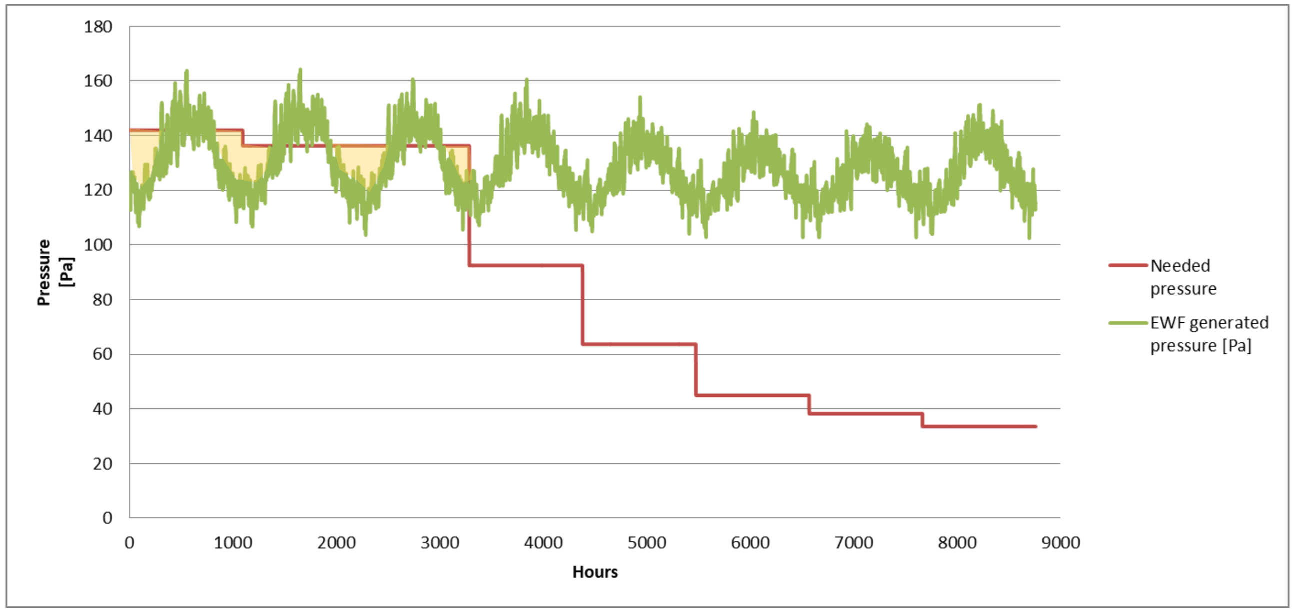
Additional Heating energy calculation

$$\textbf{Heating energy (kW)} = \frac{\textbf{Amount of air}}{\textbf{3600}} \times 1.2 \times \textbf{specific heat capacity of air} \times \textbf{Temperature difference}$$

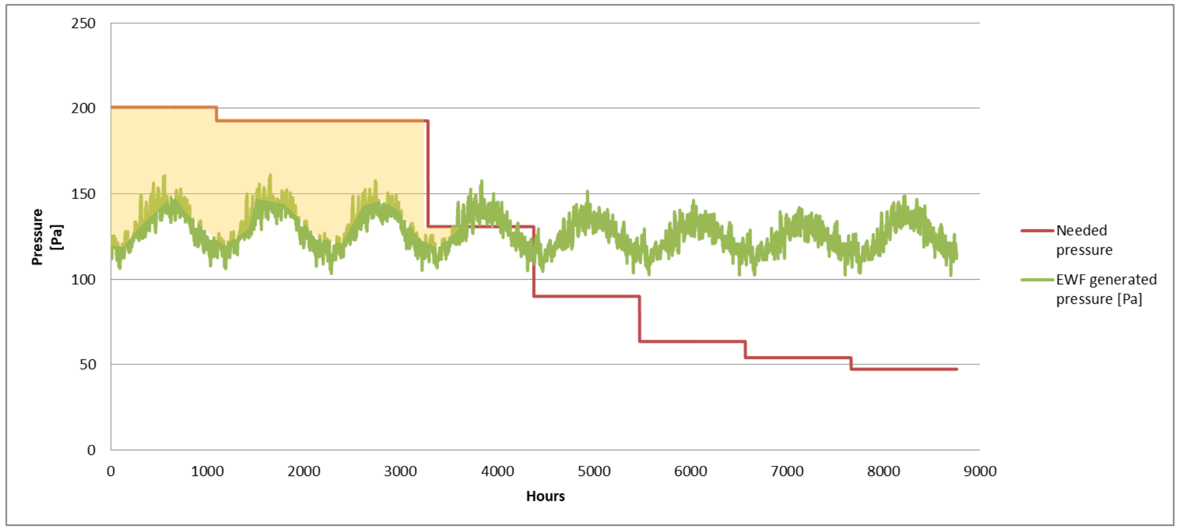
Basic Excel Model Results

CLIMATE CASCADE: GENERATED PRESSURE

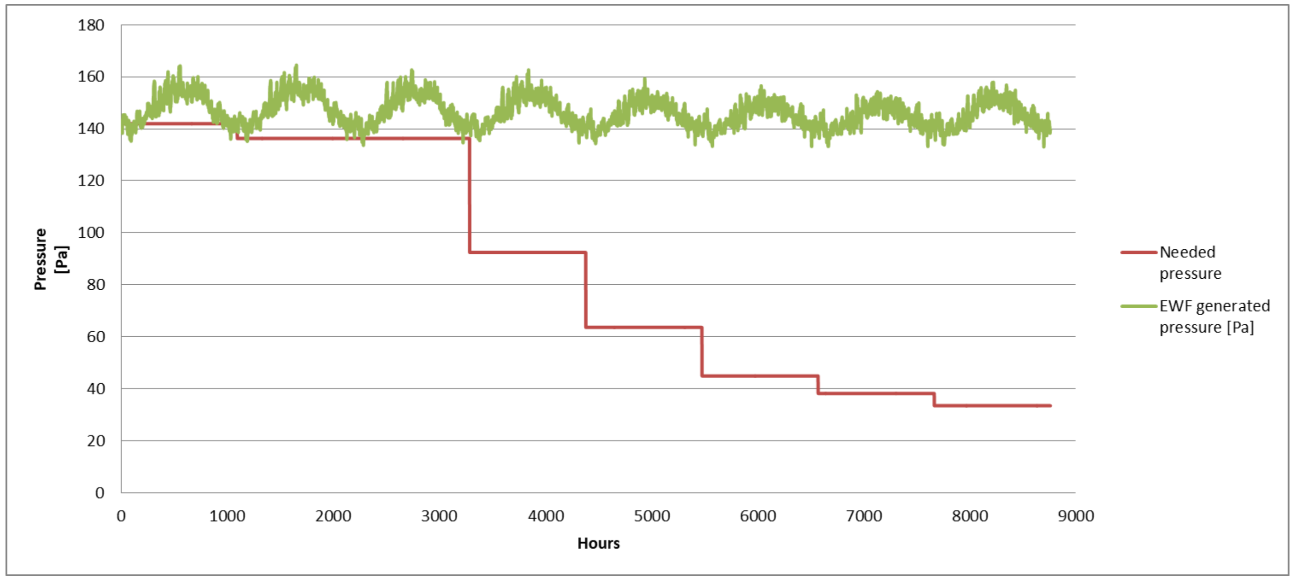
CASE 1= 1 Climate Cascade & 1 Solar Chimney



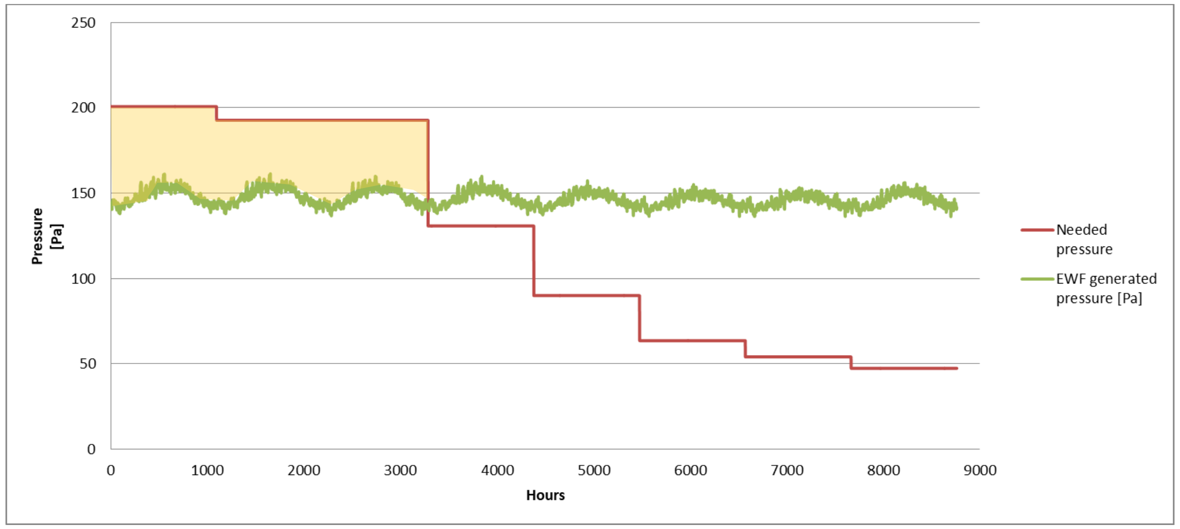
CASE 2= 2 Climate Cascades & 2 Solar Chimneys



CASE 3= 1 Climate Cascade & 2 Solar Chimneys



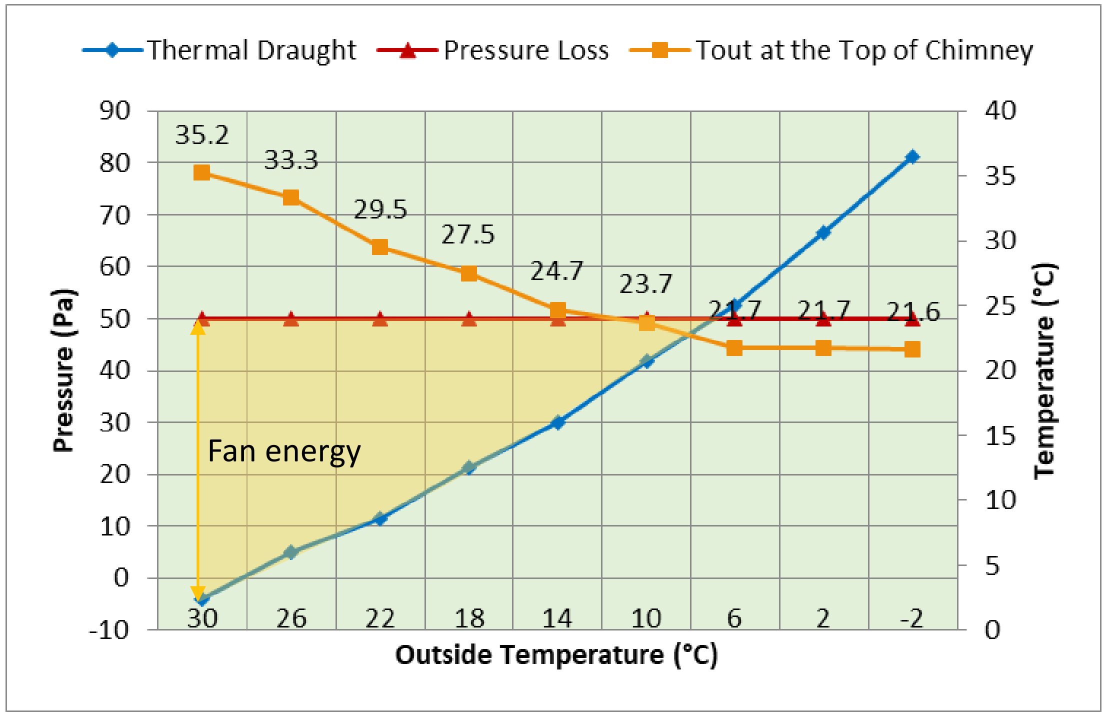
CASE 4= 2 Climate Cascades & 1 Solar Chimney



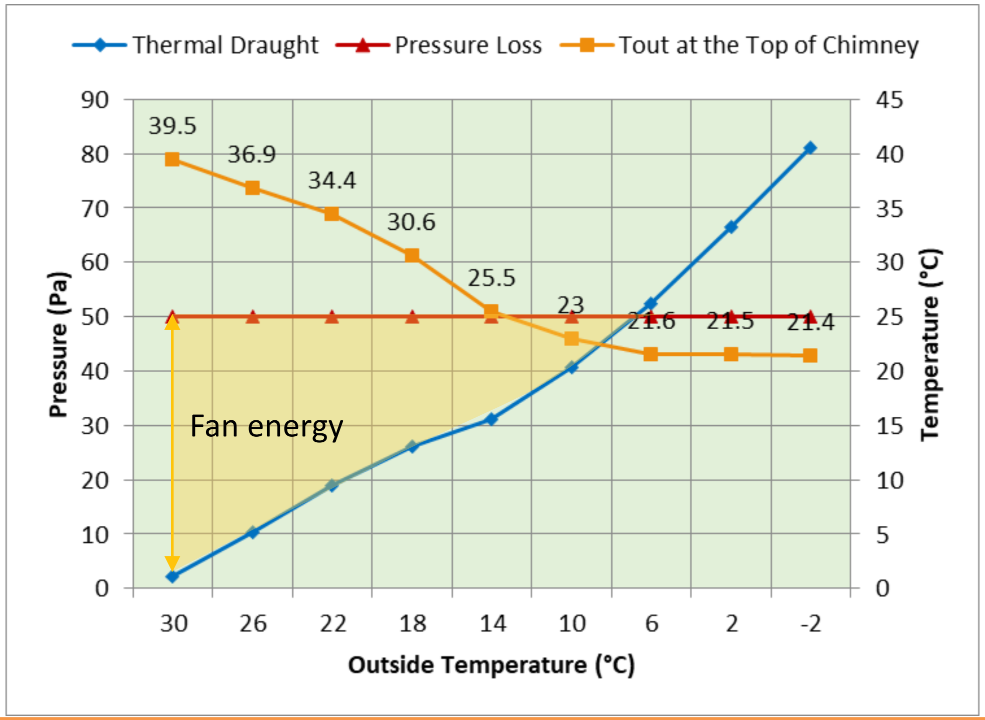
Basic Excel Model Results

SOLAR CHIMNEY: Thermal draught, Pressure loss and Tout

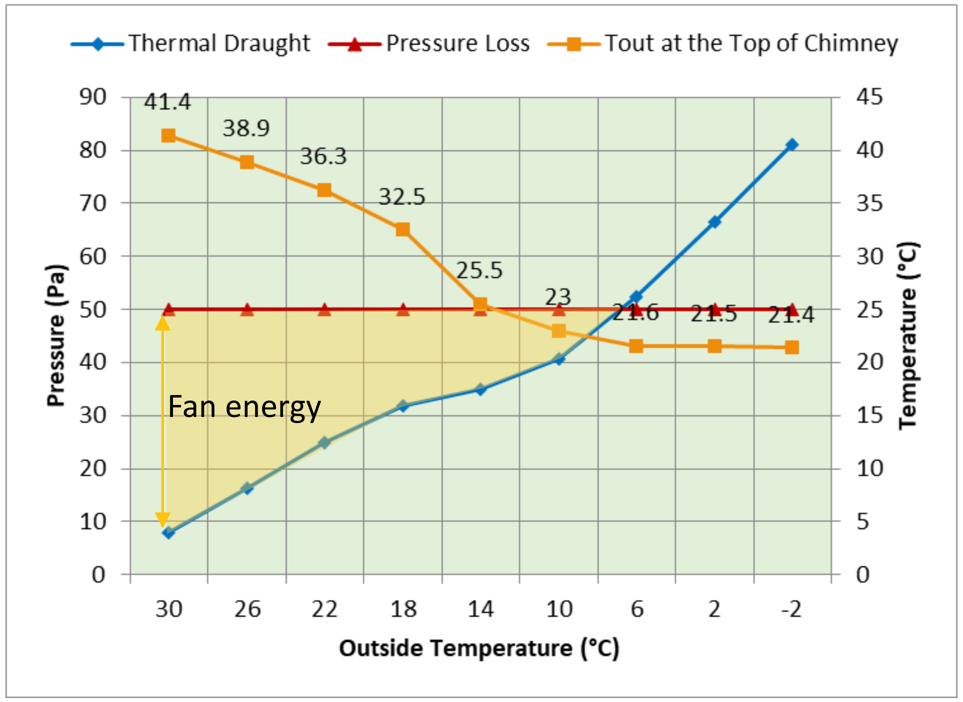
CASE 1= Single Chimney



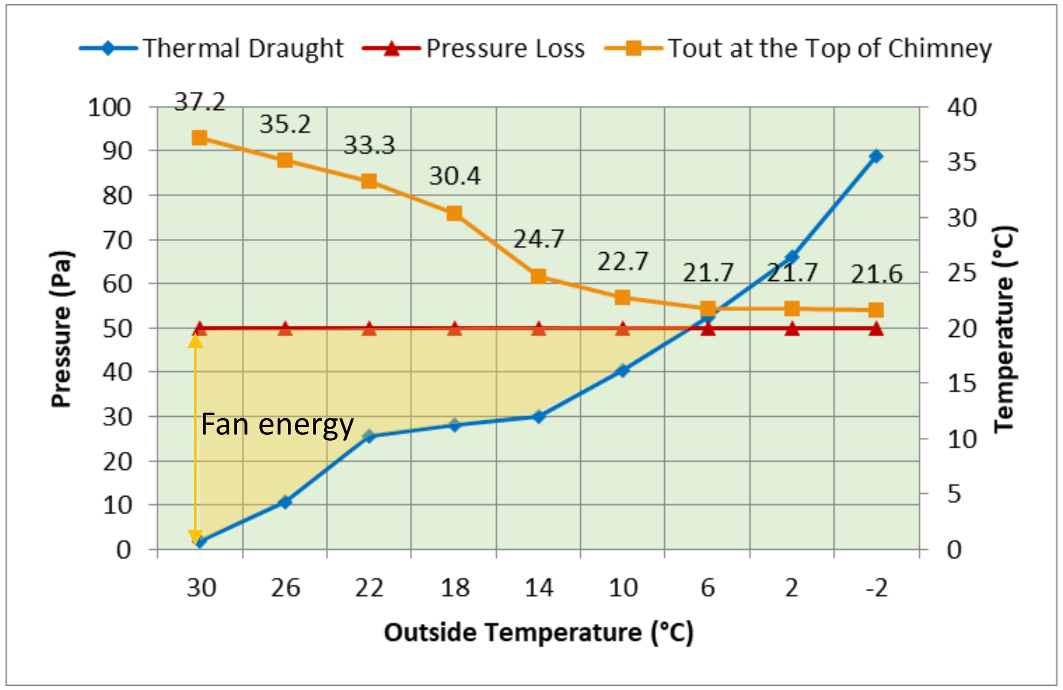
CASE 2= Double Chimney



CASE 3 = Double Chimney

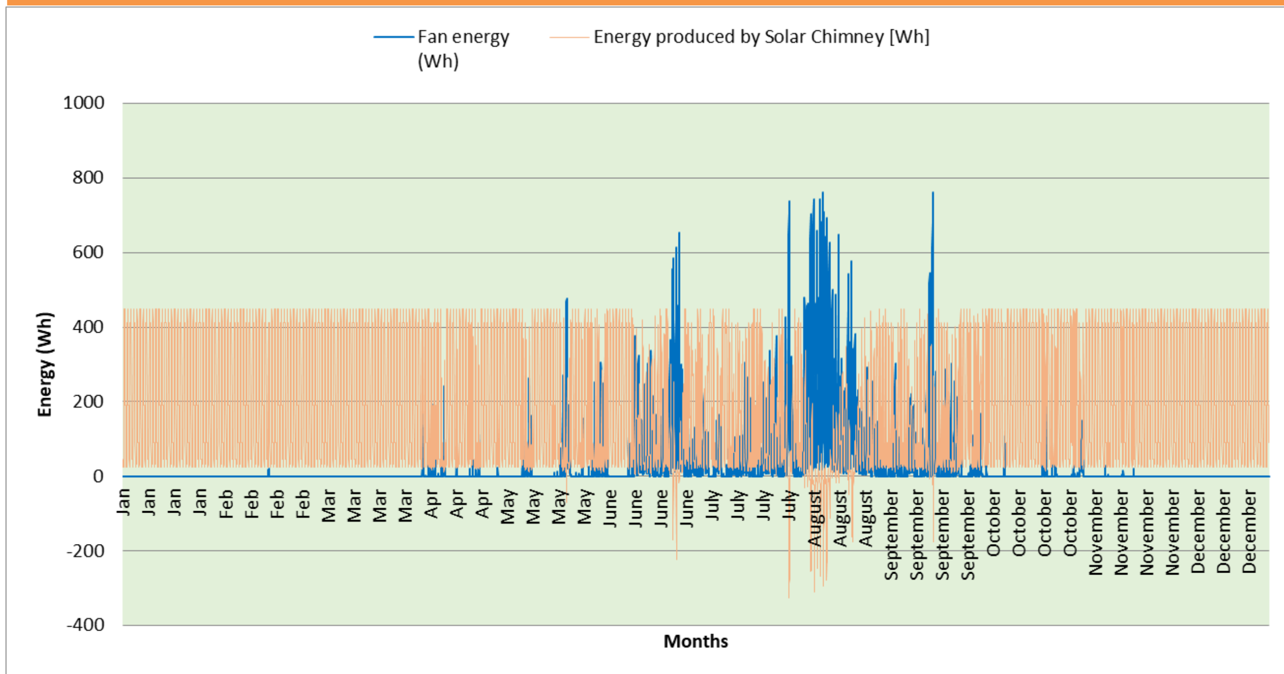


CASE 4= Single Chimney

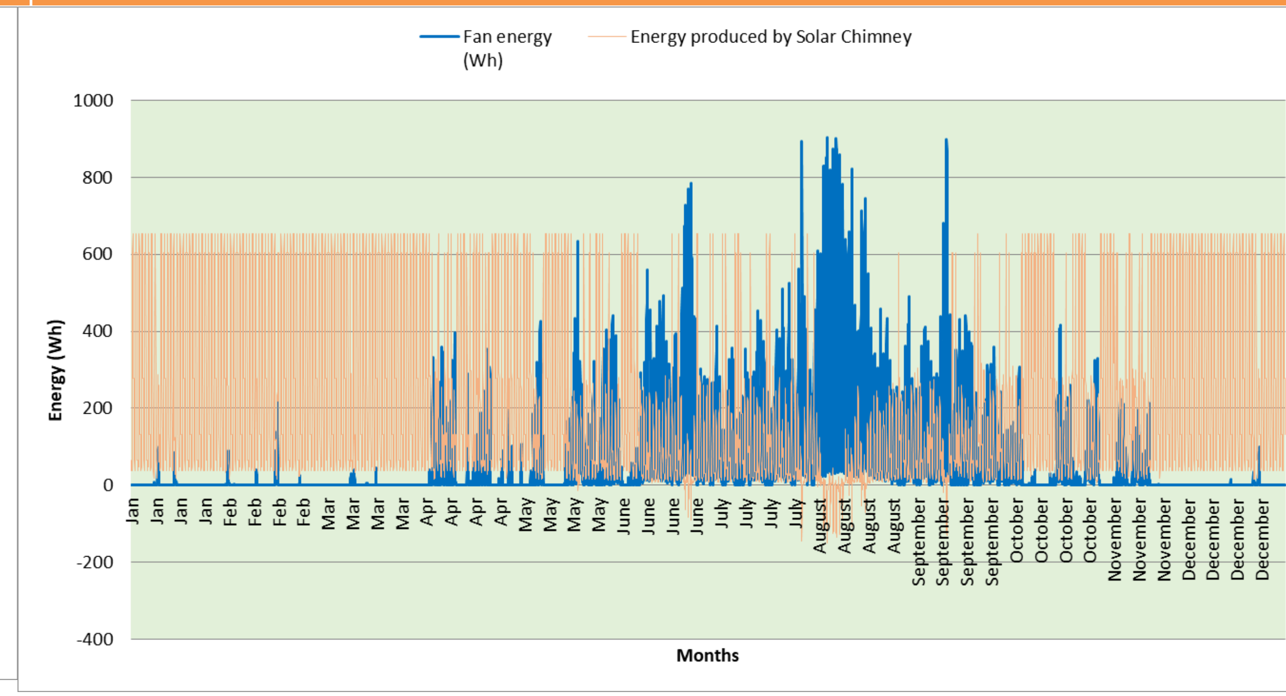


SOLAR CHIMNEY: Fan energy

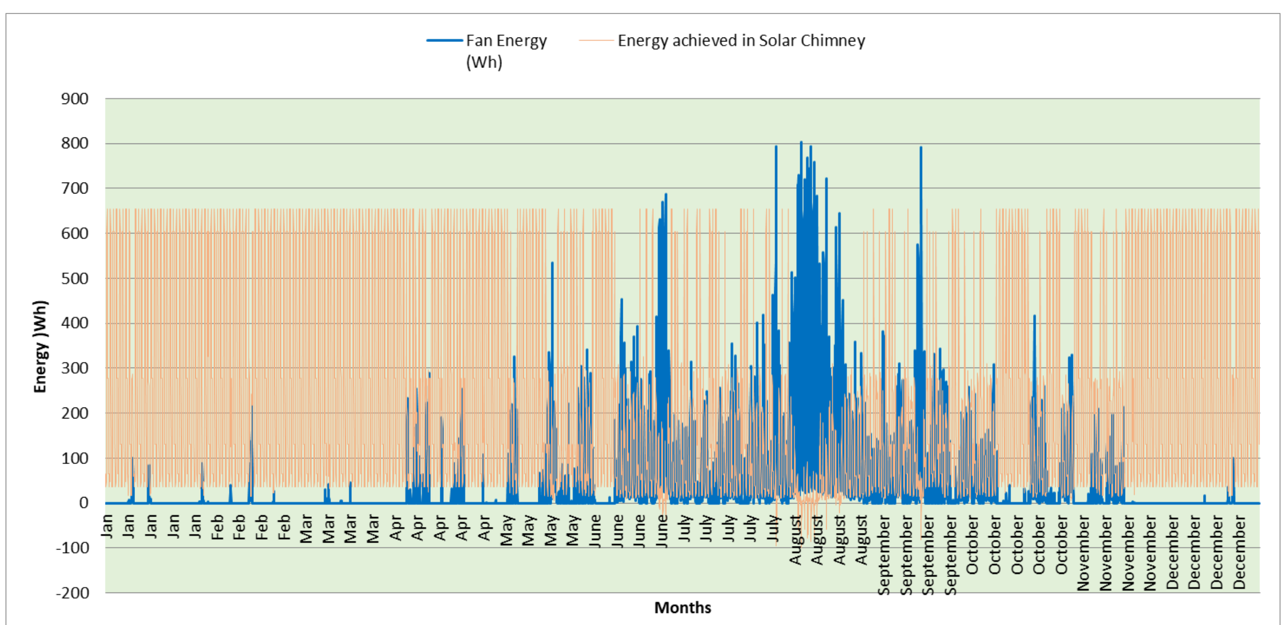
CASE 1= Single Chimney



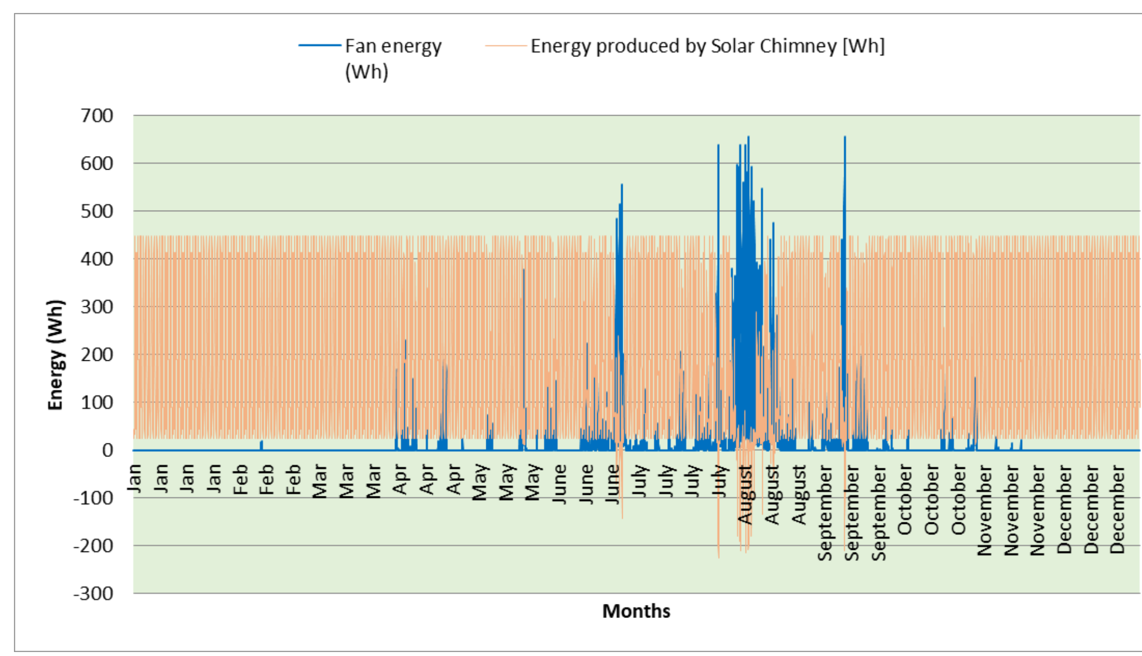
CASE 2= Double Chimney



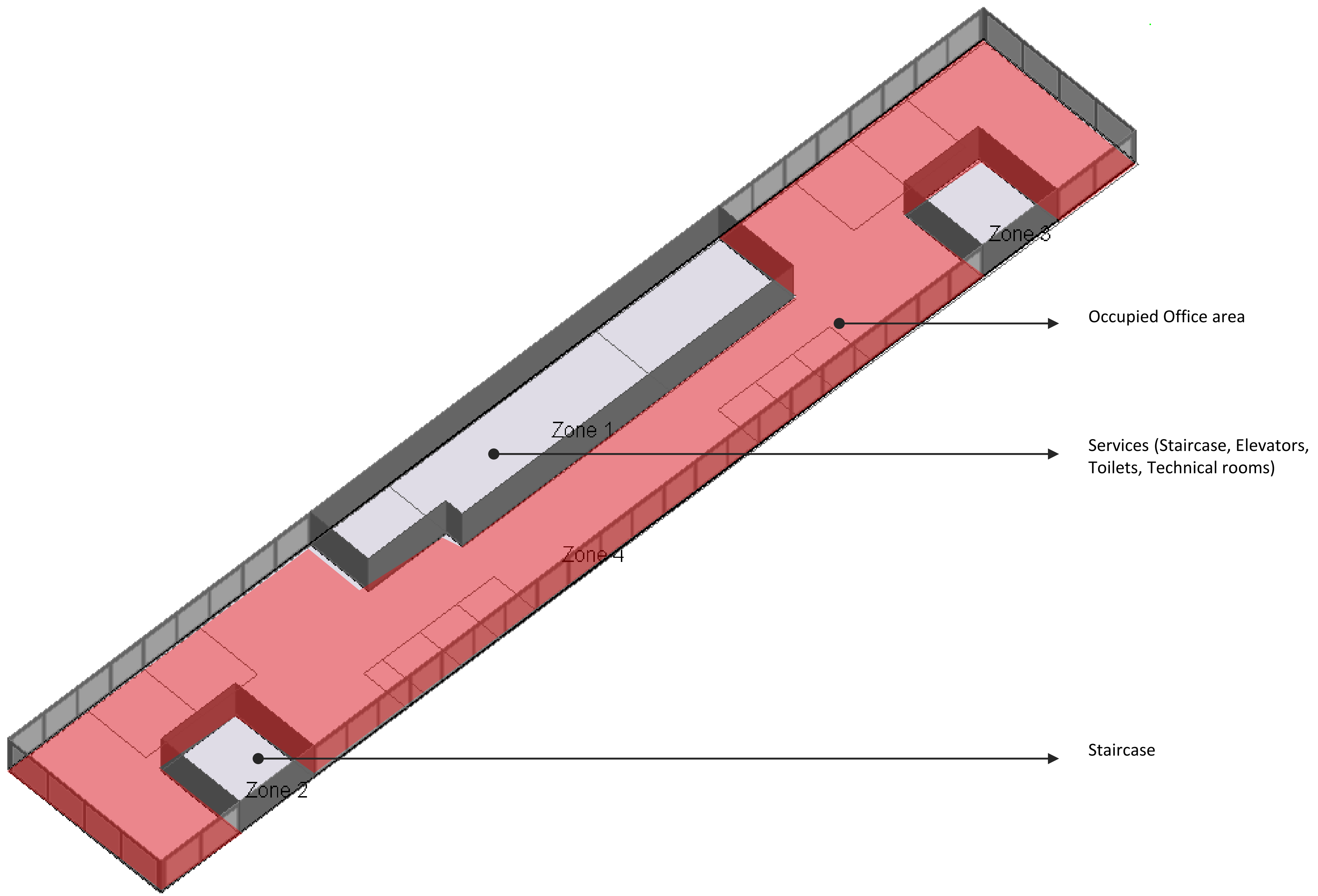
CASE 3 = Double Chimney



CASE 4= Single Chimney



Thermal zones in Design Builder Model



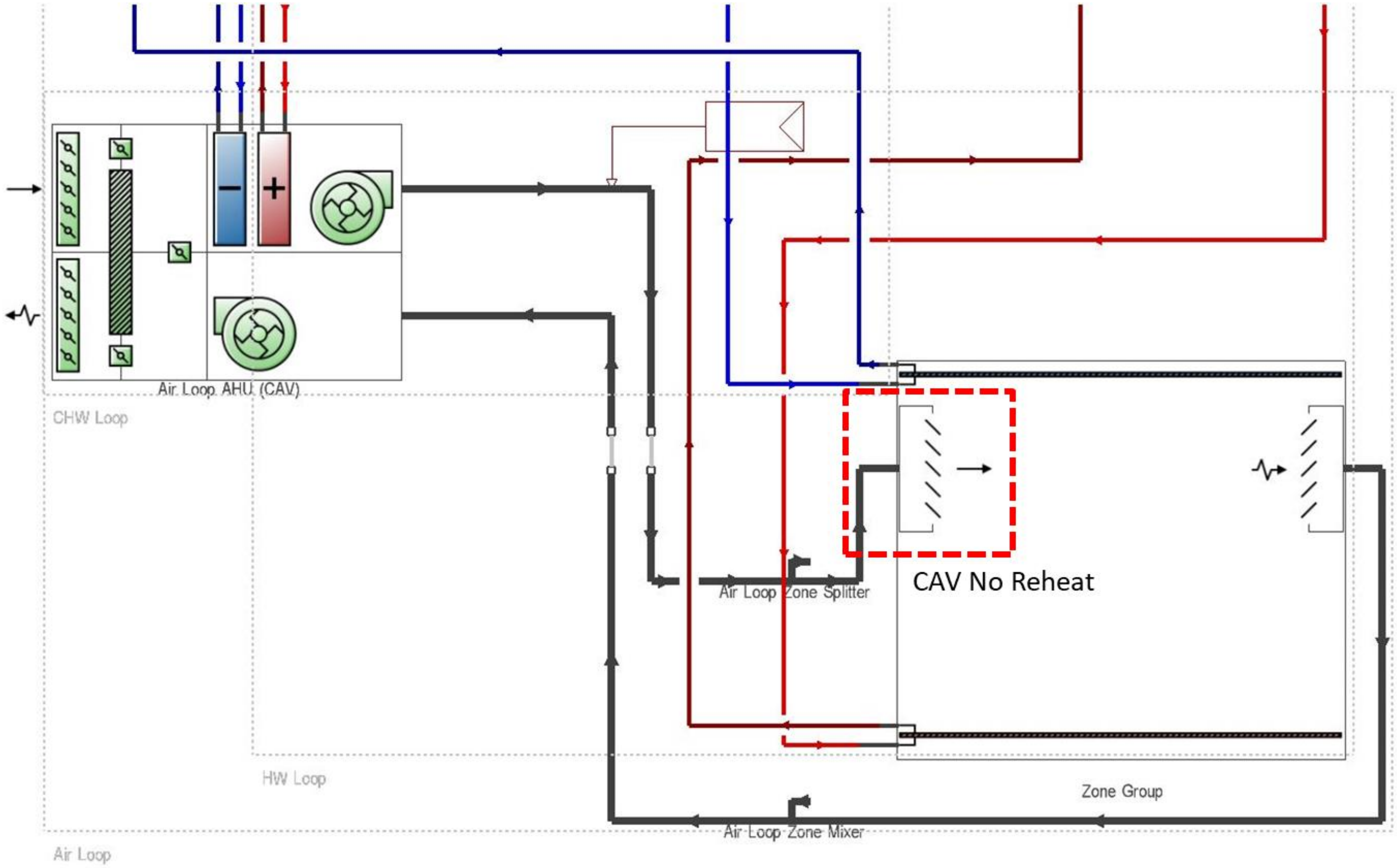
DESIGN CONDITIONS								
		Constants						
		Total Pressure loss (Pa)	Supply temperature (°C)	Exhaust temperature (°C)	Supply water temperature (°C)	Relative humidity	Height (m)	Ventilation capacity (m3/h)
1	Climate cascade	150	18	-	13	55%	80	50000
2	Solar chimney	50	-	22	-	-	80	50000

CLIMATE CASCADE											
			Evaluation Parameters								
	Design Options	Supply/ Exhaust	Size (m)	Generated pressure (Pa)	Tout of CC (°C)	No. of Nozzles	Velocity of air (m/s)	Water/ Air Ratio (kg/kg)	Pump energy (kWh/ year)	Fan Energy (kWh/ year)	Additional heating energy (kWh/m2)
1	1 Climate cascade 1 Solar chimney	Decentralized supply, Centralized Exhaust	2.0 x 2.0	160 Pa (T_supply= 28°C; RH= 55%)	18.0°C (RH= 98%)	9	3.2 m/s	0.37	61650 kWh	200 kWh	13
2	2 Climate cascade 2 Solar chimney	Decentralized supply, Decentralized exhaust	1.35 x 1.35	156 Pa (T_supply= 28°C; RH= 55%)	18.4°C (RH= 96%)	4	3.8 m/s	0.33	54800 kWh	6700 kWh	12.7
3	1 Climate cascade 2 solar chimney	Decentralized supply, Centralized exhaust	2.0 x 2.0	160 Pa (T_supply= 28°C; RH= 55%)	18.0°C (RH= 98%)	Winter = 11 Summer= 9	3.2 m/s	Winter= 0.46 Summer = 0.37	73000 kWh	0.3 kWh	12
4	2 Climate cascade 1 Solar chimney	Decentralized supply, Centralized exhaust	1.35 x 1.35	156 Pa (T_supply= 28°C; RH= 55%)	18.4°C (RH= 96%)	Winter = 5 Summer= 4	3.8 m/s	Winter= 0.42 Summer = 0.33	66200 kWh	5000 kWh	12

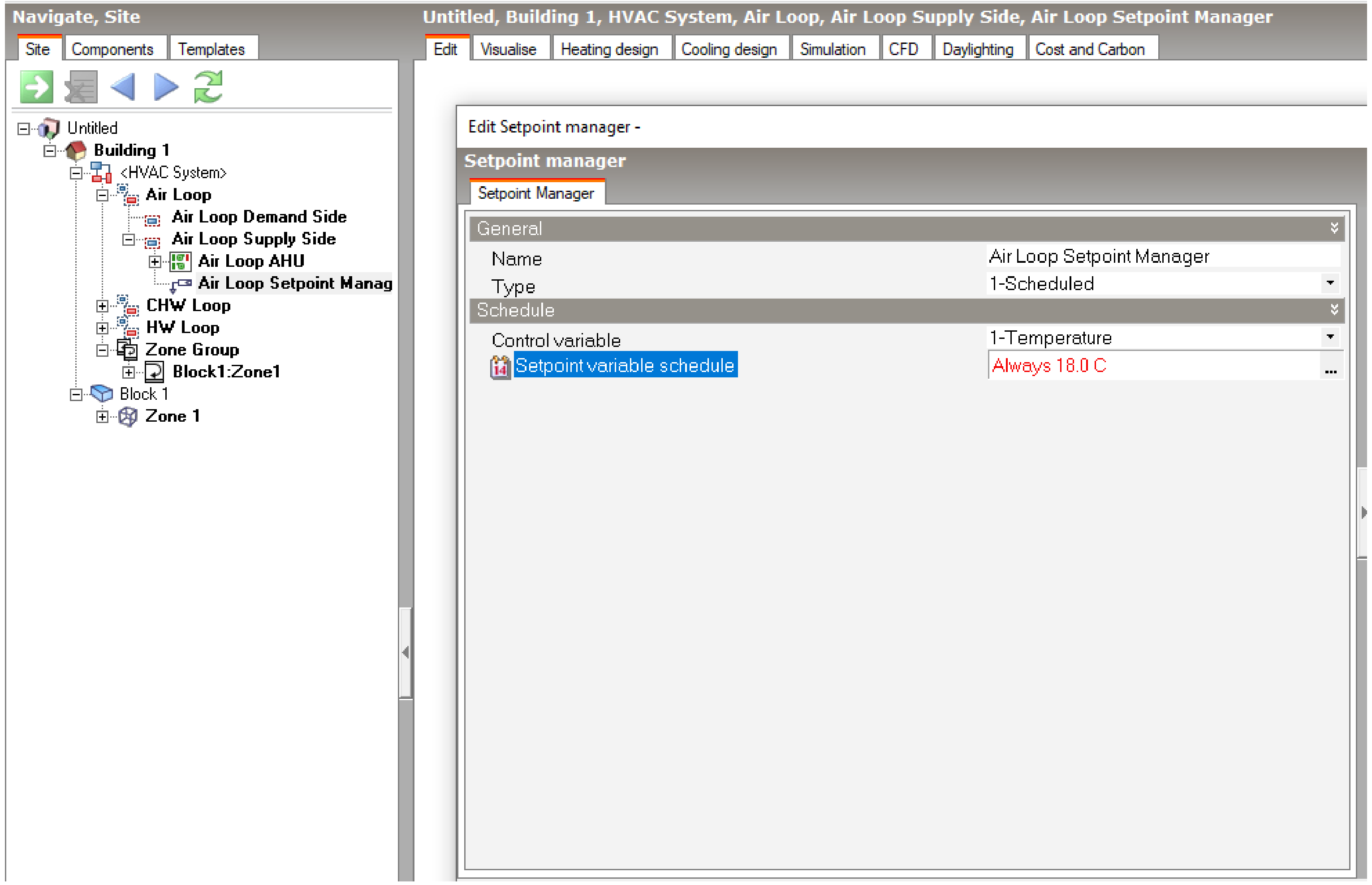
SOLAR CHIMNEY									
			Evaluation Parameters						
	Design Options	Supply/ Exhaust	Total Pressure loss (Pa)	Thermal Draught (Pa)	Velocity of air (m/s)	Tout at the top of chimney (°C)	Size (m)	Fan Energy (kWh)	Recovered Heat energy (kWh)
1	1 Climate cascade 1 Solar chimney	Decentralized supply, Centralized Exhaust	50 Pa	-4.0 Pa (T_supply= 22°C & T_out= 30°C)	1.2 m/s	35.2 °C	14.5 x 0.8	1200 kWh	592500
2	2 Climate cascade 2 Solar chimney	Decentralized supply, Decentralized exhaust	50 Pa	2.2 Pa (T_supply= 22°C & T_out= 28°C)	1.0 m/s	39.5°C	9.9 x 0.7	2000 kWh	653000
3	1 Climate cascade 2 solar chimney	Decentralized supply, Centralized exhaust	50 Pa	8 Pa (T_supply= 24°C & T_out= 28°C)	1.0 m/s	41.4°C	9.9 x 0.7	1800 kWh	700000
4	2 Climate cascade 1 Solar chimney	Decentralized supply, Centralized exhaust	50 Pa	1.7 Pa (T_supply= 24°C & T_out= 28°C)	1.2 m/s	37.2°C	14.5 x 0.8	1000 kWh	630000

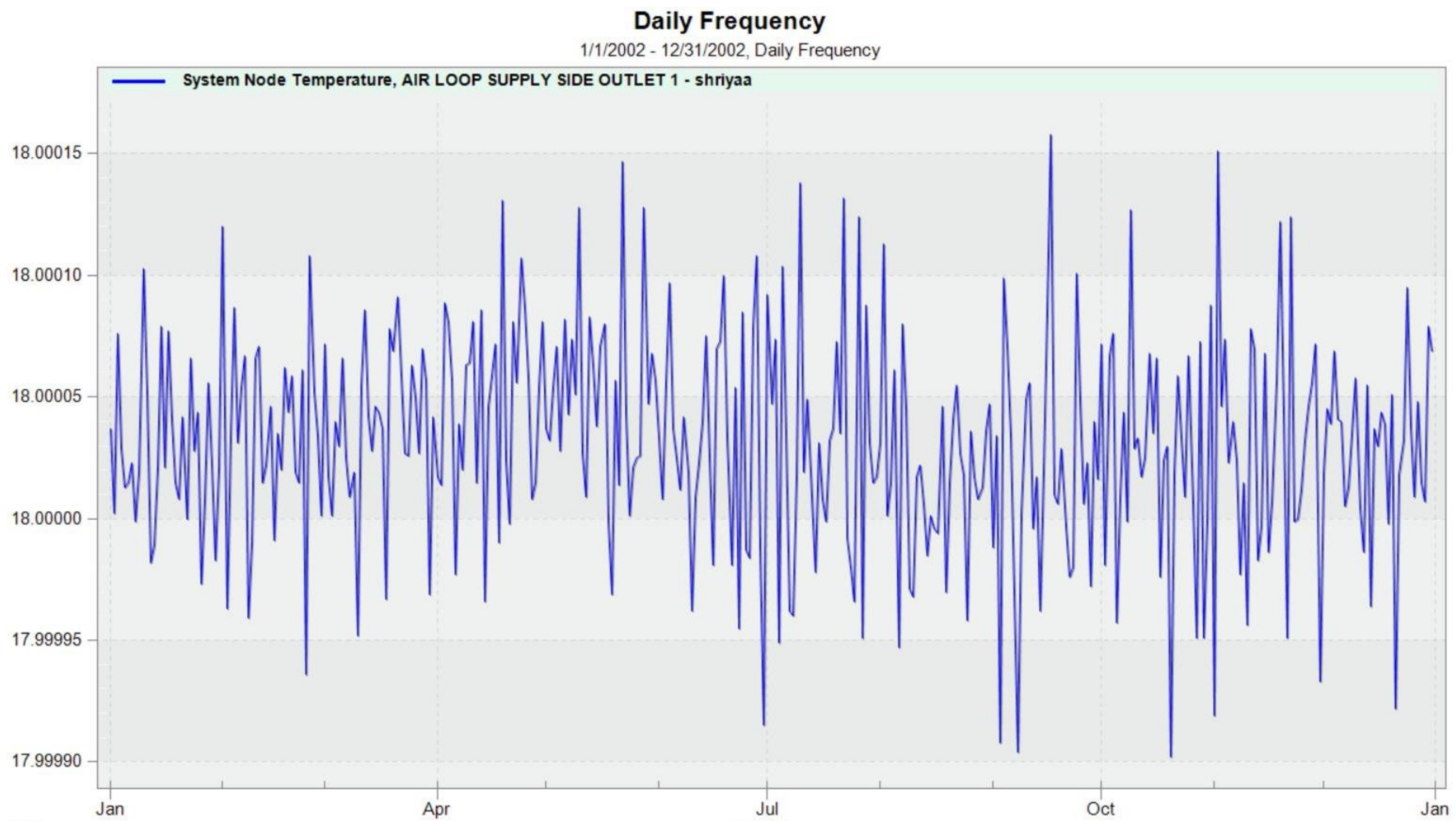
Ventilation Capacity											
	Max. amount of air needed per function (m3/h)	No. of occupants per function	Occupancy % per 3 hours								
			0:00	3:00	6:00	9:00	12:00	15:00	18:00	21:00	0:00
Offices	40,000	800	10%	5%	5%	85%	90%	85%	30%	15%	10%
Ground floor (Restaurant)	5,000	100	5%	5%	15%	85%	90%	85%	70%	30%	5%
First floor (Meeting rooms + Common areas)	5,000	100	5%	5%	10%	60%	85%	60%	70%	30%	10%
Required ventilation capacity according to occupant %	**50,000**	**1000**	**4500**	**2500**	**3250**	**41250**	**44750**	**41250**	**19000**	**9000**	**4750**
Required Pressure (Pa)	**150**		**32**	**24**	**27**	**96**	**100**	**96**	**65**	**45**	**33**

EWF HVAC Configuration

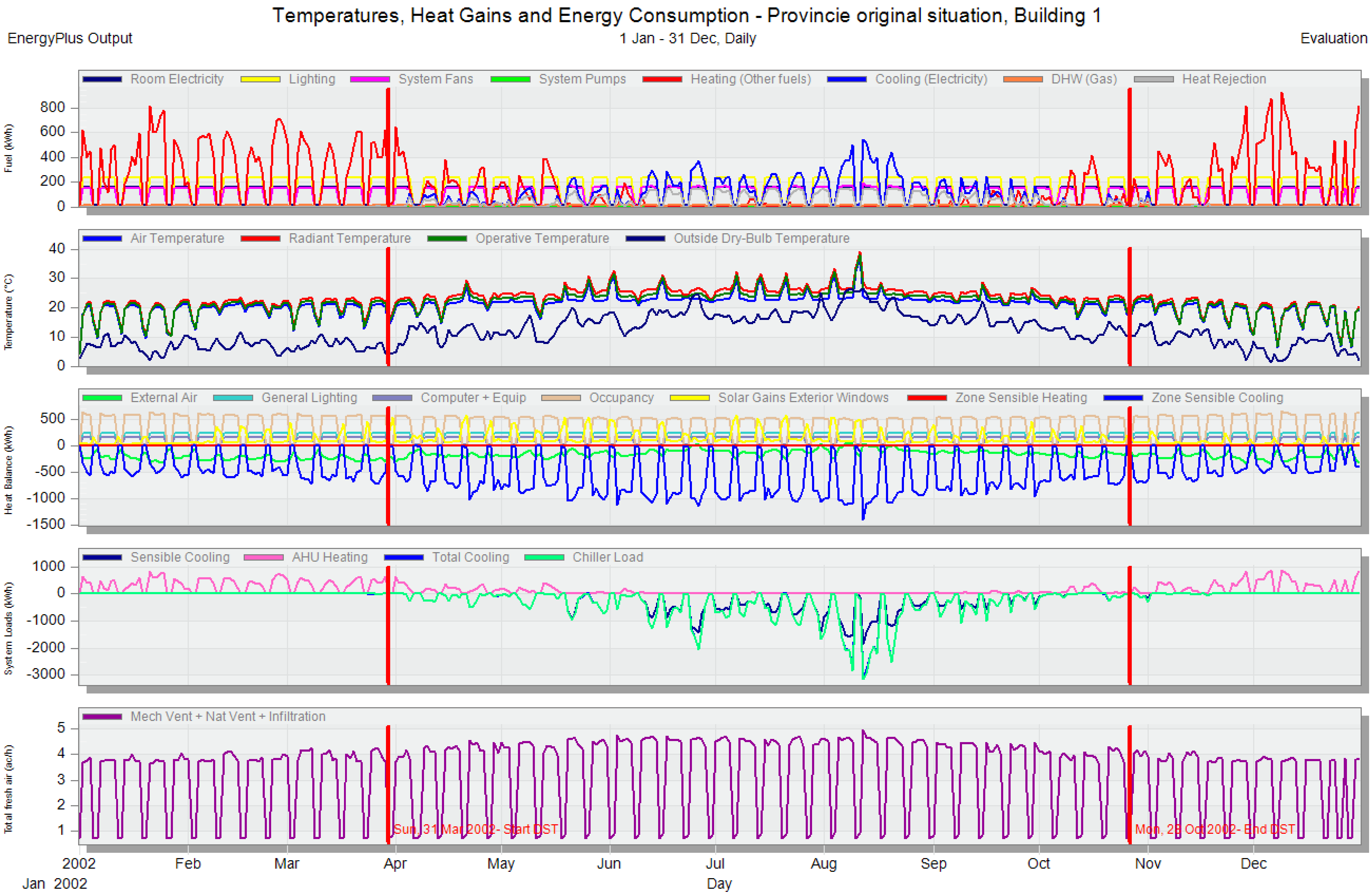


Supply of 18°C air





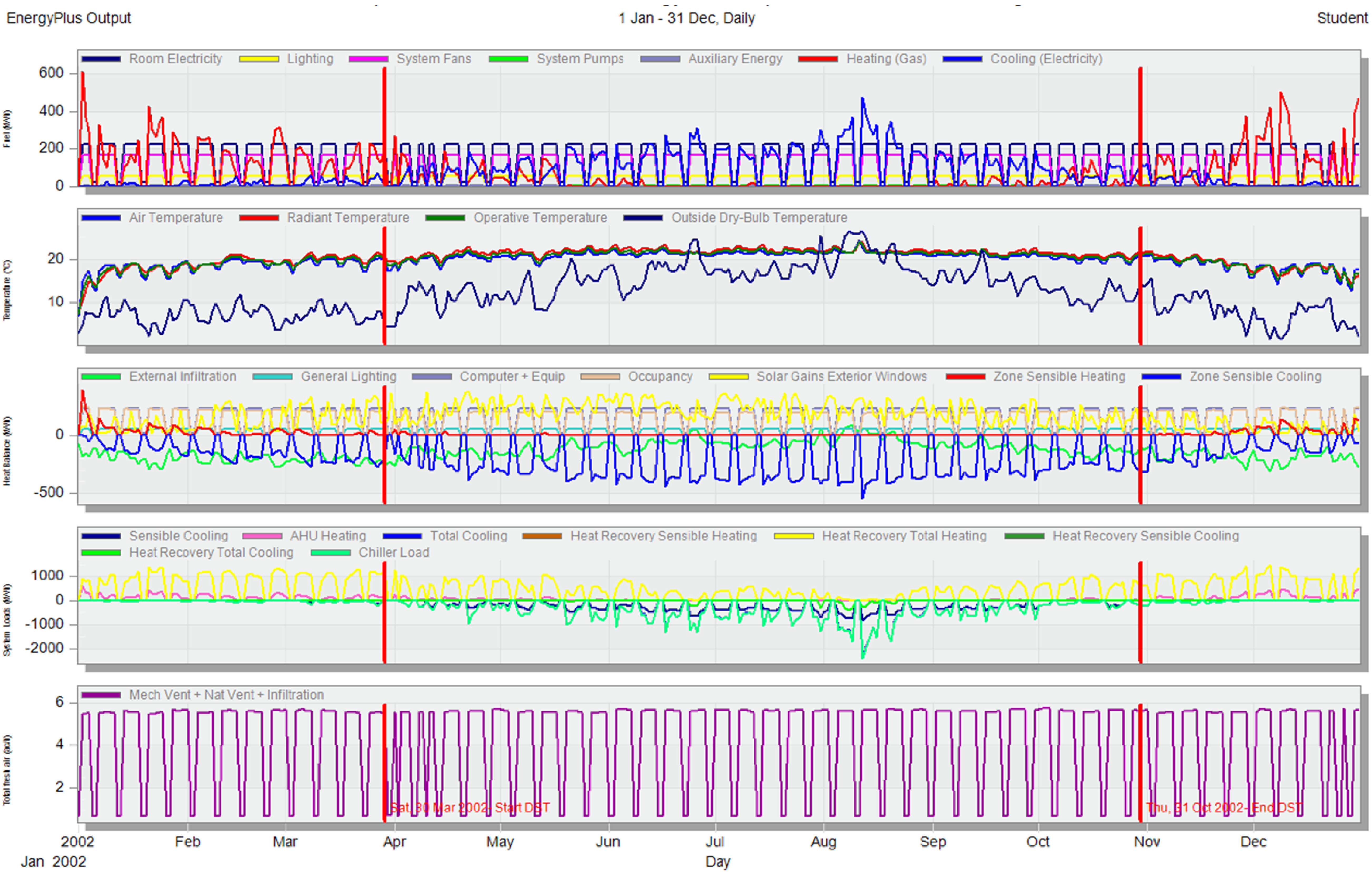
Existing system without EWF daily simulation



ENERGY CONSUMPTION: Without EWF

		Energy Consumption without EWF		
		Area (m2)	Primary Energy (kWh/year)	Primary energy (kWh/m2/year)
	Usable Floor area	17,640		
1	Space Heating		1,640,520	93
2	DHW		35,280	2
3	Cooling		740,880	42
4	Ventilation		864,360	49
5	Production Equipment		88,200	5
6	Lighting		405,720	23
	Total		**3,774,960**	**214**

New system with EWF daily simulation



ENERGY COMPARISON							
		Energy Consumption without EWF			Energy consumption with EWF		
		Area (m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Reduction %
	Usable Floor area	17,640					
1	Space Heating		1,640,520	93	447,660	25.3	72%
2	DHW		35,280	2	35,280	2	-
3	Cooling		740,880	42	469,404	26.6	36%
4	Ventilation		864,360	49	322,400	18.3	62.7%
5	Production Equipment		88,200	5	88,200	5	-
6	Lighting		405,720	23	405,720	23	-
	Total		**3,774,960**	**214**	**1,768,664**	**100.3**	**53.1%**

Improved system with EWF hourly simulation

ENERGY COMPARISON: Improved EWF system							
		Energy Consumption without EWF			Energy consumption with Improved EWF		
		Area (m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Reduction %
	Usable Floor area	17,640					
1	Space Heating		1,640,520	93	574,524	32.6	64%
2	DHW		35,280	2	35,280	2	-
3	Cooling		740,880	42	385,290	21.8	48%
4	Ventilation		864,360	49	323,100	18.3	62.7%
5	Production Equipment		88,200	5	88,200	5	-
6	Lighting		405,720	23	405,720	23	-
	Total		**3,774,960**	**214**	**1,809,414**	**102.6**	**52%**

PV Yield Calculations		
Location	South, SW, SE	
Total Surface area available to install PV (m2)	4350	
PV Panel power (WP)	300	
PV size/panel (m2)	1.5	
Angle	35°	
System size (kW)	400	
Module material	c-Si	
Module efficiency	15%	
PV Annual energy (kWh)	**224076**	
Energy Consumption: Façade Option 1		
	Primary Energy (kWh)	Reduction Factor
Energy Consumed by EWF	**1,768,664**	-
PV Yield from Facade option 2	224076	-
Energy Reduction	**1,544,588**	**12%**

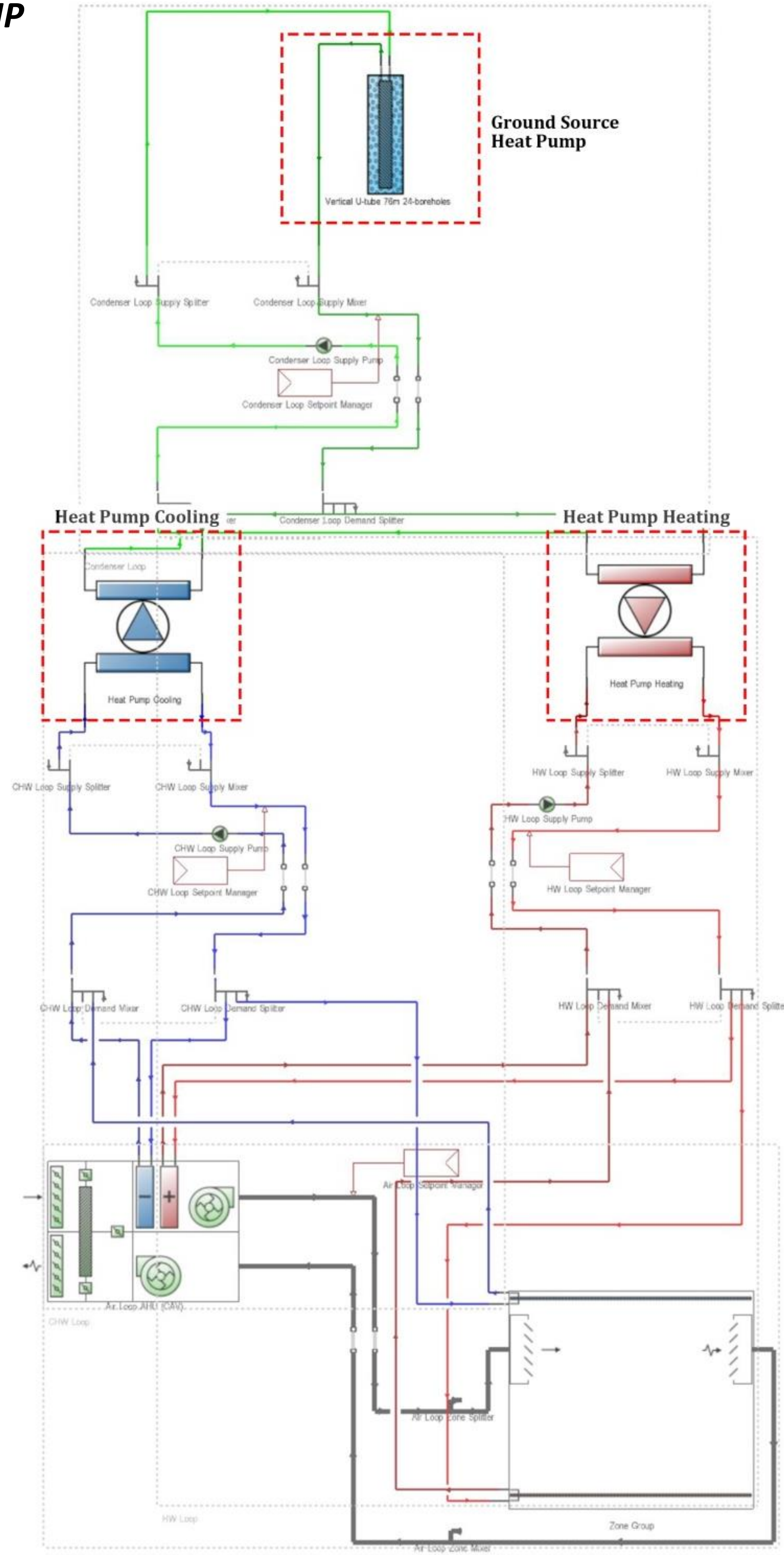
PV Yield Calculations	
Location	South, SW, SE
Total Surface area available to install PV (m2)	4350
PV Panel power (WP)	300
PV size/panel (m2)	1.5
Angle ▯	35°
System size (kW)	400
Module material	c-Si
Module efficiency	15%
PV Annual energy (kWh)	**150237**

Energy Consumption: Façade Option 2		
	Primary Energy (kWh)	Reduction Factor
Energy Consumed by EWF	**1,768,664**	-
Energy Consumed by EWF: after refurbished façade	**1,684,820**	
PV Yield from Facade option 2	150237	-
Energy Reduction	**1,534,583**	**13%**

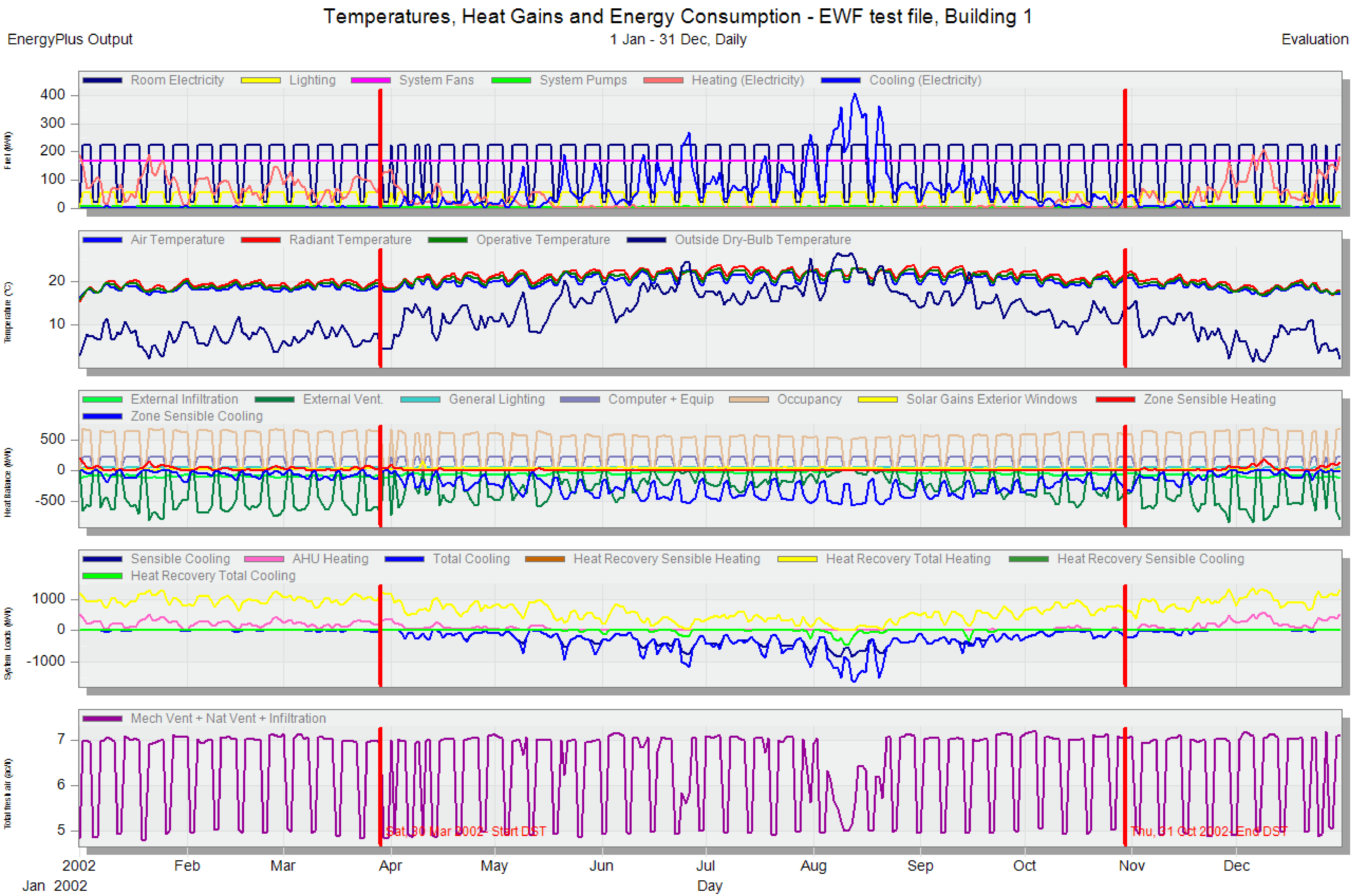
Thermal Insulation Improvements					
R-Value				Wall-Window Ratio	
Existing Façade- Opaque part (m2K/W)	Existing Façade- complete unit (m2K/W)	Refurbished Façade- Opaque part (m2K/W)	Refurbished Façade- complete unit (m2K/W)	Wall-Window Ratio: Existing	Wall-Window Ratio: Refurbihed
4.2	2	**5.9**	**3.6**	75%	**30%**

Energy Consumption: Façade Option 3		
	Primary Energy (kWh)	Reduction Factor
Energy Consumed by EWF: before refurbished facade	**1,768,664**	-
Energy Consumed by EWF: after refurbished façade	**1,654,616**	-
PV Yield from Facade option 3	224076	-
Energy Reduction	**1,430,540**	**19%**

Improved system with EWF and GSHP



Improved system with EWF and GSHP daily simulation



ENERGY COMPARISON: Refurbished Façade option 3 with GSHP							
			Energy Consumption without EWF and with GSHP		Energy consumption with EWF and GSHP		
		Area (m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Primary Energy (kWh)	Primary energy (kWh/m2)	Reduction %
	Usable Floor area	17,640					
1	Heating		846,000	48	247,644	14.0	70%
2	DHW		35,280	2	35,280	2	-
3	Cooling		403,200	22.8	296,190	16.7	26.5%
4	Ventilation		864,360	49	224,993	12.75	74%
5	Production Equipment		88,200	5	88,200	5	-
6	Lighting		405,720	23	405,720	23	-
	Total		**2,642,760**	**150**	**1,298,027**	**73.6**	**50.8%**


THANK YOU
Earth
Wind
Fire