



Optimized Green Walls

*Study of Vertical Green Systems'
Performance in an Urban Setting*

Francisco Guzmán | 4710487 | CiTG

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URBAN ENVIRONMENT

URBAN ENVIRONMENT



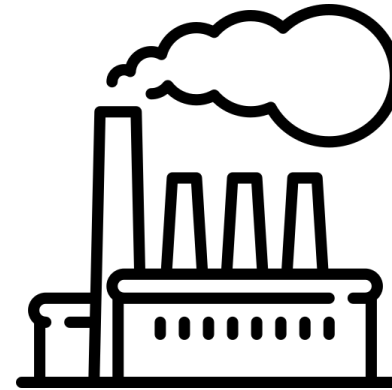
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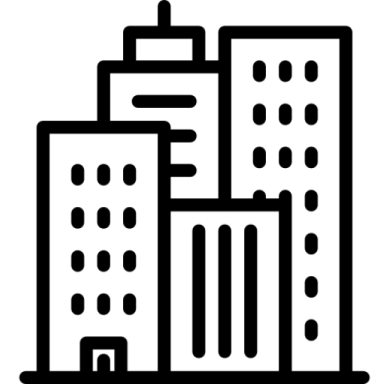
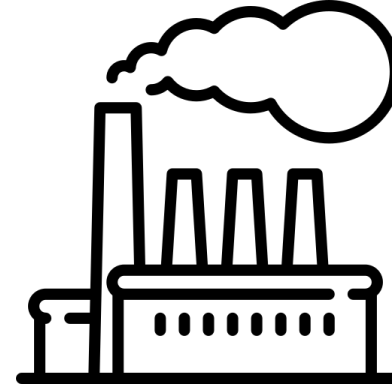
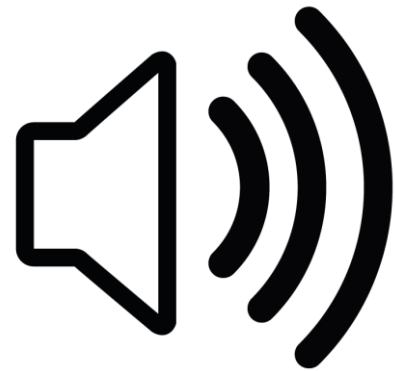
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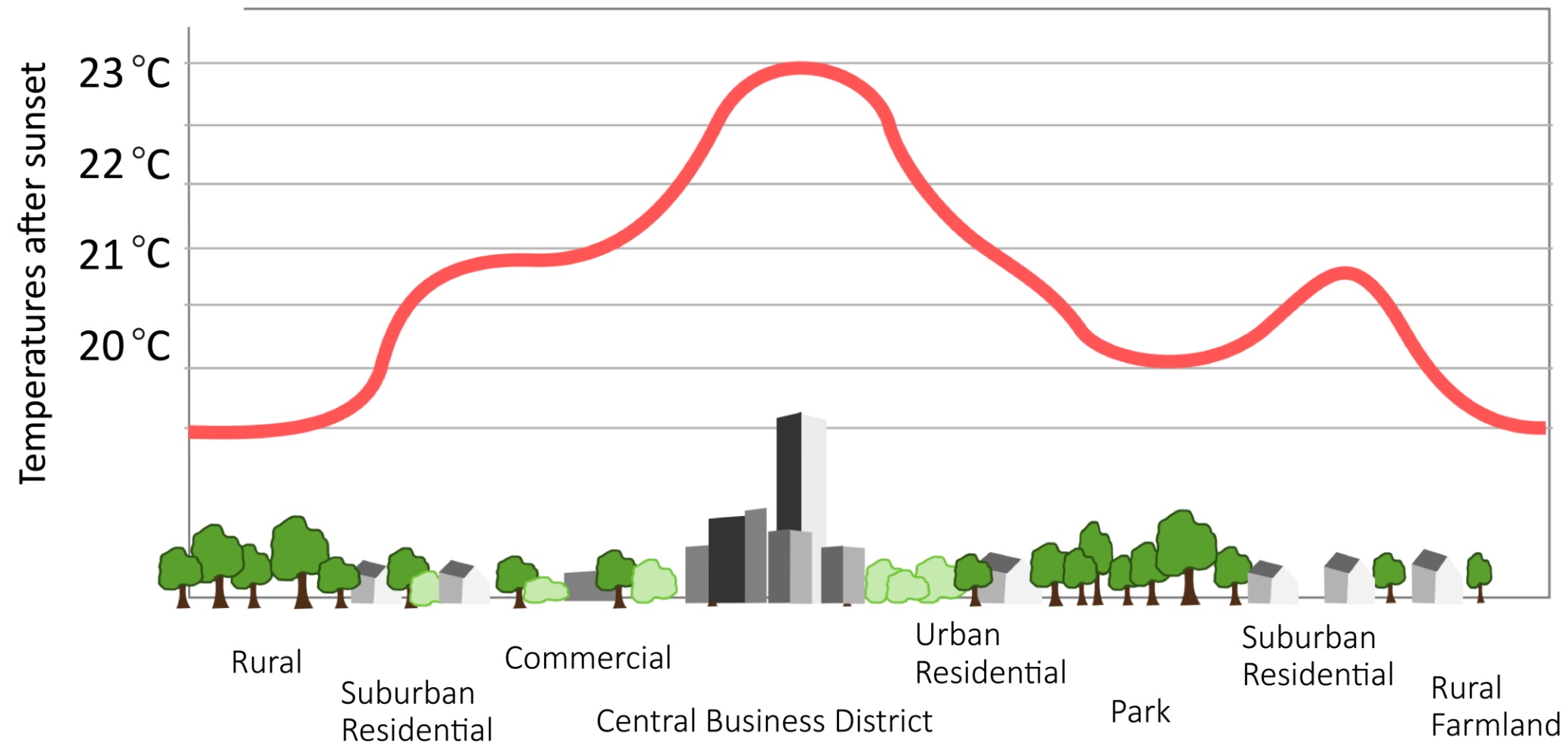
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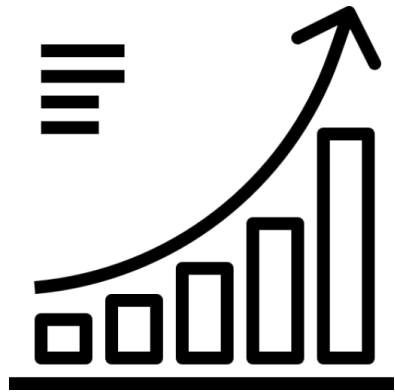
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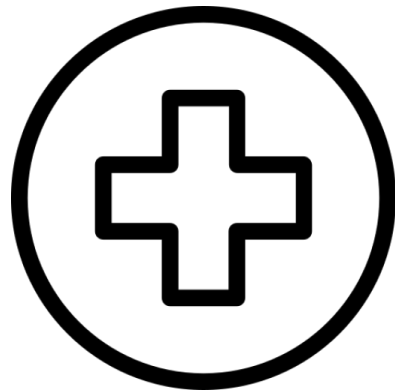
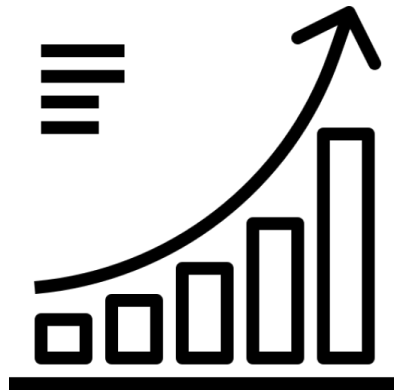
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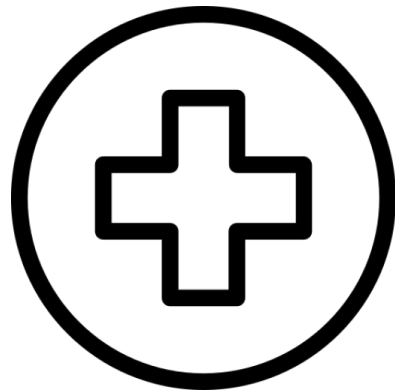
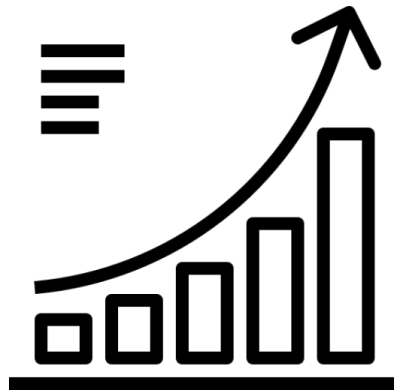
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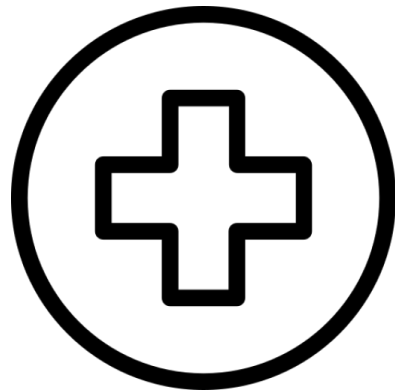
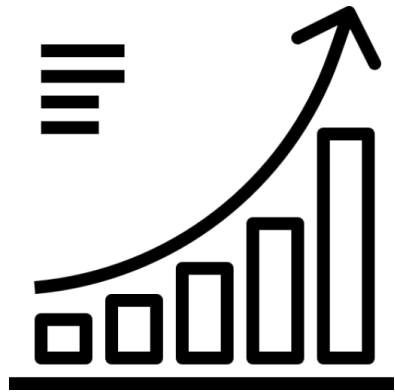
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URBAN ENVIRONMENT



ALTERNATIVES

ALTERNATIVES



Barcelona



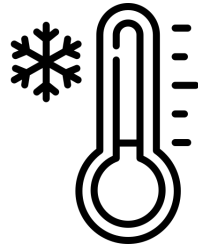
New York

URBAN VEGETATION

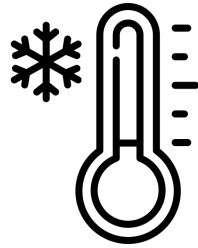
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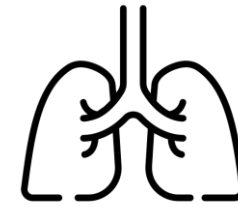
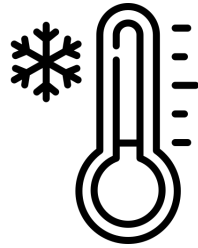
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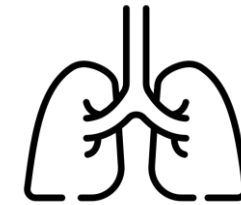
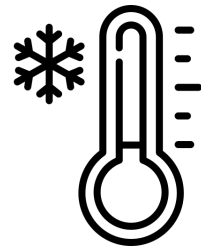
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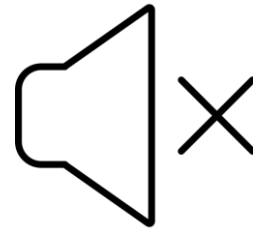
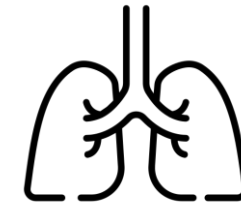
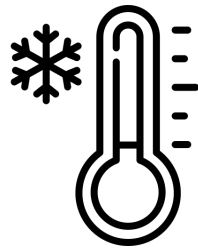
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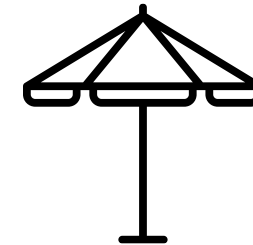
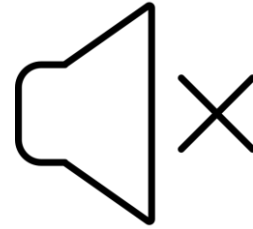
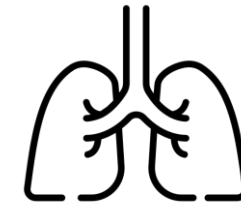
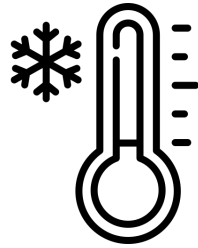
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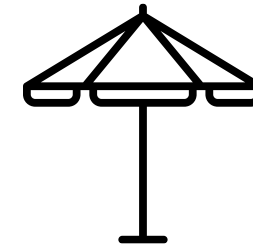
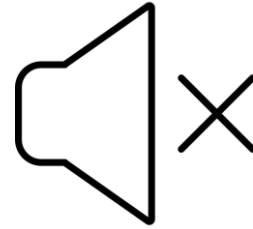
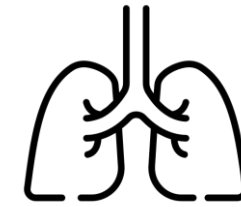
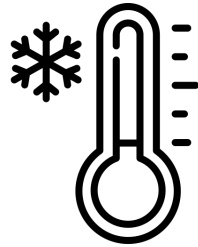
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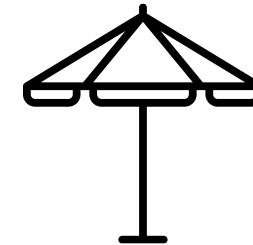
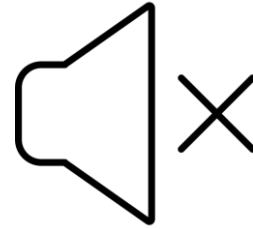
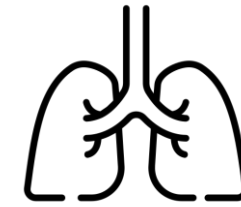
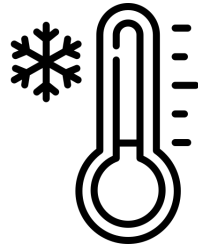
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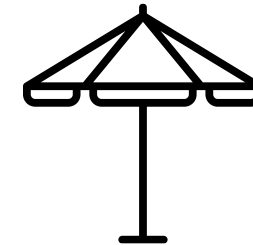
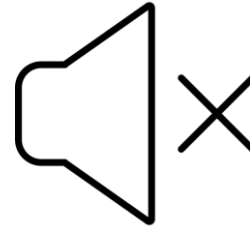
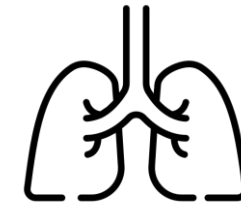
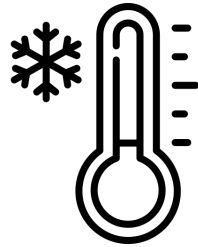
URBAN VEGETATION



URBAN VEGETATION



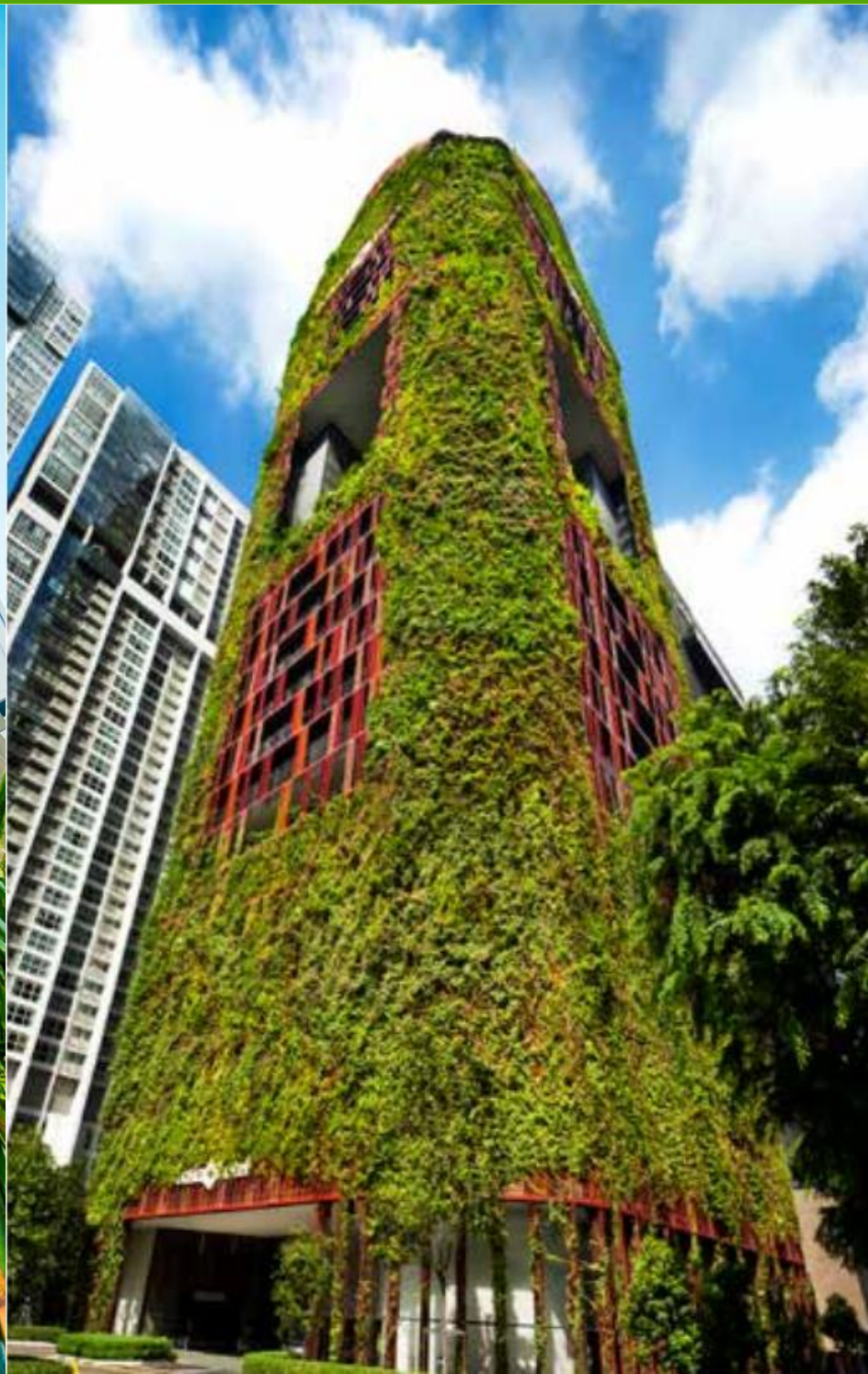
URBAN VEGETATION



BUT WHY?

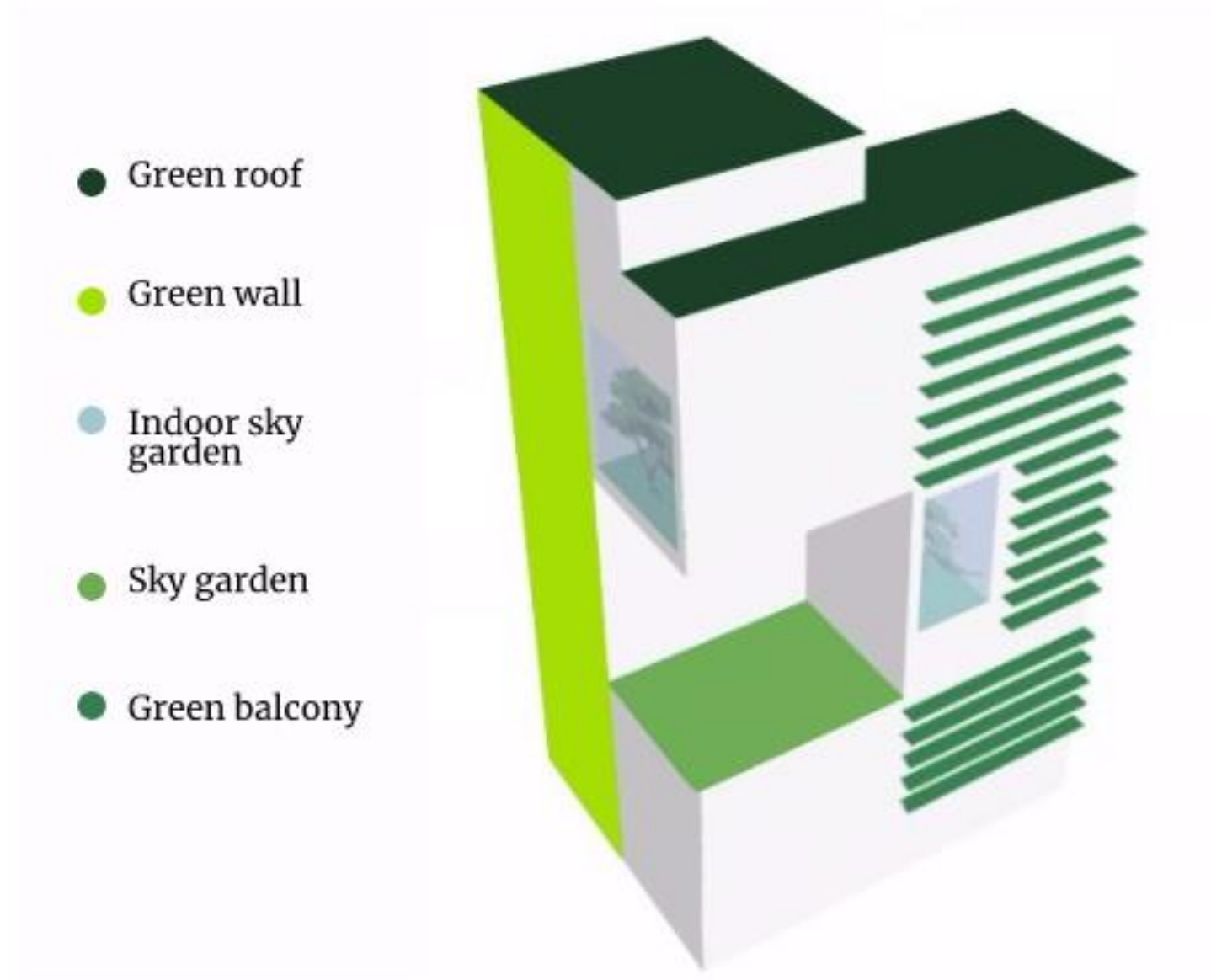


REAL PROJECTS

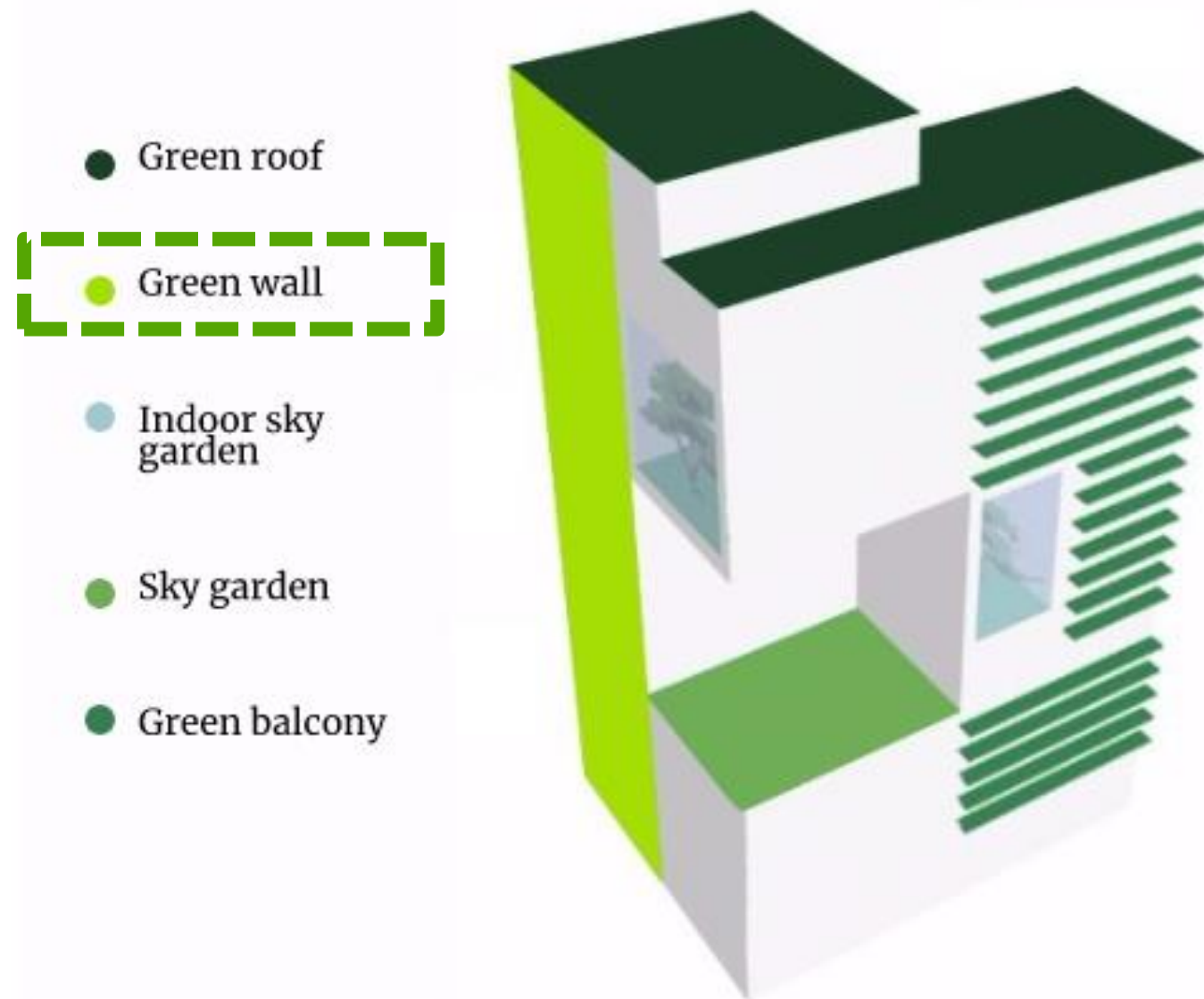


BUILDING INTEGRATED VEGETATION

BUILDING INTEGRATED VEGETATION



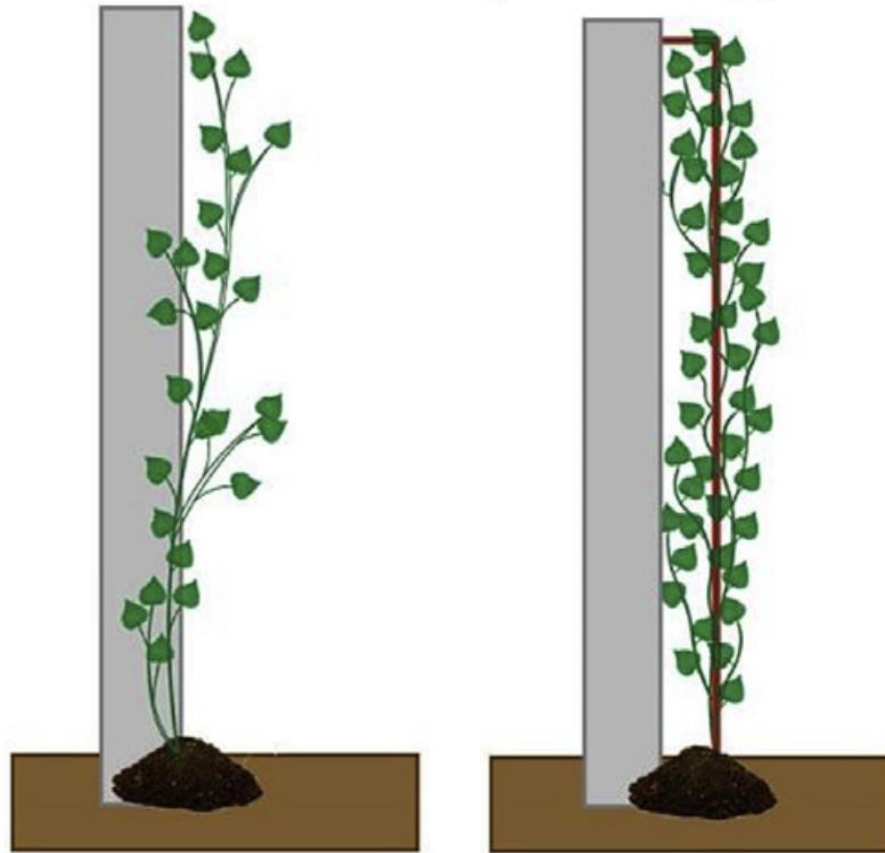
BUILDING INTEGRATED VEGETATION



VERTICAL GREENERY SYSTEM

VERTICAL GREENERY SYSTEM

Green Façades

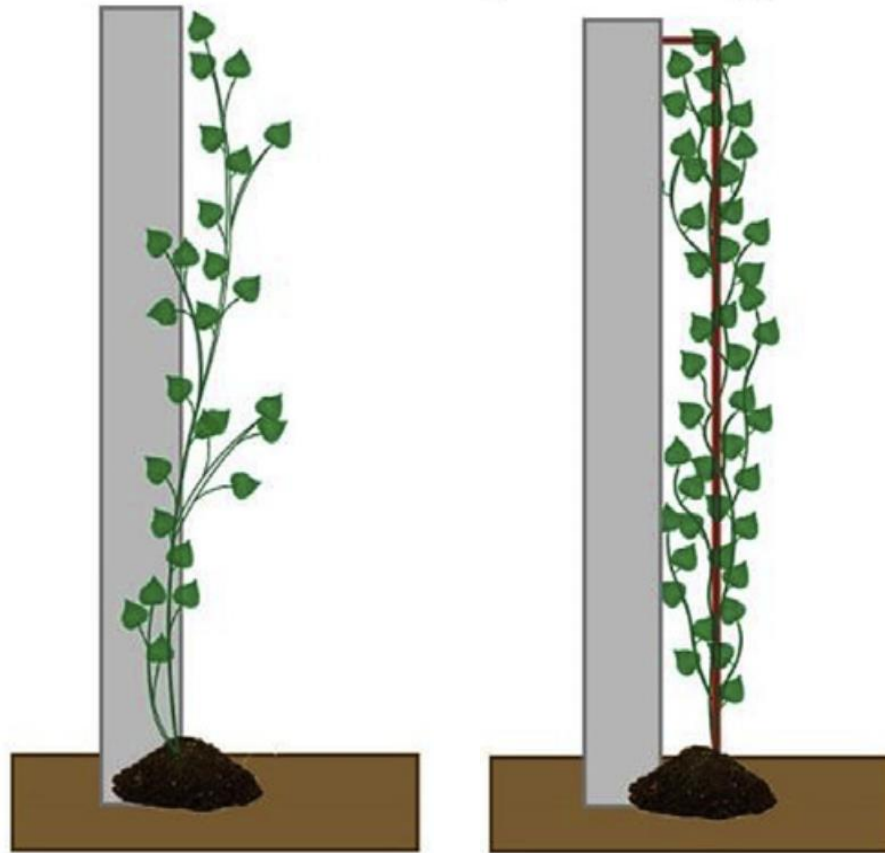


Direct

Indirect

VERTICAL GREENERY SYSTEM

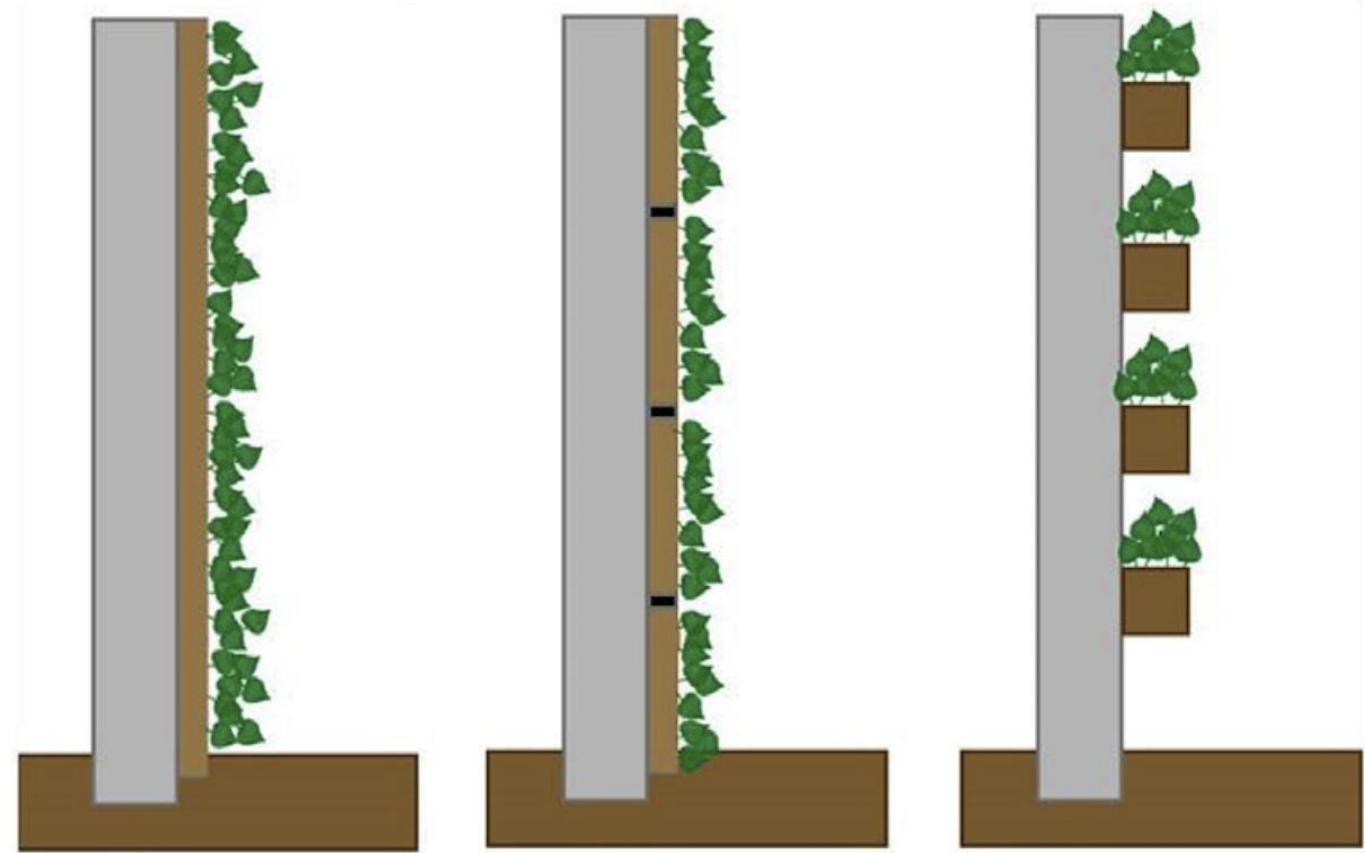
Green Façades



Direct

Indirect

Living wall systems



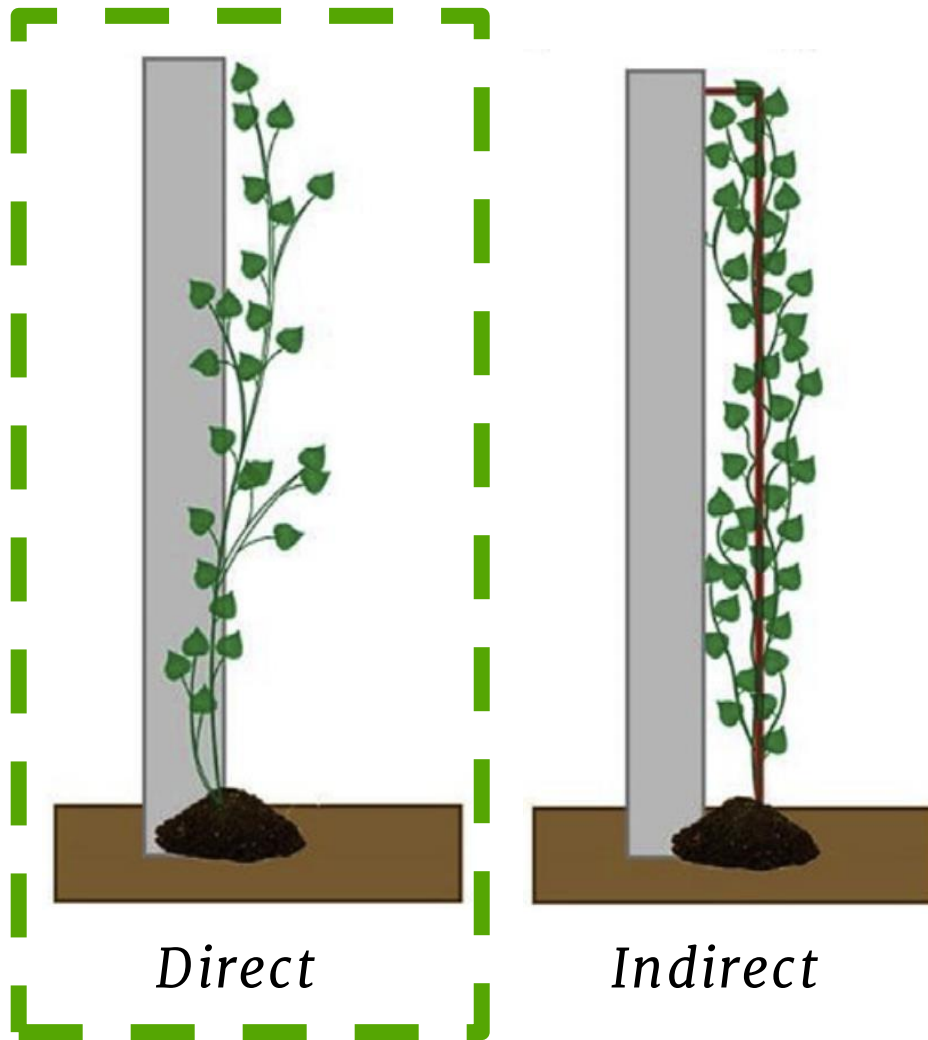
Continuous

Modular

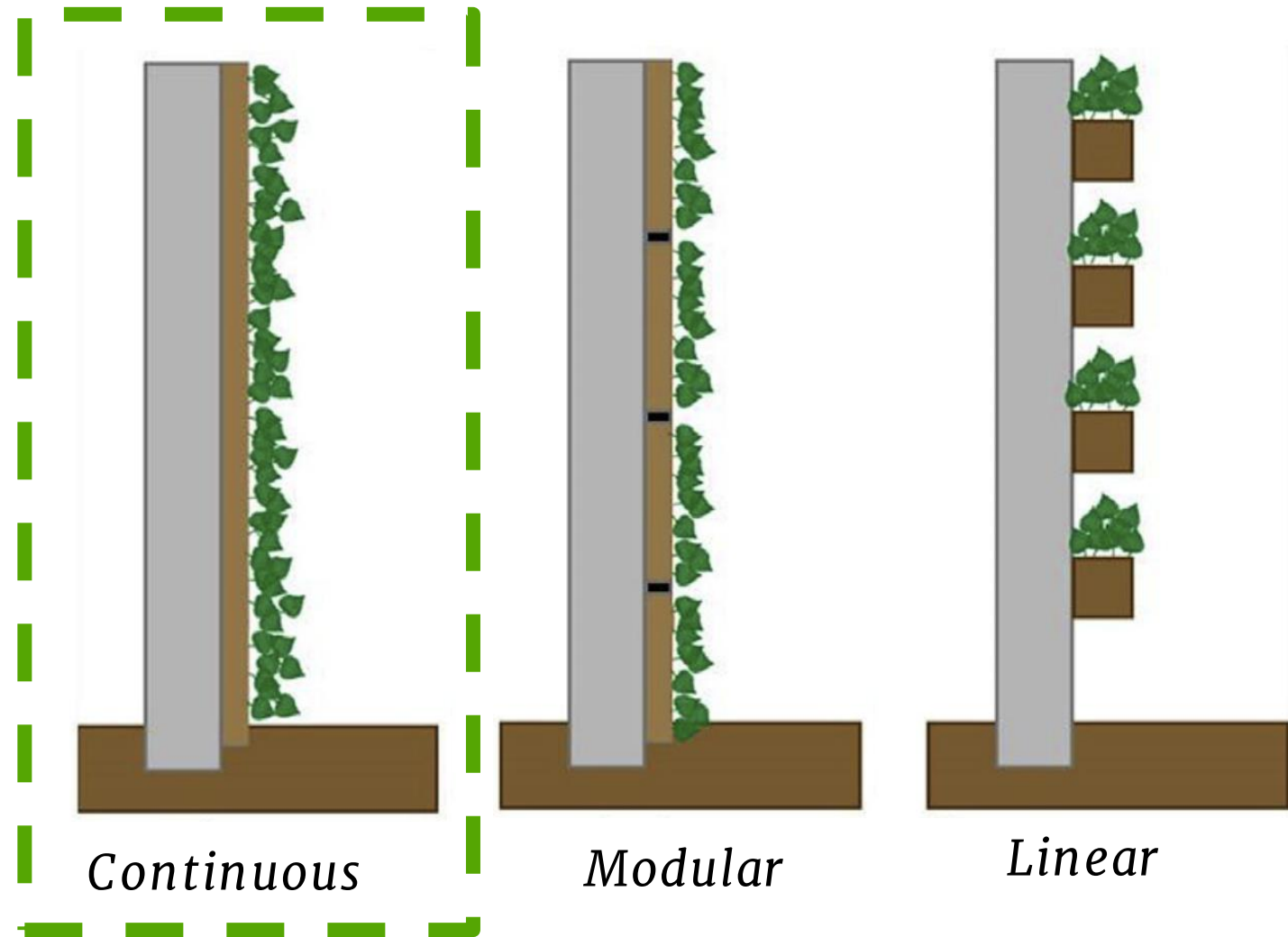
Linear

VERTICAL GREENERY SYSTEM

Green Façades



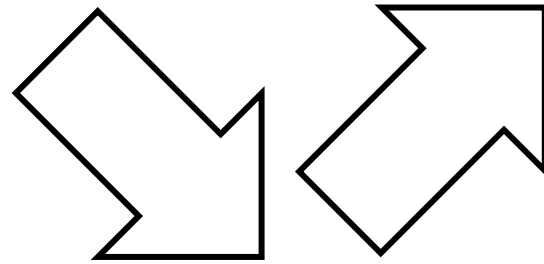
Living wall systems



PARAMETRIZATION

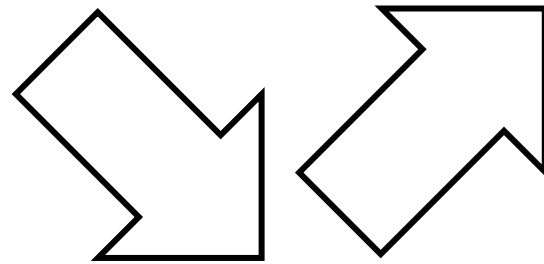
PARAMETRIZATION

Leaf Surface Albedo

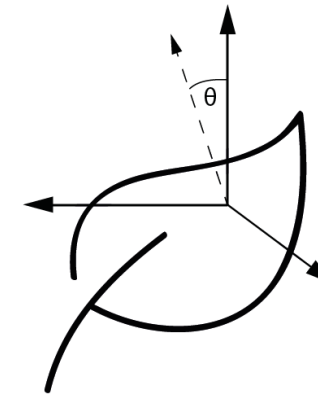


PARAMETRIZATION

Leaf Surface Albedo

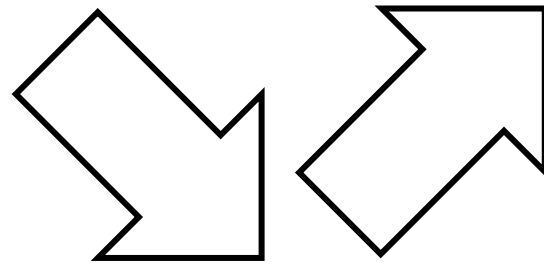


Leaf Angle Distribution

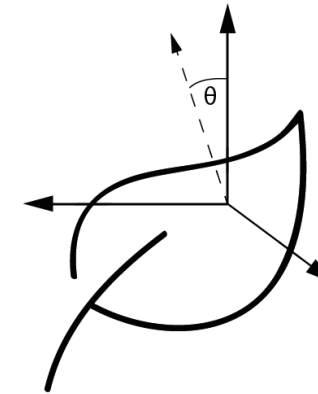


PARAMETRIZATION

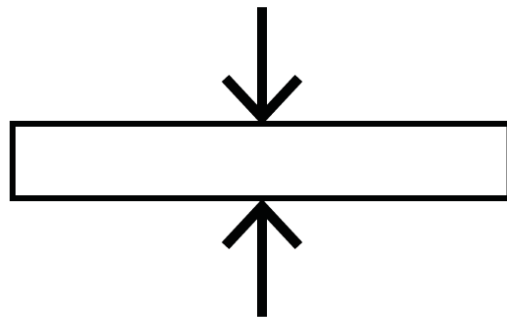
Leaf Surface Albedo



Leaf Angle Distribution

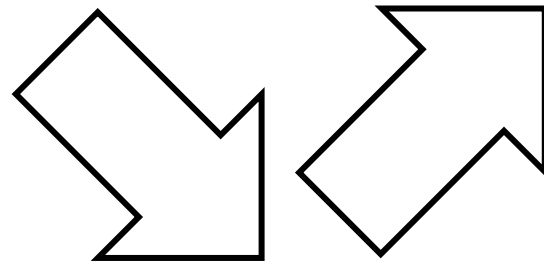


Soil Substrate Thickness

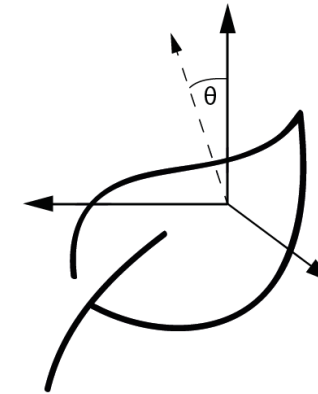


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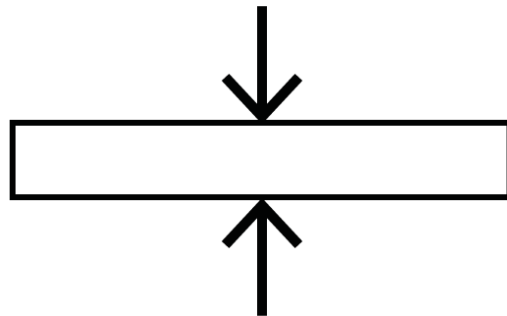
Leaf Surface Albedo



Leaf Angle Distribution



Soil Substrate Thickness



Soil Moisture Content



PARAMETRIZATION

Leaf Area Index

PARAMETRIZATION

Leaf Area Index



$LAI \approx 0.25$



$LAI \approx 0.75$



$LAI \approx 1.50$

RESEARCH QUESTION

RESEARCH QUESTION

How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

METHODOLOGY

METHODOLOGY

I Model definition

METHODOLOGY

I Model definition

II Optimization study of heat transmission

METHODOLOGY

I Model definition

II Optimization study of heat transmission

III Impact on an urban setting

PART I – MODEL DEFINITION

```
// life motto  
if (sad() === true) {  
  sad().stop();  
  beAwesome();  
}
```

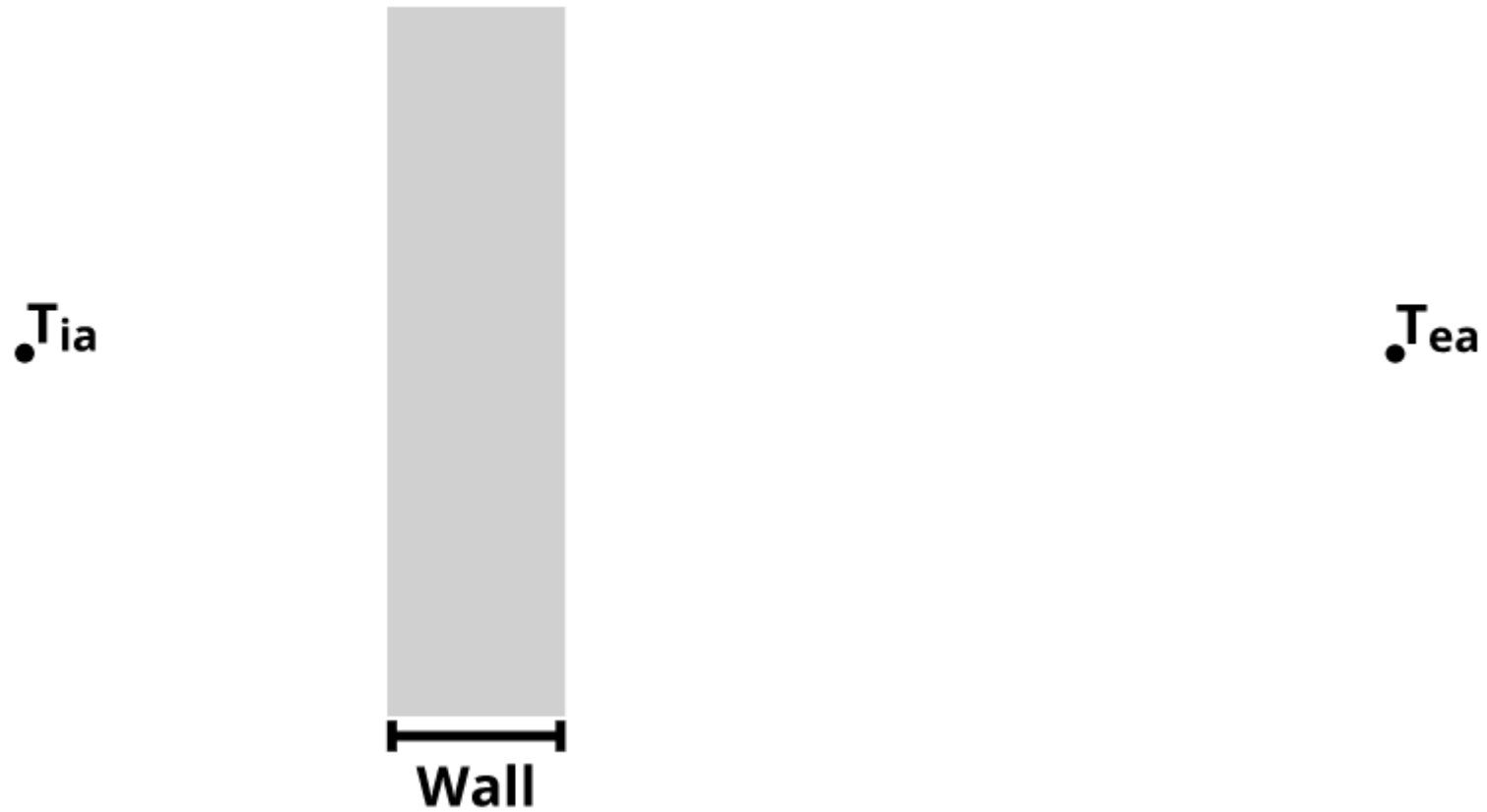
MODEL CASES

MODEL CASES

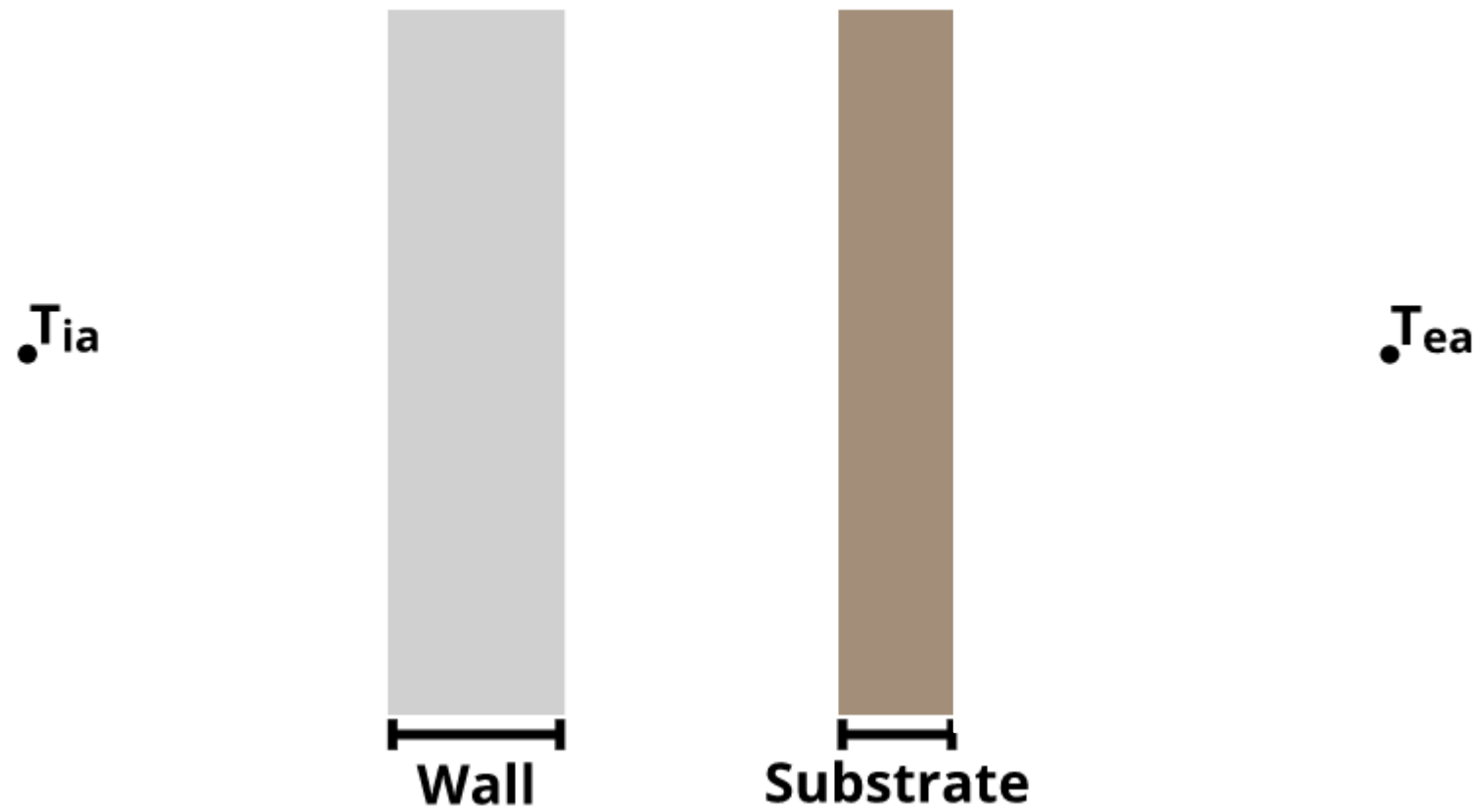
•Tia

•Tea

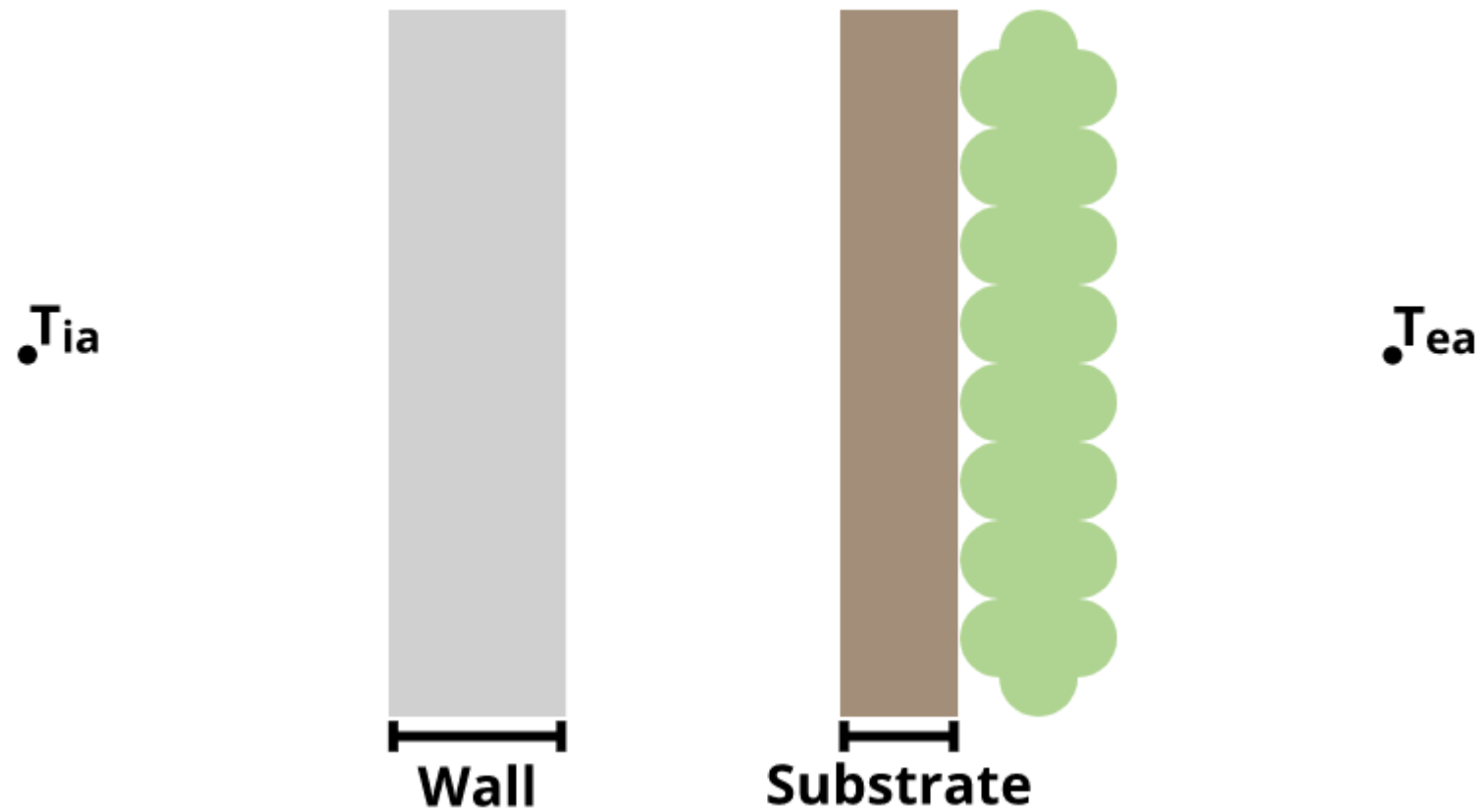
MODEL CASES



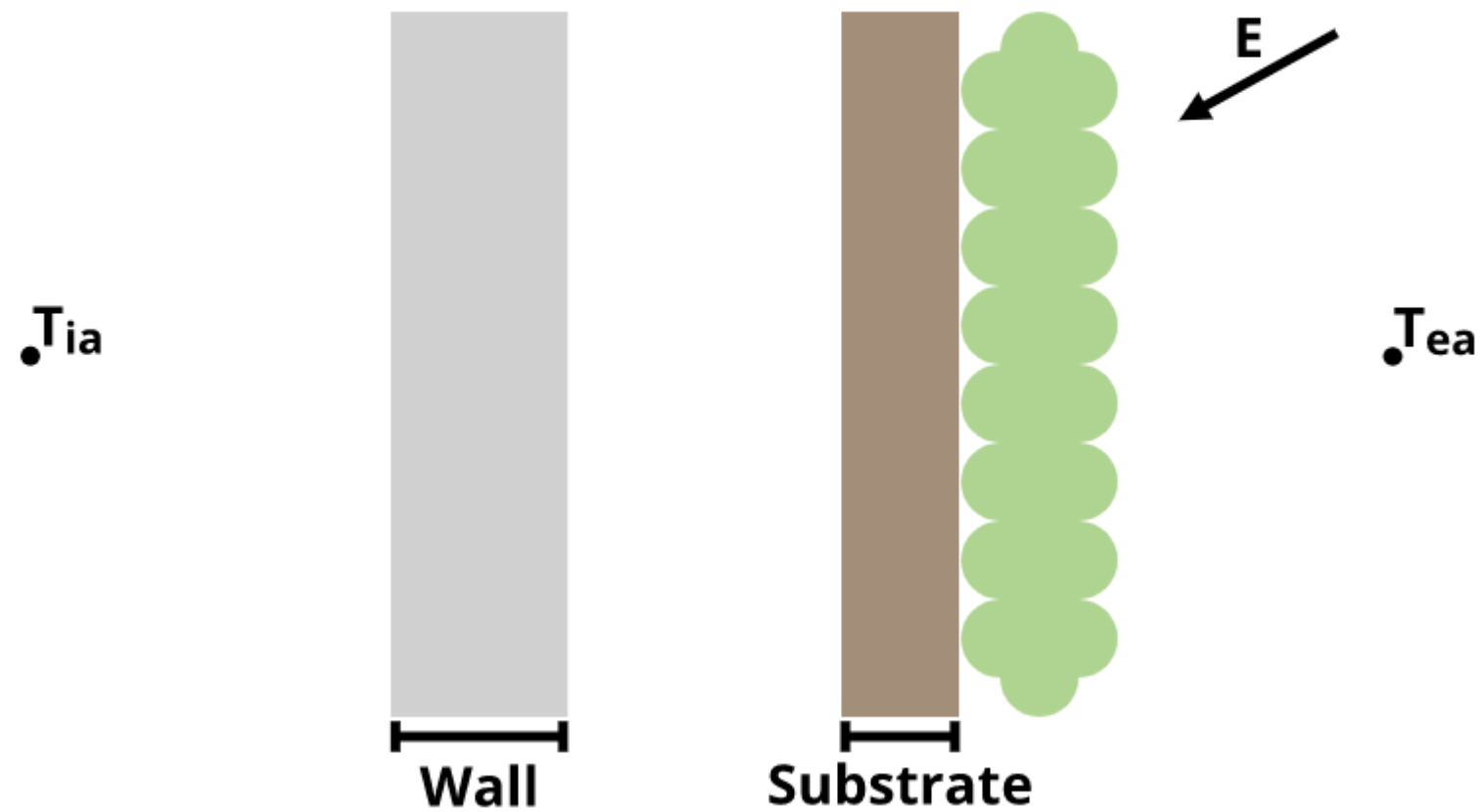
MODEL CASES



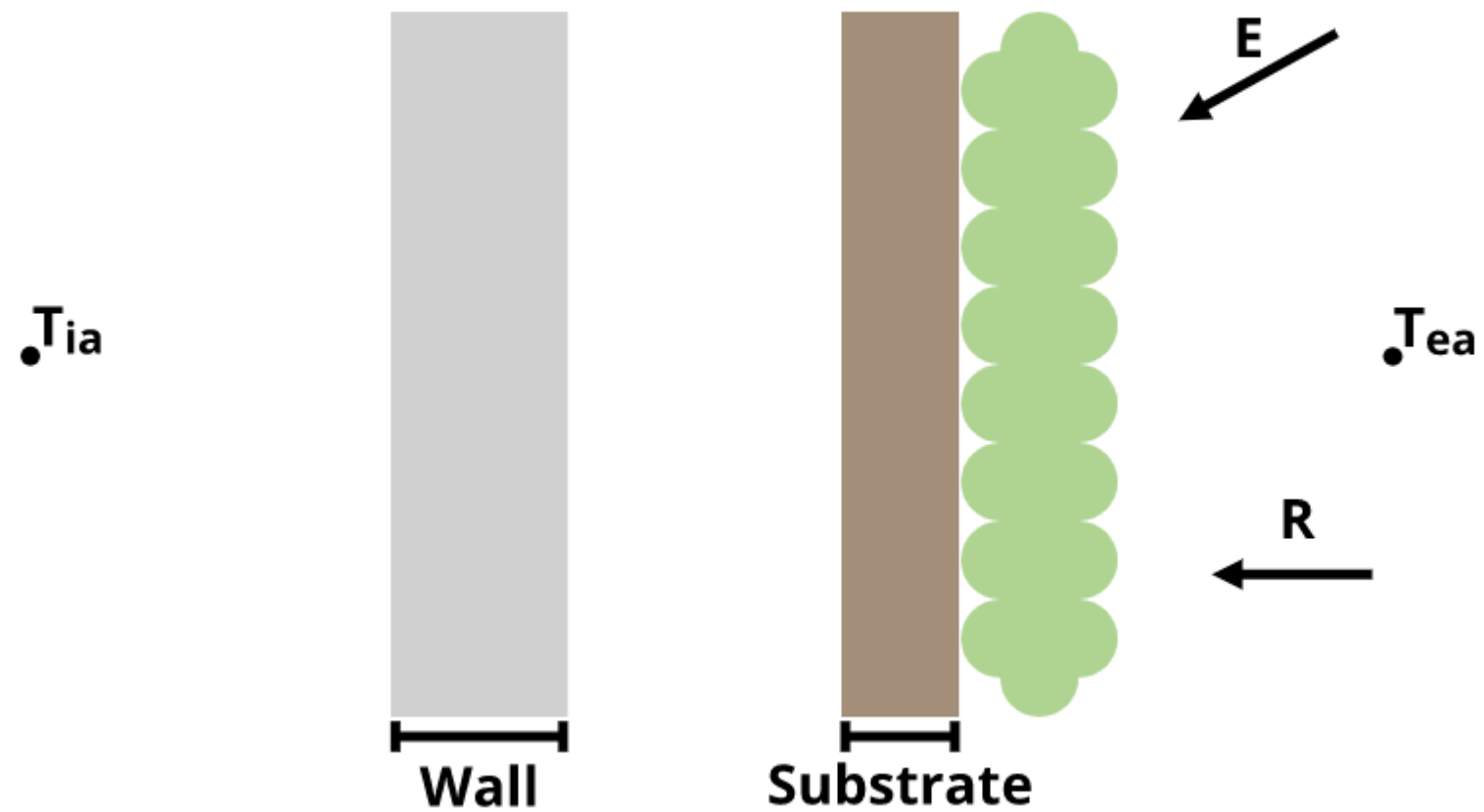
MODEL CASES



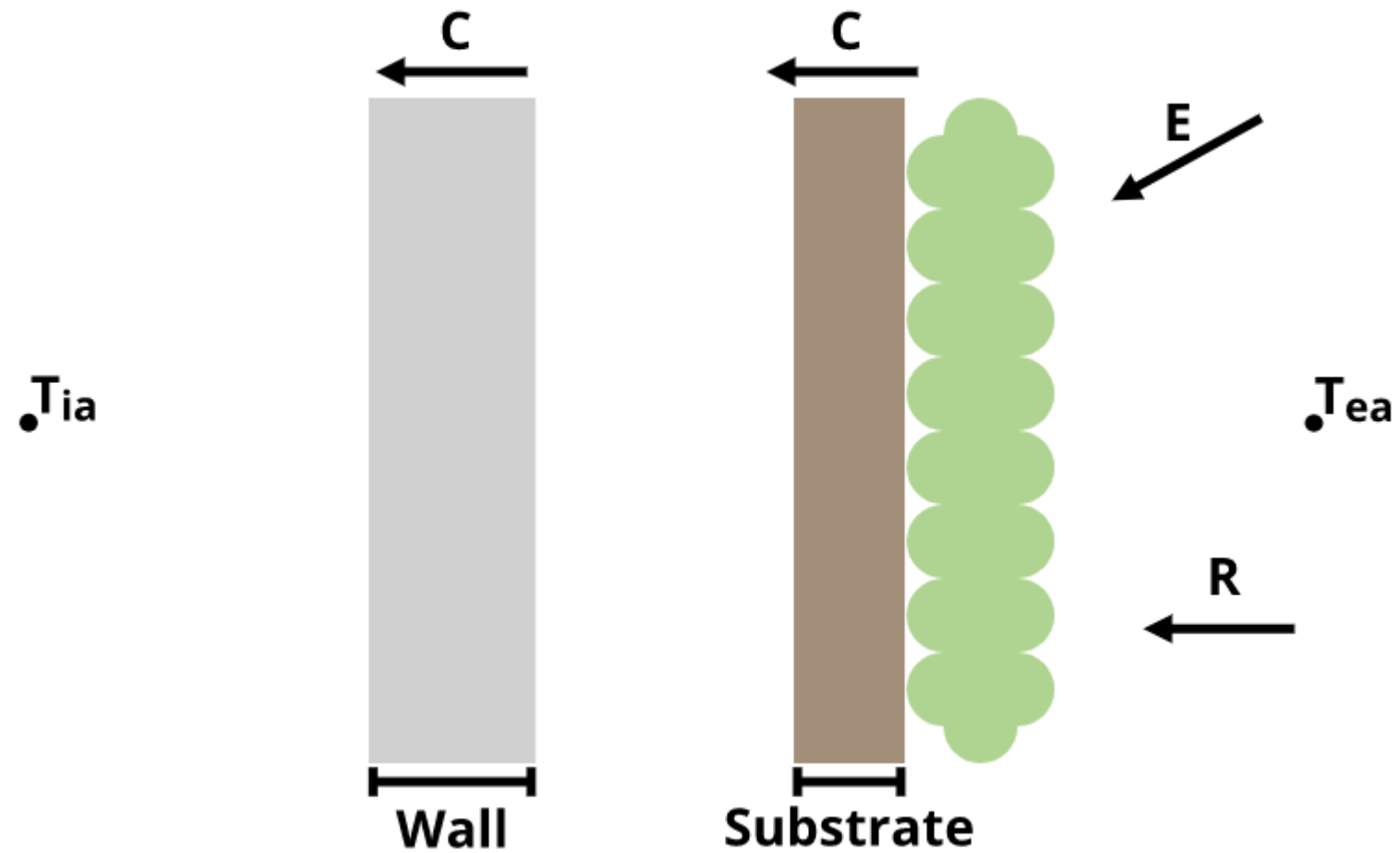
MODEL CASES



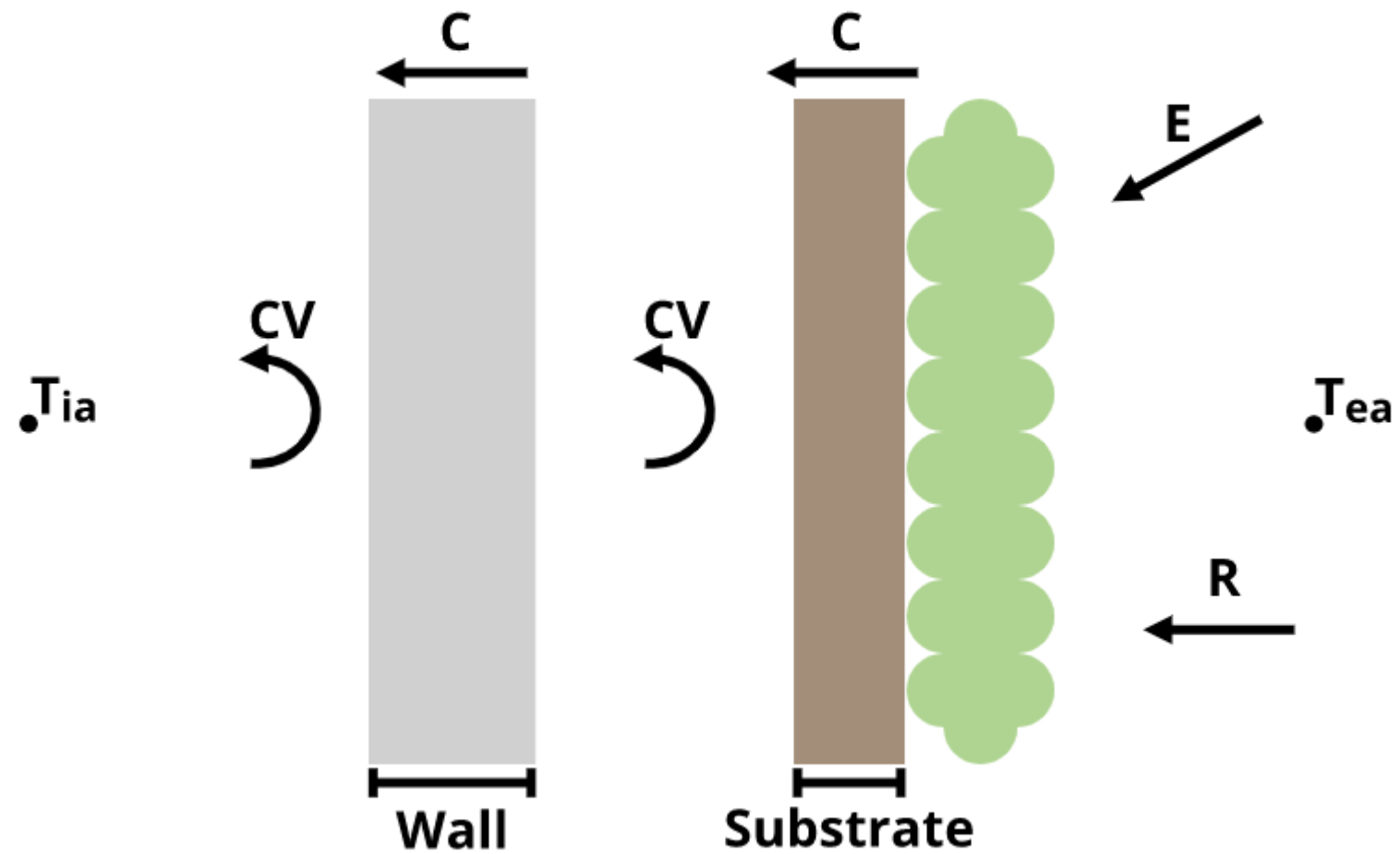
MODEL CASES



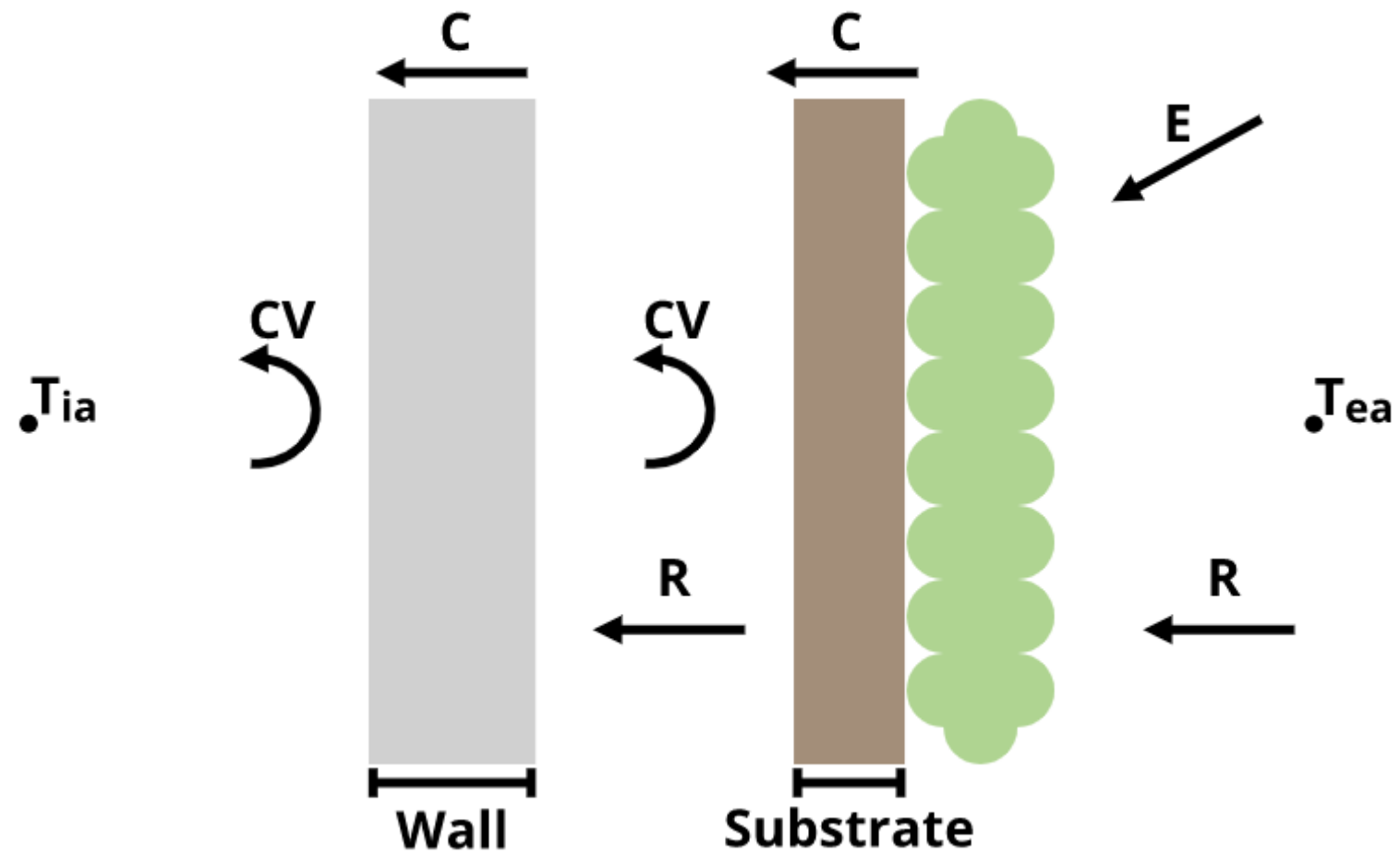
MODEL CASES



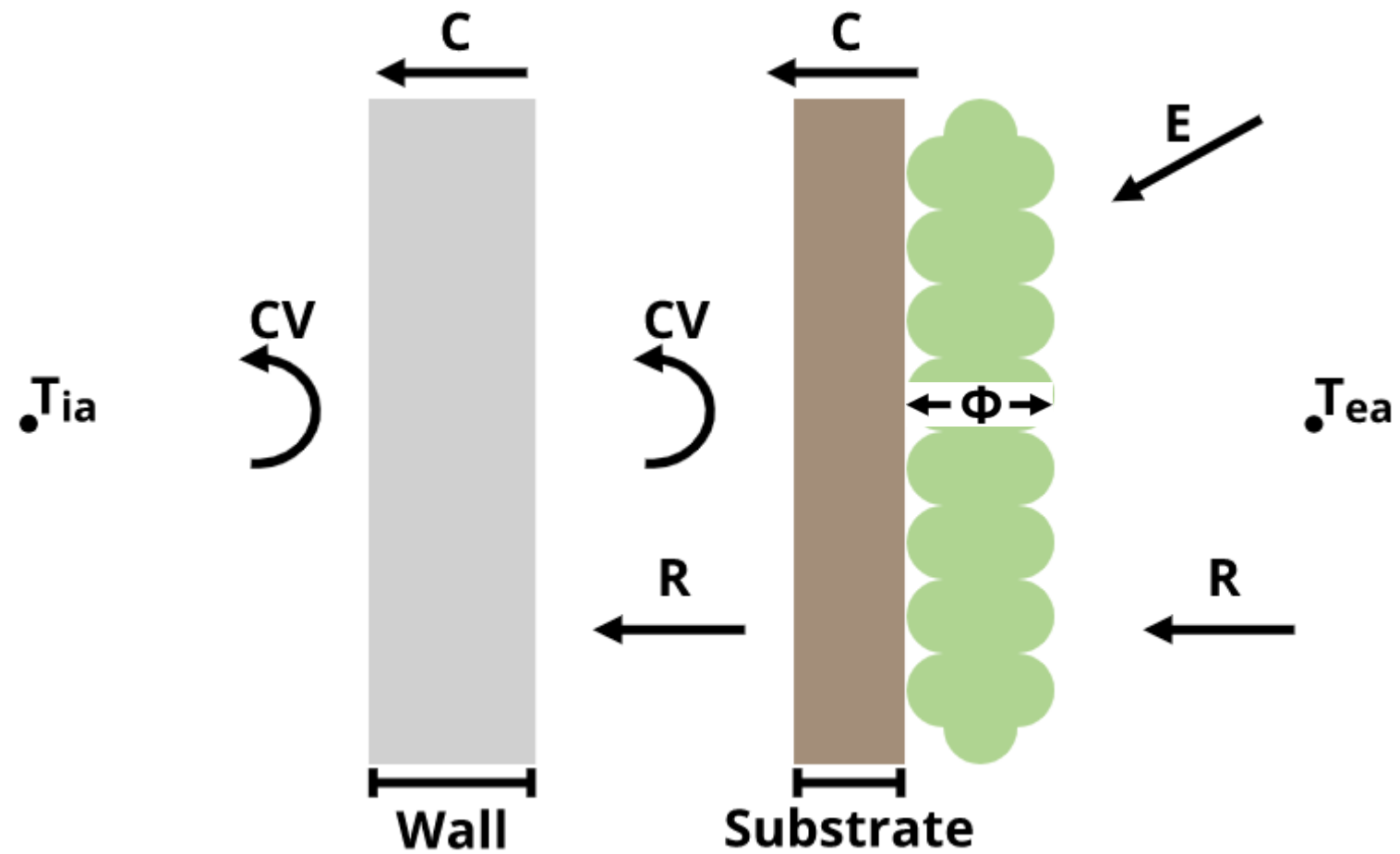
MODEL CASES



MODEL CASES

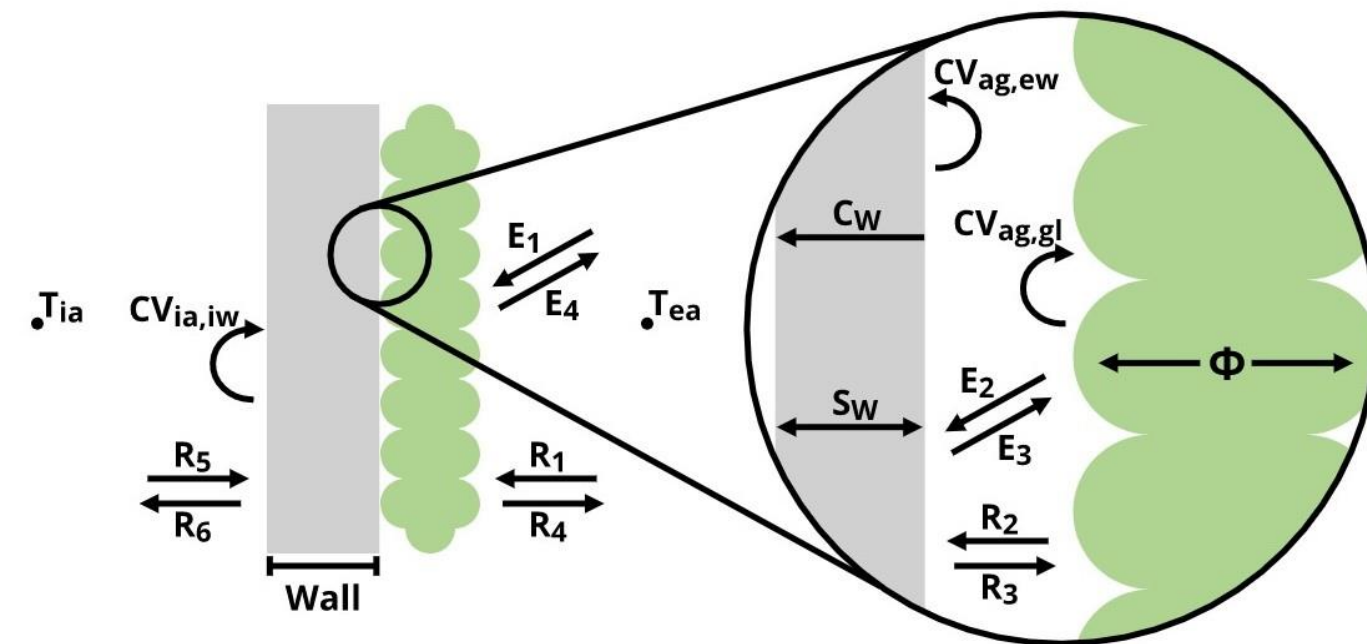


MODEL CASES



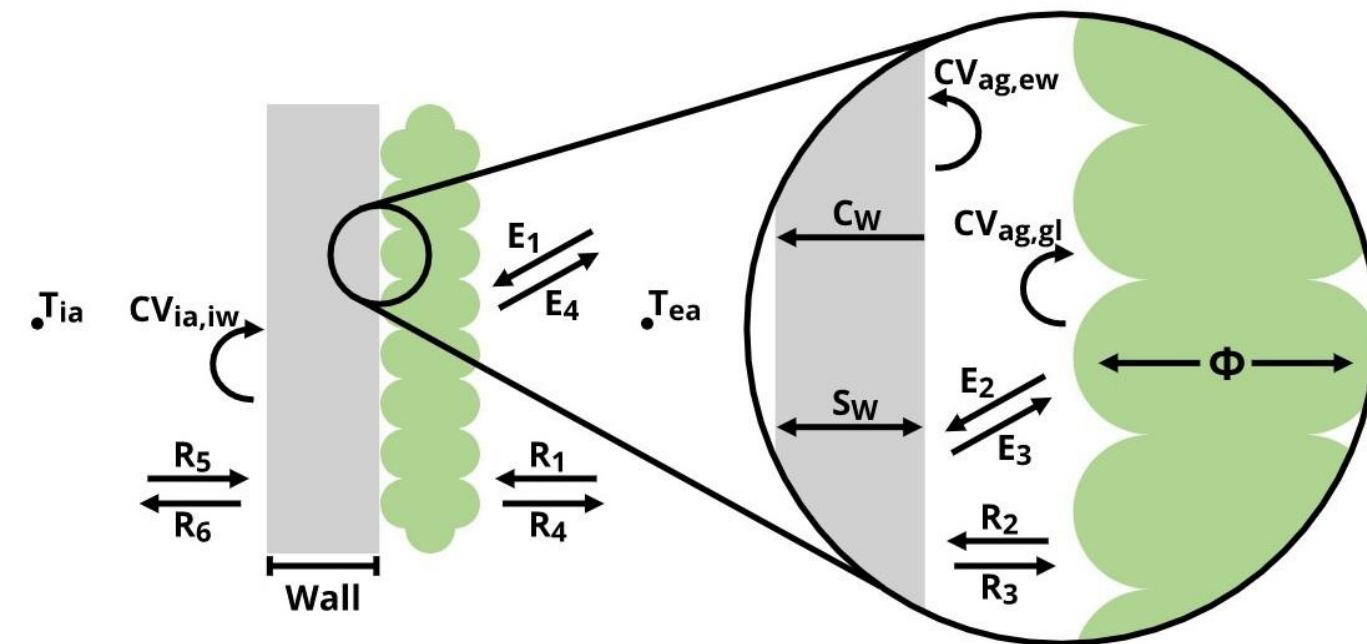
MODEL CASES

Green Façade

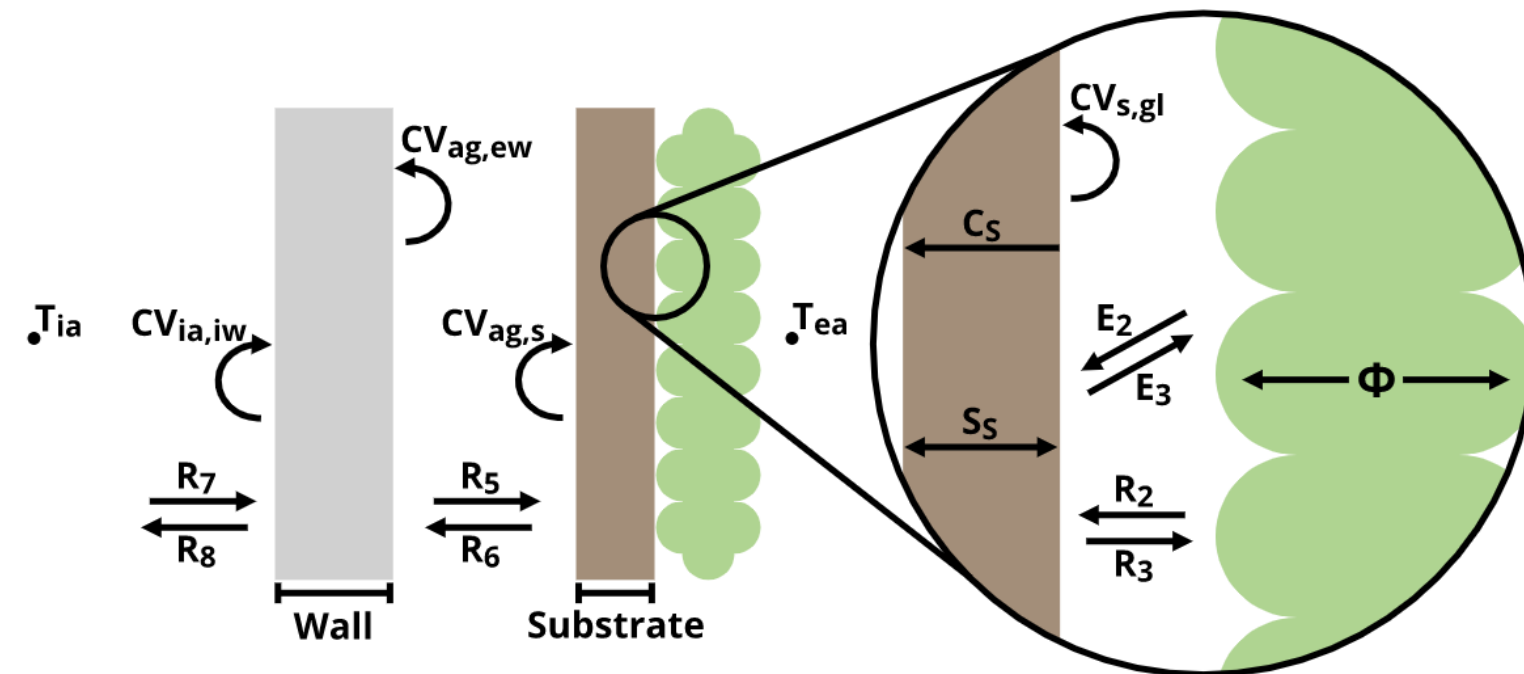


MODEL CASES

Green Façade

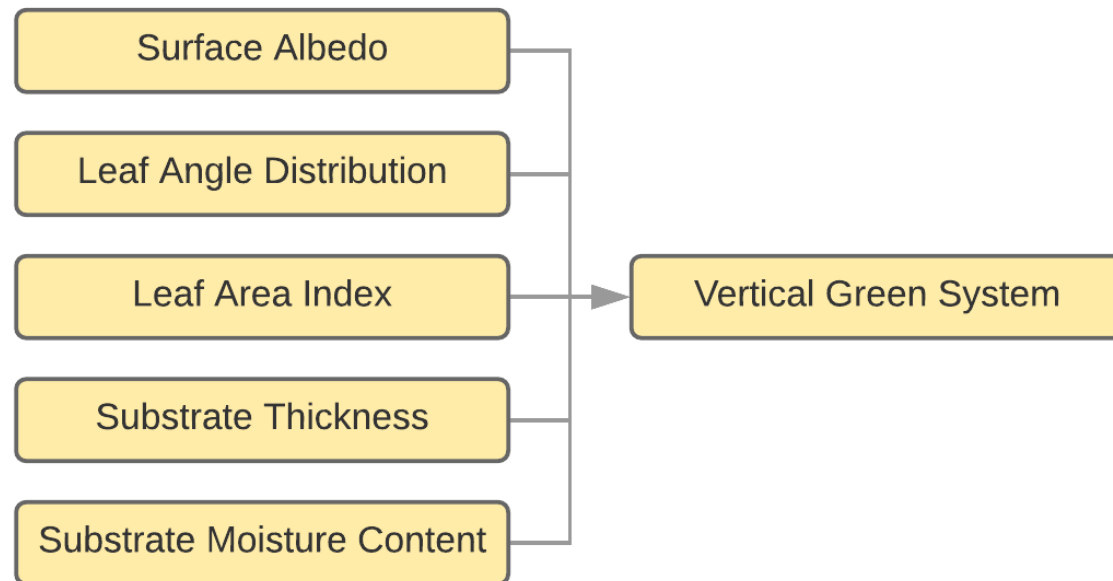


Living Wall System

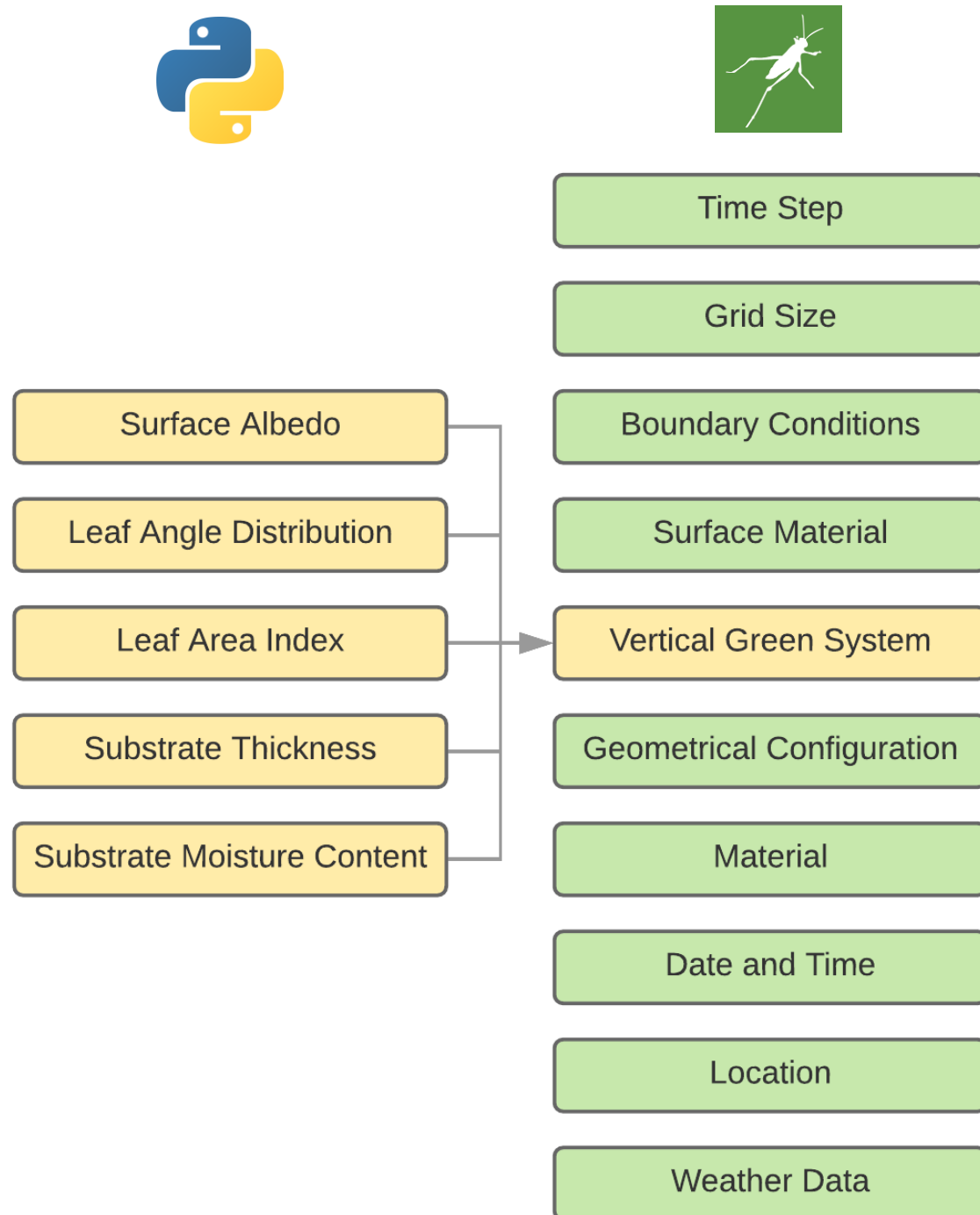


COMPUTATIONAL WORKFLOW

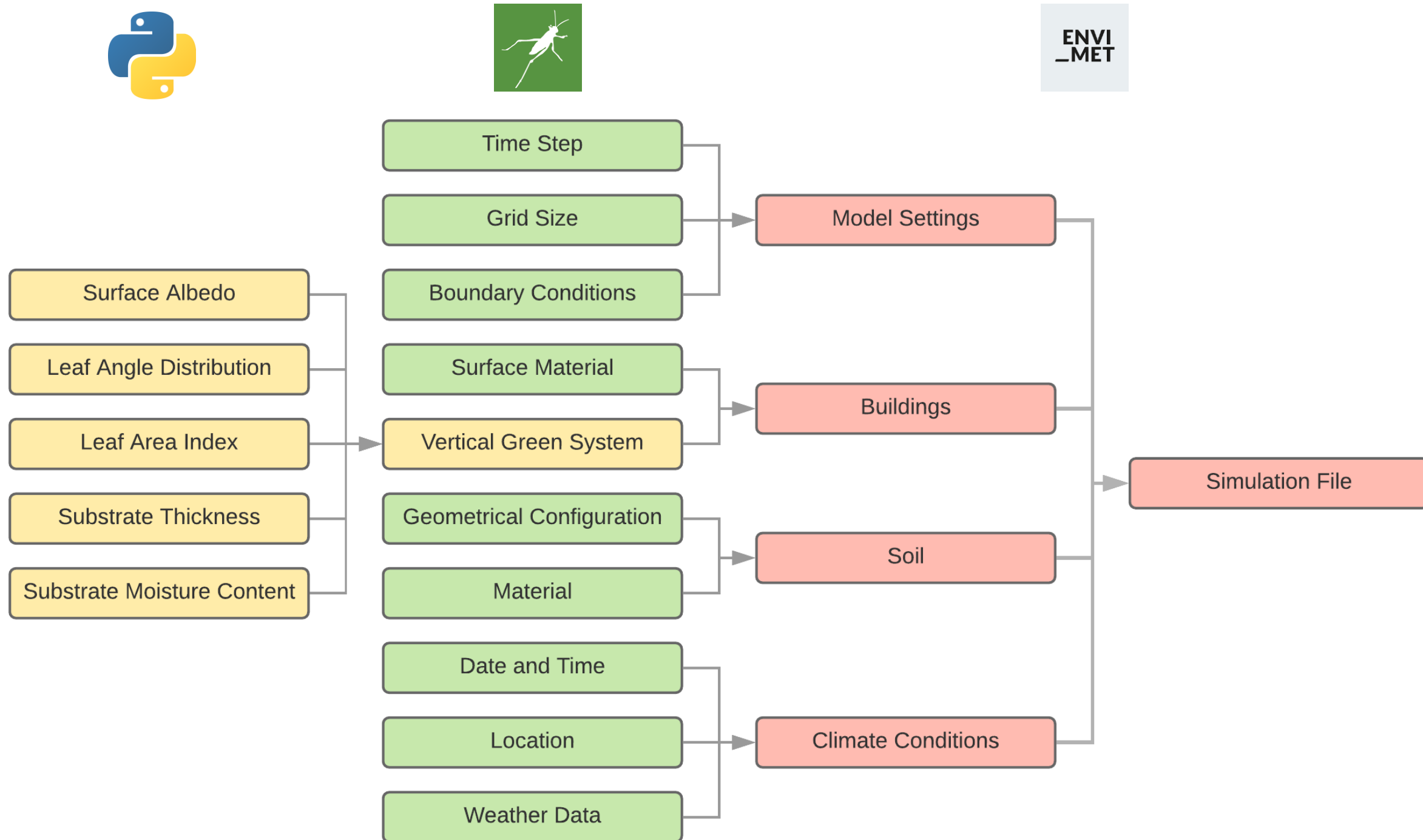
COMPUTATIONAL WORKFLOW



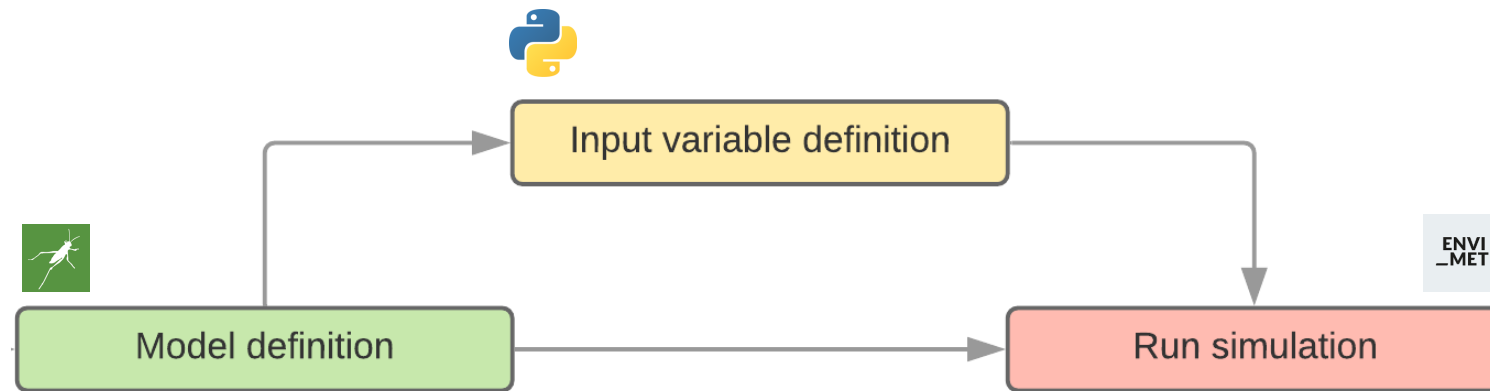
COMPUTATIONAL WORKFLOW



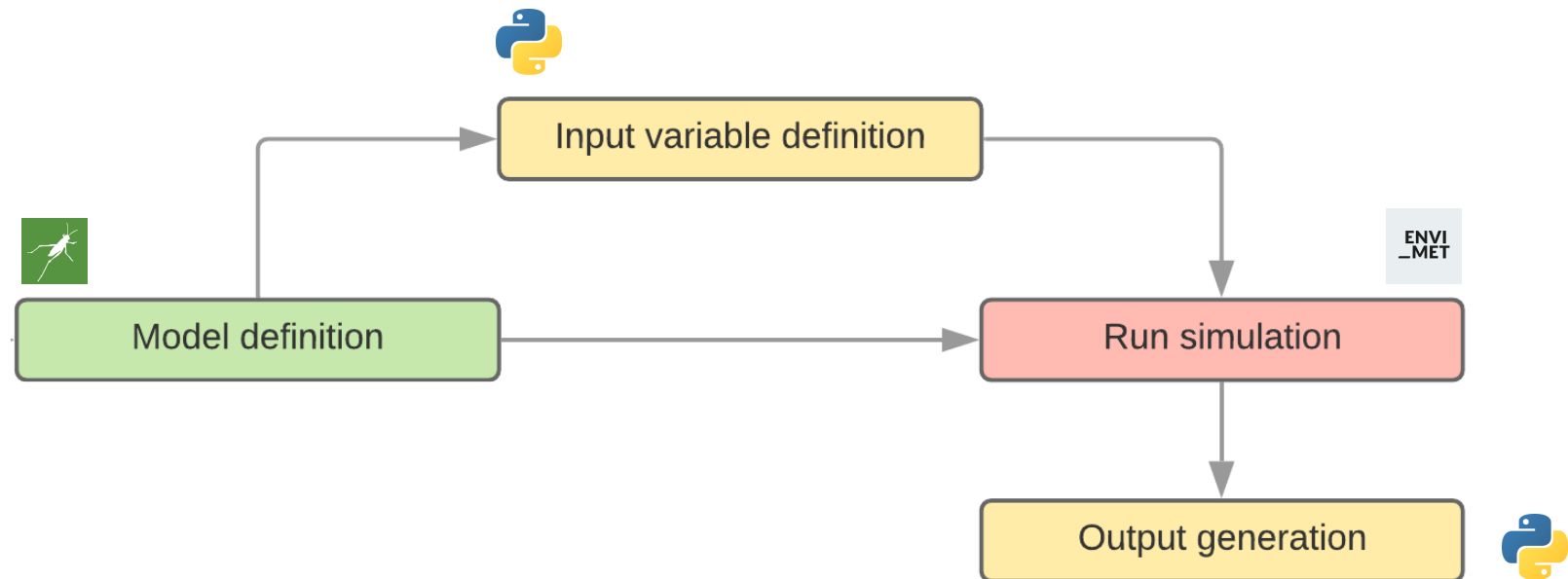
COMPUTATIONAL WORKFLOW



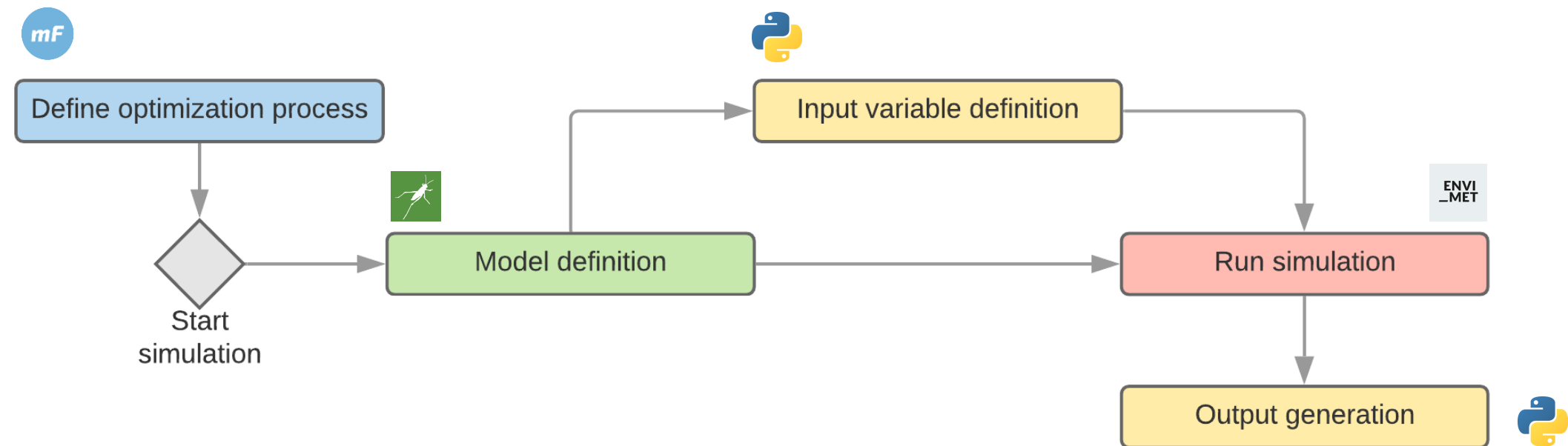
COMPUTATIONAL WORKFLOW



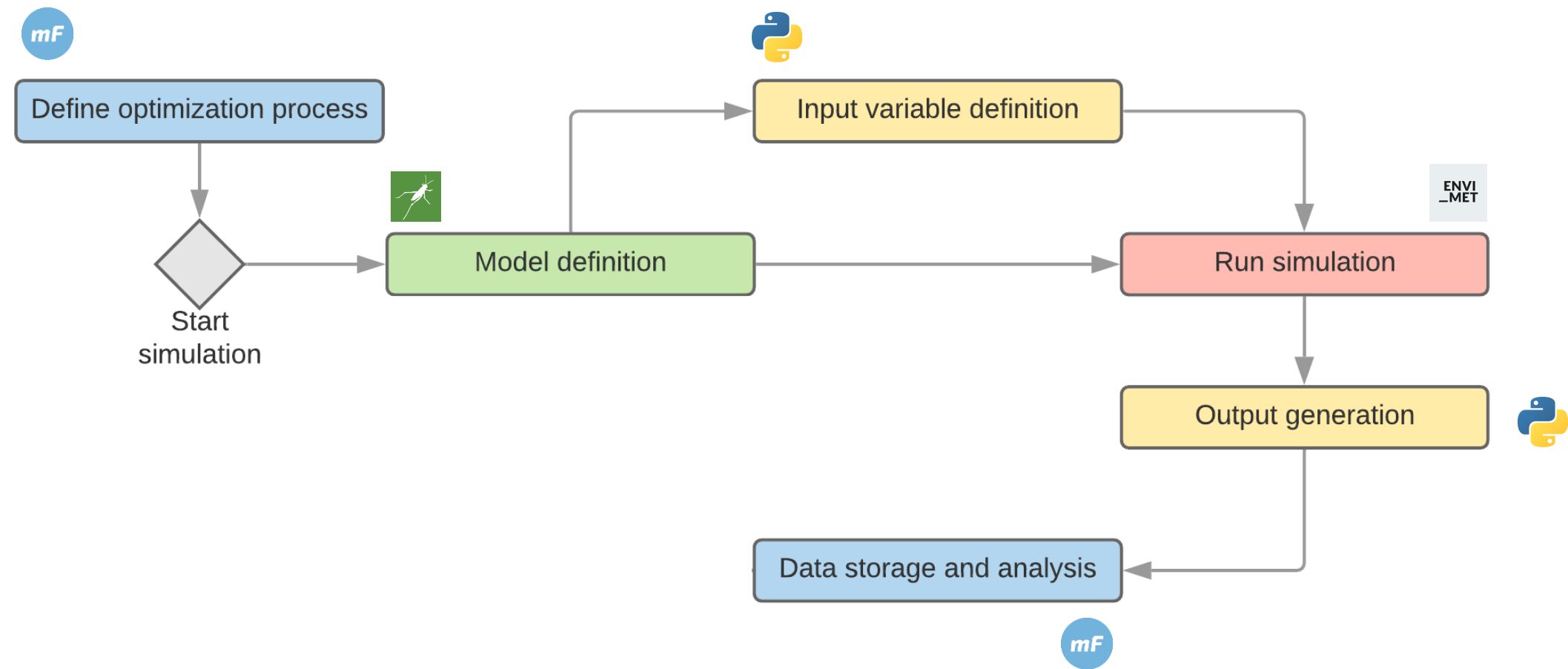
COMPUTATIONAL WORKFLOW



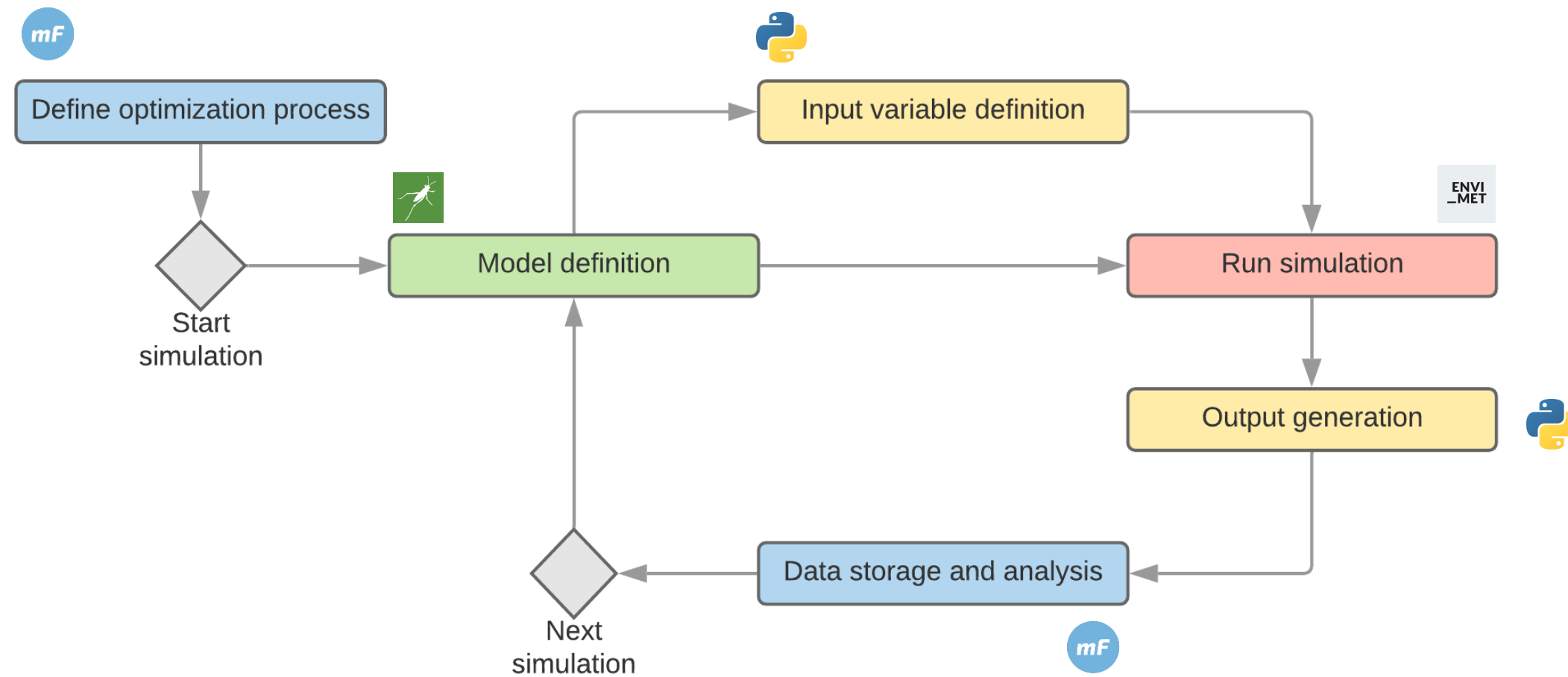
COMPUTATIONAL WORKFLOW



COMPUTATIONAL WORKFLOW

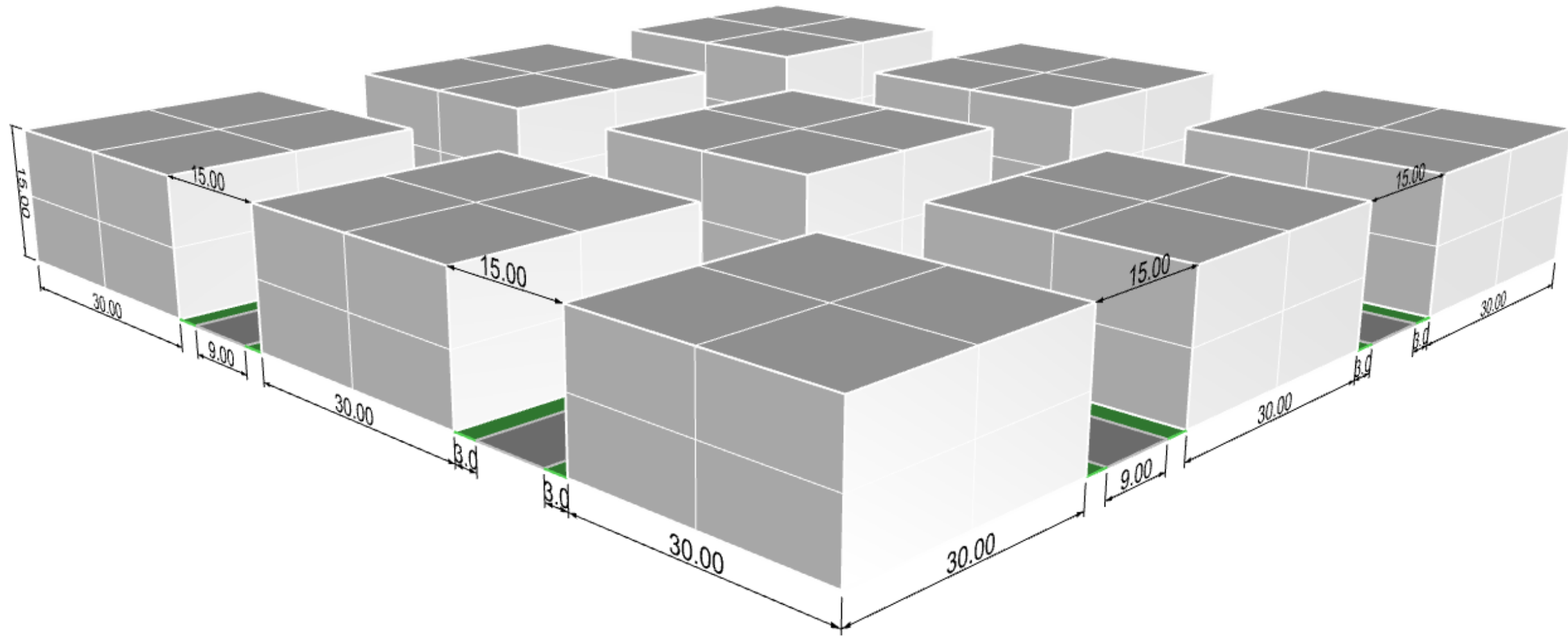


COMPUTATIONAL WORKFLOW

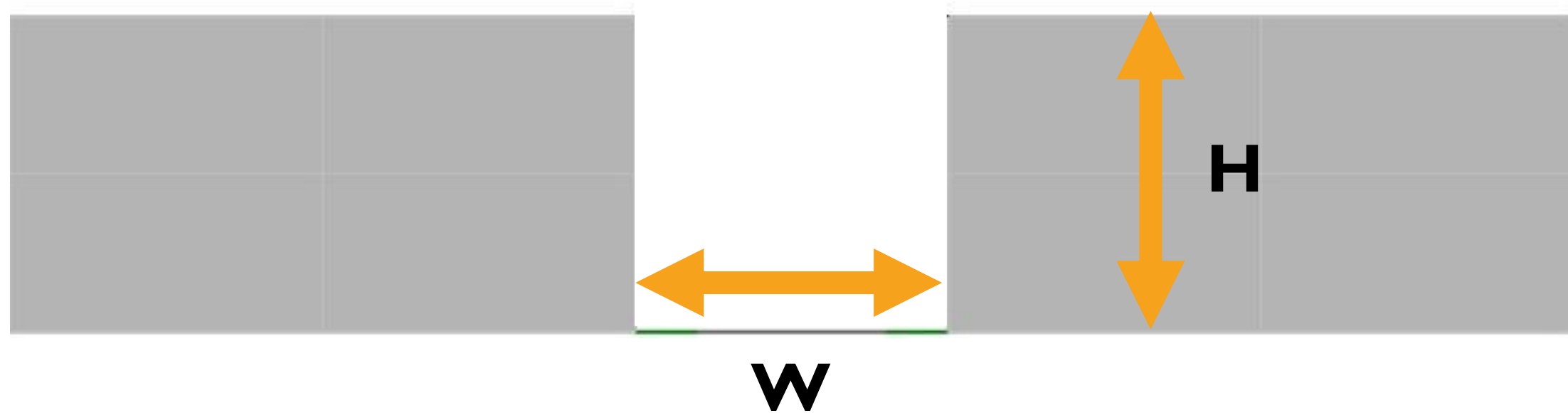


URBAN STREET CANYON

URBAN STREET CANYON

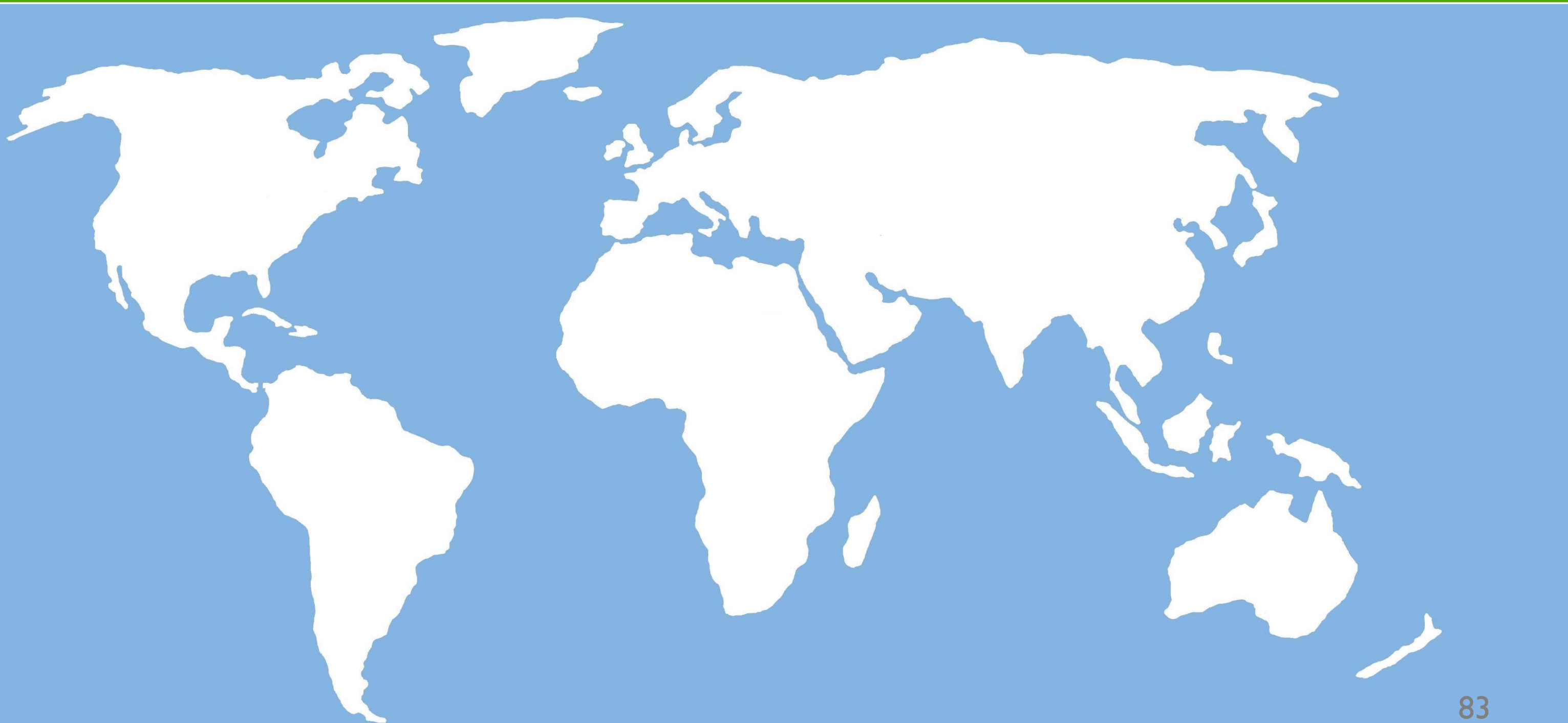


URBAN STREET CANYON



CLIMATE SELECTION

CLIMATE SELECTION



CLIMATE SELECTION



CLIMATE SELECTION



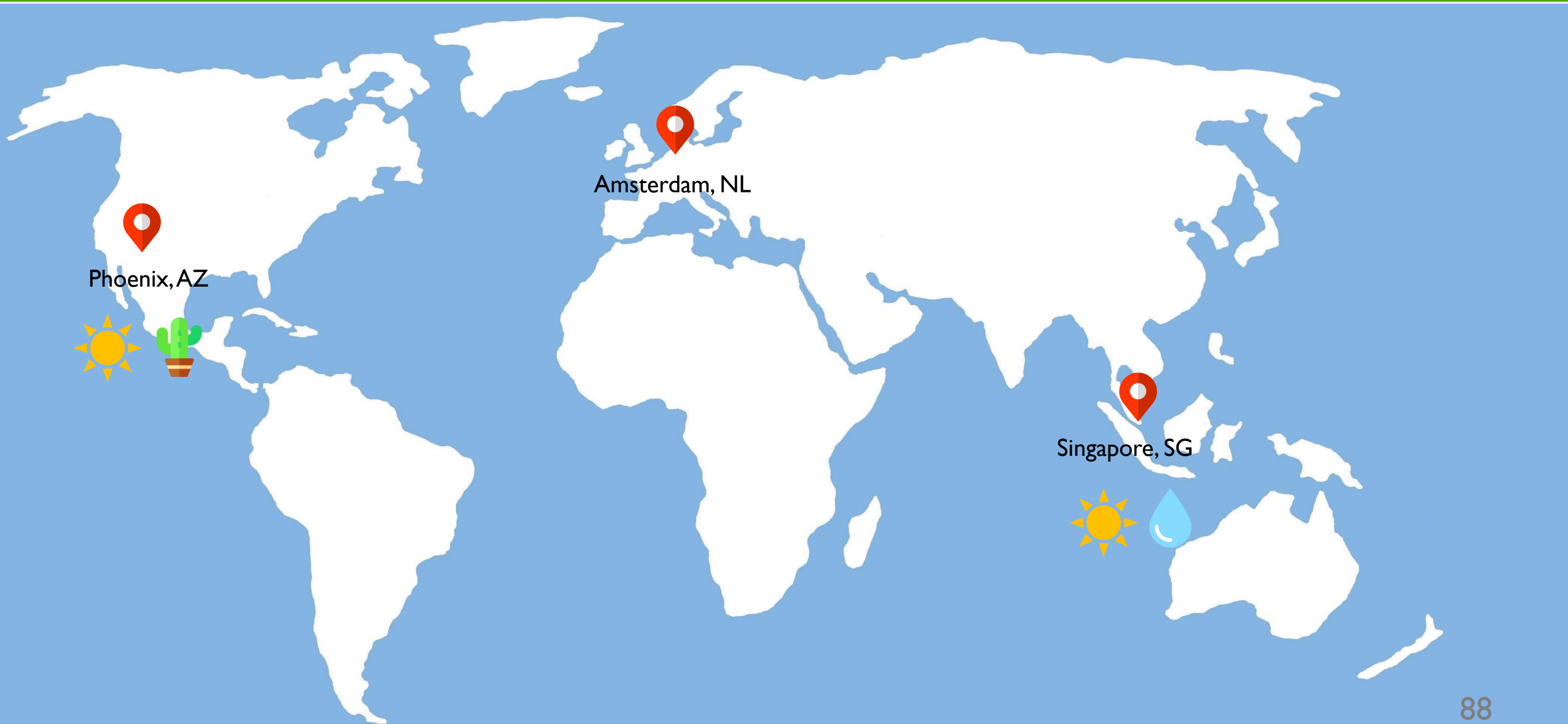
CLIMATE SELECTION



CLIMATE SELECTION



CLIMATE SELECTION



CLIMATE SELECTION



CLIMATE SELECTION



PART II – HEAT TRANSMISSION STUDY



CORRELATION FACTORS

CORRELATION FACTORS

Green Façades

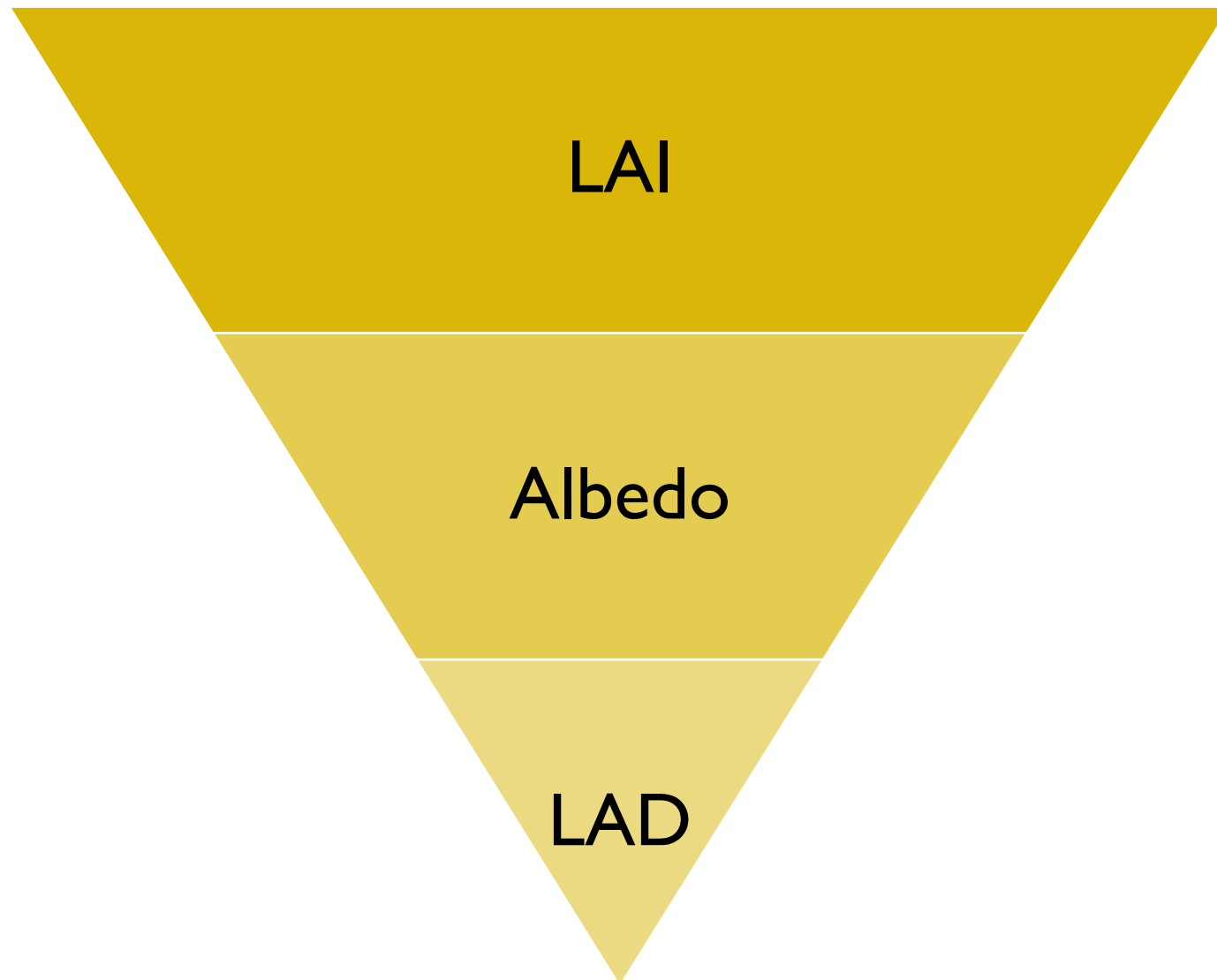
LAI

Albedo

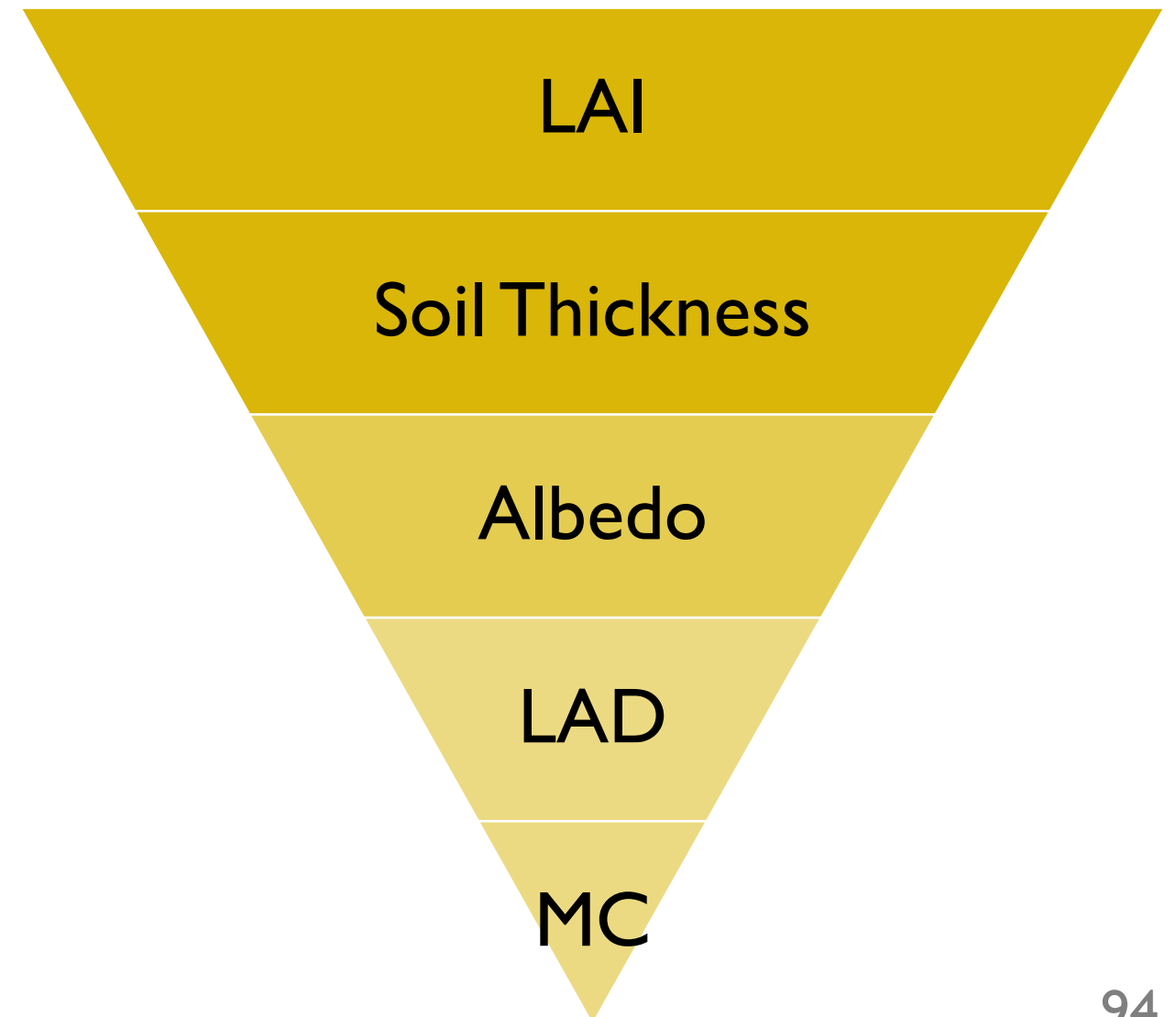
LAD

CORRELATION FACTORS

Green Façades

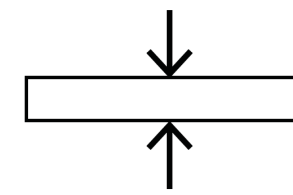


Living Wall Systems

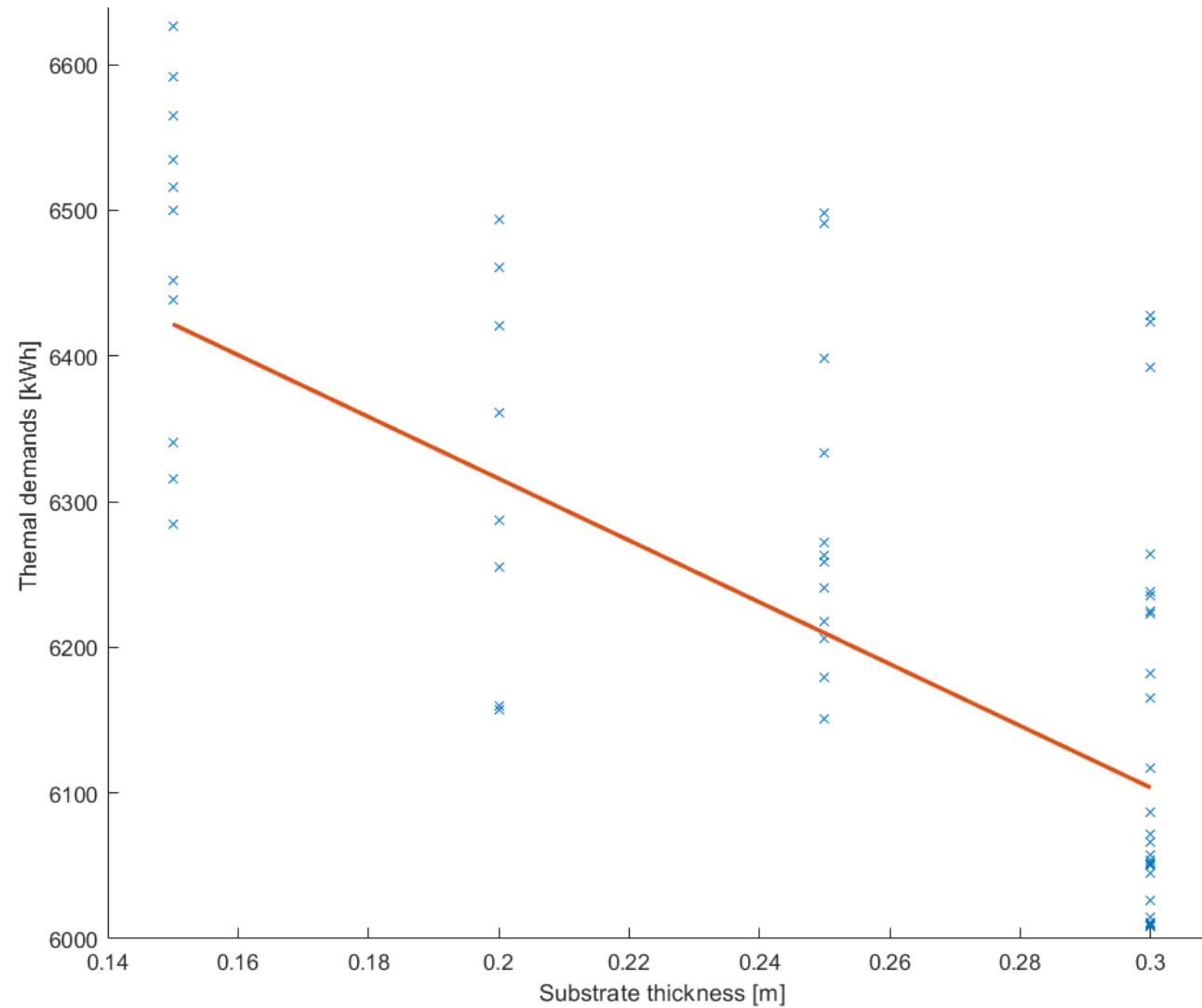


SUBSTRATE LAYER

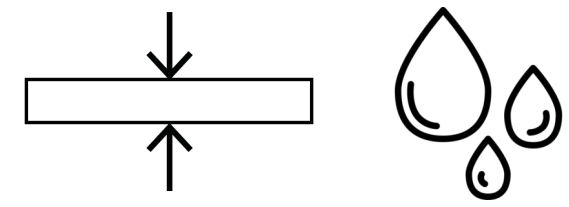
SUBSTRATE LAYER



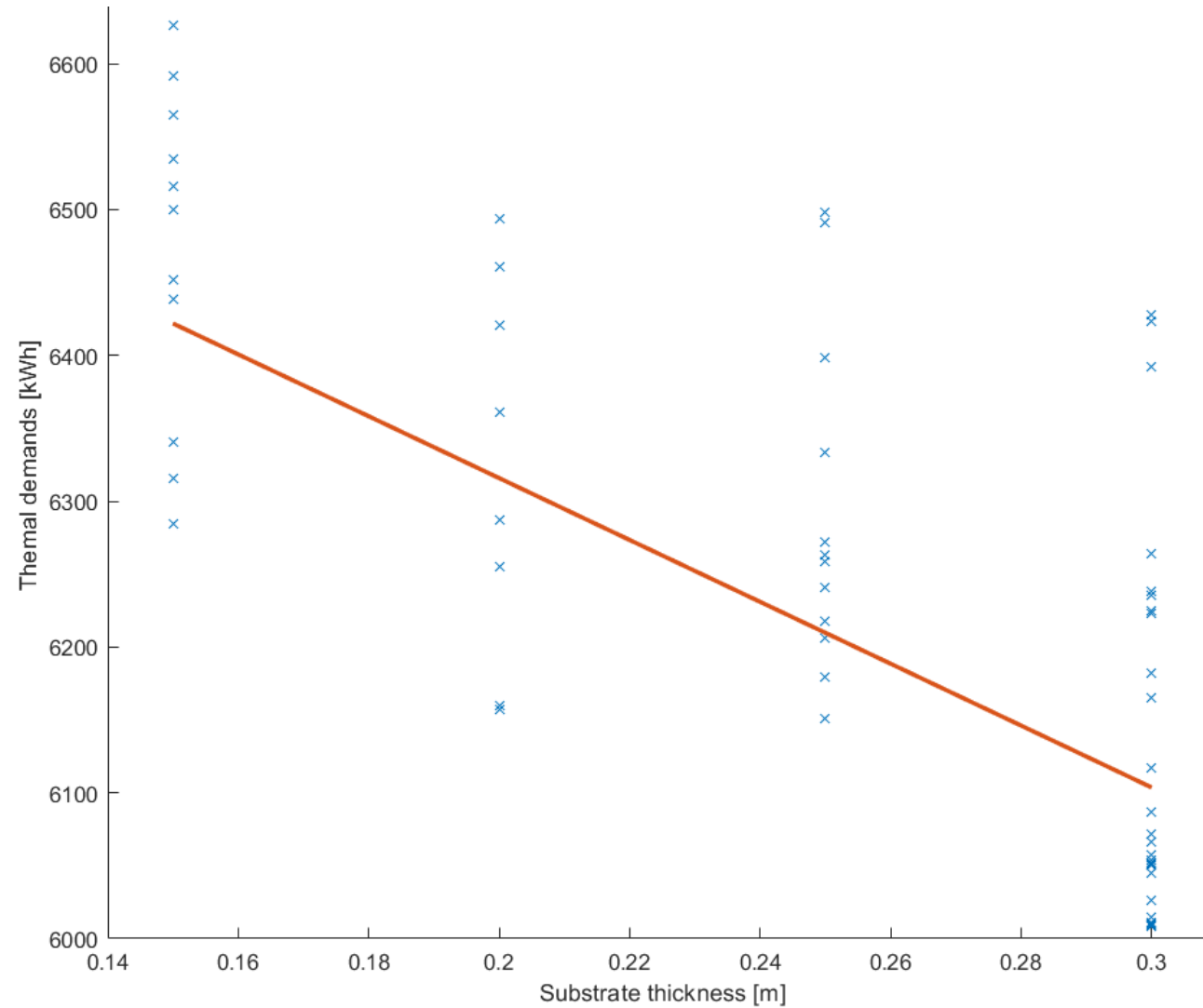
Substrate thickness



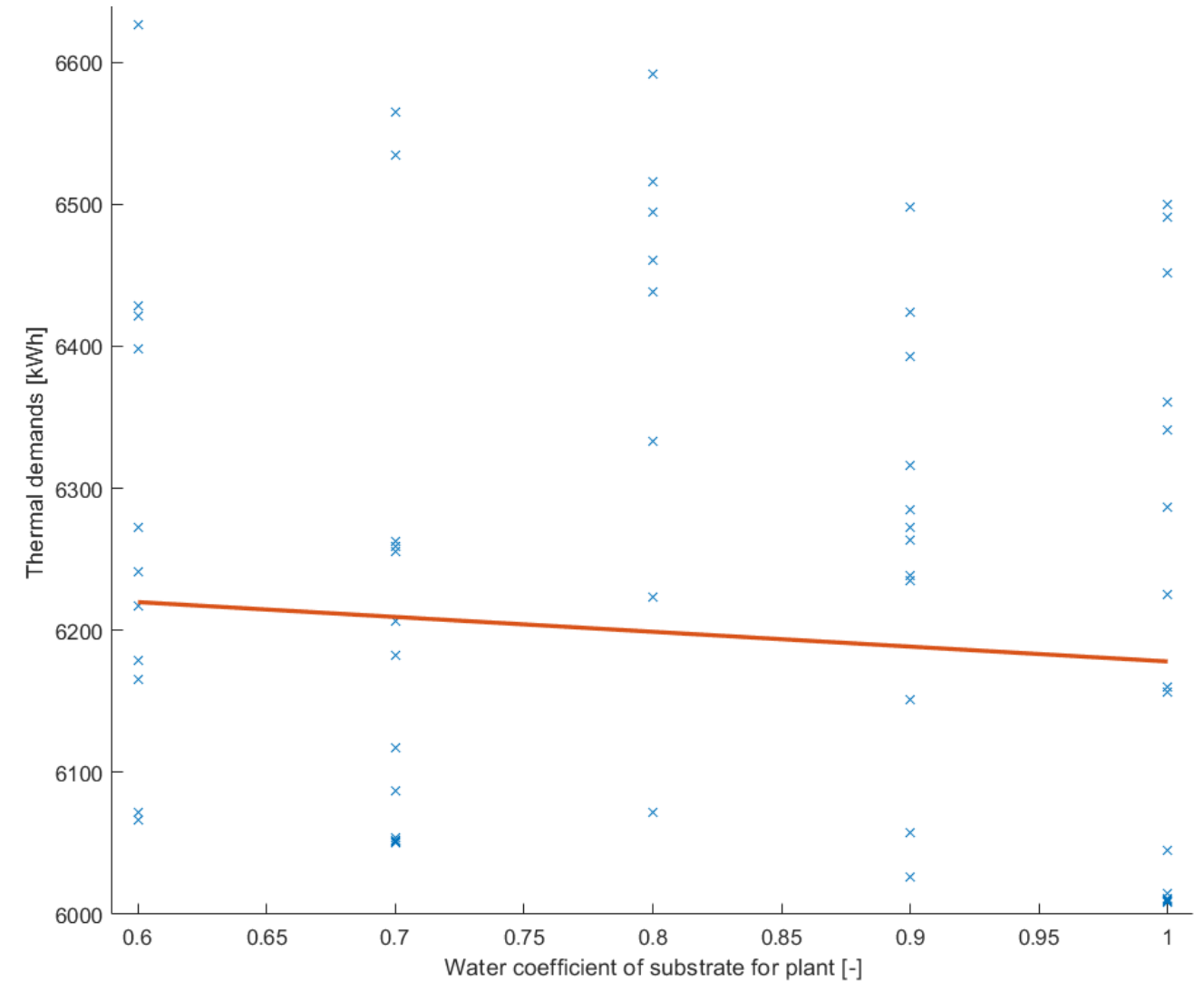
SUBSTRATE LAYER



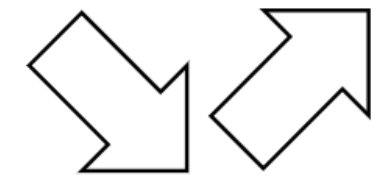
Substrate thickness



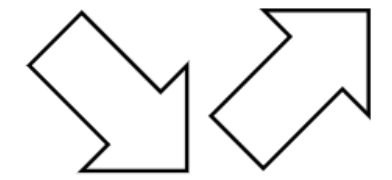
Moisture Content



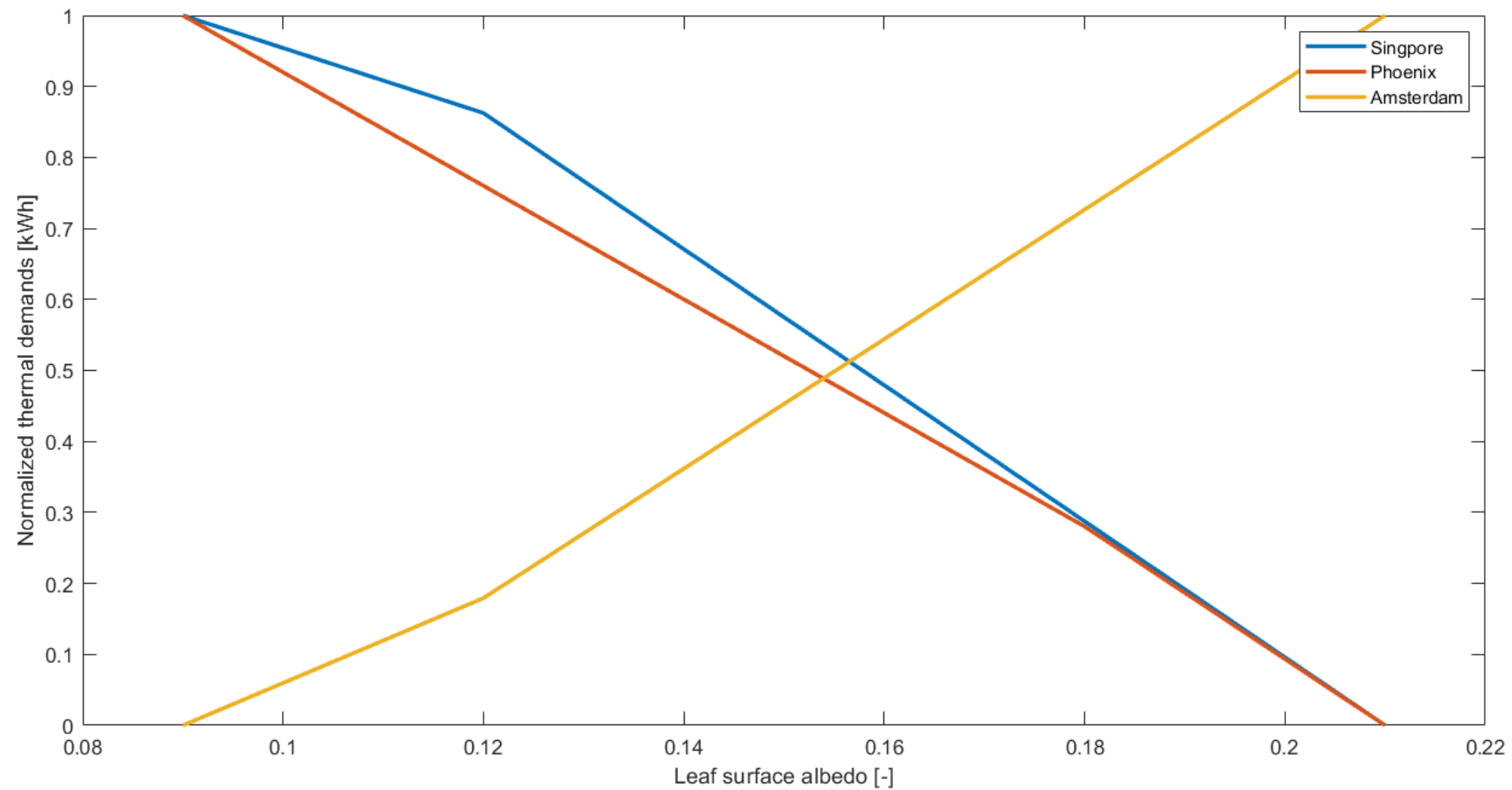
VEGETATION LAYER



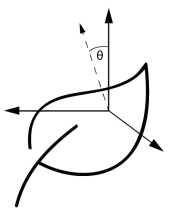
Leaf Surface Albedo



Leaf Surface Albedo

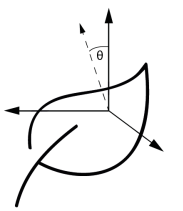


VEGETATION LAYER

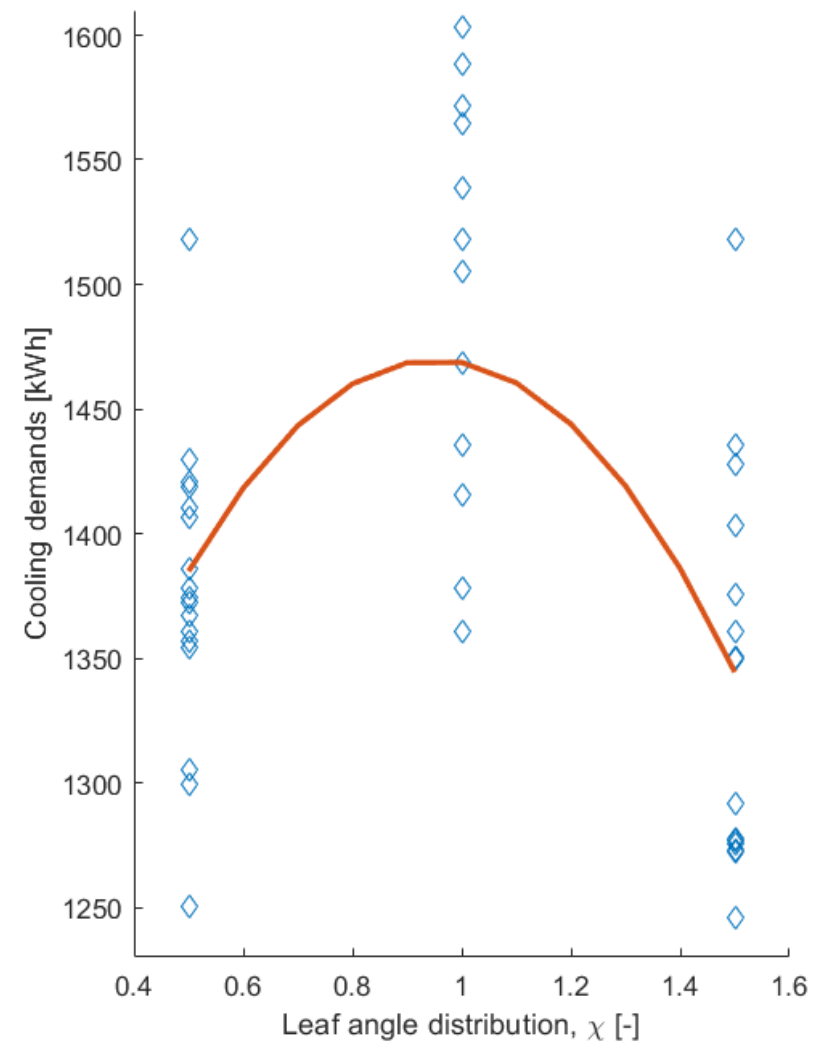


Leaf Angle Distribution

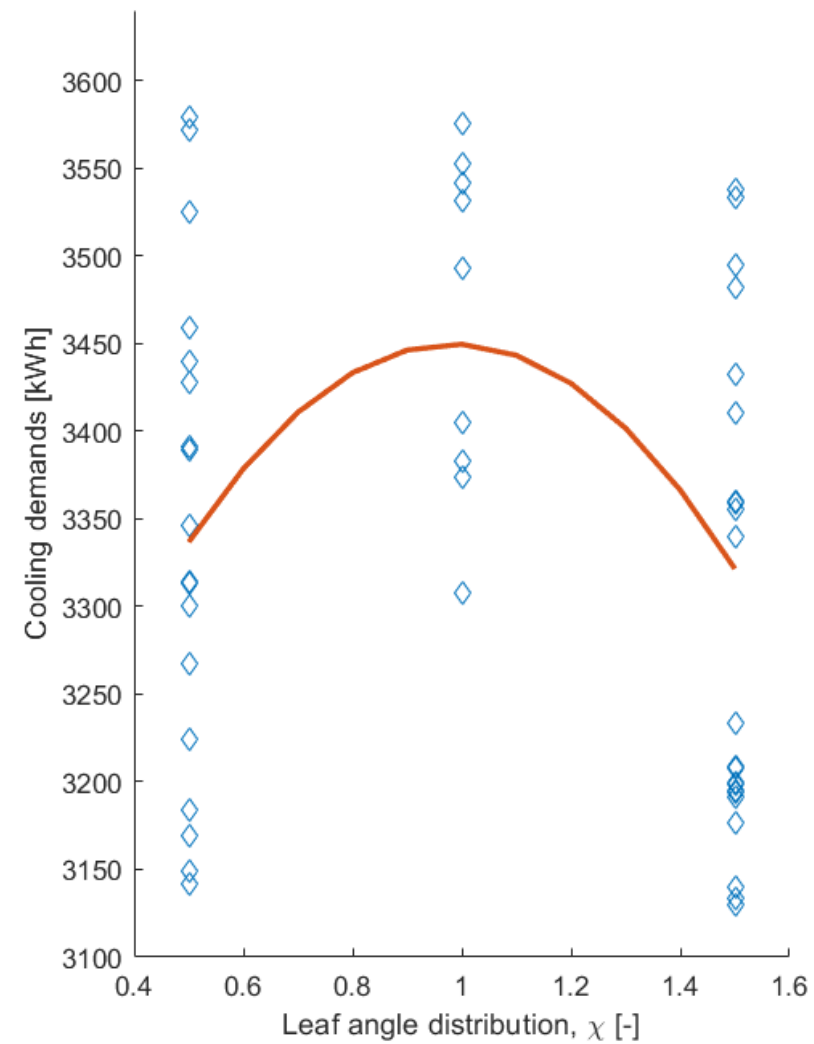
VEGETATION LAYER



Leaf Angle Distribution

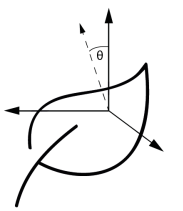


Singapore

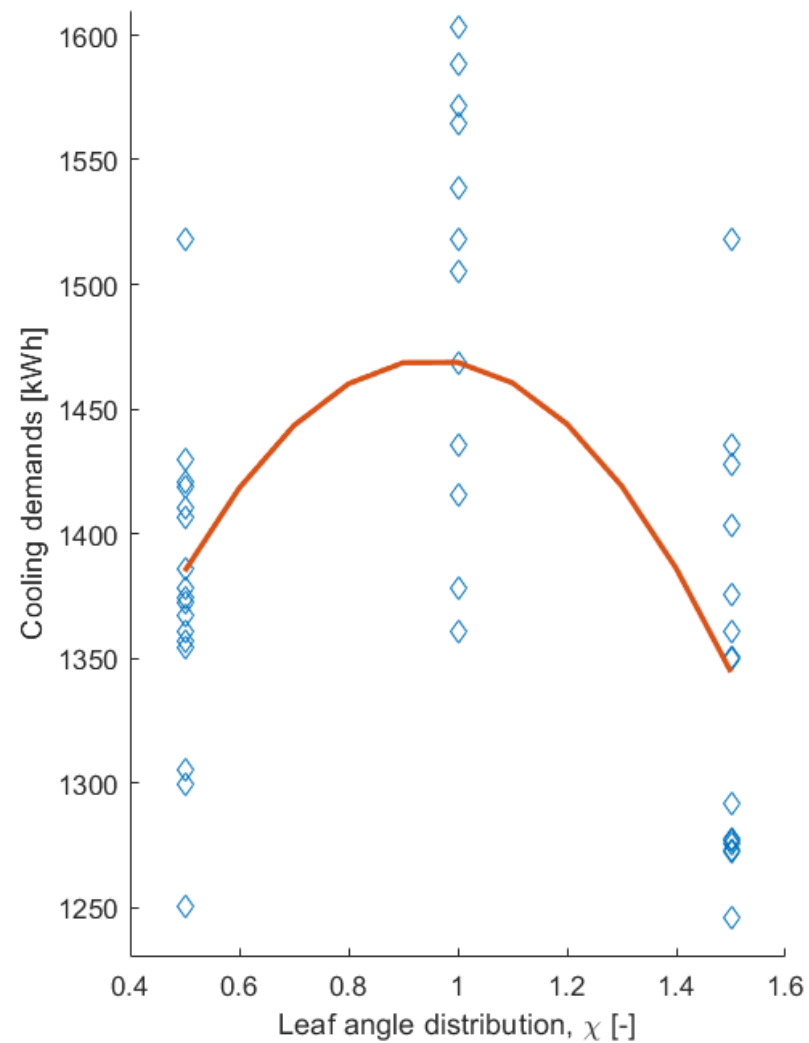


Phoenix

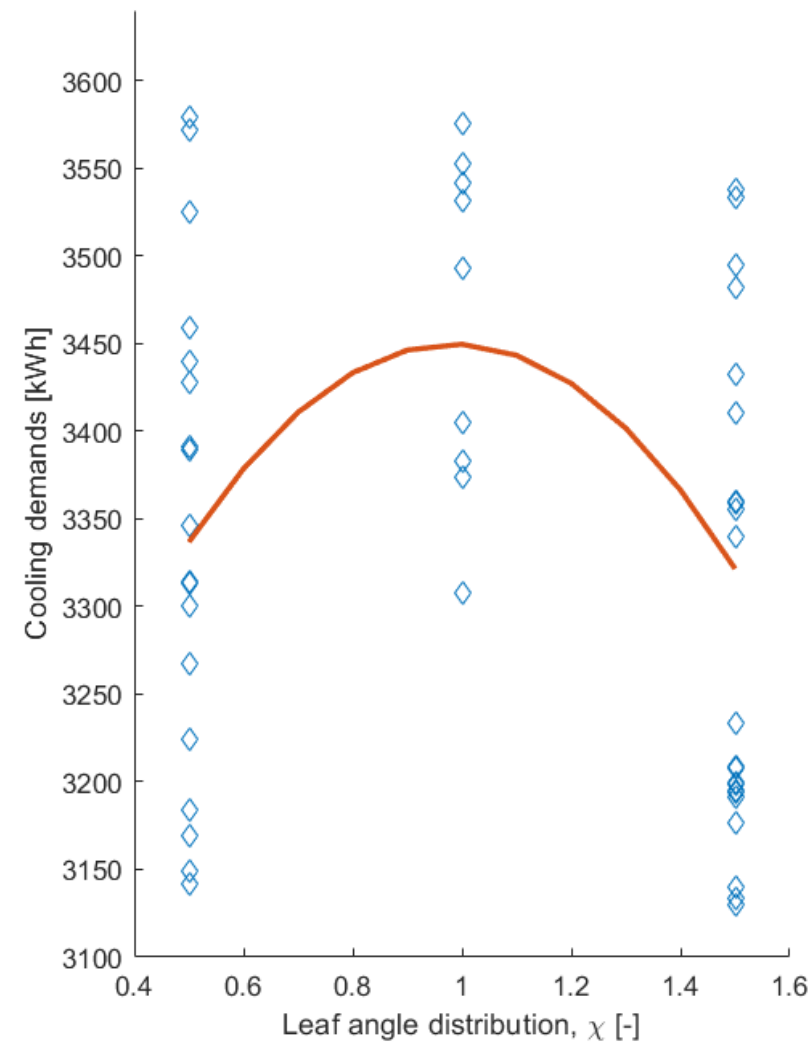
VEGETATION LAYER



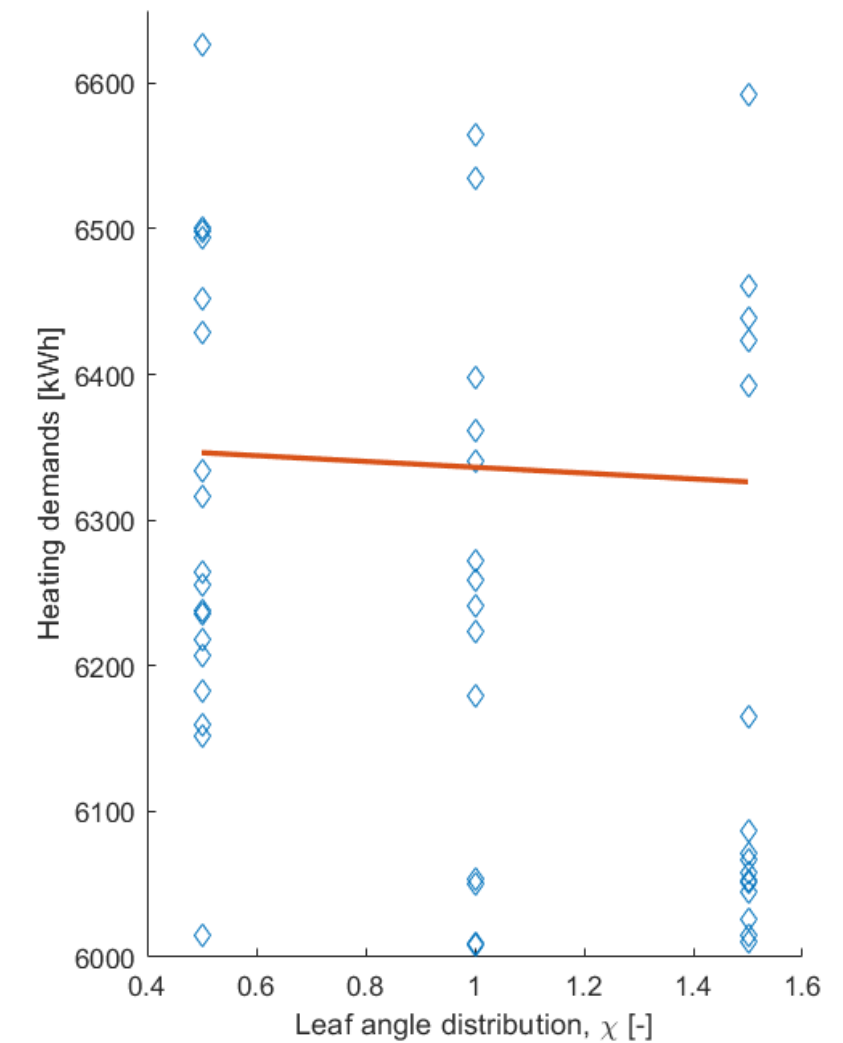
Leaf Angle Distribution



Singapore



Phoenix



Amsterdam

LEAF AREA INDEX



LEAF AREA INDEX

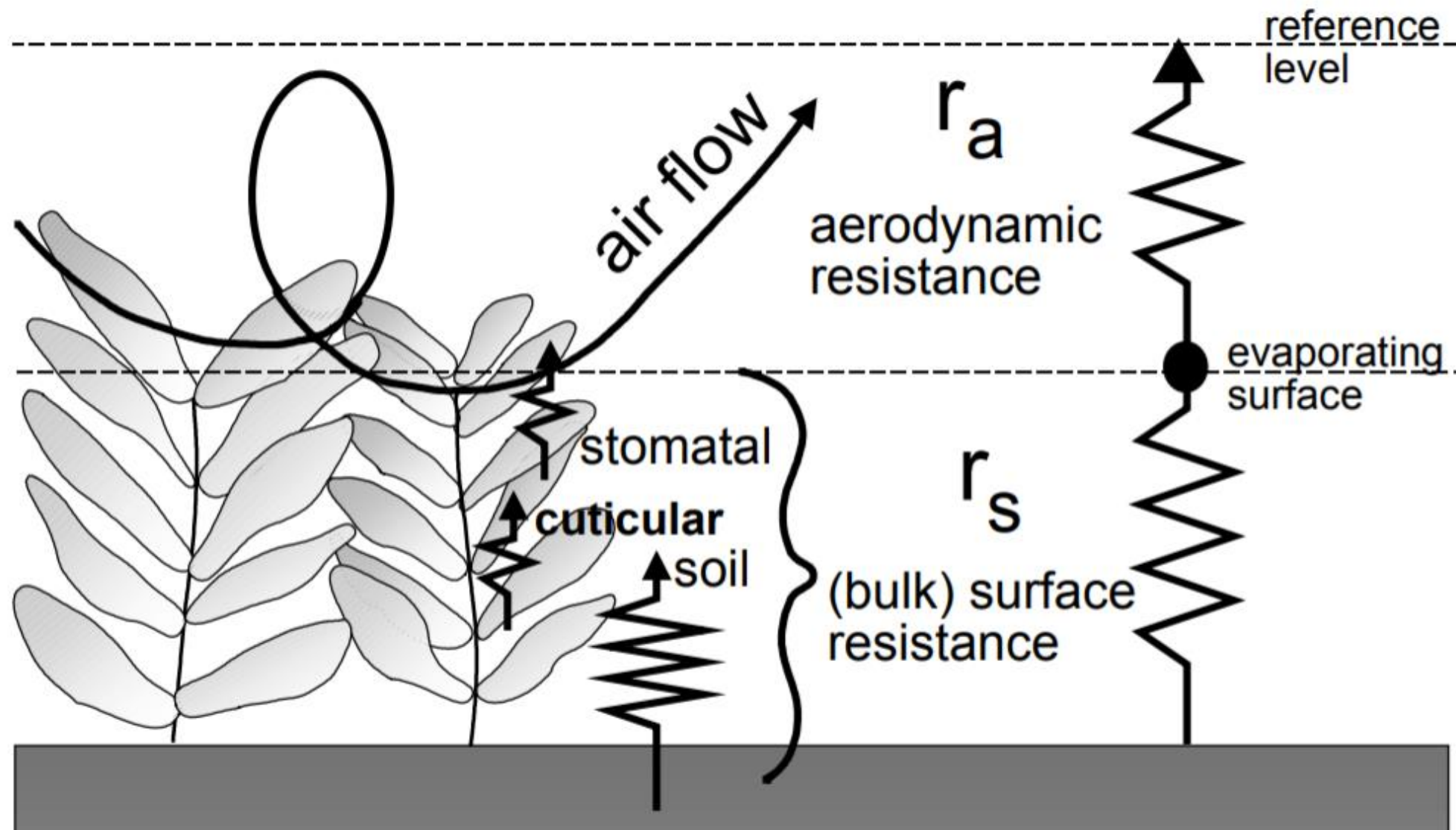


Evapotranspiration

LEAF AREA INDEX



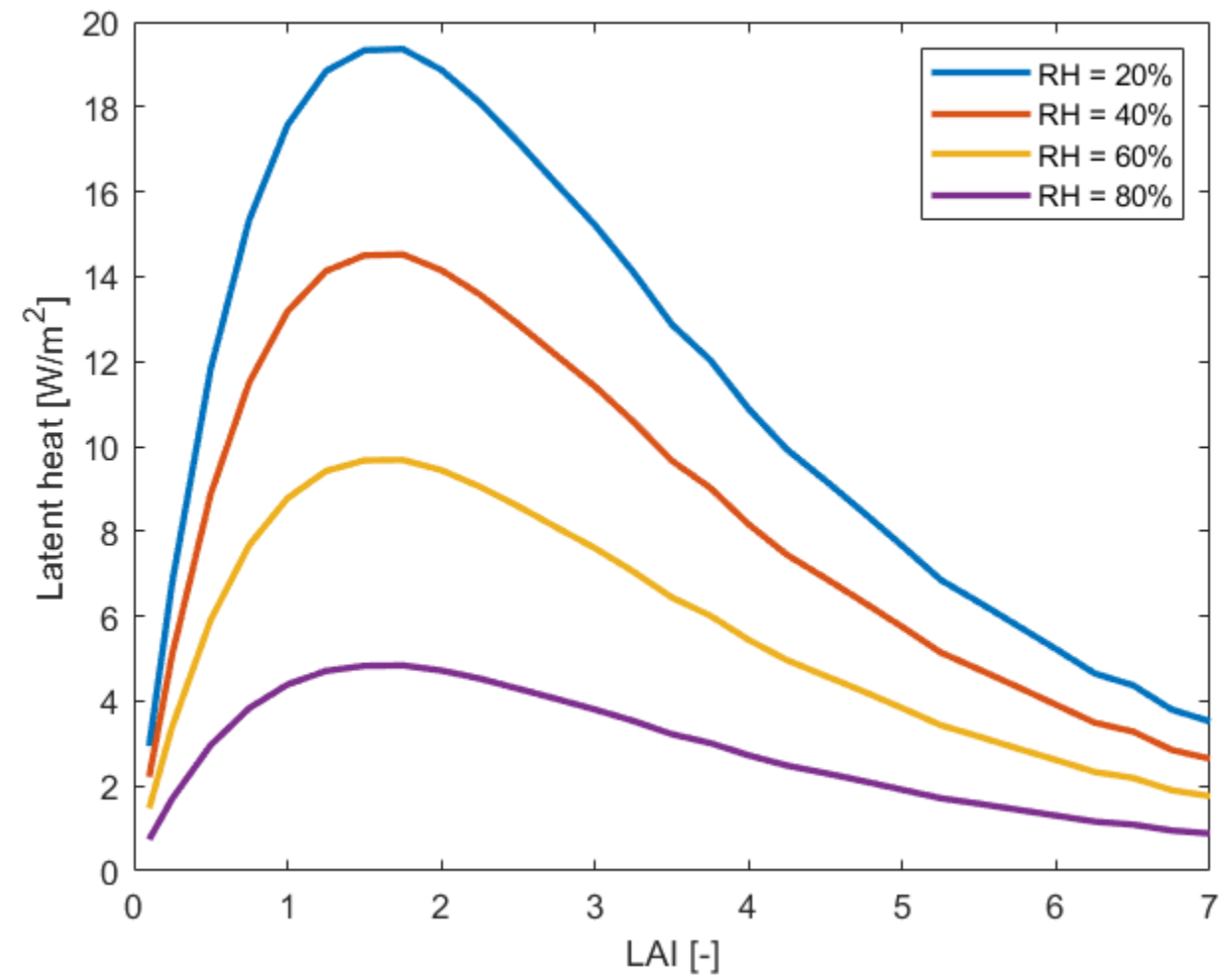
Evapotranspiration



LEAF AREA INDEX



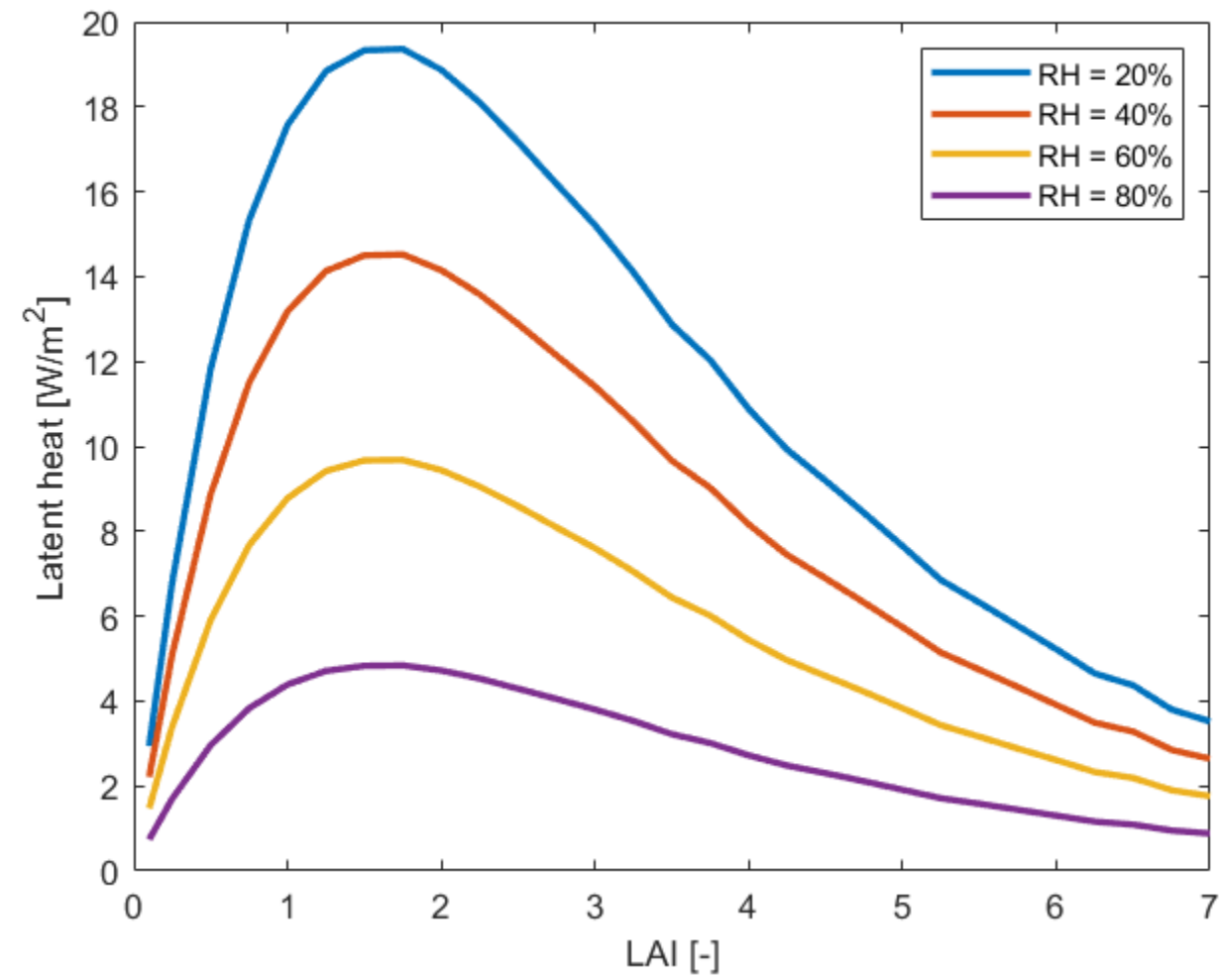
Relative Humidity



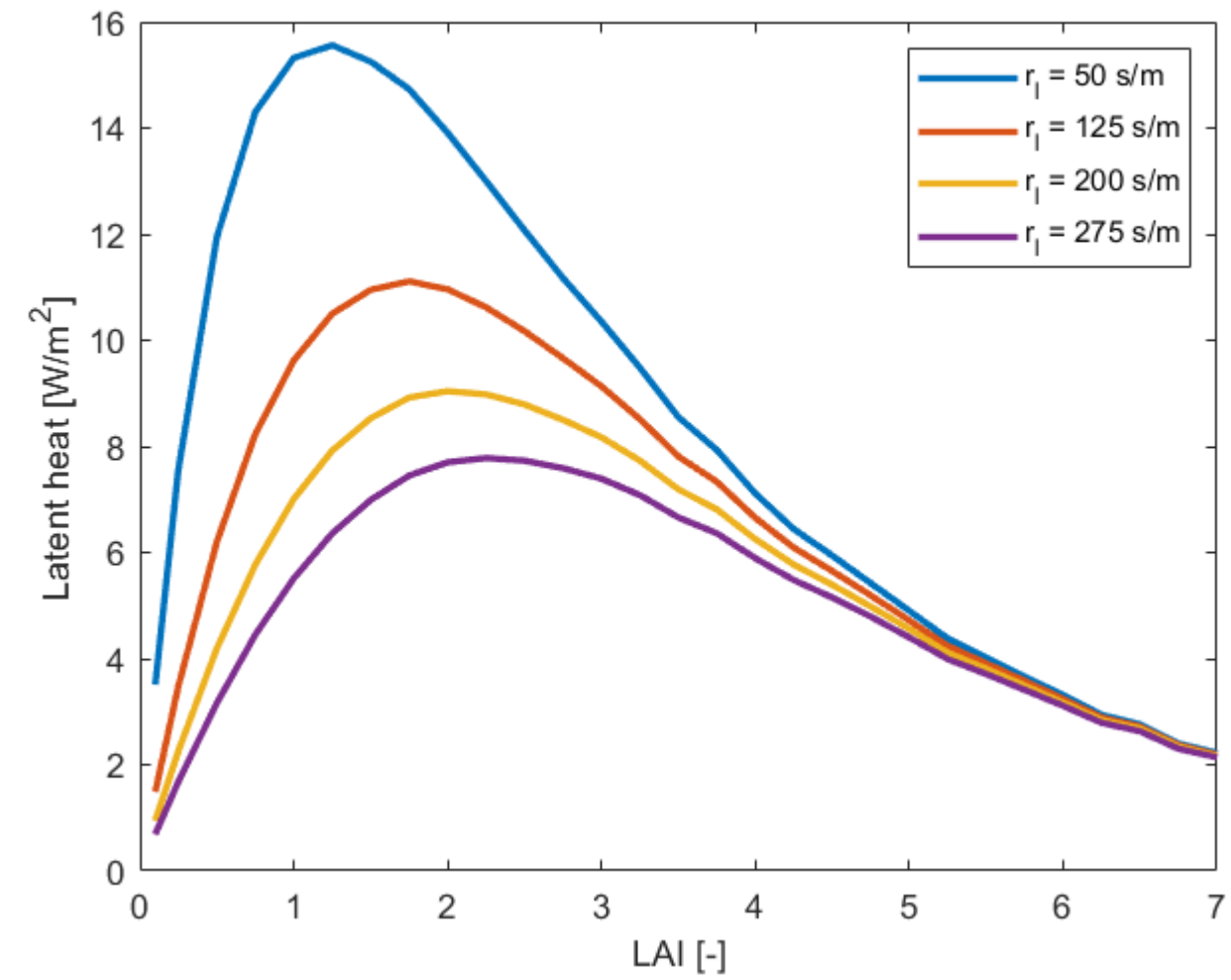
LEAF AREA INDEX



Relative Humidity



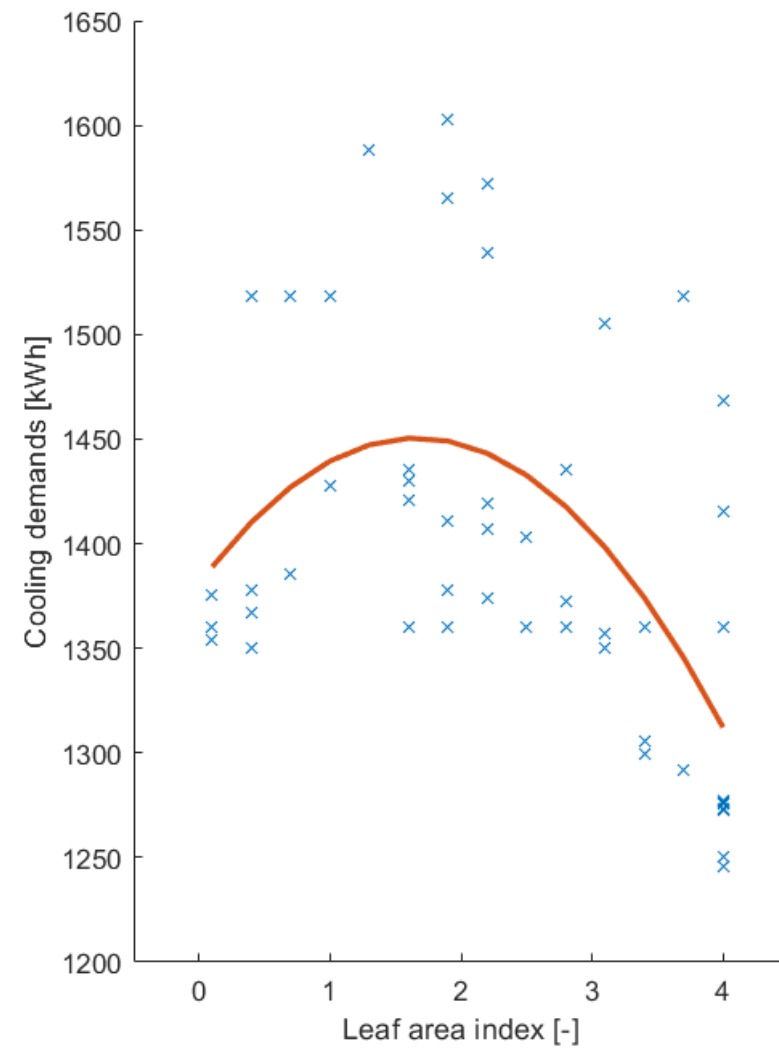
Stomatal Resistance



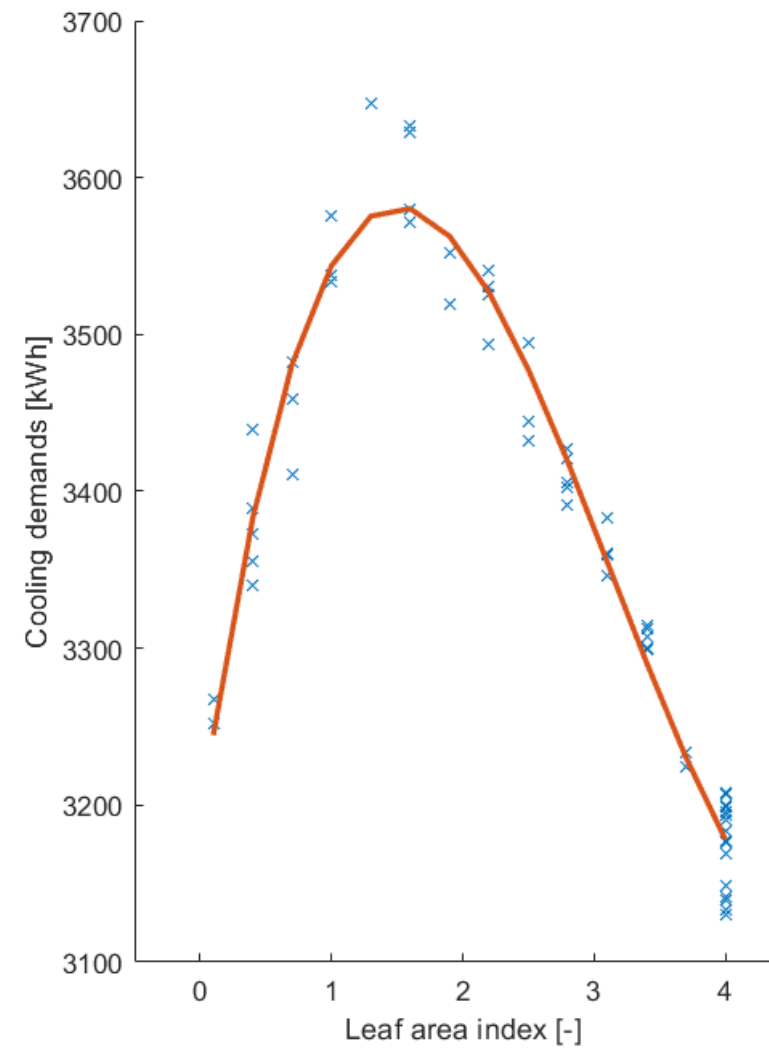
LEAF AREA INDEX



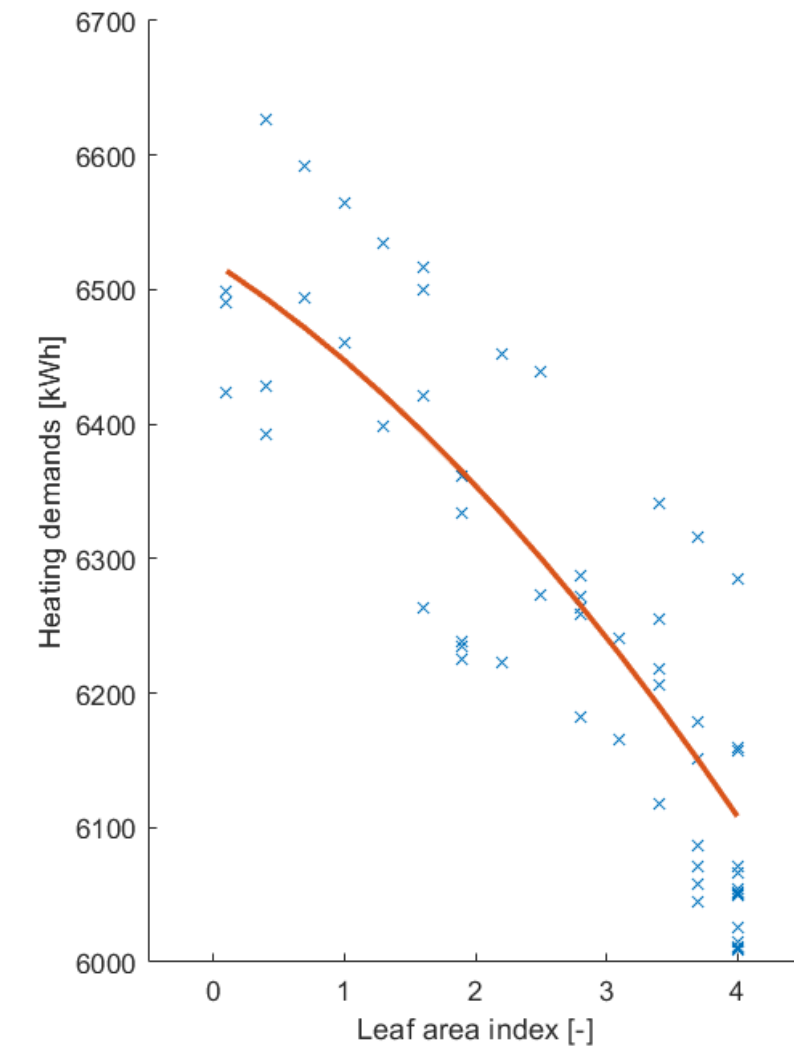
Living Wall System



Singapore



Phoenix

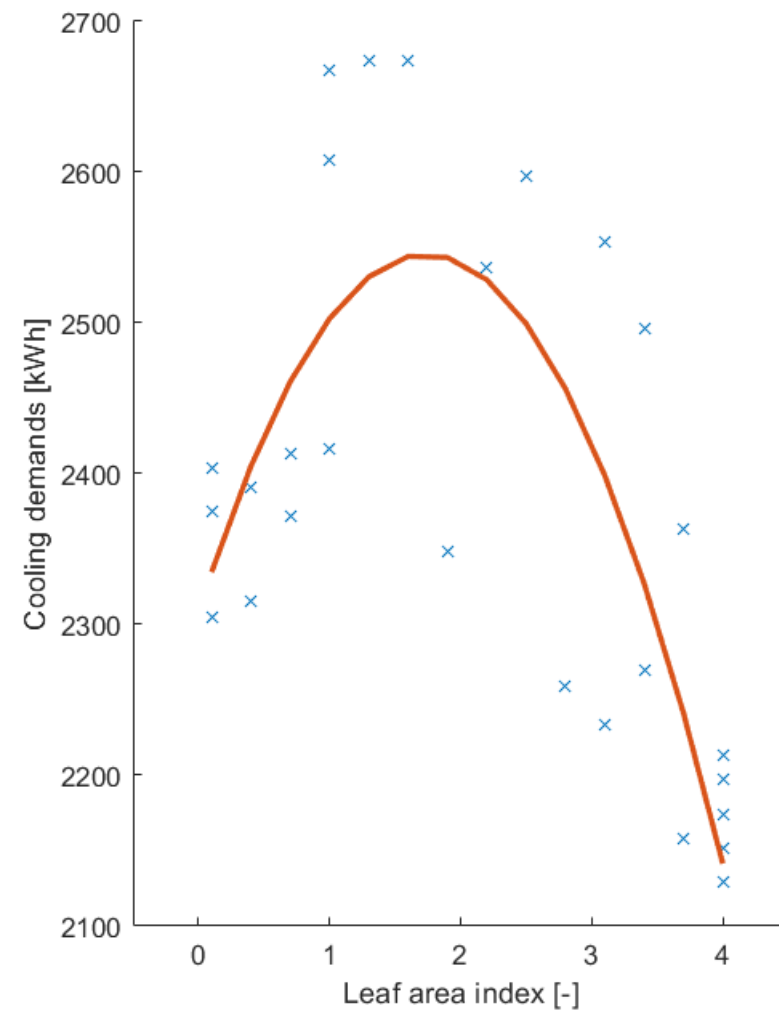


Amsterdam

LEAF AREA INDEX



Green Façade

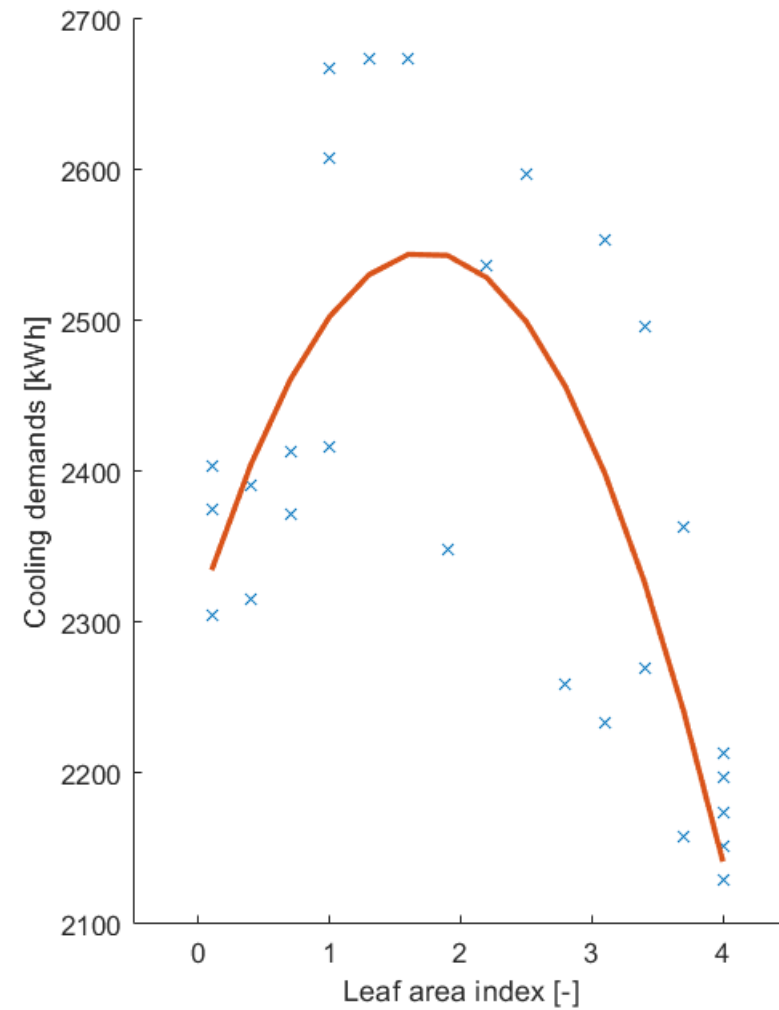


Singapore

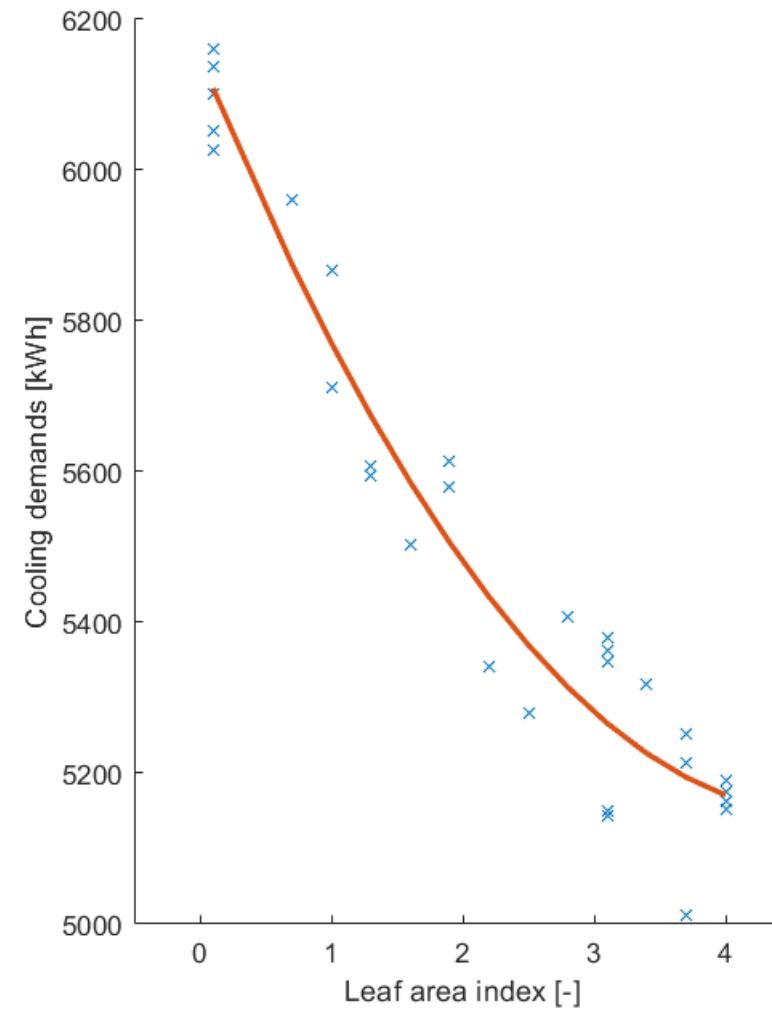
LEAF AREA INDEX



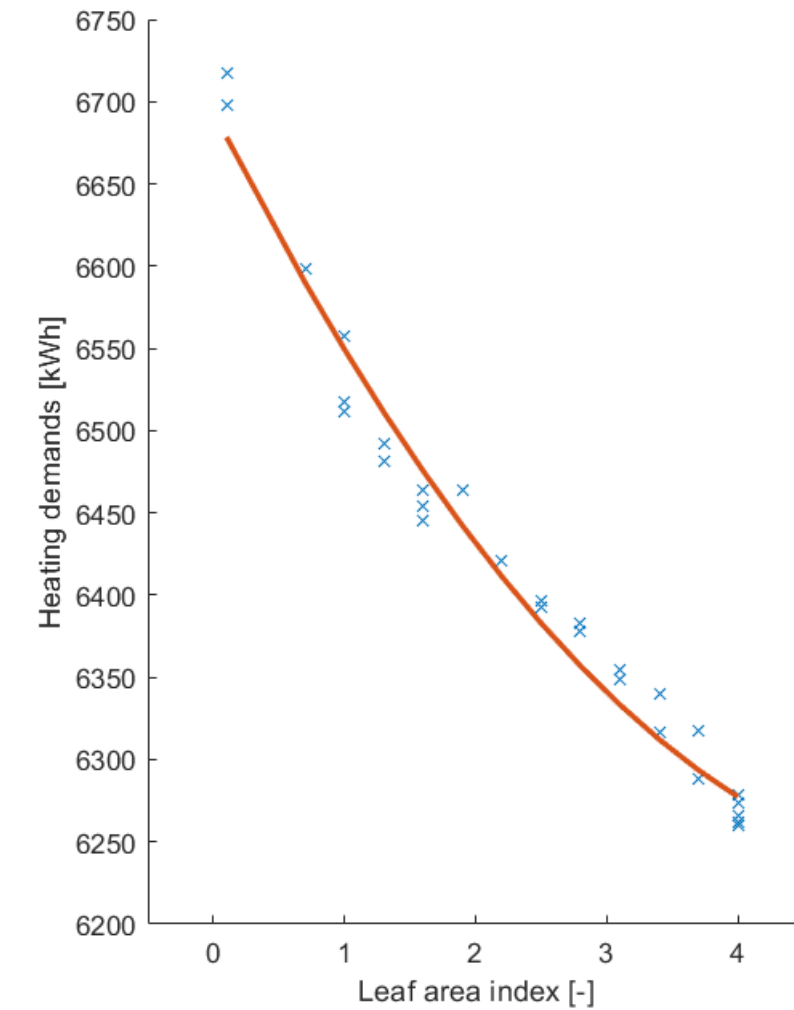
Green Façade



Singapore



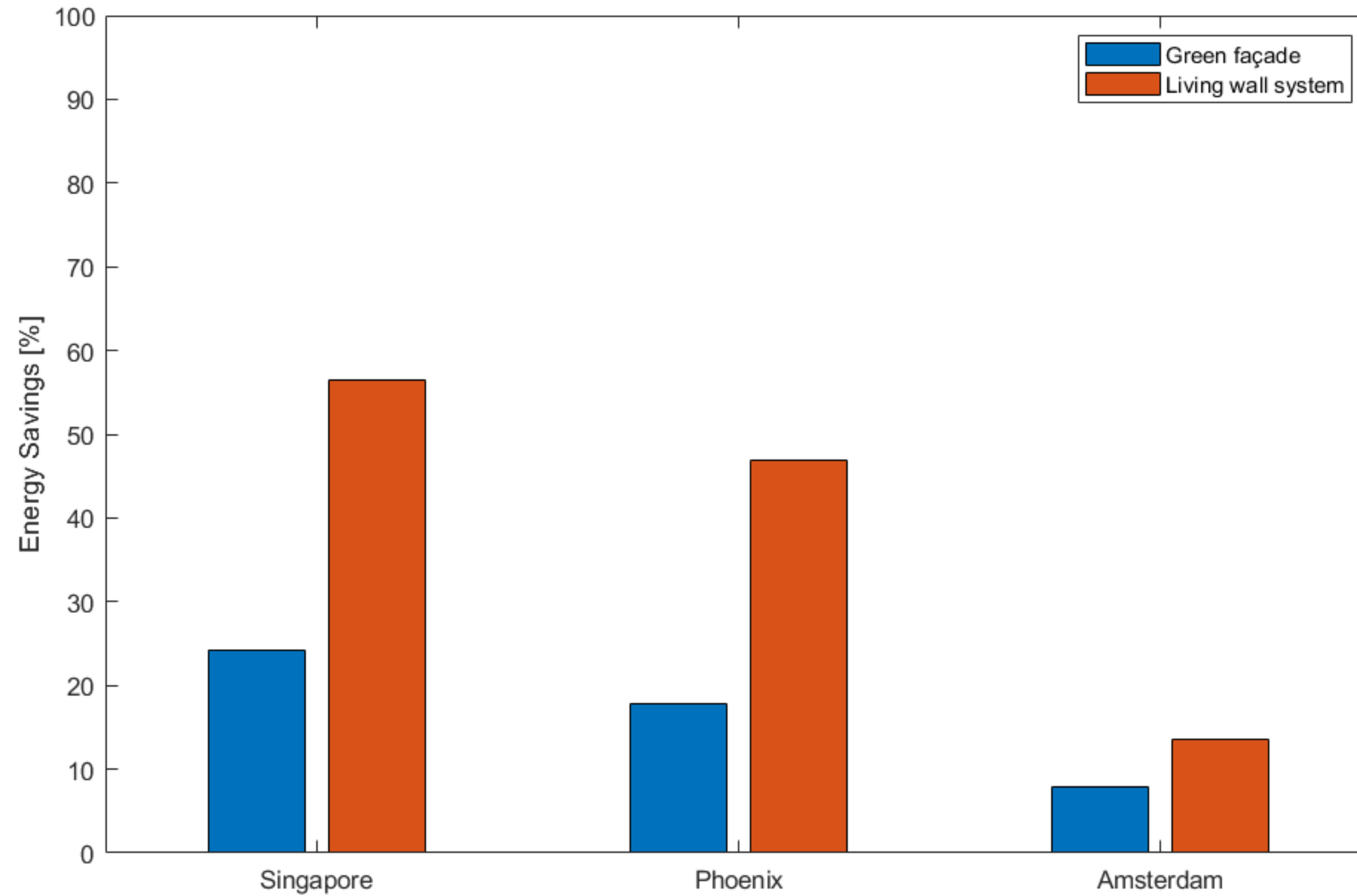
Phoenix



Amsterdam

ENERGY SAVINGS DUE TO TRANSMISSION

ENERGY SAVINGS DUE TO TRANSMISSION



PART III – URBAN EFFECTS



URBAN EFFECTS

URBAN EFFECTS

I Wind speed

URBAN EFFECTS

I Wind speed

II Ambient temperature

URBAN EFFECTS

I Wind speed

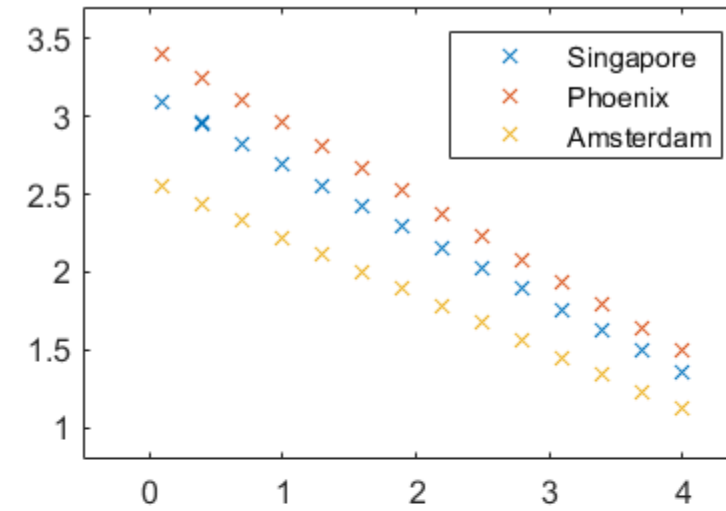
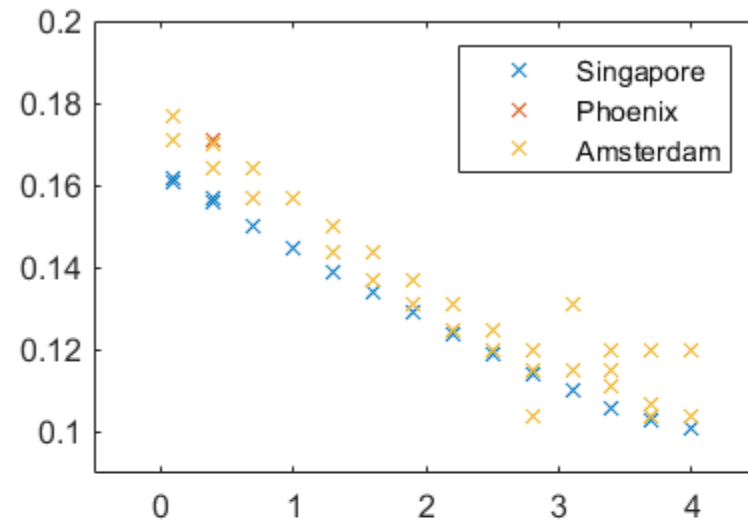
II Ambient temperature

III Incoming short-wave radiation

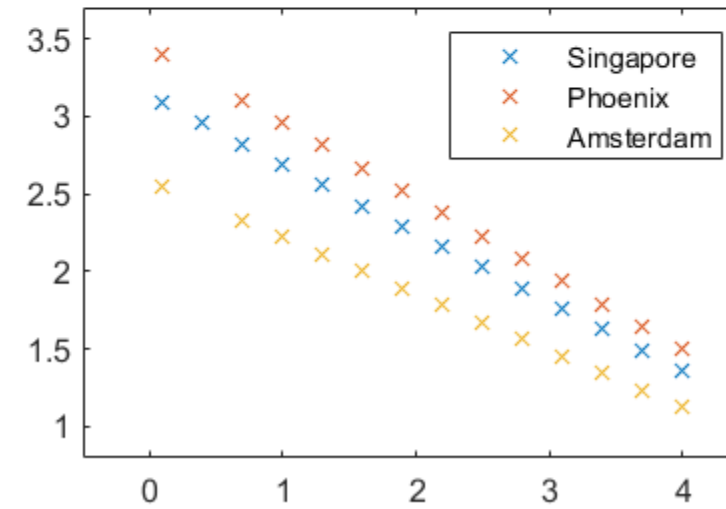
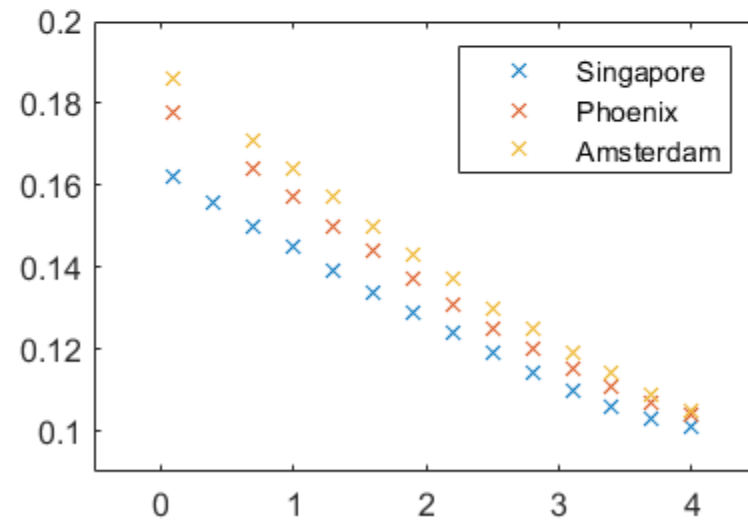
WIND SPEED

WIND SPEED

*Living Wall
System*



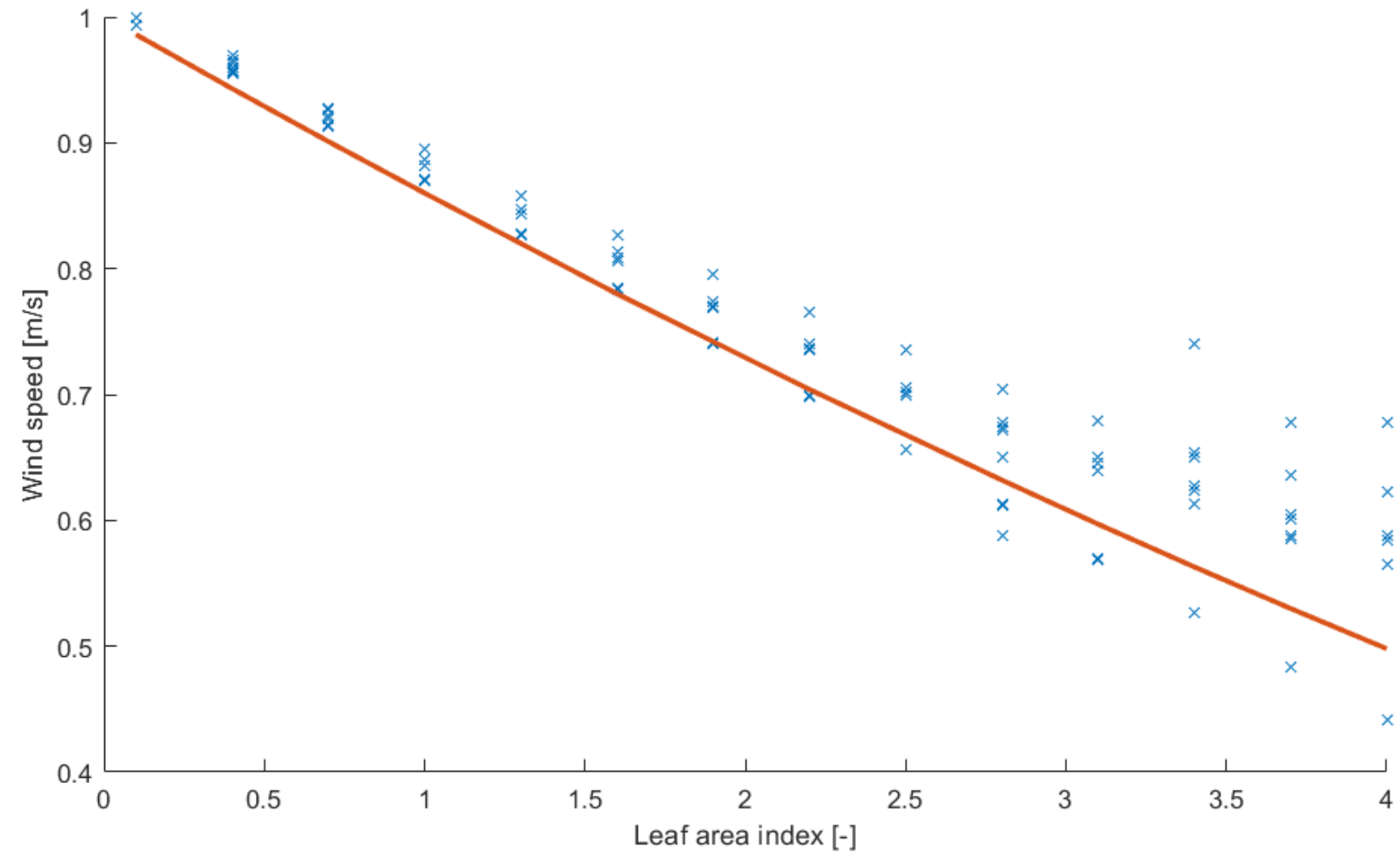
Green Façade



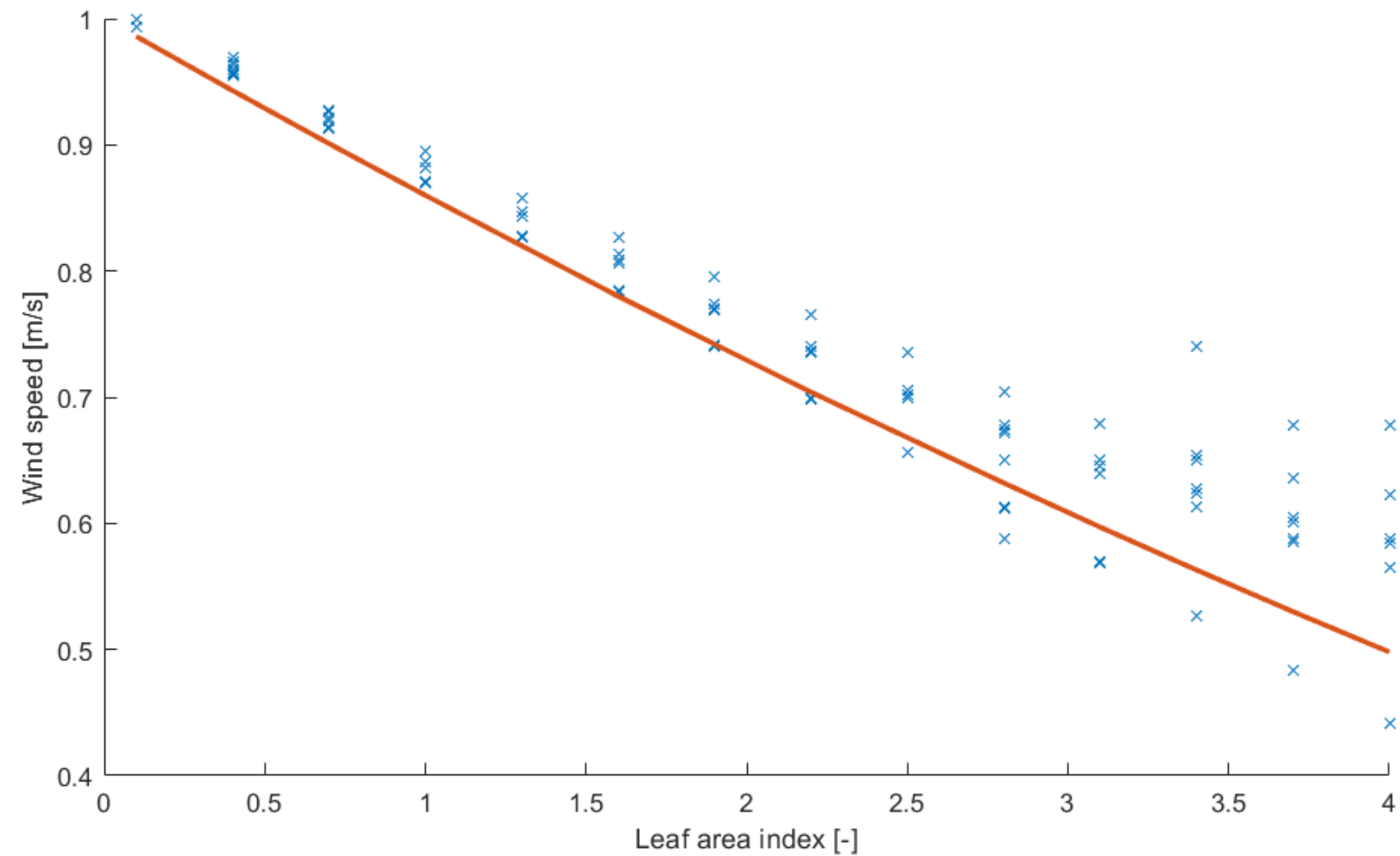
South

West

WIND SPEED

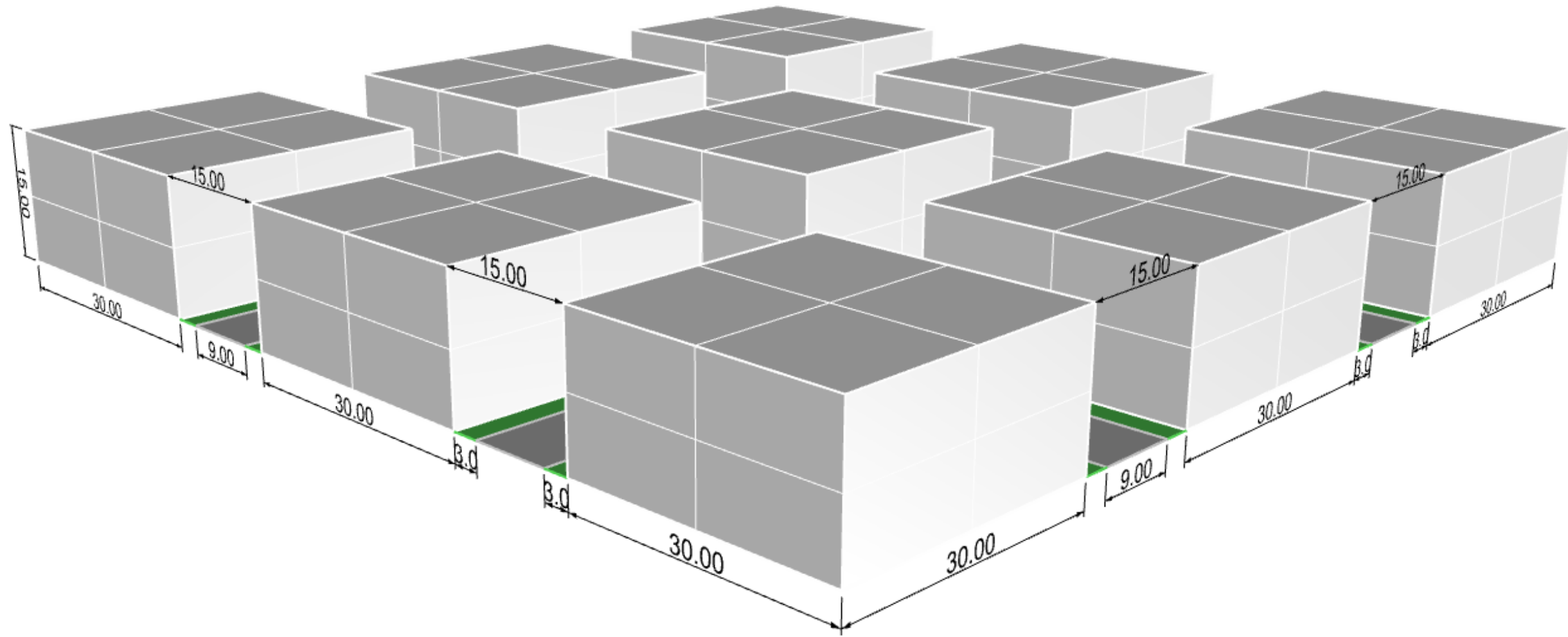


WIND SPEED

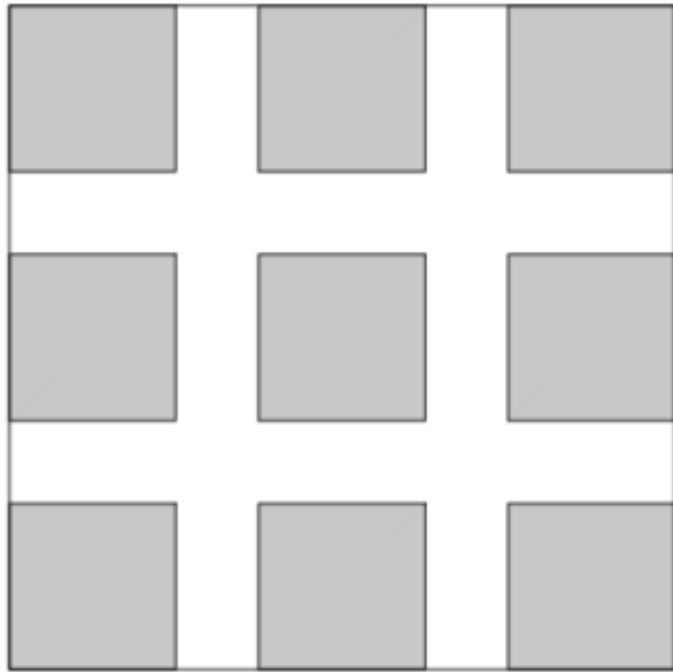


$$V_w = V_0 * (0.0049 * LAI^2 - 0.1451 * LAI + 1)$$

AMBIENT TEMPERATURE

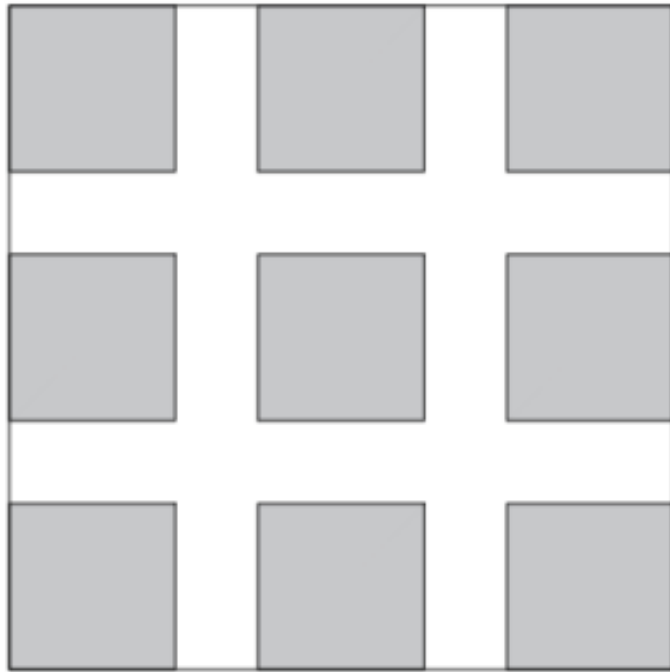


AMBIENT TEMPERATURE

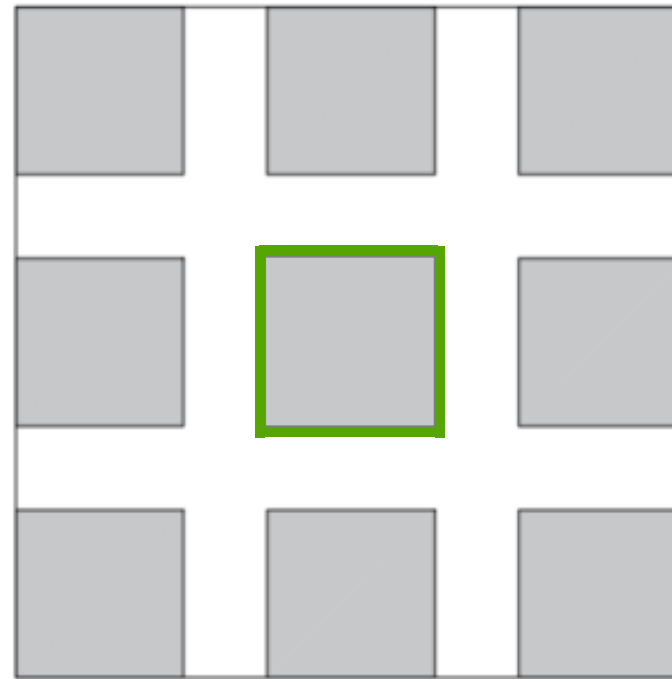


*Case A: Reference
scenario*

AMBIENT TEMPERATURE

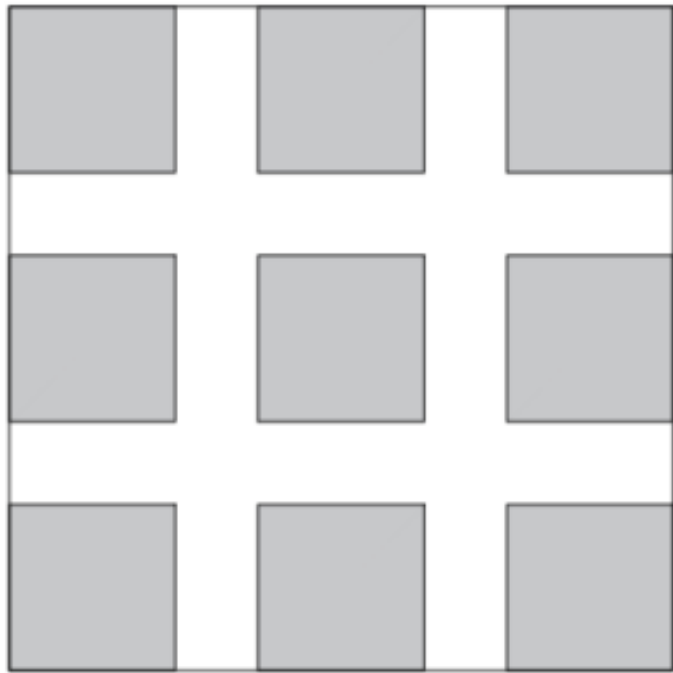


*Case A: Reference
scenario*

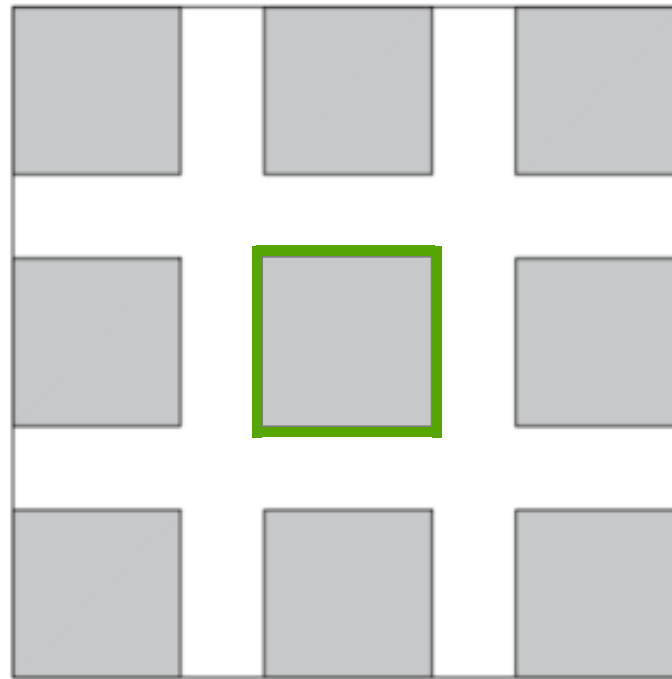


*Case B: Single green
building*

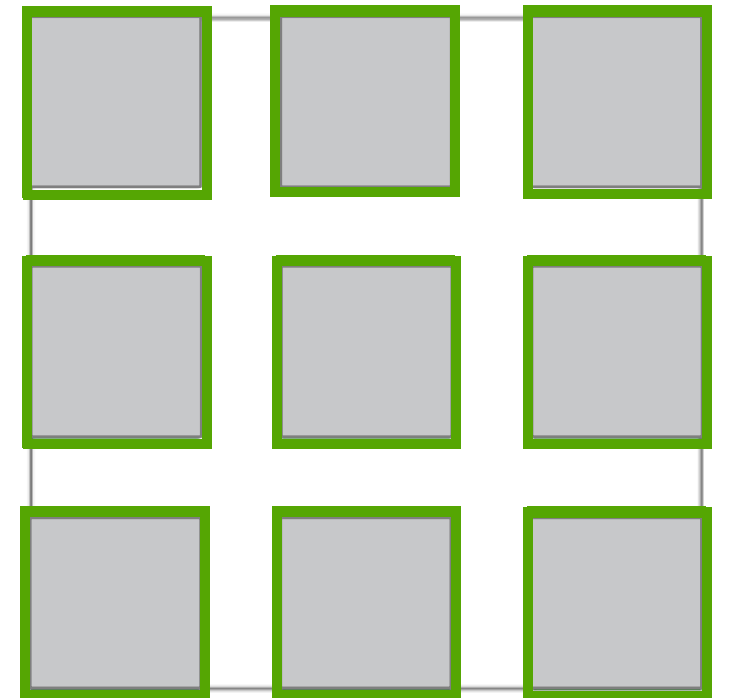
AMBIENT TEMPERATURE



*Case A: Reference
scenario*



*Case B: Single green
building*



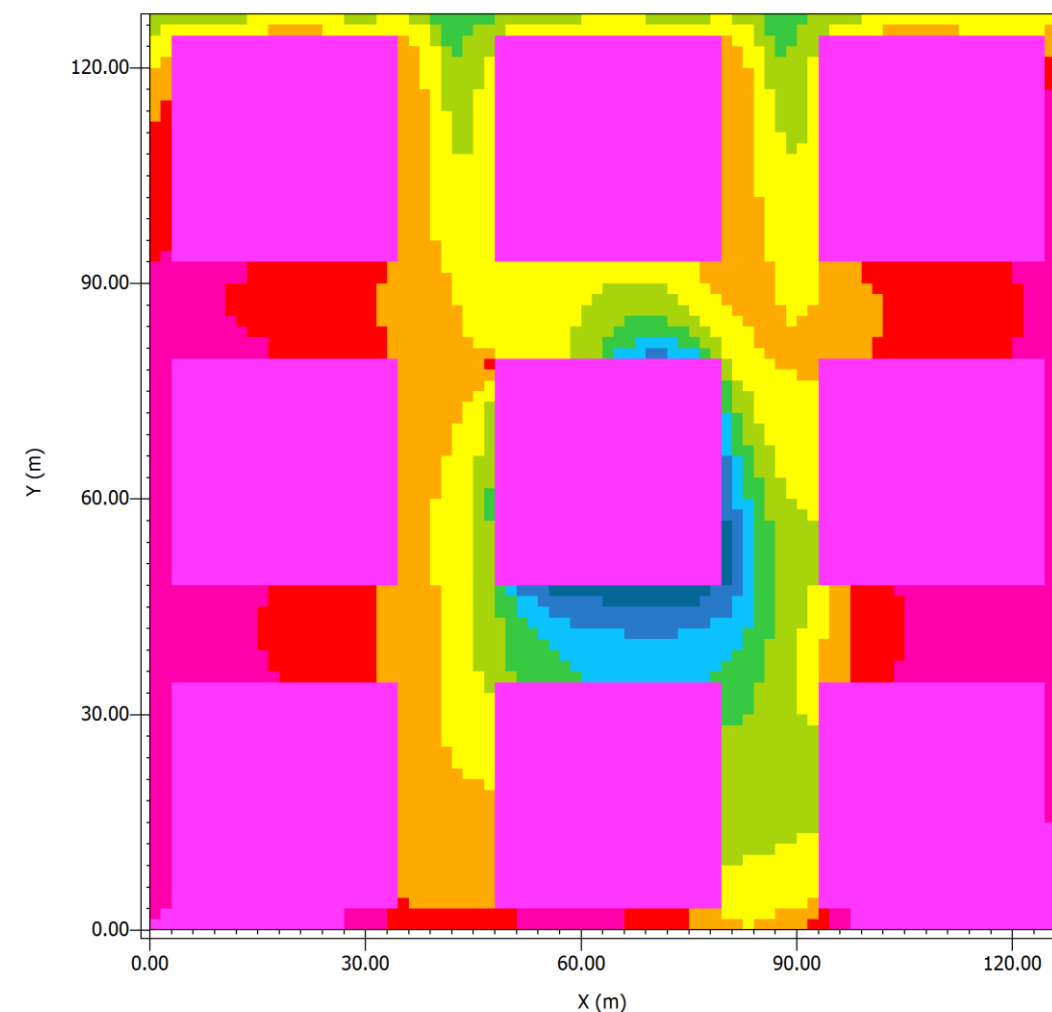
*Case C: Full green
environment*

AMBIENT TEMPERATURE

Singapore & Phoenix

AMBIENT TEMPERATURE

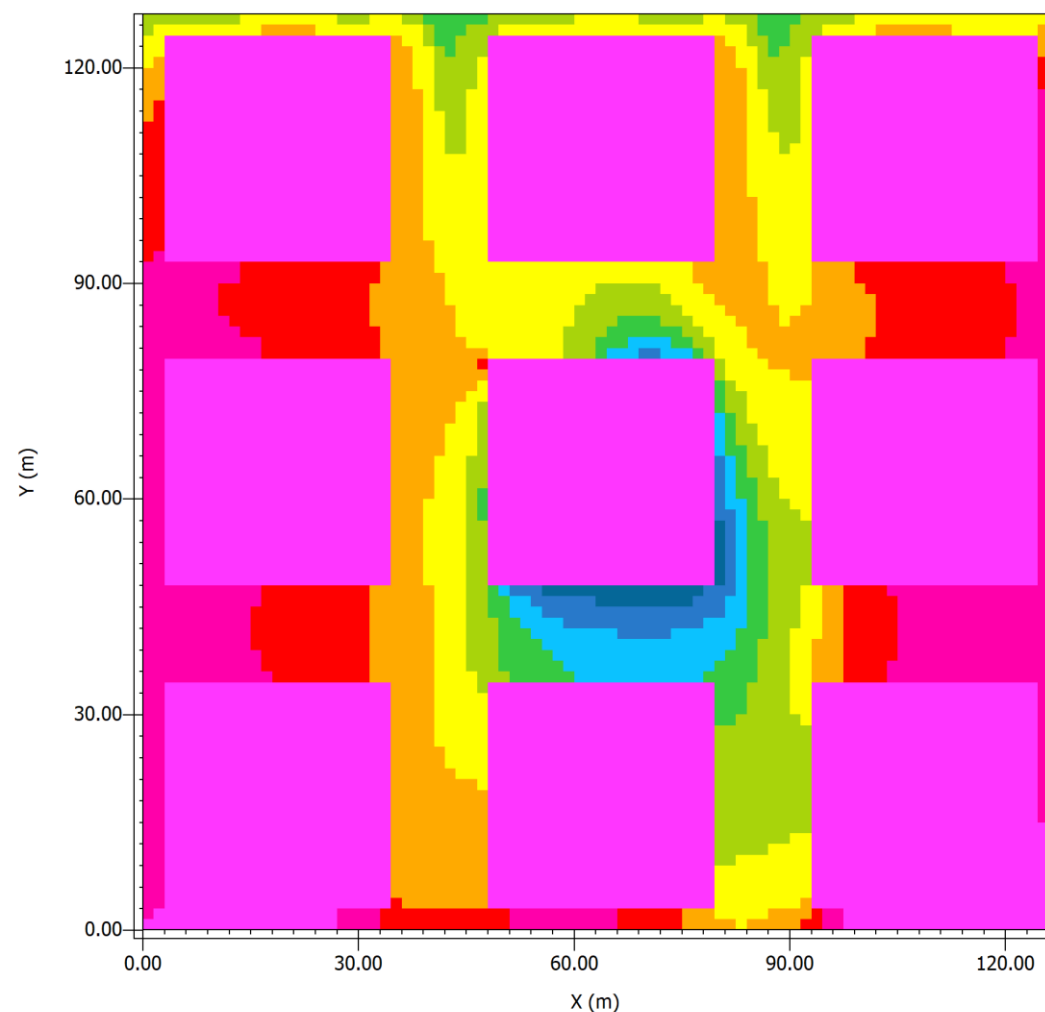
Singapore & Phoenix



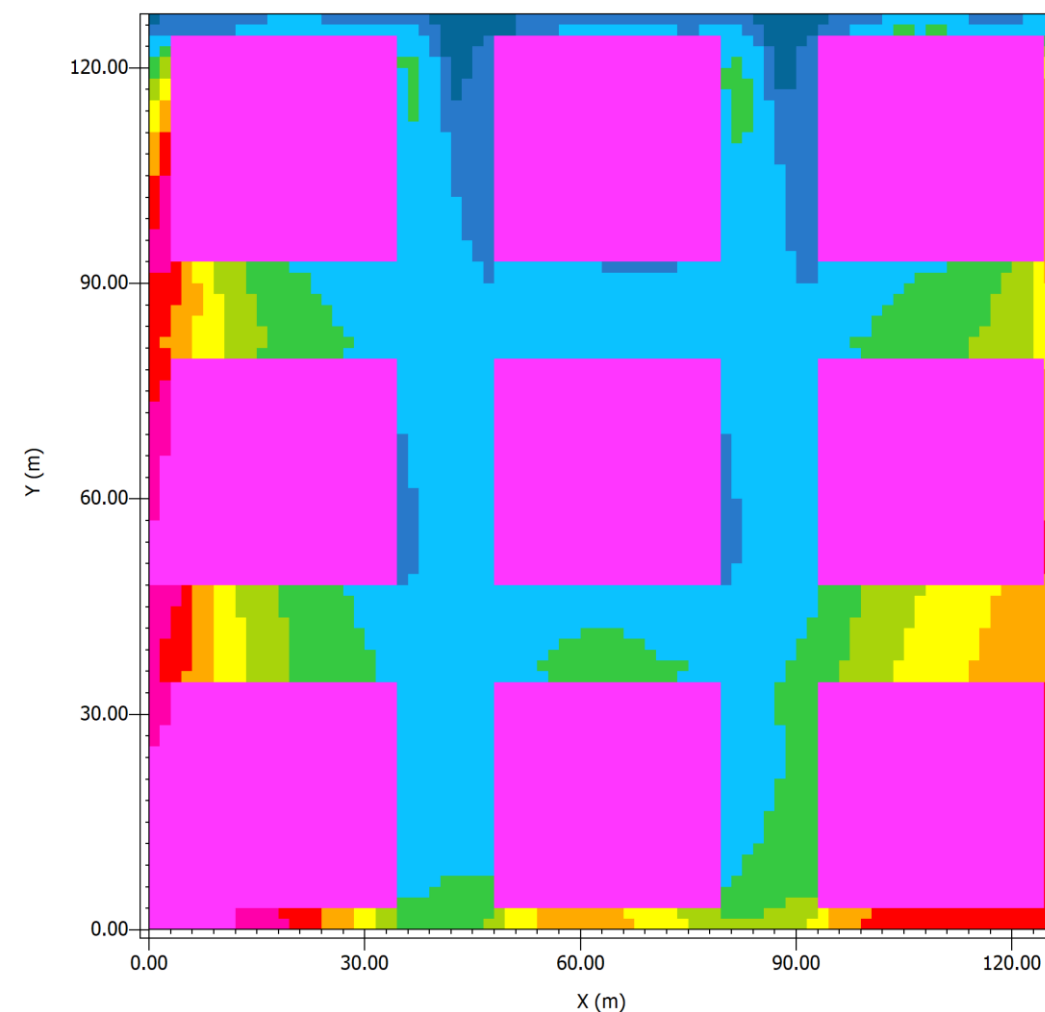
Case B

AMBIENT TEMPERATURE

Singapore & Phoenix



Case B



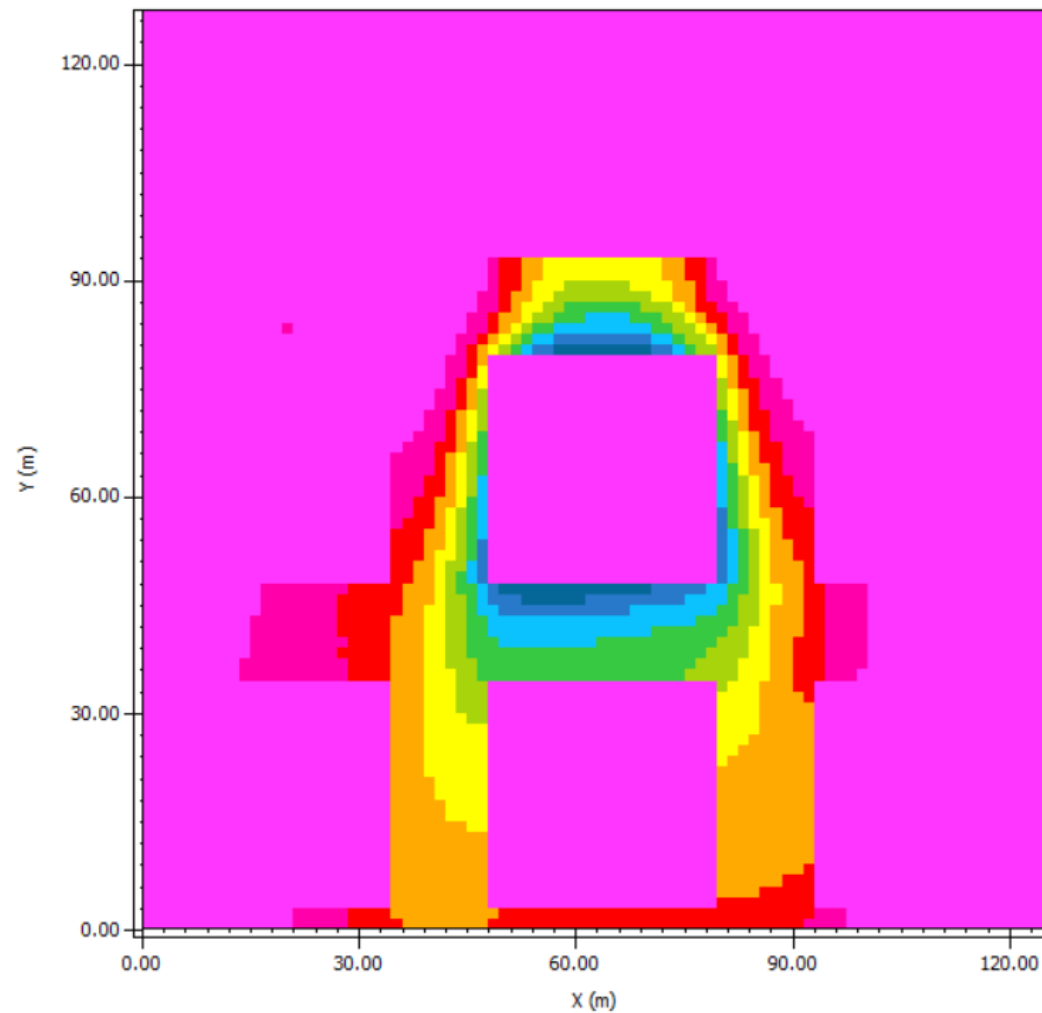
Case C

AMBIENT TEMPERATURE

Amsterdam

AMBIENT TEMPERATURE

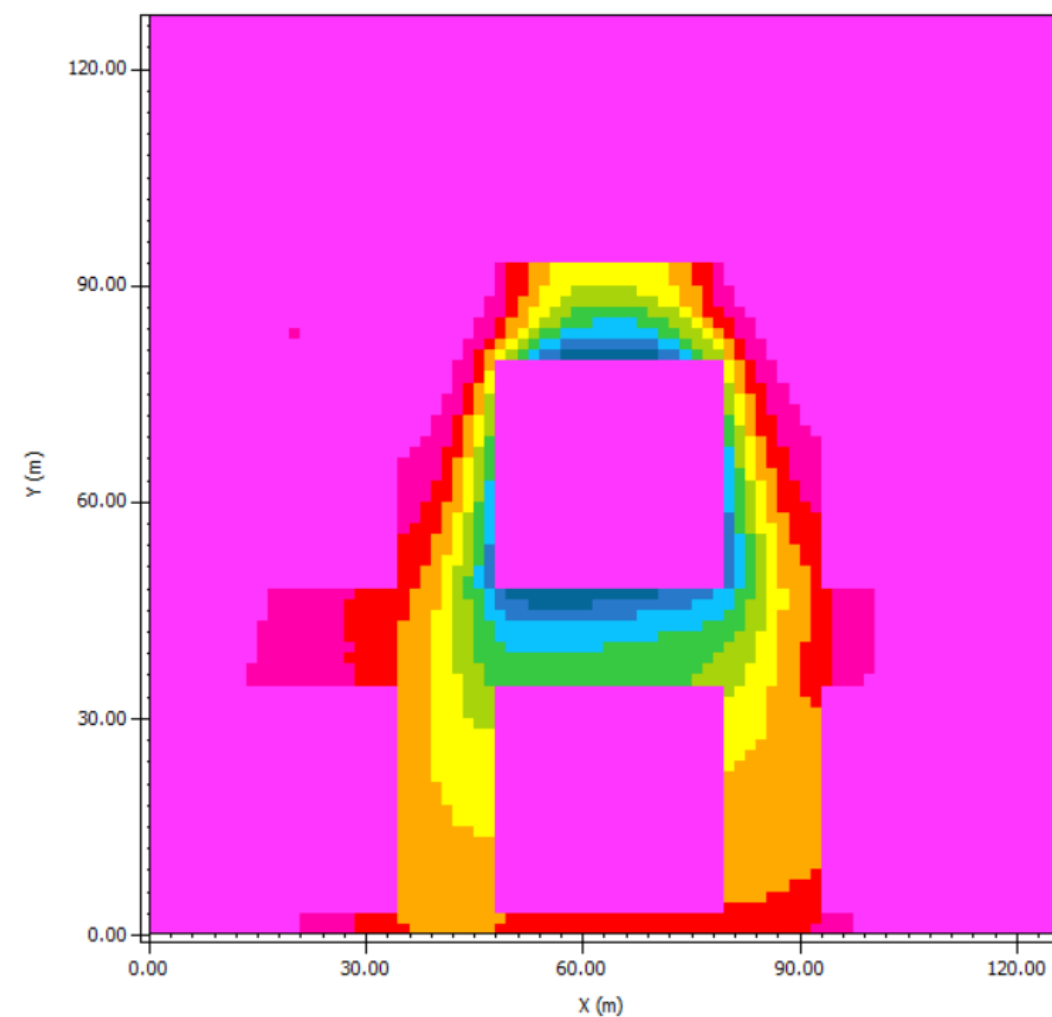
Amsterdam



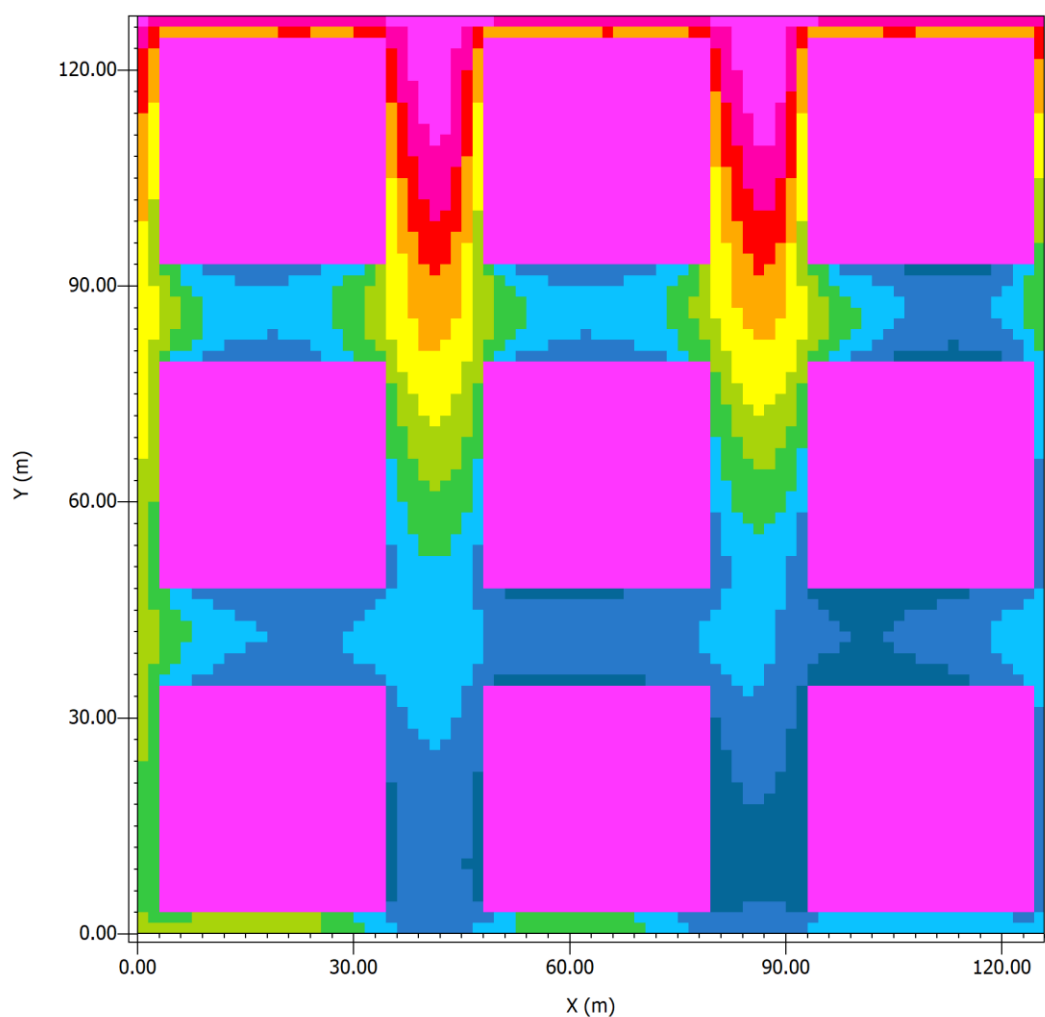
Case B

AMBIENT TEMPERATURE

Amsterdam

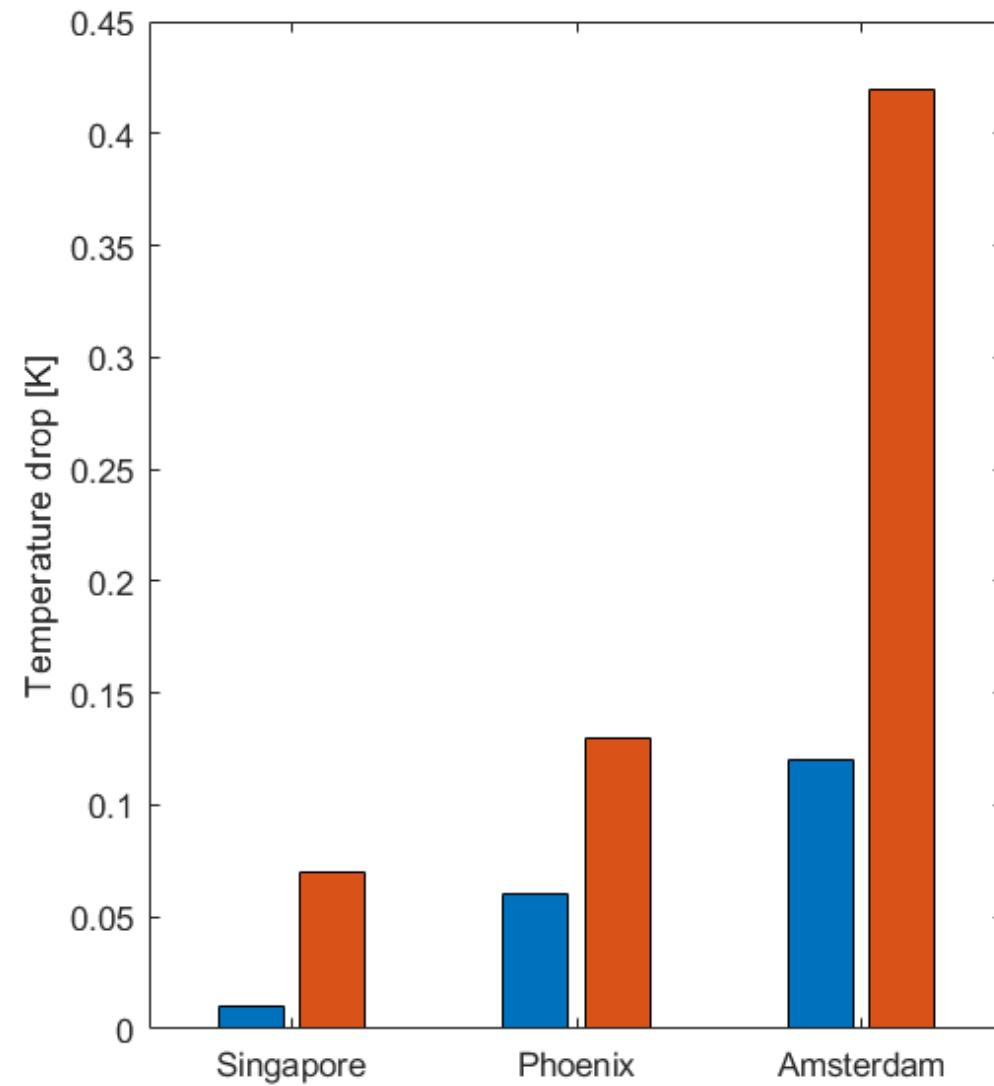


Case B

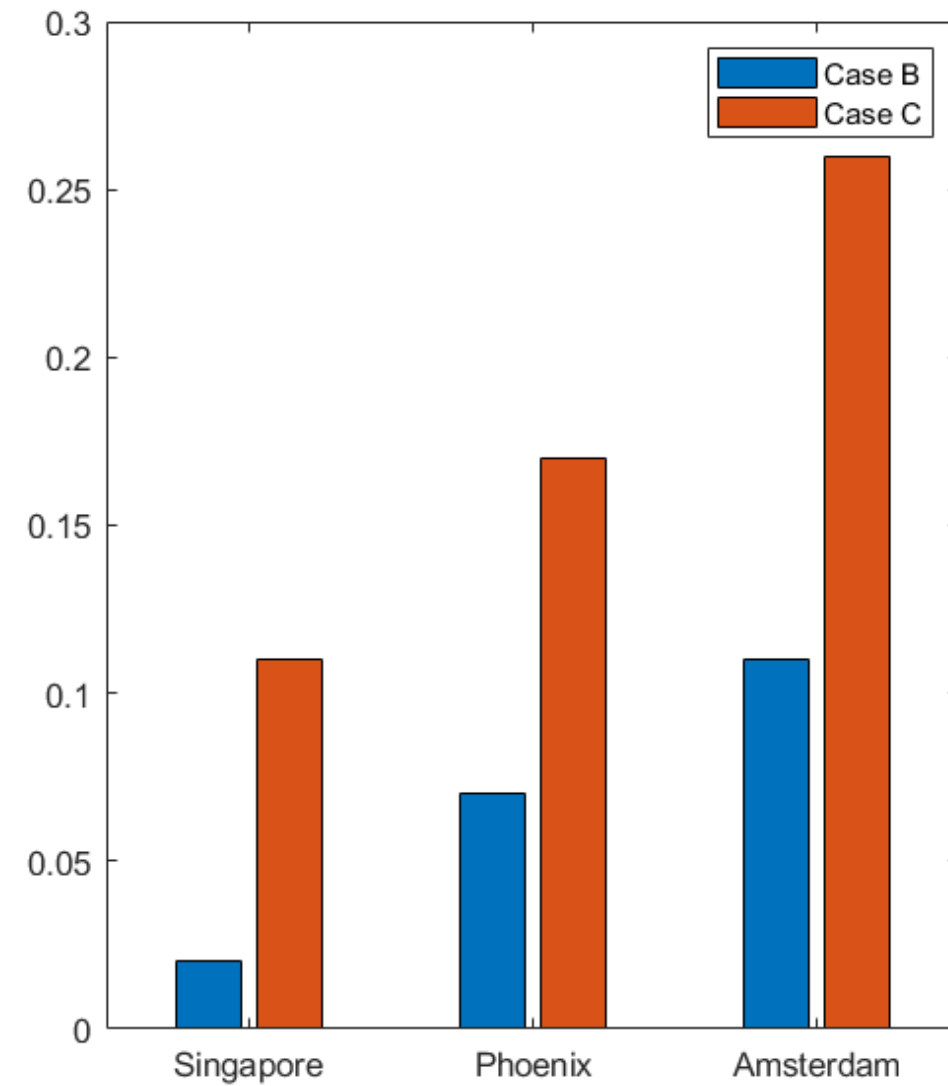


Case C

AMBIENT TEMPERATURE



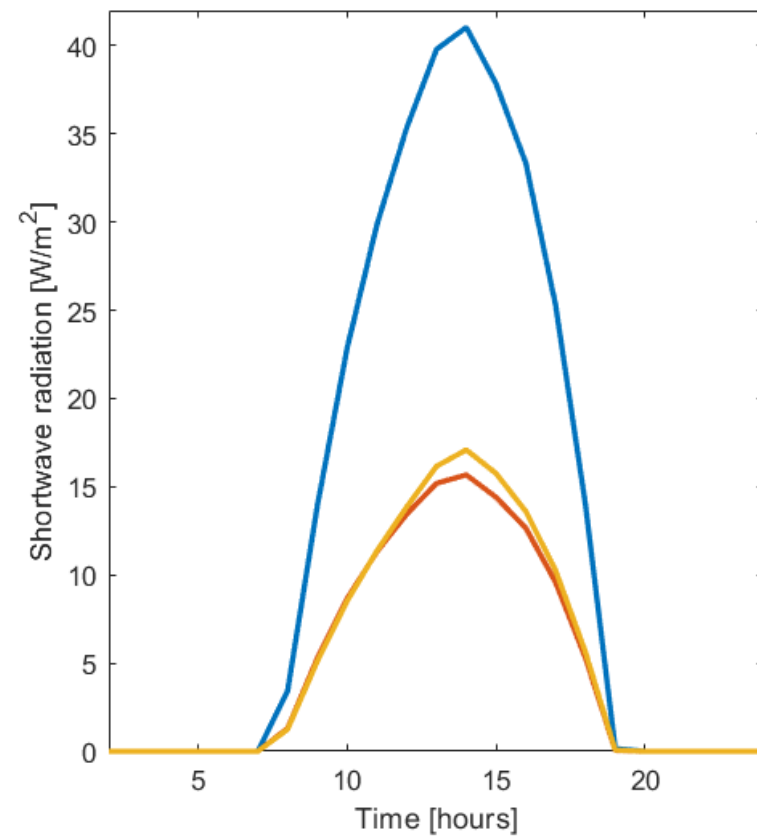
Green Façade



Living Wall System

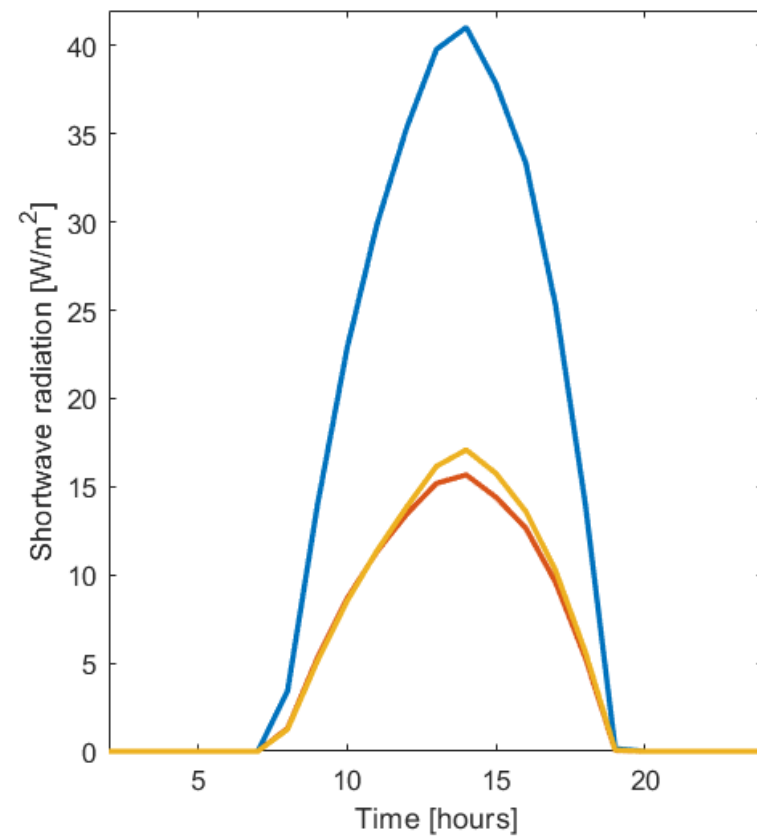
SHORT-WAVE RADIATION

SHORT-WAVE RADIATION

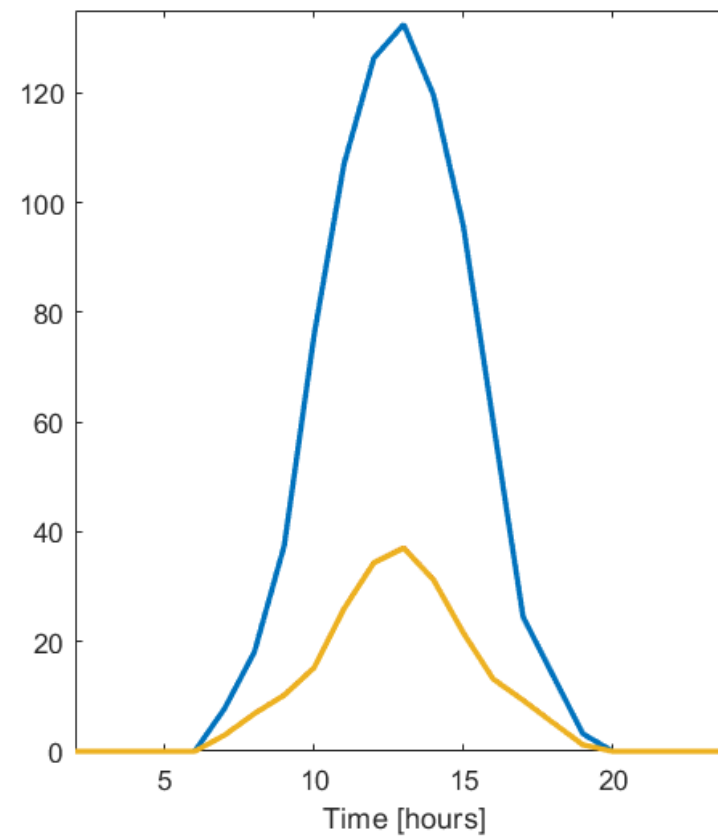


Singapore

SHORT-WAVE RADIATION

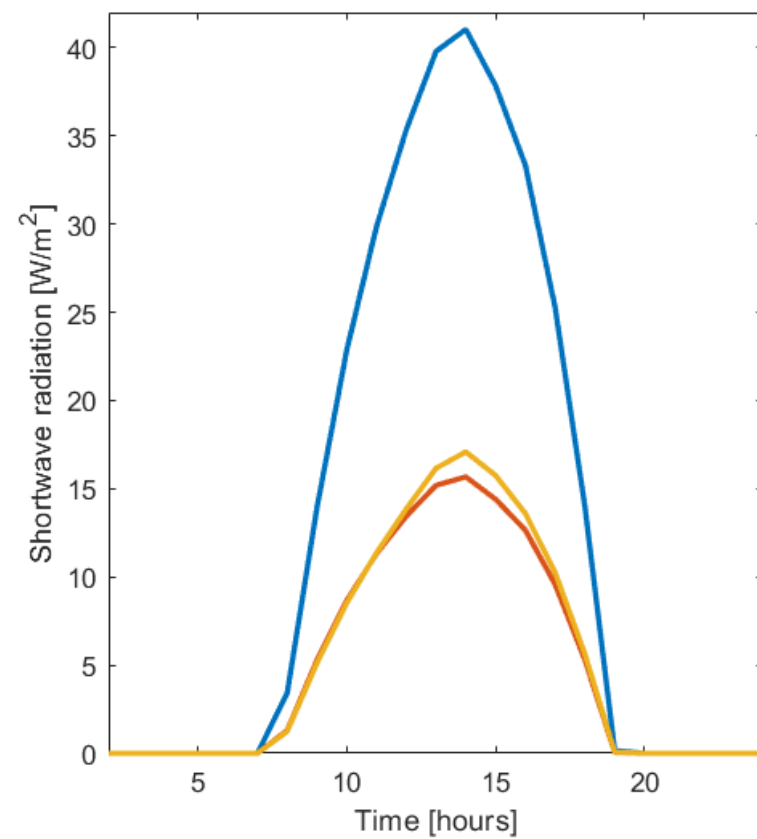


Singapore

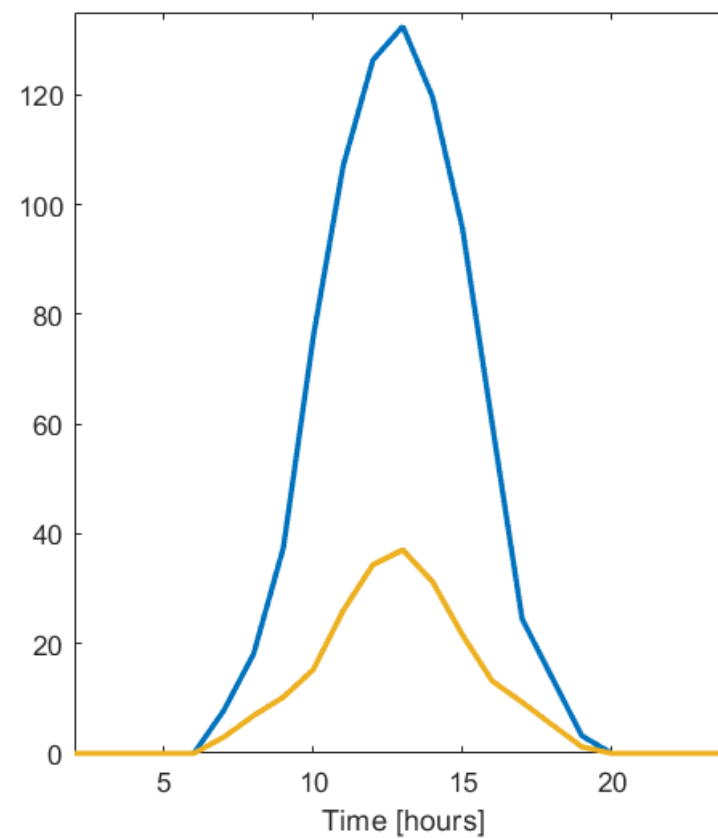


Phoenix

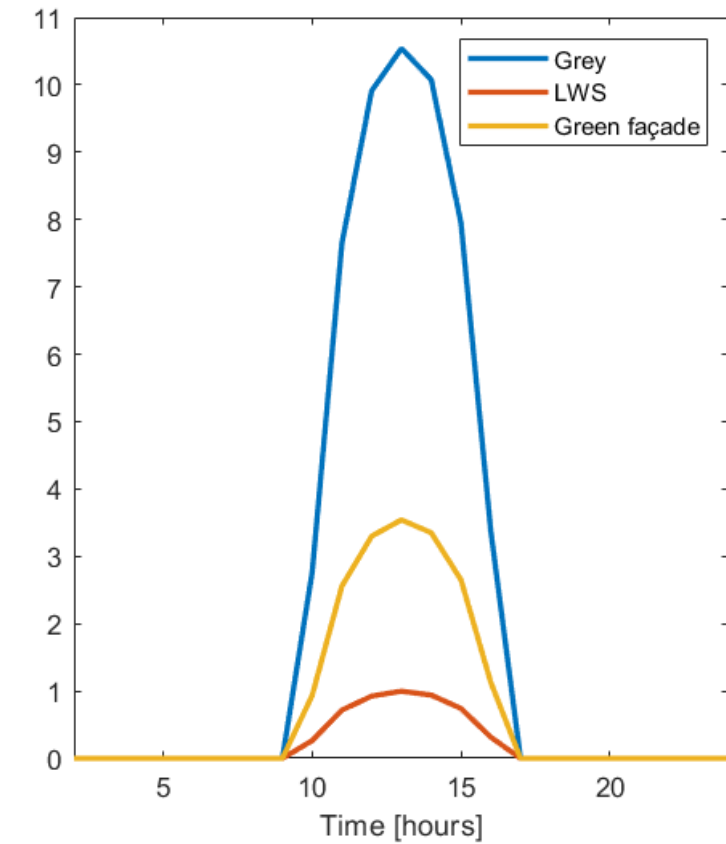
SHORT-WAVE RADIATION



Singapore



Phoenix

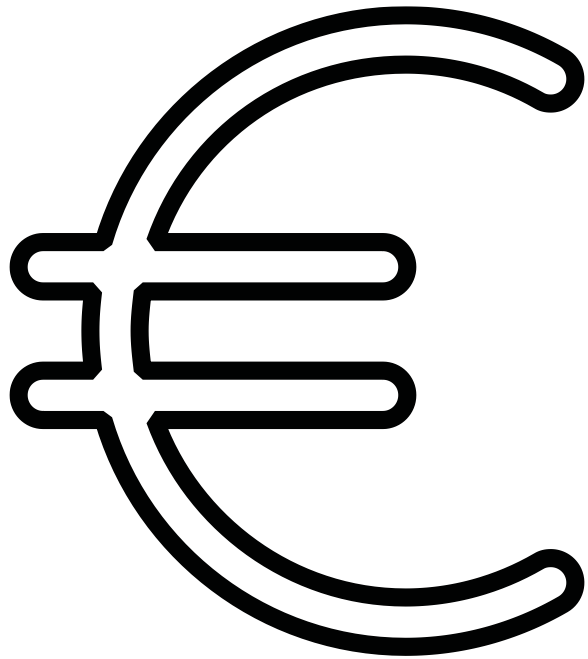


Amsterdam

DISCUSSIONS

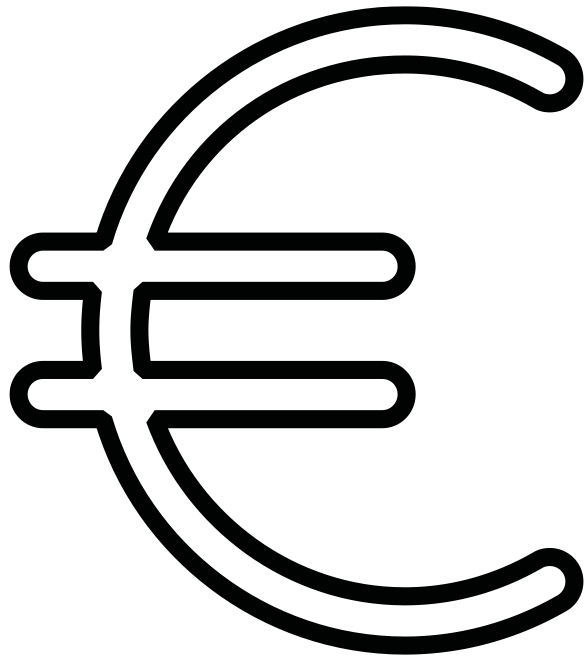
DISCUSSIONS

Economy

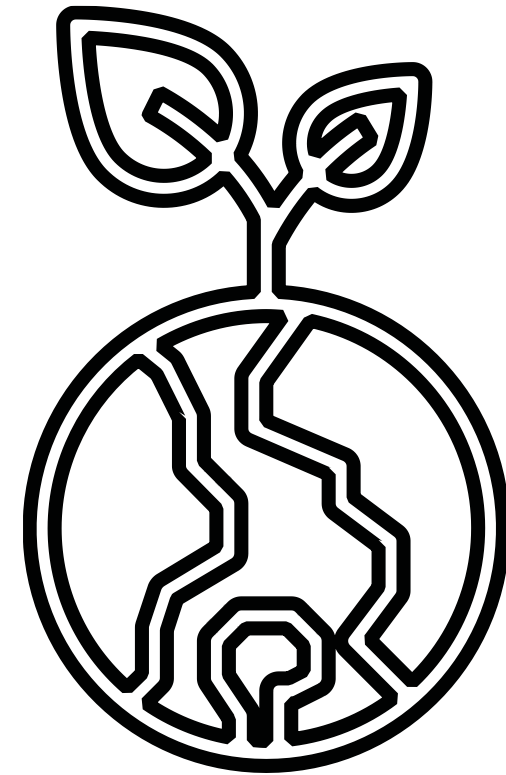


DISCUSSIONS

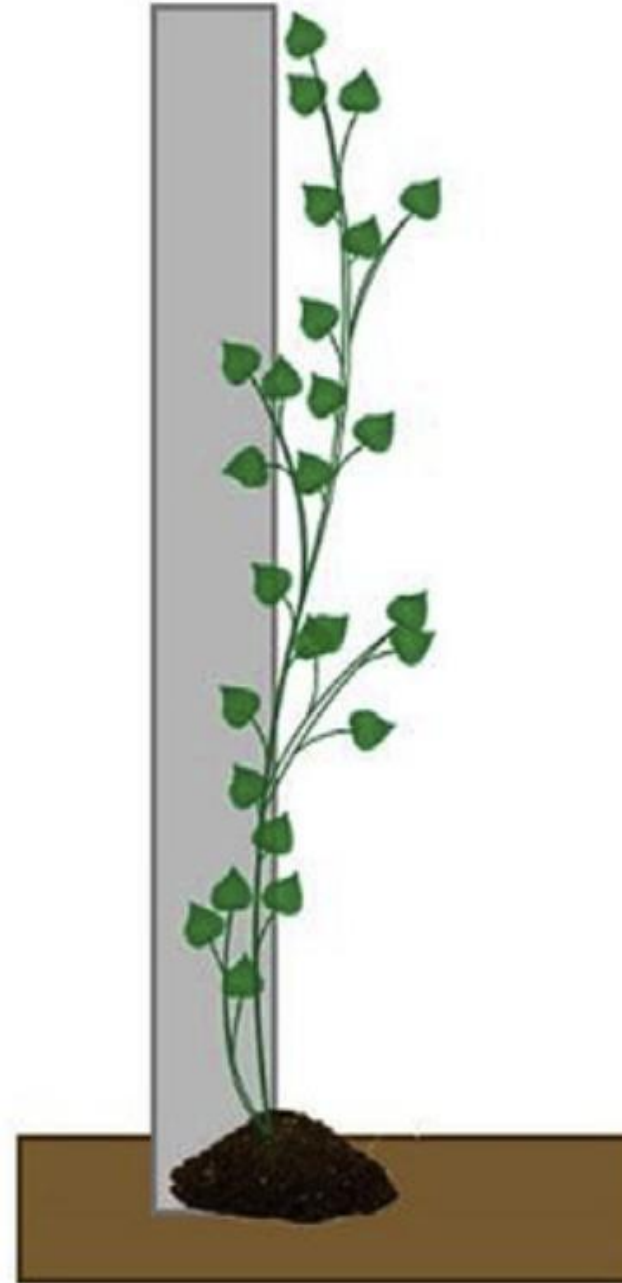
Economy



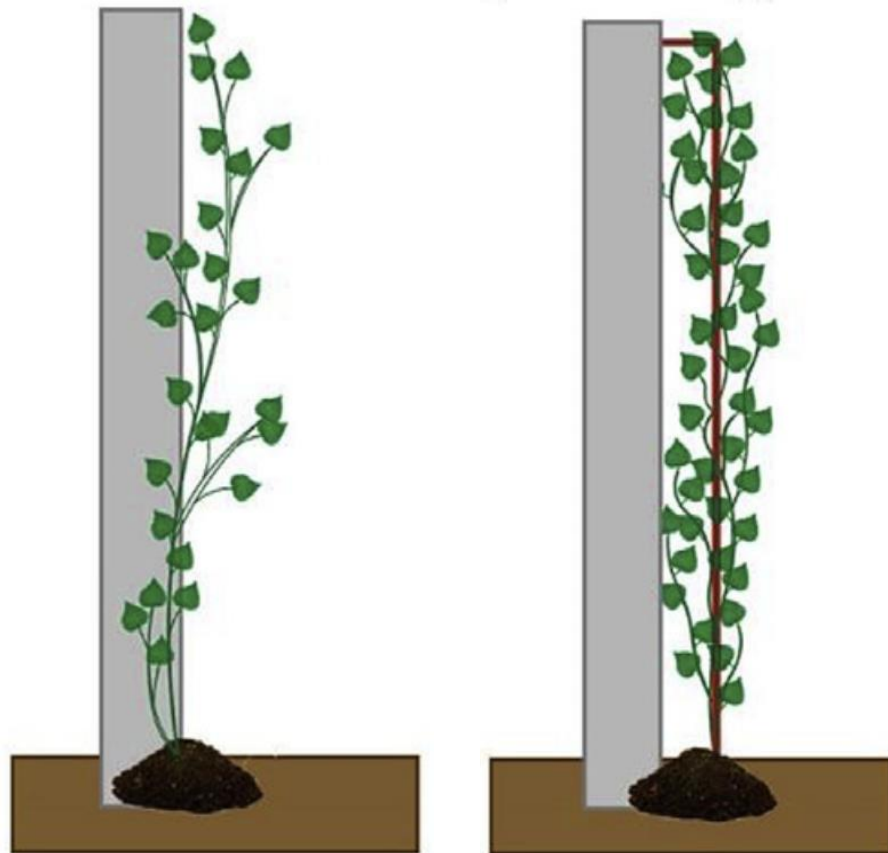
Environment



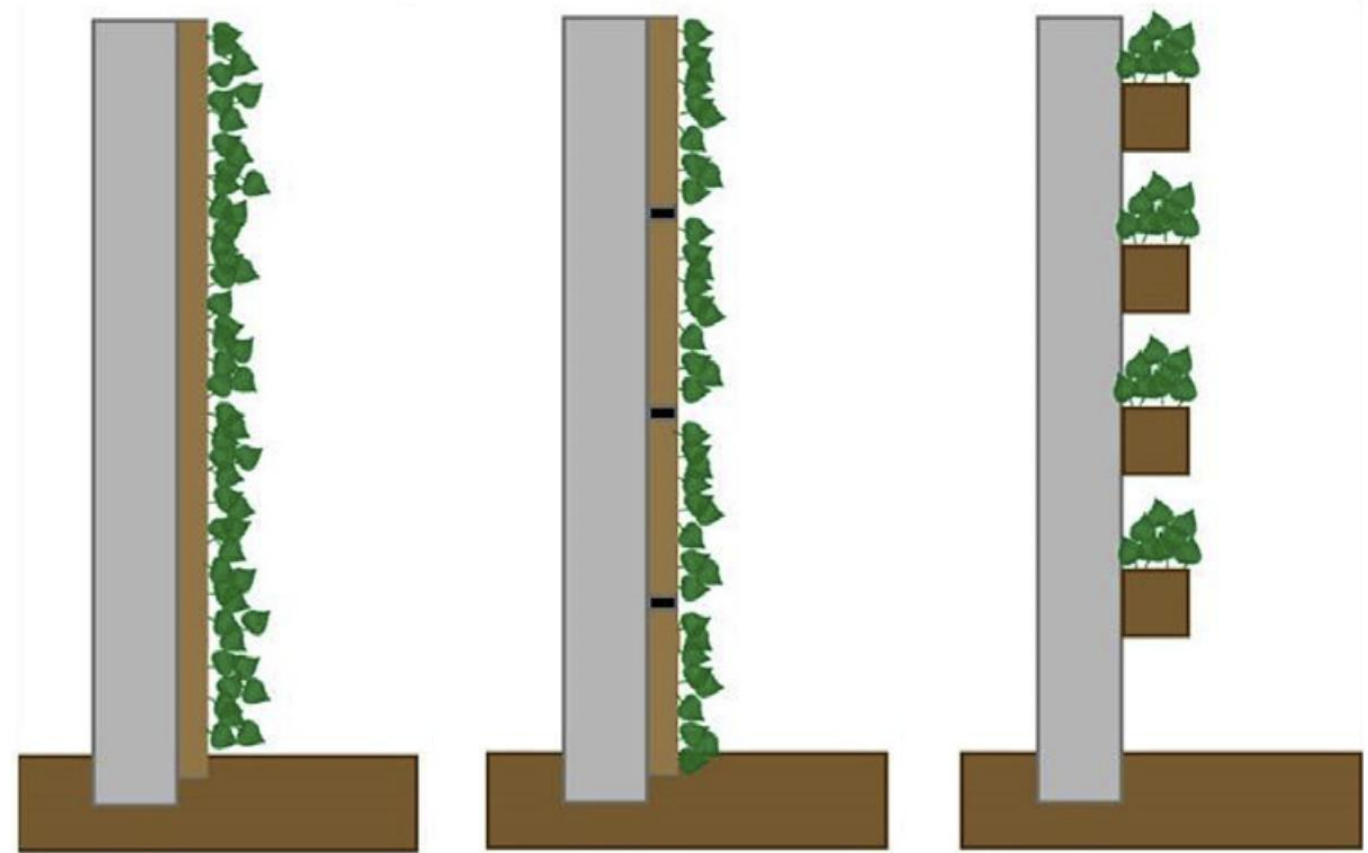
DISCUSSIONS



DISCUSSIONS

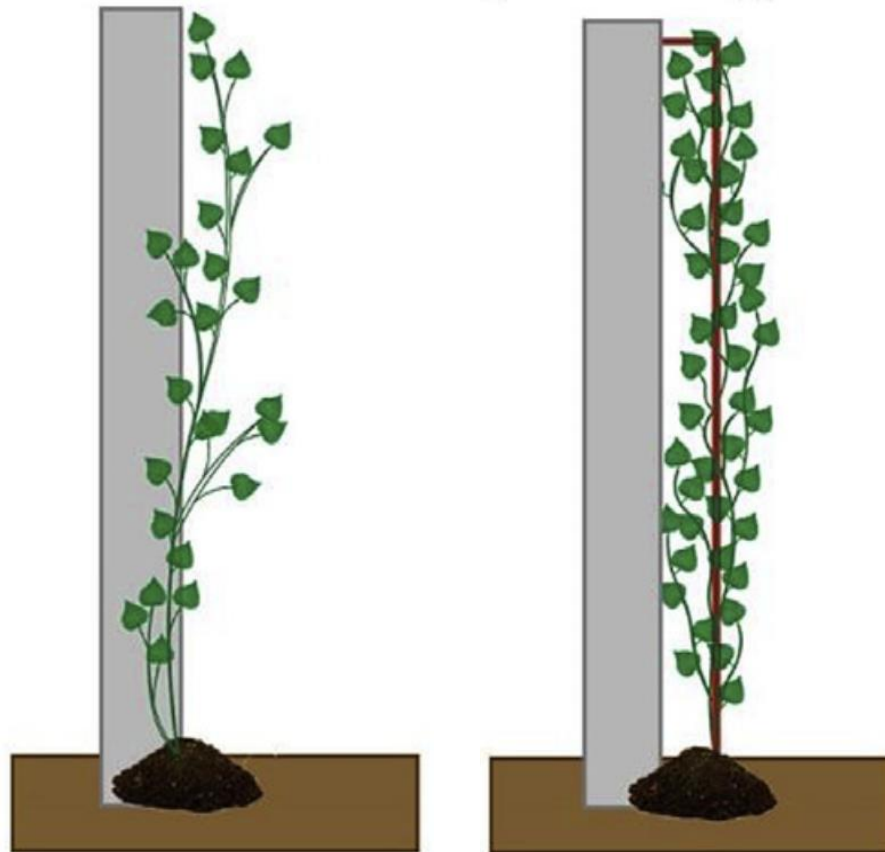
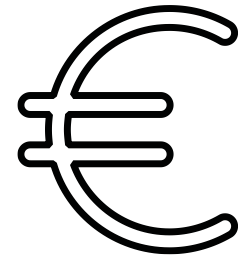


Green Façades

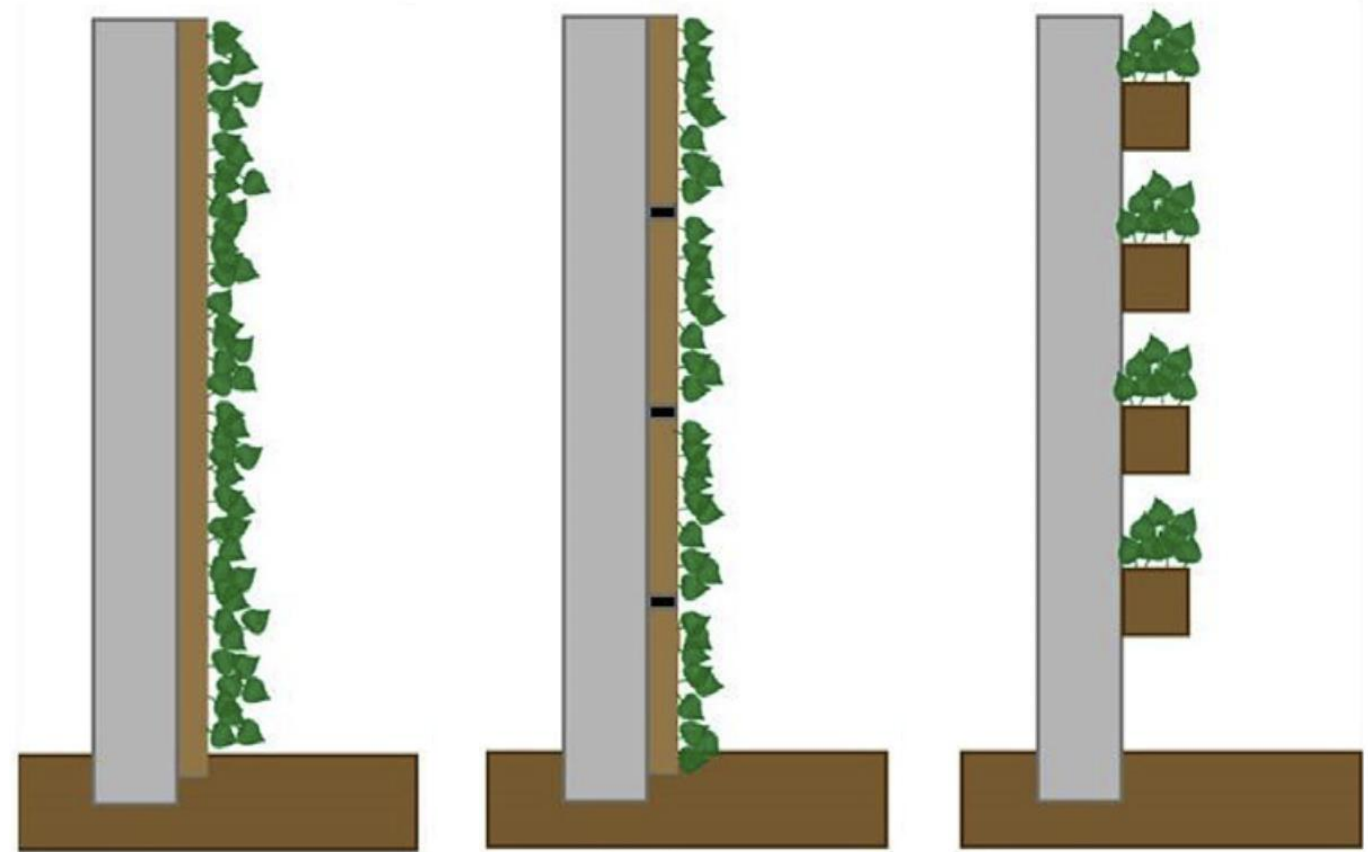


Living wall systems

DISCUSSIONS



Green Façades



Living wall systems

CONCLUSION

CONCLUSION

How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

CONCLUSION

How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

<i>Living Wall system</i>				<i>Green Façade</i>		
<i>Climate</i>	<i>Singapore</i>	<i>Phoenix</i>	<i>Amsterdam</i>	<i>Singapore</i>	<i>Phoenix</i>	<i>Amsterdam</i>
<i>Latitude</i>	<i>Low</i>	<i>Mid</i>	<i>High</i>	<i>Low</i>	<i>Mid</i>	<i>High</i>

CONCLUSION



How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

Living Wall system				Green Façade		
Climate	Singapore	Phoenix	Amsterdam	Singapore	Phoenix	Amsterdam
Latitude	Low	Mid	High	Low	Mid	High
LAI	+/-	+/-	+/-	+/-		

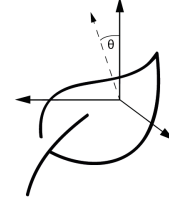
CONCLUSION



How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

Living Wall system				Green Façade			
Climate	Singapore	Phoenix	Amsterdam	Singapore	Phoenix	Amsterdam	
Latitude	Low	Mid	High	Low	Mid	High	
LAI	+/-	+/-	+/-	+/-	+	+	

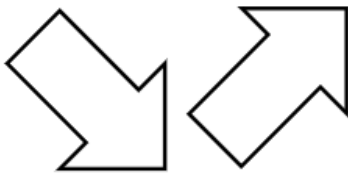
CONCLUSION



How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

Living Wall system				Green Façade			
Climate	Singapore	Phoenix	Amsterdam	Singapore	Phoenix	Amsterdam	
Latitude	Low	Mid	High	Low	Mid	High	
LAI	+/-	+/-	+/-	+/-	+	+	
LAD	H/V	H/V	Ø	H/V	H/V	Ø	

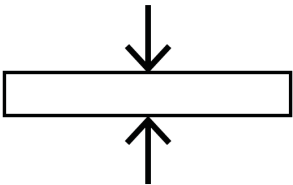
CONCLUSION



How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

	Living Wall system				Green Façade		
Climate	Singapore	Phoenix	Amsterdam		Singapore	Phoenix	Amsterdam
Latitude	Low	Mid	High		Low	Mid	High
LAI	+/-	+/-	+/-		+/-	+	+
LAD	H/V	H/V	Ø		H/V	H/V	Ø
Albedo	+	+	-		+	+	-

CONCLUSION



How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

	Living Wall system				Green Façade		
Climate	Singapore	Phoenix	Amsterdam		Singapore	Phoenix	Amsterdam
Latitude	Low	Mid	High		Low	Mid	High
LAI	+/-	+/-	+/-		+/-	+	+
LAD	H/V	H/V	Ø		H/V	H/V	Ø
Albedo	+	+	-		+	+	-
Thickness	+	+	+				

CONCLUSION

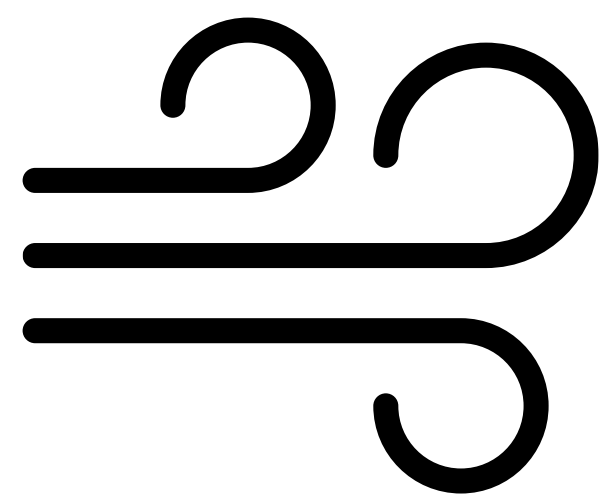


How can vertical greenery systems be optimized to improve the performance of a building for different climate types?

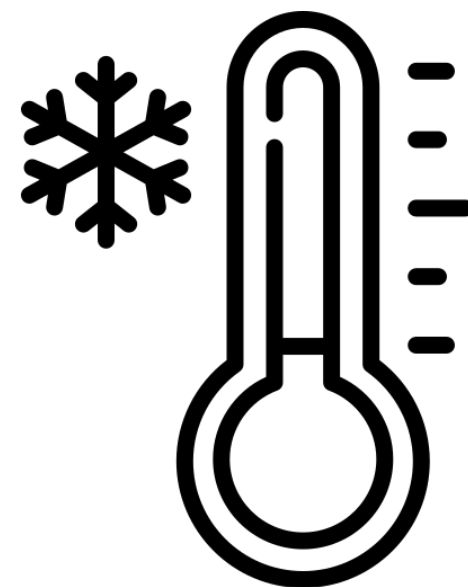
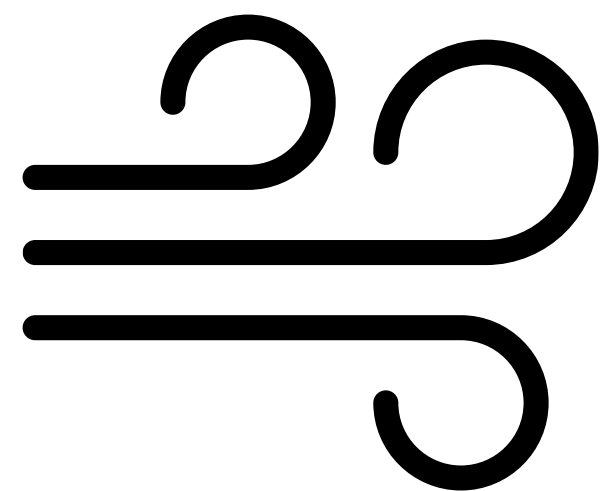
	Living Wall system				Green Façade		
Climate	Singapore	Phoenix	Amsterdam		Singapore	Phoenix	Amsterdam
Latitude	Low	Mid	High		Low	Mid	High
LAI	+/-	+/-	+/-		+/-	+	+
LAD	H/V	H/V	Ø		H/V	H/V	Ø
Albedo	+	+	-		+	+	-
Thickness	+	+	+				
MC	+	+	+				

CONCLUSION

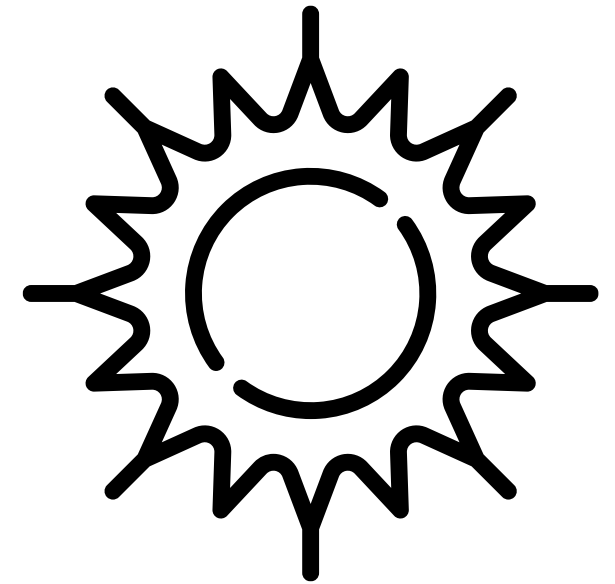
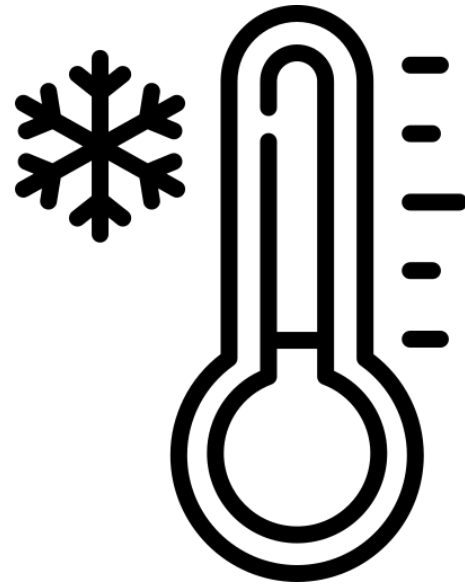
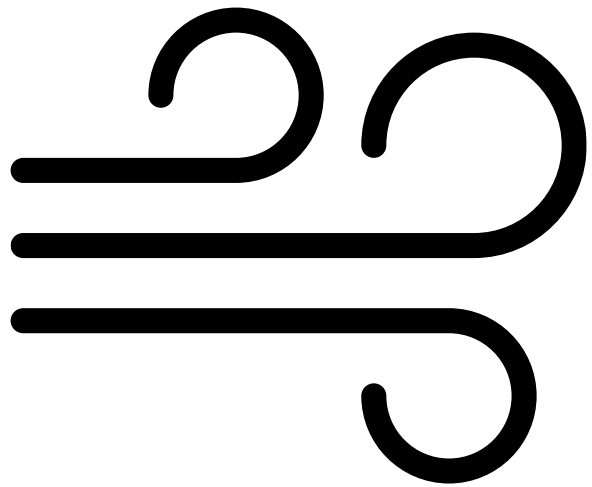
CONCLUSION



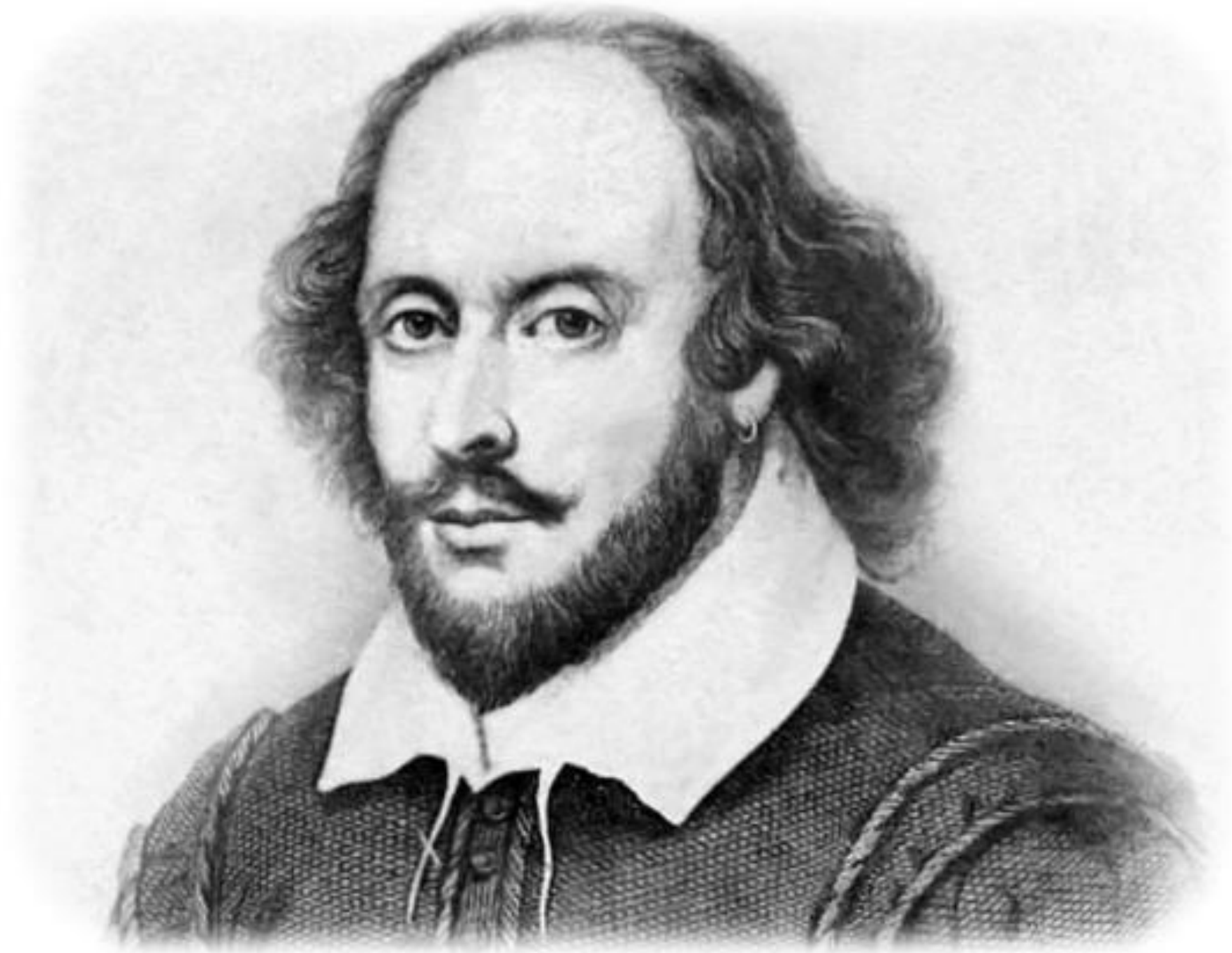
CONCLUSION



CONCLUSION



TO GREEN OR NOT TO GREEN?





Optimized Green Walls

*Study of Vertical Green Systems'
Performance in an Urban Setting*

Francisco Guzmán | 4710487 | CiTG

SUB-RESEARCH QUESTIONS

- 1) *Which parameters have the highest influence in the VGS?*
- 2) *To what extent can evapotranspiration reduce a building's energy demand?*
- 3) *How large is the influence of the substrate layer in the performance of the system?*
- 4) *How does a VGS respond under the UHI effect?*
- 5) *How does the LAI influence wind velocity in the surroundings of a building?*

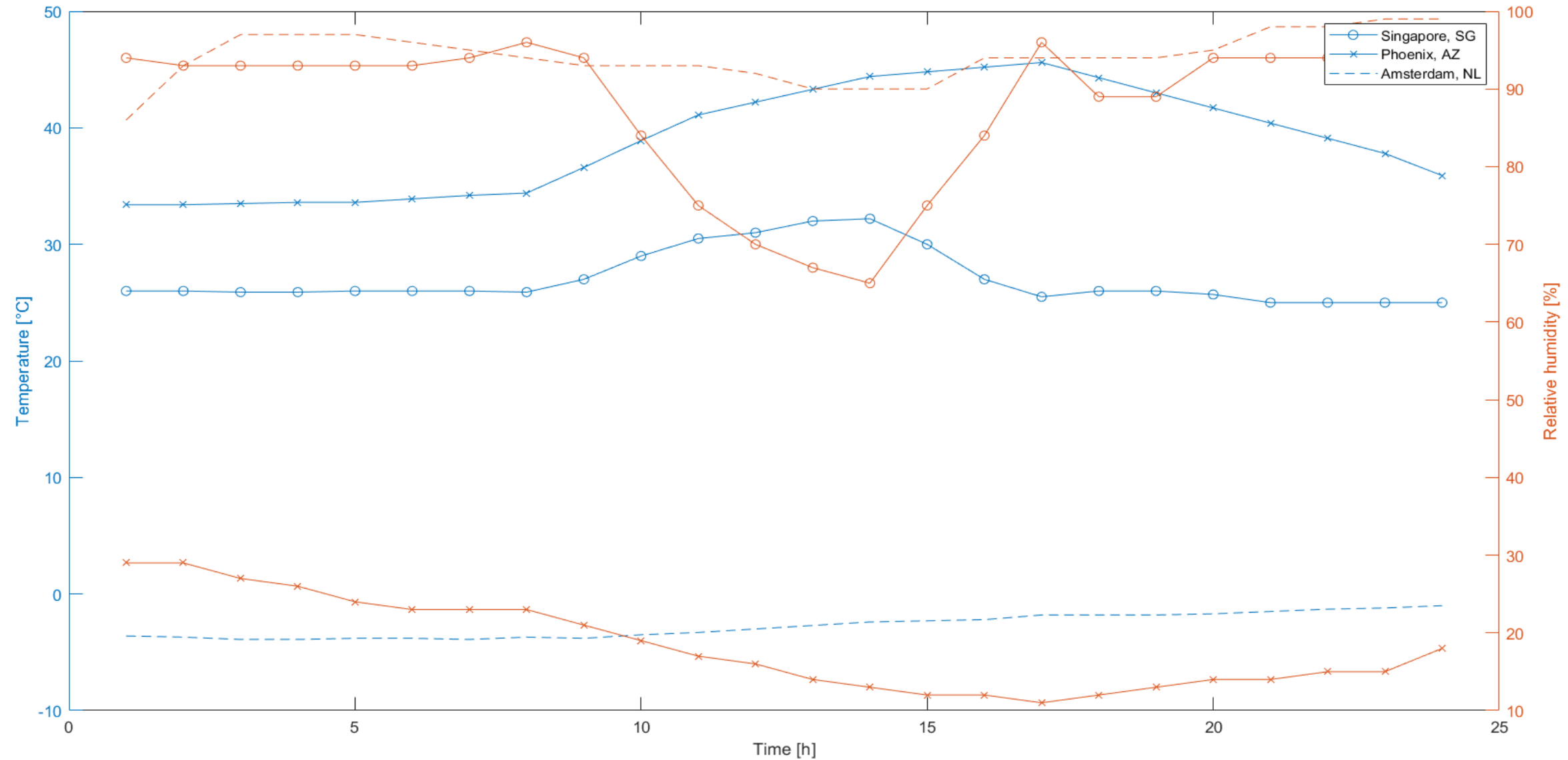
LIMITATIONS

- *24-hour period*
- *Constant moisture content*
- *Influence of Stomatal resistance*
- *Plant selection*

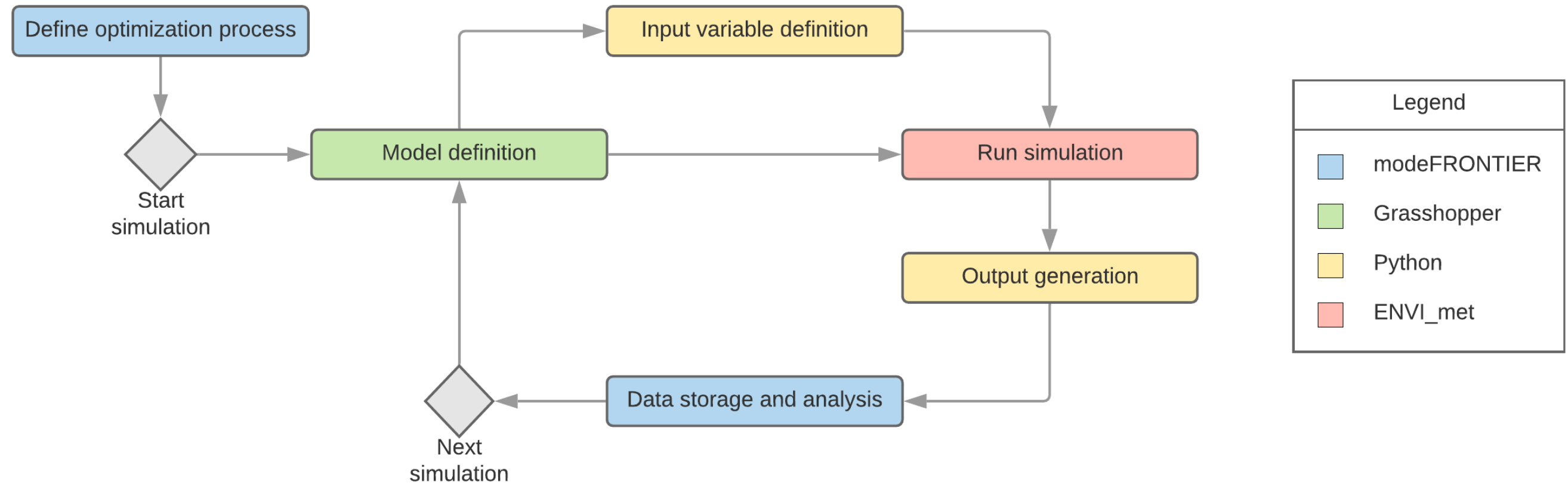
FUTURE WORK

- *Quantification of moisture release*
- *Flexibility in the computational model*
- *Spatial distribution of cooling effect*
- *Irregular urban configuration*

CLIMATE SELECTION

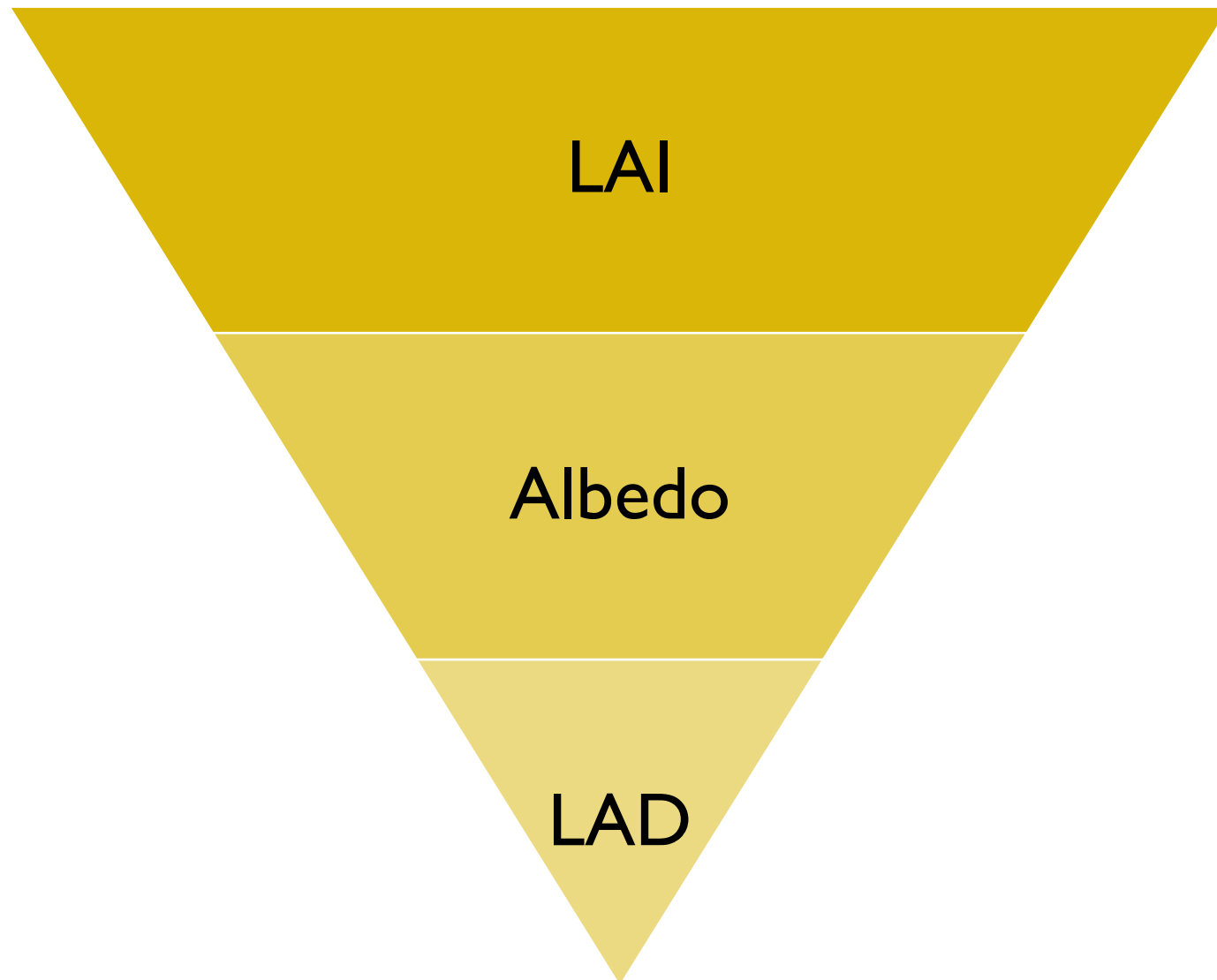


COMPUTATIONAL WORKFLOW

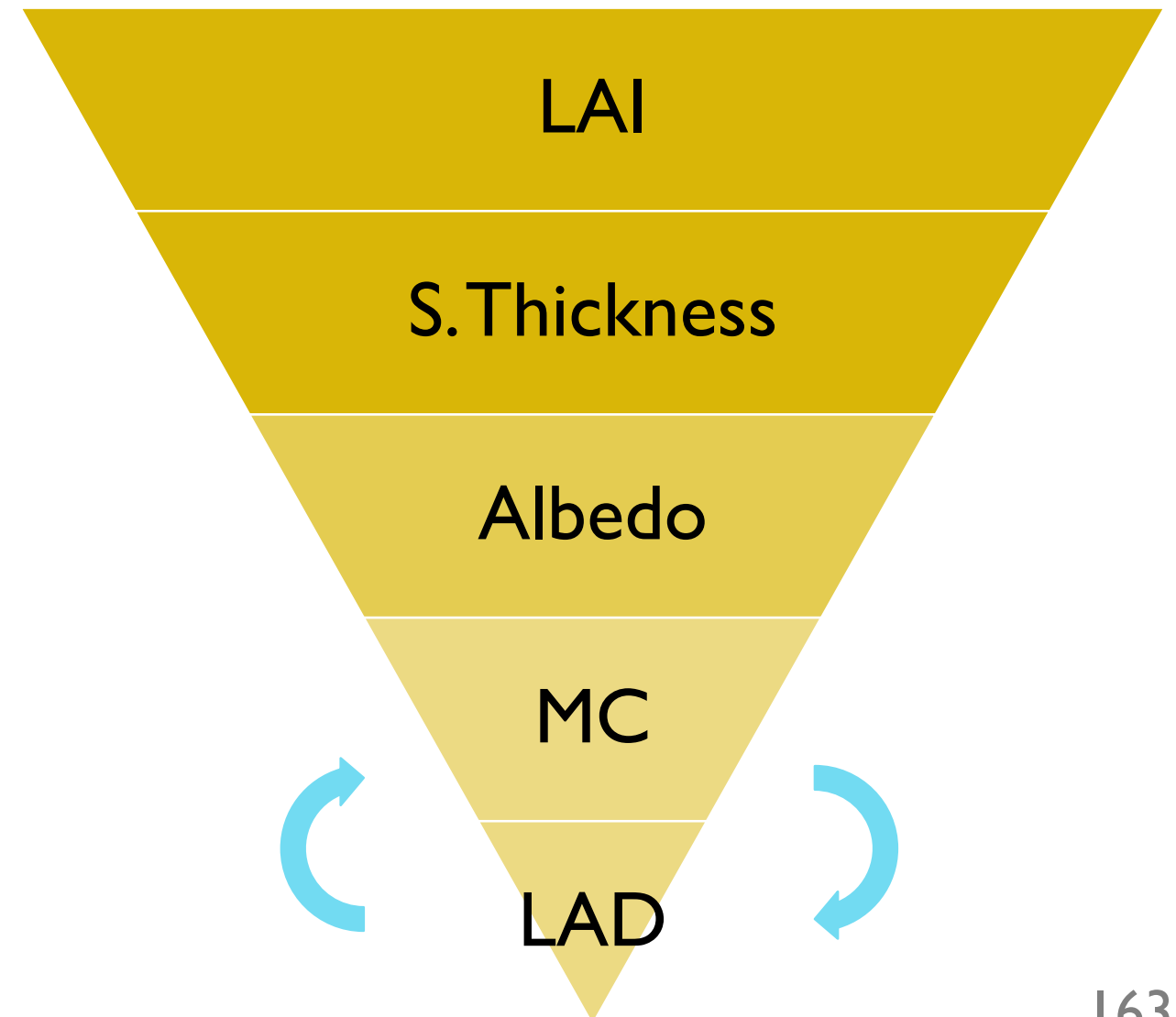


CORRELATION FACTORS

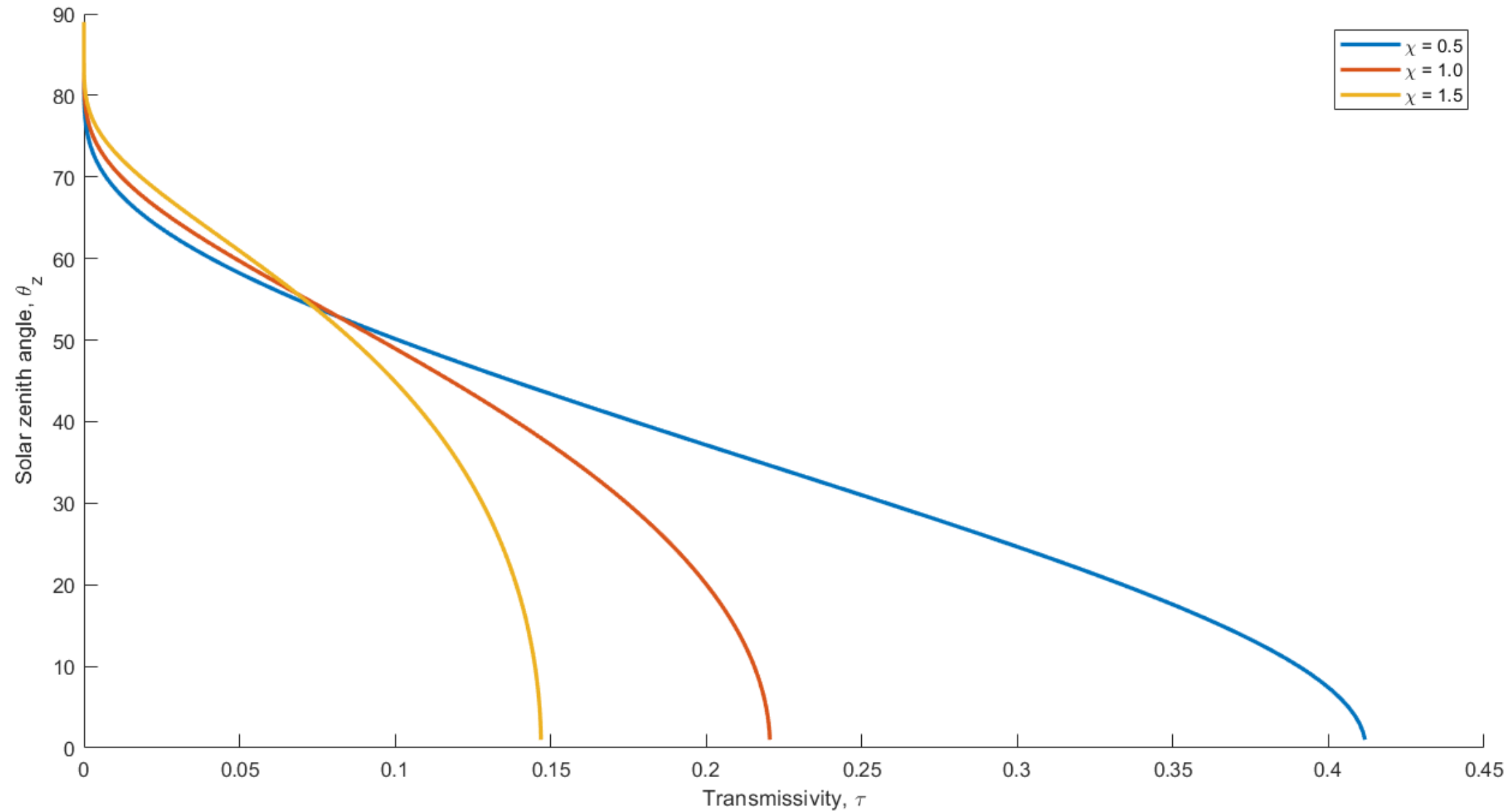
Green Façades



Living Wall Systems



LEAF ANGLE DISTRIBUTION



PART I – MODEL DEFINITION

