Bioreceptive Urban Facades:

Integration of Bryophytes Into Facades and Their Impact on External Building Temperatures

P5 Presentation: July 24th 2019
Diego Valencia - 4742699
First Mentor: Alejandro Prieto
Second Mentor: Marc Ottelé
Delft University of Technology
Track: Building Technology

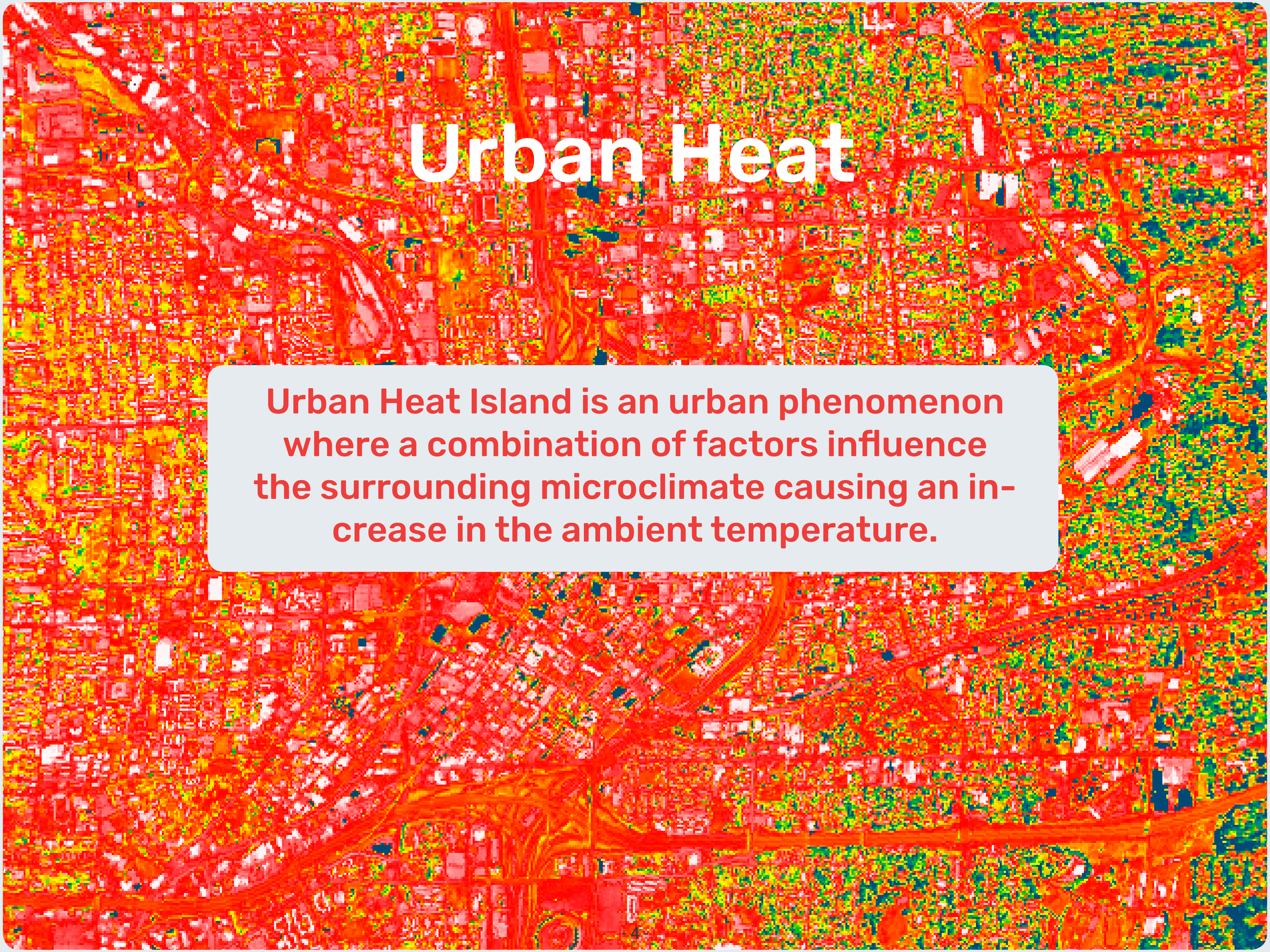
Rapid Urbanization

Photo by Matías Santana on Unsplash

Urban Environments

- Air Pollution
- Noise Pollution
- Lack of biodiversity
- Storm-water management
- Lack urban greenery
- Urban Heat Island

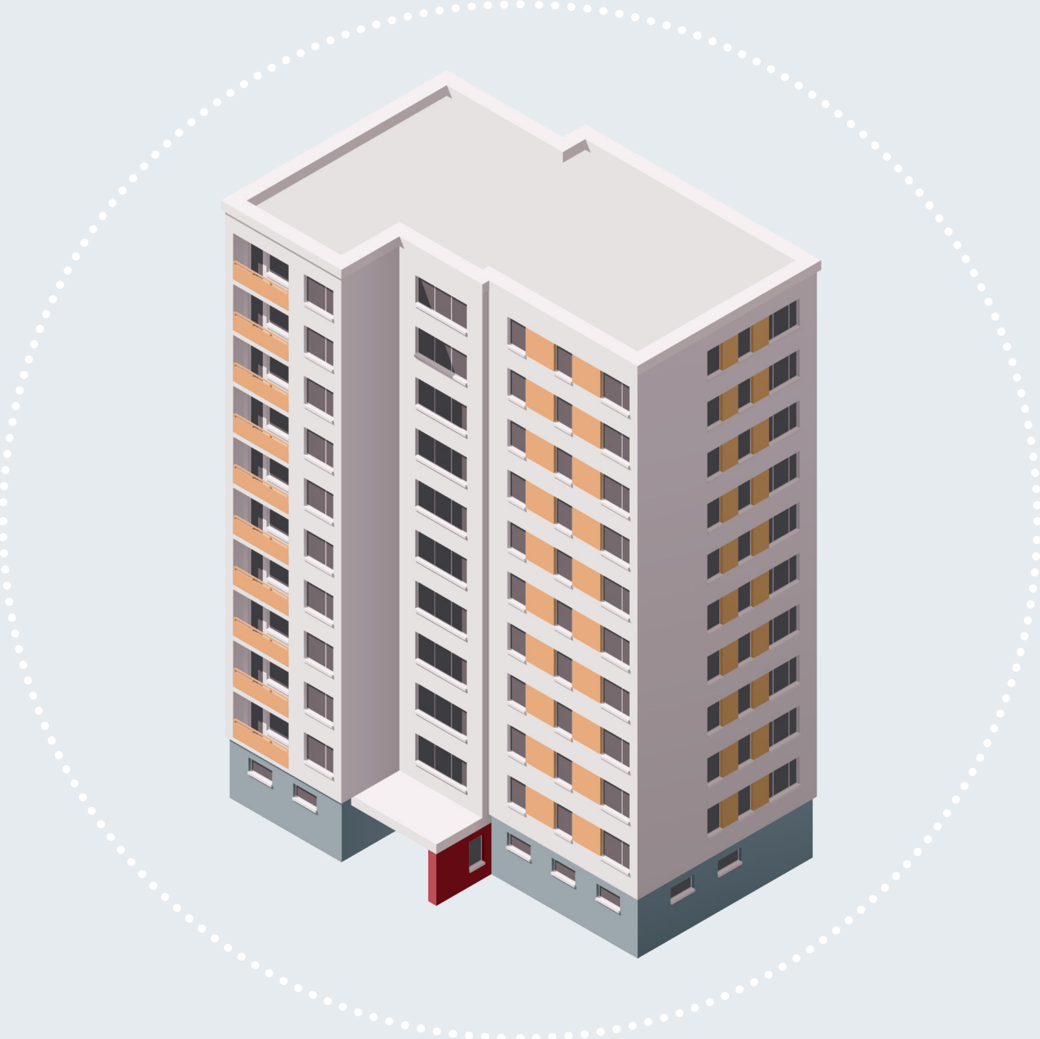
http://defotograaf.eu/blog/wp-content/uploads/2015/05/Rotterdam4.jpg



Urban Heat

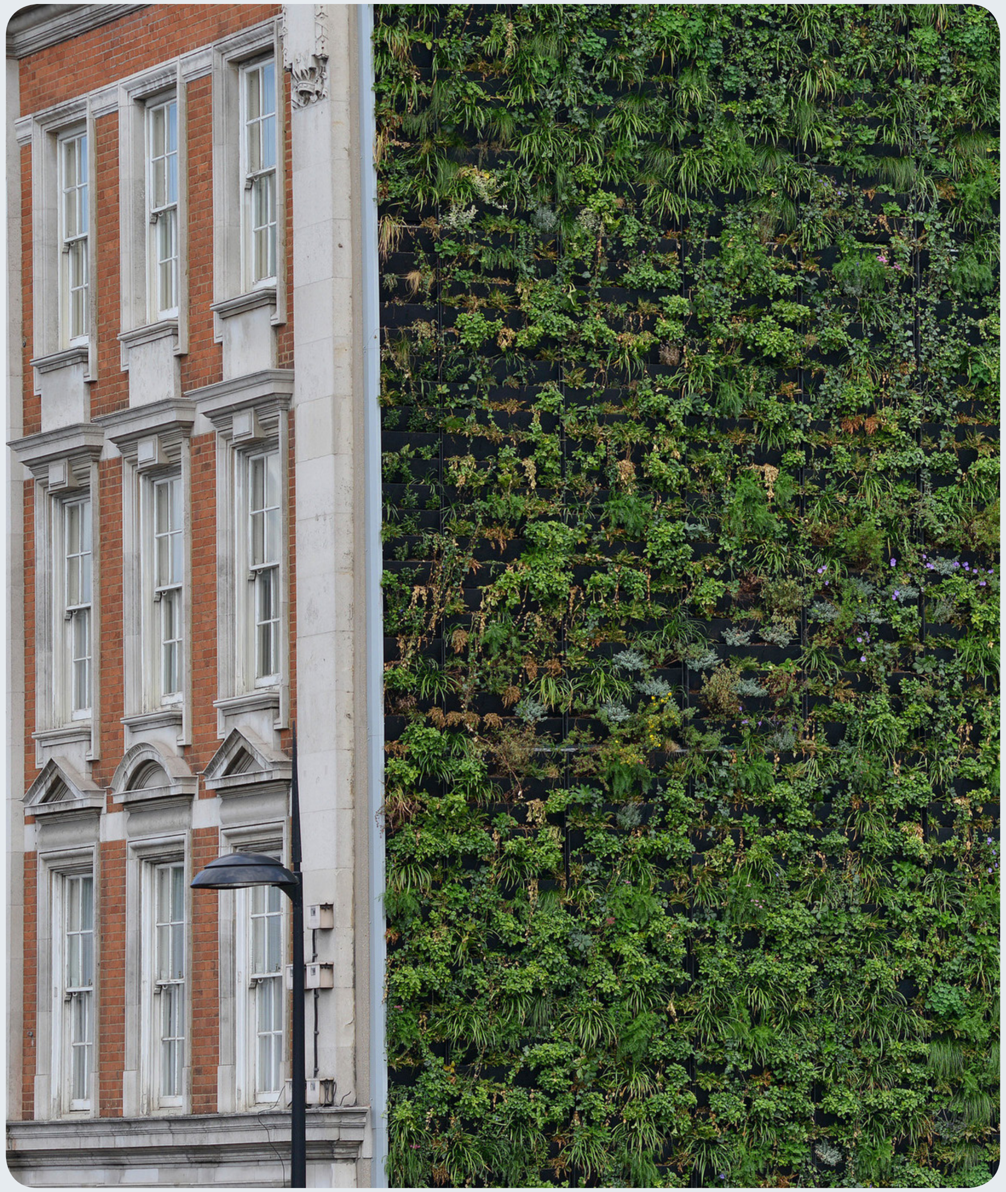
Urban Heat Island is an urban phenomenon where a combination of factors influence the surrounding microclimate causing an increase in the ambient temperature.

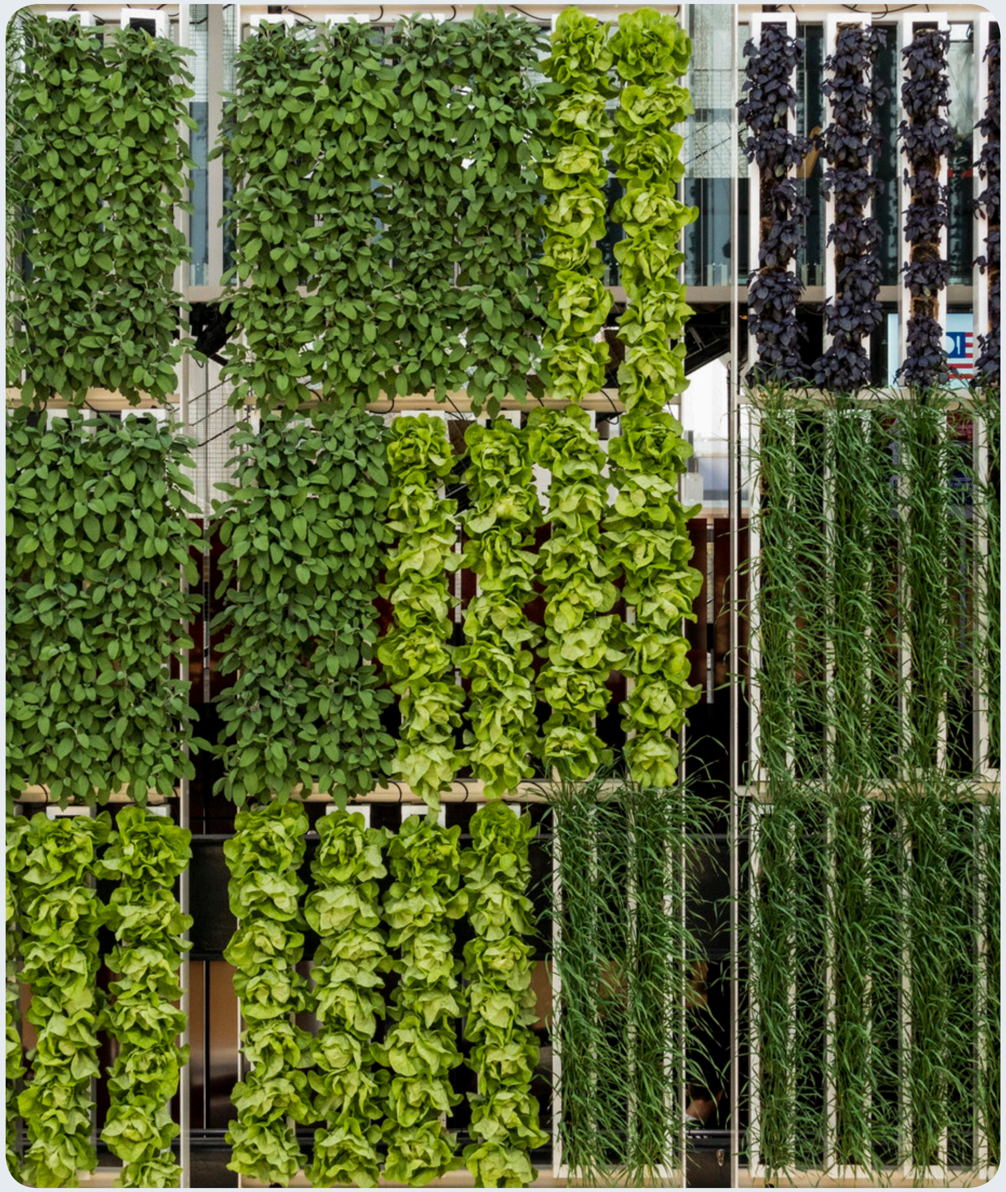
What can be changed when we design and build our cities?



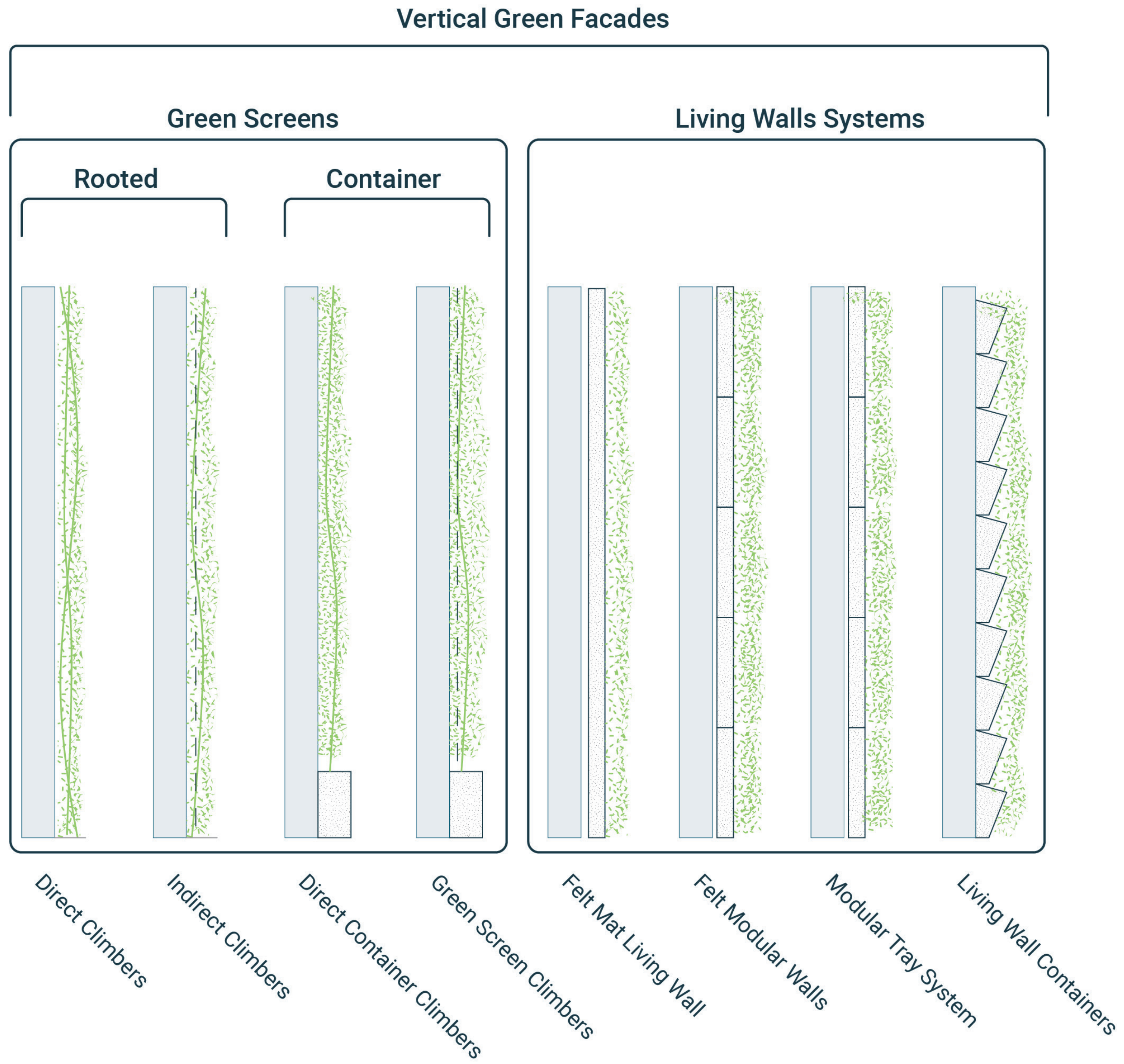
- Surface water
- Surface albedo
- Vegetation indexes
- Shadow
- Sky view factor
- Building volume
- Building envelope

Urban facades





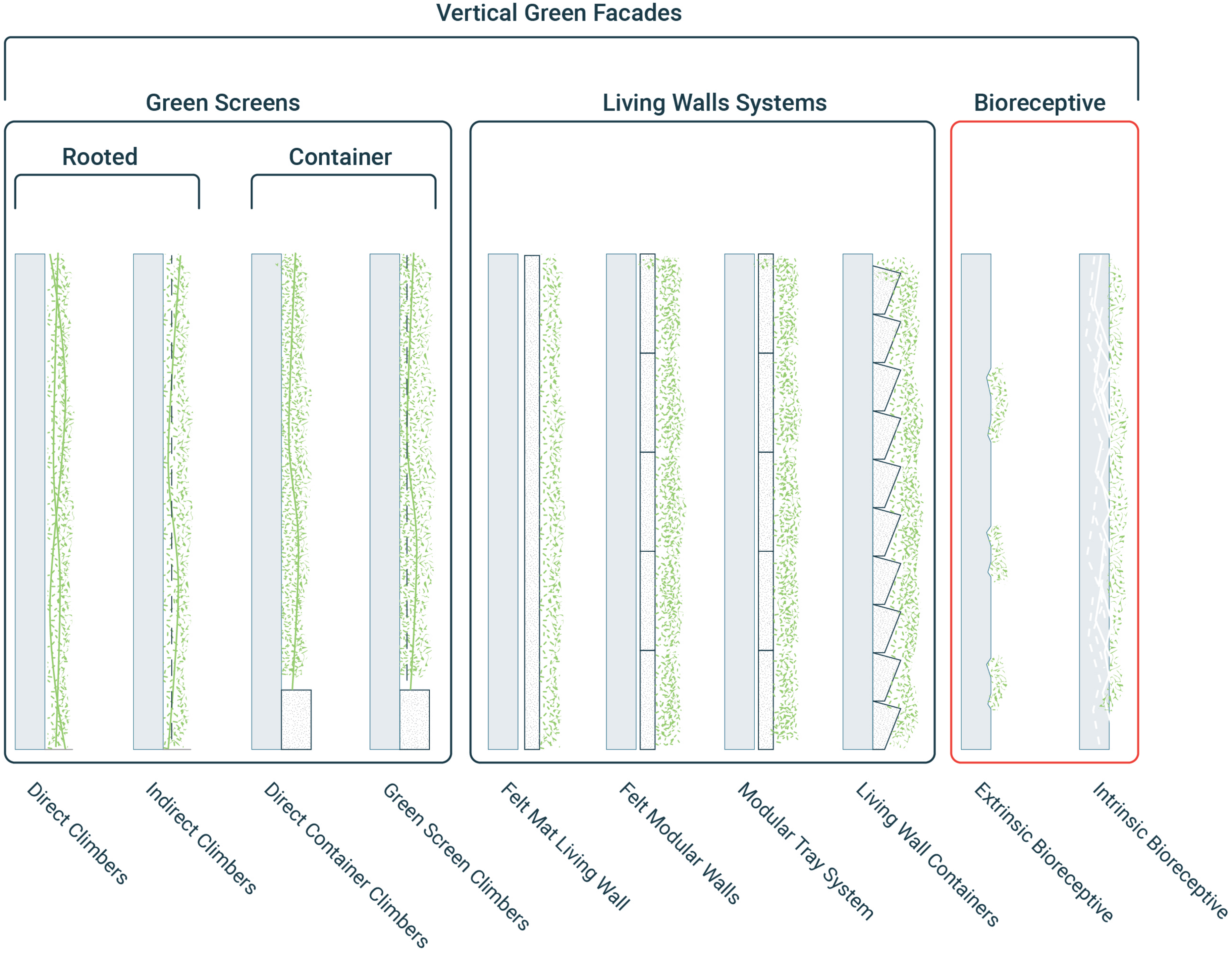
Green Facades



Vertical Green Facades

- Green Screens
  - Rooted
    - Direct Climbers
    - Indirect Climbers
  - Container
    - Direct Container Climbers
    - Green Screen Climbers
- Living Walls Systems
  - Felt Mat Living Wall
  - Felt Modular Walls
  - Modular Tray System
  - Living Wall Containers

Bioreceptive Materials



Vertical Green Facades

Green Screens

Rooted

Container

Living Walls Systems

Bioreceptive

Direct Climbers

Indirect Climbers

Direct Container Climbers

Green Screen Climbers

Felt Mat Living Wall

Felt Modular Walls

Modular Tray System

Living Wall Containers

Extrinsic Bioreceptive

Intrinsic Bioreceptive

What is Bioreceptivity?

“the aptitude of a material to be colonized by one or several groups of living organisms without necessarily undergoing any biodeterioration” (Guillitte 1995)

Moss on Tufa stone a naturally bioreceptive material

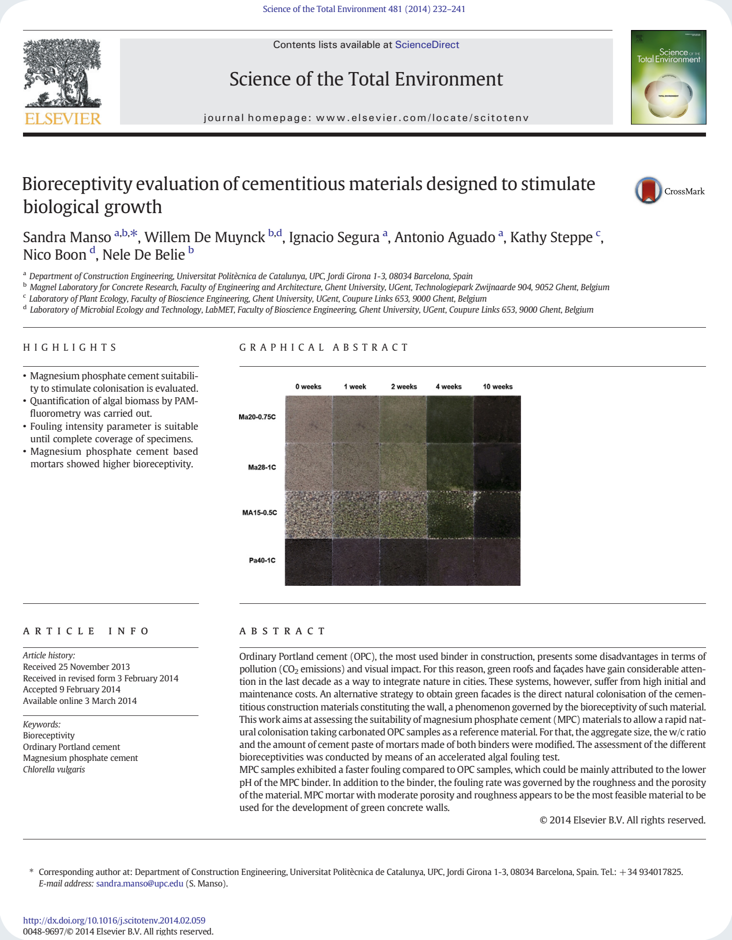
Naturally Occurring Phenomenon

Material Property that is intrinsically present
or develops over a period of time.

Understand the Phenomenon

& Recreating it

Research and Development



Science of the Total Environment 481 (2014) 232–241

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Bioreceptivity evaluation of cementitious materials designed to stimulate biological growth

Sandra Manso [a,b,*], Willem De Muynck [b,d], Ignacio Segura [a], Antonio Aguado [a], Kathy Steppe [c], Nico Boon [d], Nele De Belie [b]

[a] *Department of Construction Engineering, Universitat Politècnica de Catalunya, UPC, Jordi Girona 1-3, 08034 Barcelona, Spain*
[b] *Magnel Laboratory for Concrete Research, Faculty of Engineering and Architecture, Ghent University, UGent, Technologiepark Zwijnaarde 904, 9052 Ghent, Belgium*
[c] *Laboratory of Plant Ecology, Faculty of Bioscience Engineering, Ghent University, UGent, Coupure Links 653, 9000 Ghent, Belgium*
[d] *Laboratory of Microbial Ecology and Technology, LabMET, Faculty of Bioscience Engineering, Ghent University, UGent, Coupure Links 653, 9000 Ghent, Belgium*

HIGHLIGHTS

- Magnesium phosphate cement suitability to stimulate colonisation is evaluated.
- Quantification of algal biomass by PAM-fluorometry was carried out.
- Fouling intensity parameter is suitable until complete coverage of specimens.
- Magnesium phosphate cement based mortars showed higher bioreceptivity.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form 3 February 2014
Accepted 9 February 2014
Available online 3 March 2014

Keywords:
Bioreceptivity
Ordinary Portland cement
Magnesium phosphate cement
Chlorella vulgaris

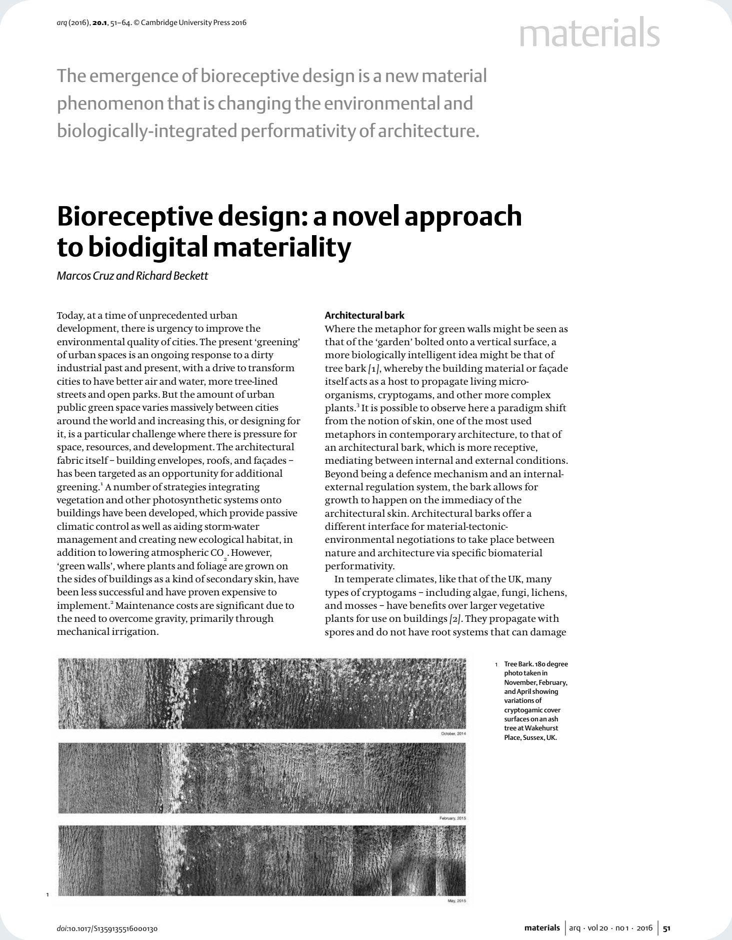
ABSTRACT

Ordinary Portland cement (OPC), the most used binder in construction, presents some disadvantages in terms of pollution (CO_2 emissions) and visual impact. For this reason, green roofs and façades have gain considerable attention in the last decade as a way to integrate nature in cities. These systems, however, suffer from high initial and maintenance costs. An alternative strategy to obtain green facades is the direct natural colonisation of the cementitious construction materials constituting the wall, a phenomenon governed by the bioreceptivity of such material. This work aims at assessing the suitability of magnesium phosphate cement (MPC) materials to allow a rapid natural colonisation taking carbonated OPC samples as a reference material. For that, the aggregate size, the w/c ratio and the amount of cement paste of mortars made of both binders were modified. The assessment of the different bioreceptivities was conducted by means of an accelerated algal fouling test.
MPC samples exhibited a faster fouling compared to OPC samples, which could be mainly attributed to the lower pH of the MPC binder. In addition to the binder, the fouling rate was governed by the roughness and the porosity of the material. MPC mortar with moderate porosity and roughness appears to be the most feasible material to be used for the development of green concrete walls.

---

[*] Corresponding author at: Department of Construction Engineering, Universitat Politècnica de Catalunya, UPC, Jordi Girona 1-3, 08034 Barcelona, Spain. Tel.: +34 934017825.
E-mail address: sandra.manso@upc.edu (S. Manso).

http://dx.doi.org/10.1016/j.scitotenv.2014.02.059
0048-9697/© 2014 Elsevier B.V. All rights reserved.



arq (2016), **20.1**, 51–64. © Cambridge University Press 2016

materials

The emergence of bioreceptive design is a new material phenomenon that is changing the environmental and biologically-integrated performativity of architecture.

Bioreceptive design: a novel approach to biodigital materiality

Marcos Cruz and Richard Beckett

Today, at a time of unprecedented urban development, there is urgency to improve the environmental quality of cities. The present 'greening' of urban spaces is an ongoing response to a dirty industrial past and present, with a drive to transform cities to have better air and water, more tree-lined streets and open parks. But the amount of urban public green space varies massively between cities around the world and increasing this, or designing for it, is a particular challenge where there is pressure for space, resources, and development. The architectural fabric itself – building envelopes, roofs, and façades – has been targeted as an opportunity for additional greening.[1] A number of strategies integrating vegetation and other photosynthetic systems onto buildings have been developed, which provide passive climatic control as well as aiding storm-water management and creating new ecological habitat, in addition to lowering atmospheric CO_2. However, 'green walls', where plants and foliage are grown on the sides of buildings as a kind of secondary skin, have been less successful and have proven expensive to implement.[2] Maintenance costs are significant due to the need to overcome gravity, primarily through mechanical irrigation.

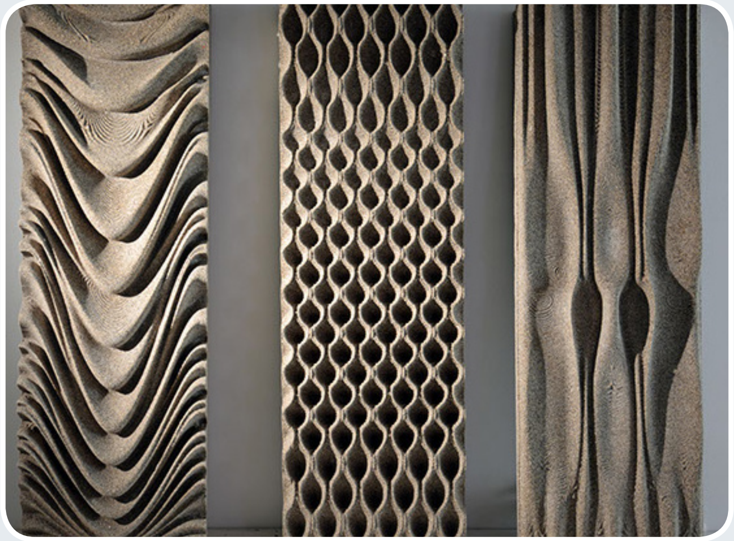
Architectural bark

Where the metaphor for green walls might be seen as that of the 'garden' bolted onto a vertical surface, a more biologically intelligent idea might be that of tree bark *[1]*, whereby the building material or façade itself acts as a host to propagate living micro-organisms, cryptogams, and other more complex plants.[3] It is possible to observe here a paradigm shift from the notion of skin, one of the most used metaphors in contemporary architecture, to that of an architectural bark, which is more receptive, mediating between internal and external conditions. Beyond being a defence mechanism and an internal-external regulation system, the bark allows for growth to happen on the immediacy of the architectural skin. Architectural barks offer a different interface for material-tectonic-environmental negotiations to take place between nature and architecture via specific biomaterial performativity.

In temperate climates, like that of the UK, many types of cryptogams – including algae, fungi, lichens, and mosses – have benefits over larger vegetative plants for use on buildings *[2]*. They propagate with spores and do not have root systems that can damage

1 **Tree Bark. 180 degree photo taken in November, February, and April showing variations of cryptogamic cover surfaces on an ash tree at Wakehurst Place, Sussex, UK.**

doi:10.1017/S1359135516000130



What is the benefit of using bioreceptive materials?

- Adding greenery - Biophillic Design
- Creating Biodiversity
- Cleaning the Air
- Creating Habitat
- Reducing Surface Temperatures

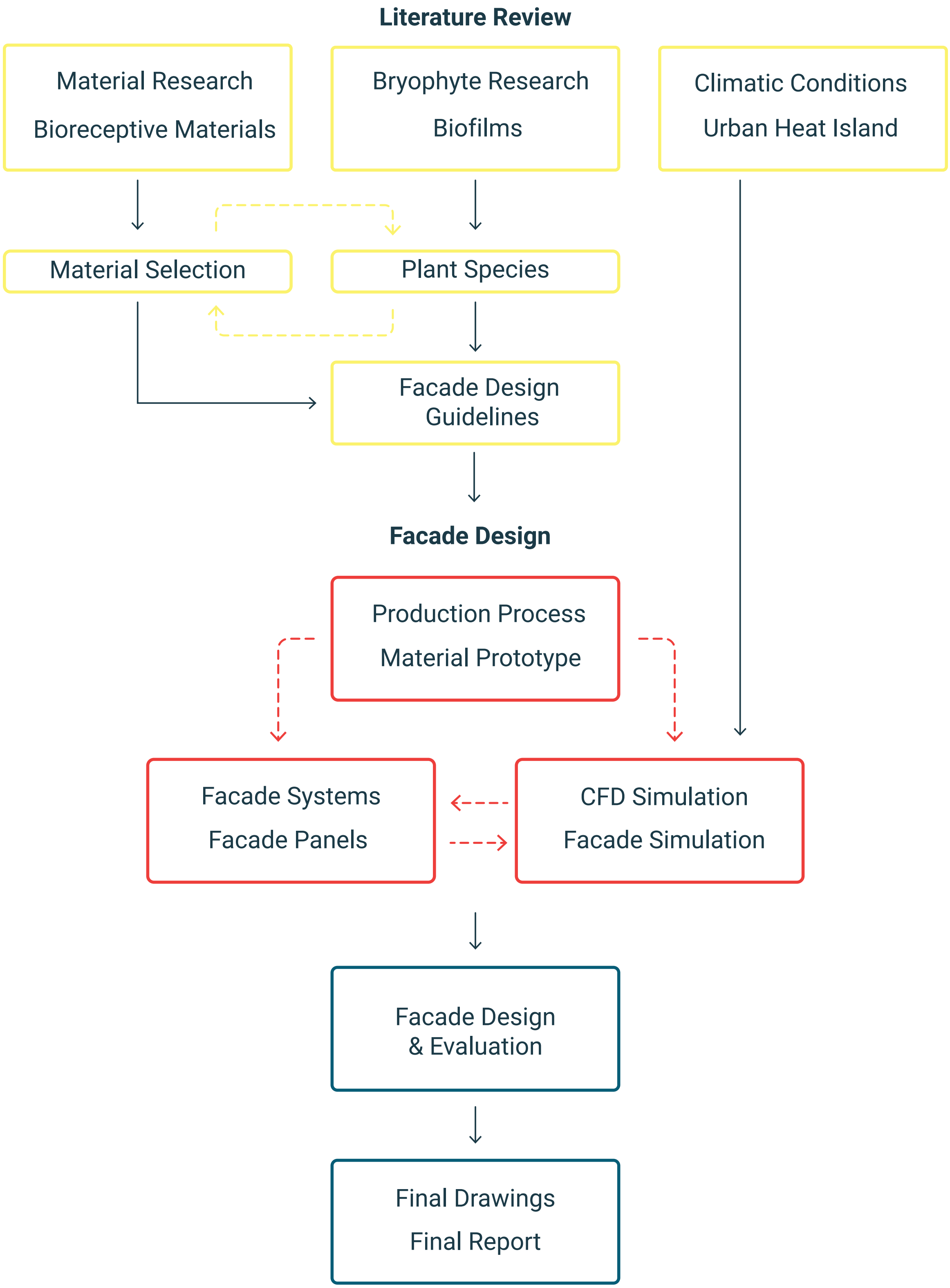
How can bioreceptive materials be integrated into urban facades to reduce external surface temperatures?

Literature Review:

- Investigate the properties of bioreceptivity
- Understand the limitations and potentials
- Grasp the biological requirements for growth

Literature Matrix:

Theme / Source	Bioreceptivity	Materials	MPC	Biofilm	Bryophytes Biology	Moss Selection	Moss Habitat	Urban Green Facades	Urban Enviornment	Urban Heat Island (UHI)	UHI Netherlands
Working on the Delta. The Decisions to Keep the Netherlands Safe and Liveable									X	X	X
Assessment of vertical element distribution in street canyons using the moss Sphagnum girgensohnii							X		X		
Bioreceptivity: a new concept for building ecology studies	X	X		X							
Biofilm colonization of metamorphic lithotypes of a renaissance cathedral exposed to urban atmosphere	X			X					X		
Enhancing microalgae biofilm formation and growth by fabricating microgrooves onto the substrate surface.	X	X		X							
Reasons to adapt to urban heat (in the Netherlands)									X	X	X
Bioreceptivity evaluation of cementitious materials designed to stimulate biological growth.	X	X	X	X							
Development of a low pH cementitious material to enlarge bioreceptivity.	X	X	X	X							
Bioreceptivity of building stones: A review.	X			X							
The Green Building Envelope								X	X		
Quantitative moss cell biology.					X	X	X				
A review of energy characteristic of vertical greenery systems.								X			
Effects of the urban environmental conditions on the physiology of lichen and moss.					X		X		X		
Mold growth and moss growth on tropical walls.	X	X			X						
Heat waves and urban heat islands in Europe: A review of relevant drivers									X	X	X
Bioreceptive design: a novel approach to biodigital materiality.	X	X		X	X	X		X			
Preparation and properties of magnesium phosphate cement foam concrete with H2O2 as foaming agent		X	X								
Dutch Bryological and Lichenological Society					X	X					
Effects of convection heat transfer on Sunagoke moss green roof: A laboratory study.					X				X	X	
Hotterdam. How space is making Rotterdam warmer, how this affects the health of its inhabitants, and what can be done about it								X	X	X	X
Bryophyte Ecology				X	X	X	X				



Literature Review

Material Research
Bioreceptive Materials

Bryophyte Research
Biofilms

Climatic Conditions
Urban Heat Island

Material Selection

Plant Species

Facade Design
Guidelines

Facade Design

Production Process
Material Prototype

Facade Systems
Facade Panels

CFD Simulation
Facade Simulation

Facade Design
& Evaluation

Final Drawings
Final Report

The Science of the Total Environment 167 (1995) 215–220

Bioreceptivity: a new concept for building ecology studies

O. Guillitte

Unité d'Enseignement et de Recherche de Biologie Végétale, Faculté des Sciences Agronomiques, Passage des Déportés 2, B-5030 Gembloux, Belgium

Abstract

A definition of the concept of bioreceptivity as the ability of a material to be colonised by living organisms is given. Related terms, such as primary, secondary, tertiary, intrinsic, extrinsic and semi-extrinsic bioreceptivity, and bioreceptivity index are also explained. The usefulness, possible uses and methodological issues arising from this concept are discussed.

Keywords: Bioreceptivity; Building ecology studies; Building material colonization

1. Introduction

Many building materials are prone to colonisation by living organisms. This colonisation causes changes in colour and in the chemical or physical properties of the materials. Since the late-60s, these changes have been grouped under the terms 'biodegradation' or 'biodeterioration'. The latter seems to be used mainly in connection with material degradation; it is missing in many specialised dictionaries in favour of the word 'biodegradation' which applies more widely to the biological degradation of substances or well-defined chemical compounds. These terms tend to give 'colonisation' negative and sometimes entirely subjective connotations. Indeed, the invasion of materials by living organisms does not necessarily lead to physical and chemical degradation but simply to reversible colour changes that are perceived differently according to the type of construction, the location and the person studying them. On the contrary, some authors consider the colour changes to be aesthetically pleasing [1], credit them with a protective role against man- or weather-induced aggression [2–4] and suggest that they have a cleansing effect which benefits the environment [5].

Therefore, if one wishes to study the colonisation of materials without being biased by its effects on the materials, one should not limit oneself to those characteristics affected by the colonisation but should include those that allow colonisation to take place. The precise role of the building material characteristics in the colonisation process is not fully understood, with the exception of acidity, whose influence on the taxonomic content of colonising organisms is well known. In a previous work [5] on the kinetics of

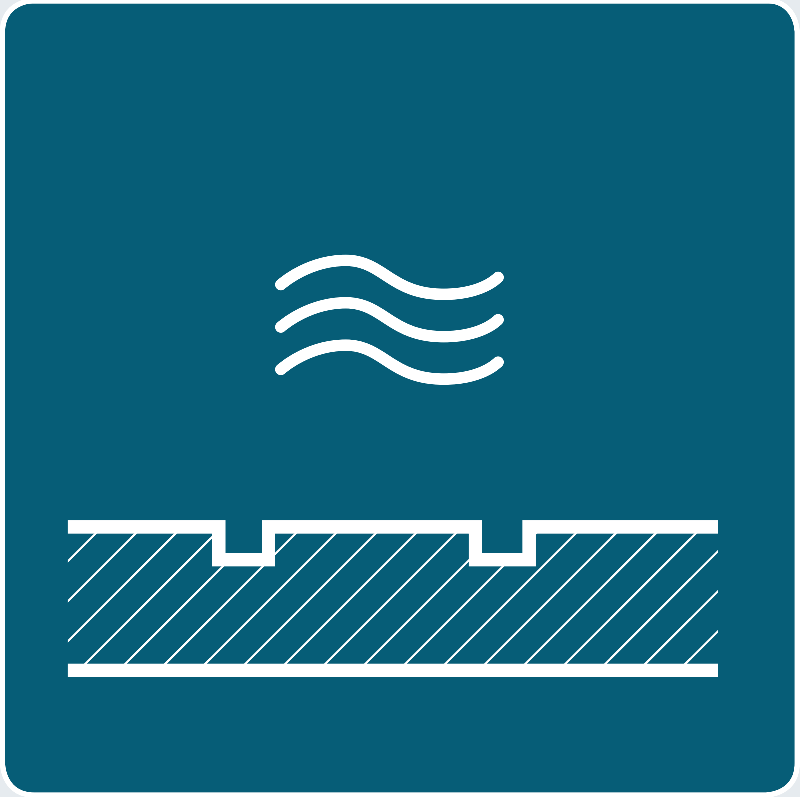
SSDI 0048-9697(95)04582-8

Translate research into design criteria

Environmental Conditions + **Bryophytes** + **Bioreceptive Material**

Surface Grooves & Wind:

Grooves on the surface of a material can create turbulence along the surface, forming pockets of air with lower wind speeds that would otherwise not exist. *

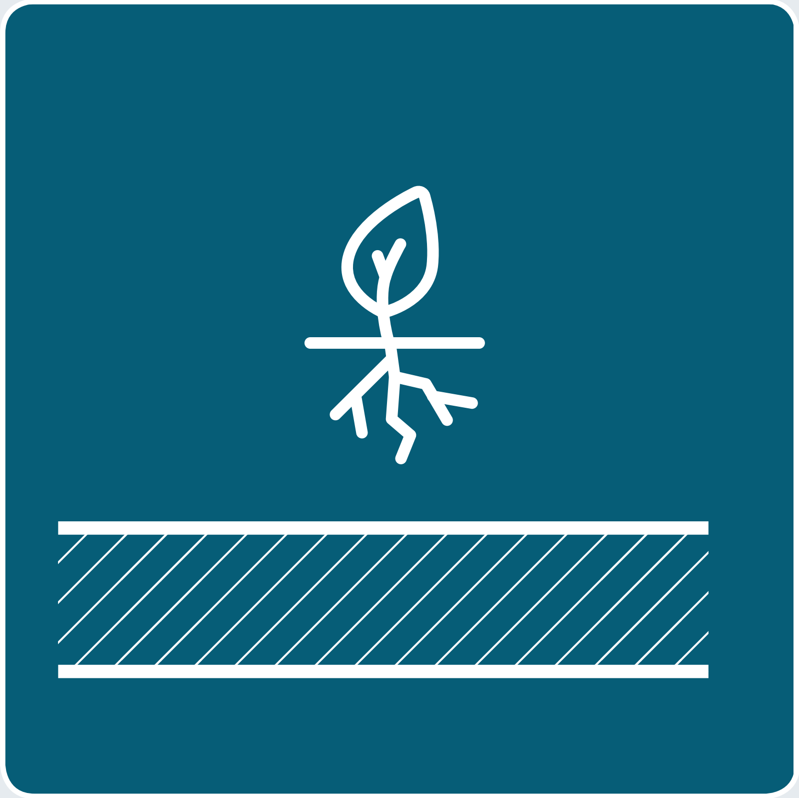


* Enhancing microalgae biofilm formation and growth by fabricating microgrooves onto the substrate surface.

Huang, Y., Zheng, Y., Li, J., Liao, Q., Fu, Q., & Xia, A. et al. (2018)

Surface & Rooting

Bryophyte spores are often carried by* the wind, higher wind speed can simply push the spores away from the surface. Mosses usually spread into areas where spores can settle, like crevasse in stone or bark.

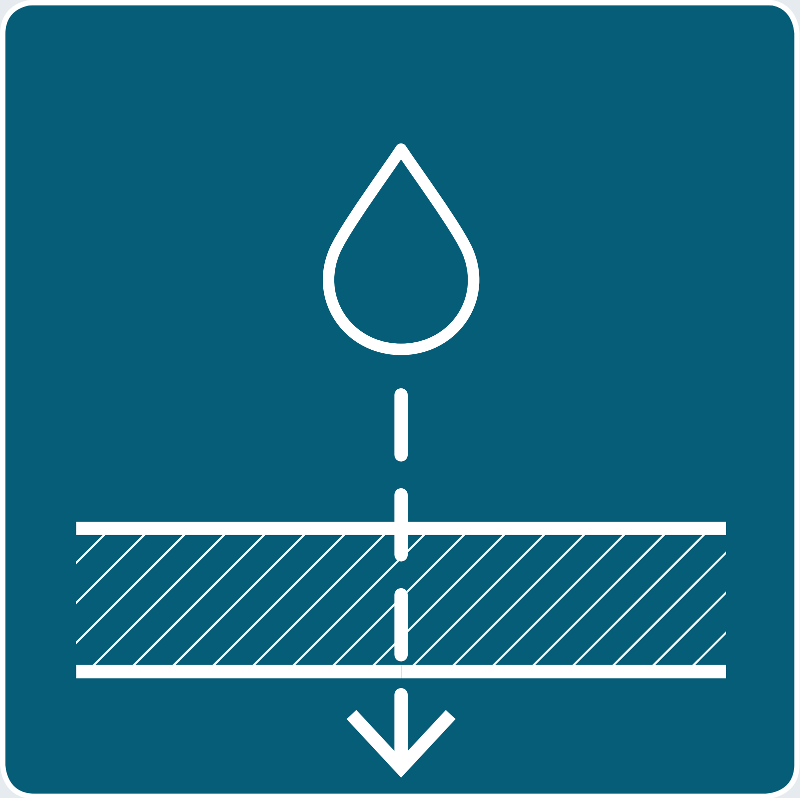


* Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Glime, J. (2017)

Porosity:

Most natural materials have pre-defined porosities, porosity is a key determining factor for bioreceptivity and the development of biofilms. *



* Bioreceptivity of building stones: A review.

Miller, A., Sanmartín, P., Pereira-Pardo, L., Dionísio, A., Saiz-Jimenez, C., Macedo, M., & Prieto, B. (2012)

Material pH:

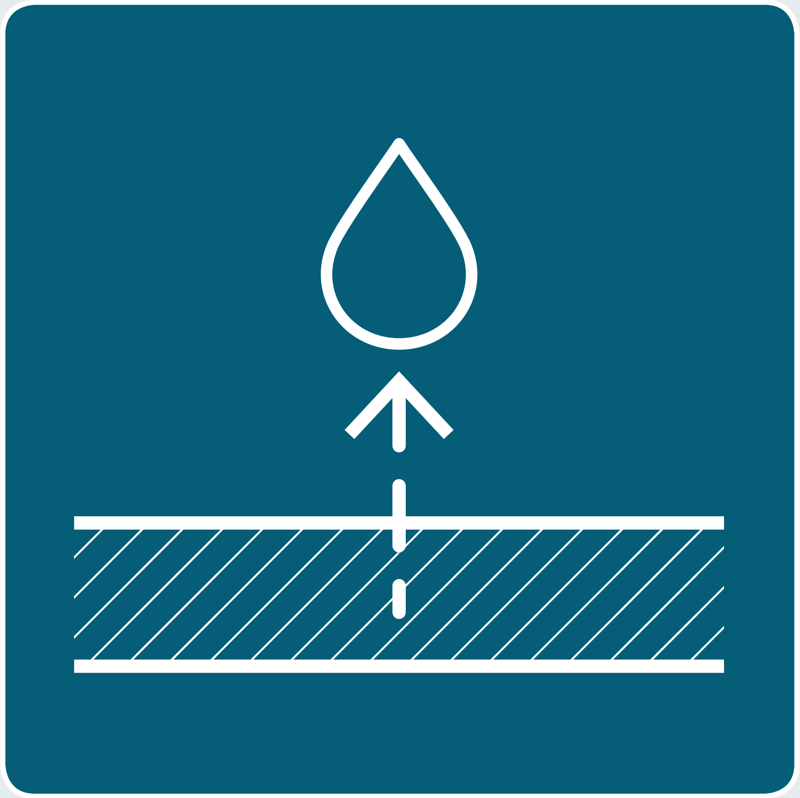
Material should have a pH level that is* as neutral as possible. Most species prefer slightly acidic substrates rather than alkali.

* Development of a low pH cementitious material to enlarge bioreceptivity.

Manso, S., Mestres, G., Ginebra, M., De Belie, N., Segura, I., & Aguado, A. (2014).

Surface Moisture:

Increasing porosity and creating an open cell pore structure creates a more permeable material that is capable of retain water for longer periods of time. *

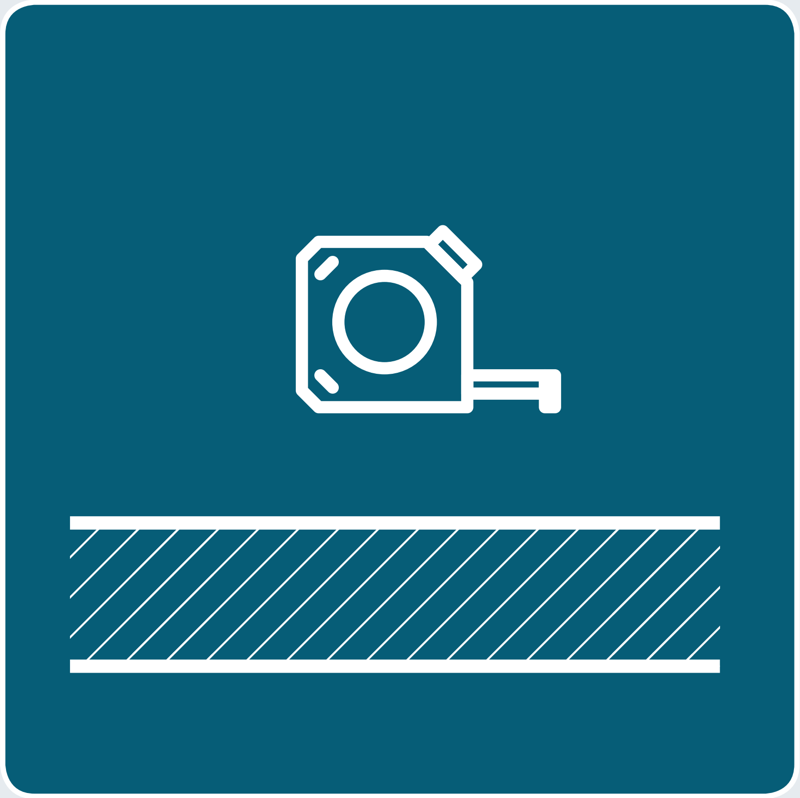


* Mold growth and moss growth on tropical walls.

Udawattha, C., Galkanda, H., Ariyarathne, I., Jayasinghe, G., & Halwatura, R. (2018).

Material Dimensions:

Higher porosity and pore size creates * weaker and more brittle materials. To counter this, a thick material should be created to prevent cracking.



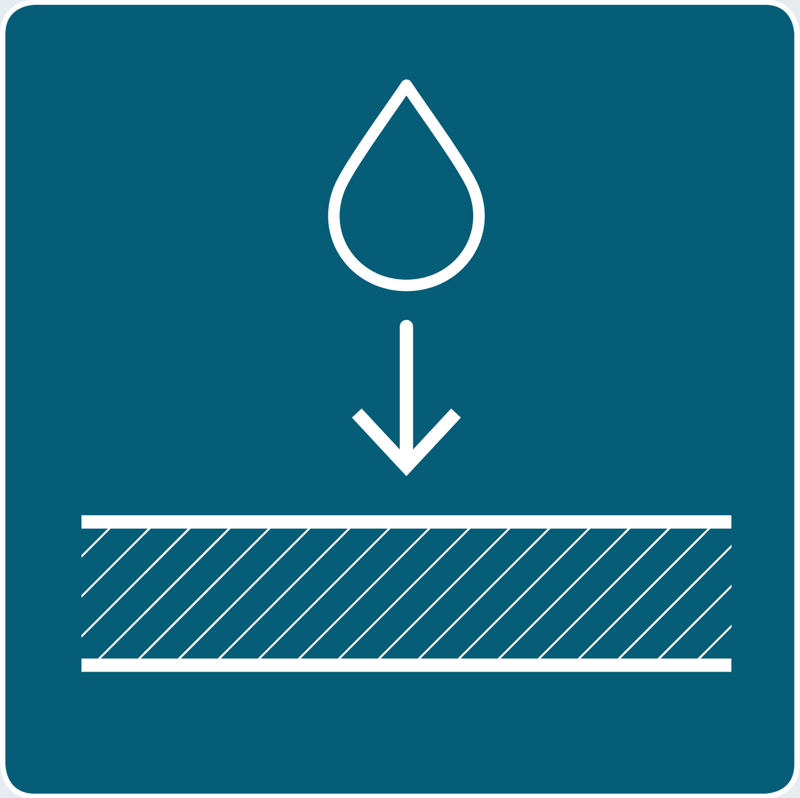
*

Preparation and properties of magnesium phosphate cement foam concrete with H_2O_2 as foaming agent.

Li, T., Wang, Z., Zhou, T., He, Y., & Huang, F. (2019)

Irrigation:

Extreme wind are present at higher elevation which increases the evaporation rates, causing some areas to dry out faster than others. Irrigation can prevent this. Although it may not actively be use an irrigation system may be needed during period of low rainfall to prevent dormancy and die off. *



*

Irrigation of ‘Green walls’ is necessary to avoid drought stress of vegetation

Medl, A., Florineth, F., Kikuta, S., & Mayr, S. (2018)

Solar Exposure:

Solar orientation of the facade panel * can be a determining factor for the species selection. Different sun exposures can be suitable for different specimens and the ideal conditions for the species should be selected. Additionally, a sudden change in solar orientation can cause the bryophyte to go into shock and stunt growth.

* Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Glime, J. (2017)

Facade Metals:

Some metals are toxic to bryophytes, * this includes zinc, copper, lead and mercury. Zinc and copper are commonly used and should be avoided.

* Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Glime, J. (2017)

Water Source:

Rainwater runoff should be properly filtered for metals and contaminants before being used as an irrigation source. Chloride should also be avoided. *

* Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Glime, J. (2017)

Nutrition:

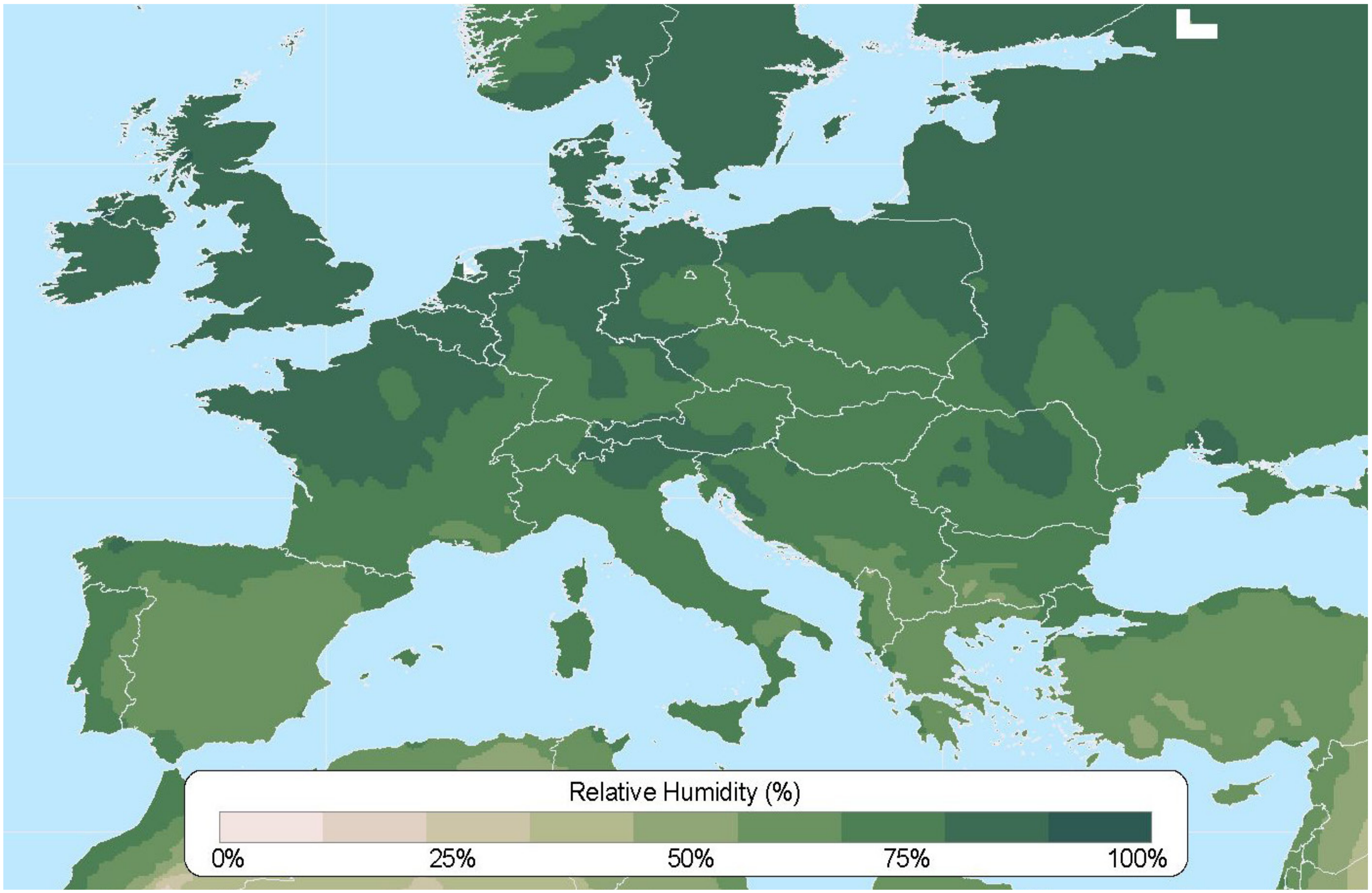
Bryophytes gain their nutrients from * air and water, not soil. Periodically the plants need to be fertilized given no natural organic matter is present. Liquid NPK fertilizer would be an ideal solution.

* Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Glime, J. (2017)

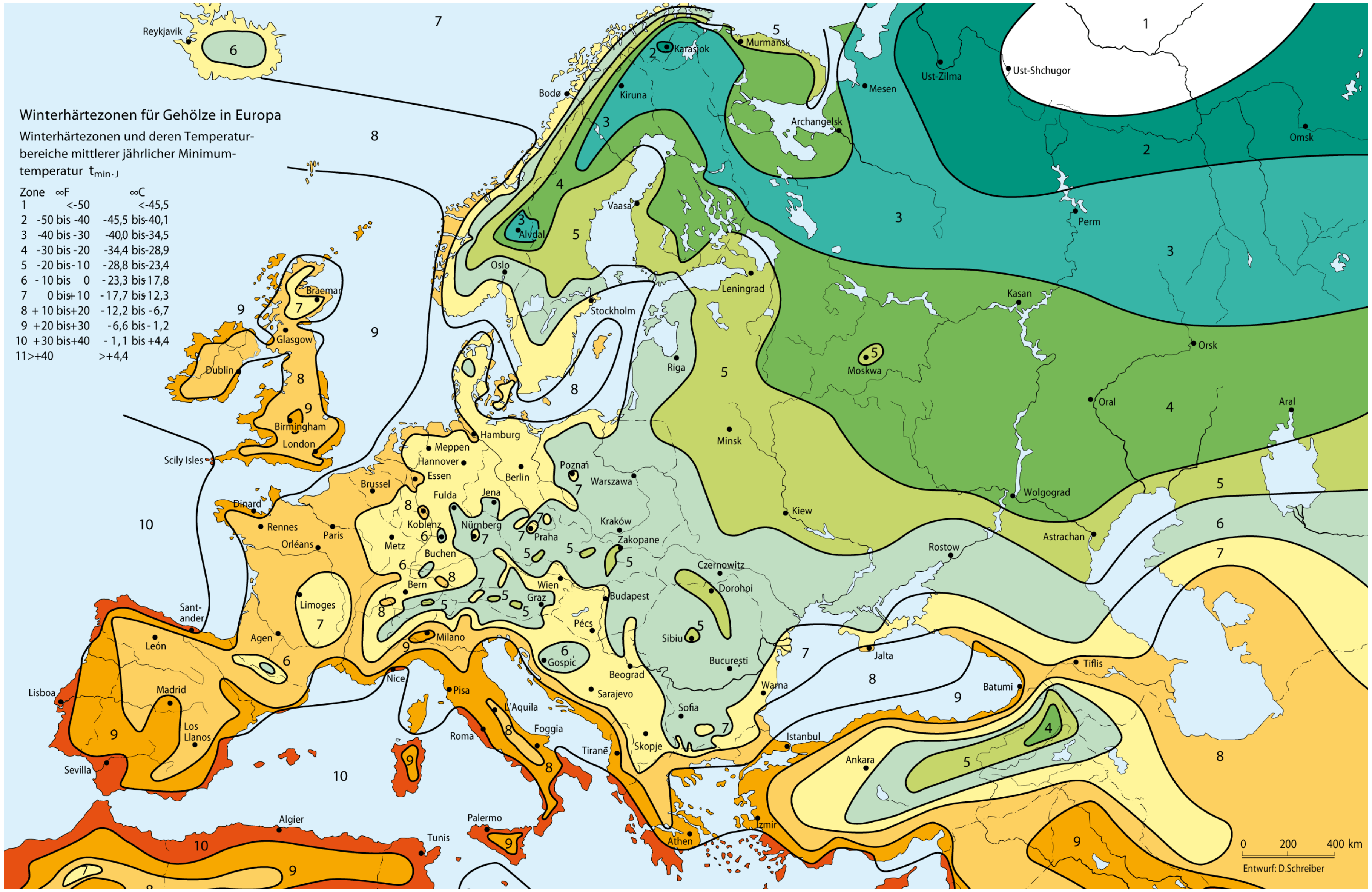
Environmental Conditions

Regional Conditions:



Relative Humidity
arid areas are not ideal for bryophytes

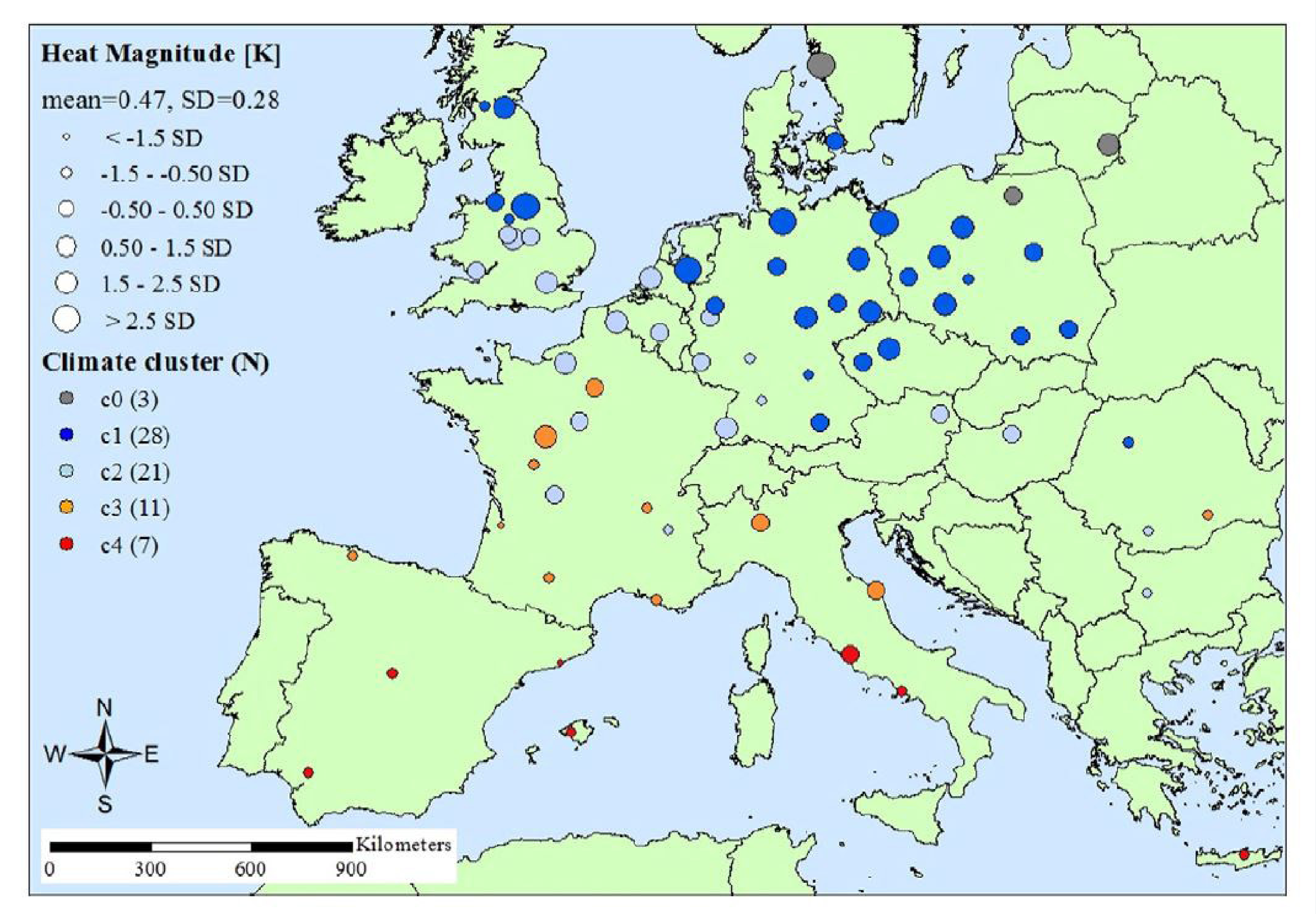
Regional Conditions:



Hardiness Zones
prolonged freezing is not ideal

https://www.gardenia.net/guide/european-hardiness-zones

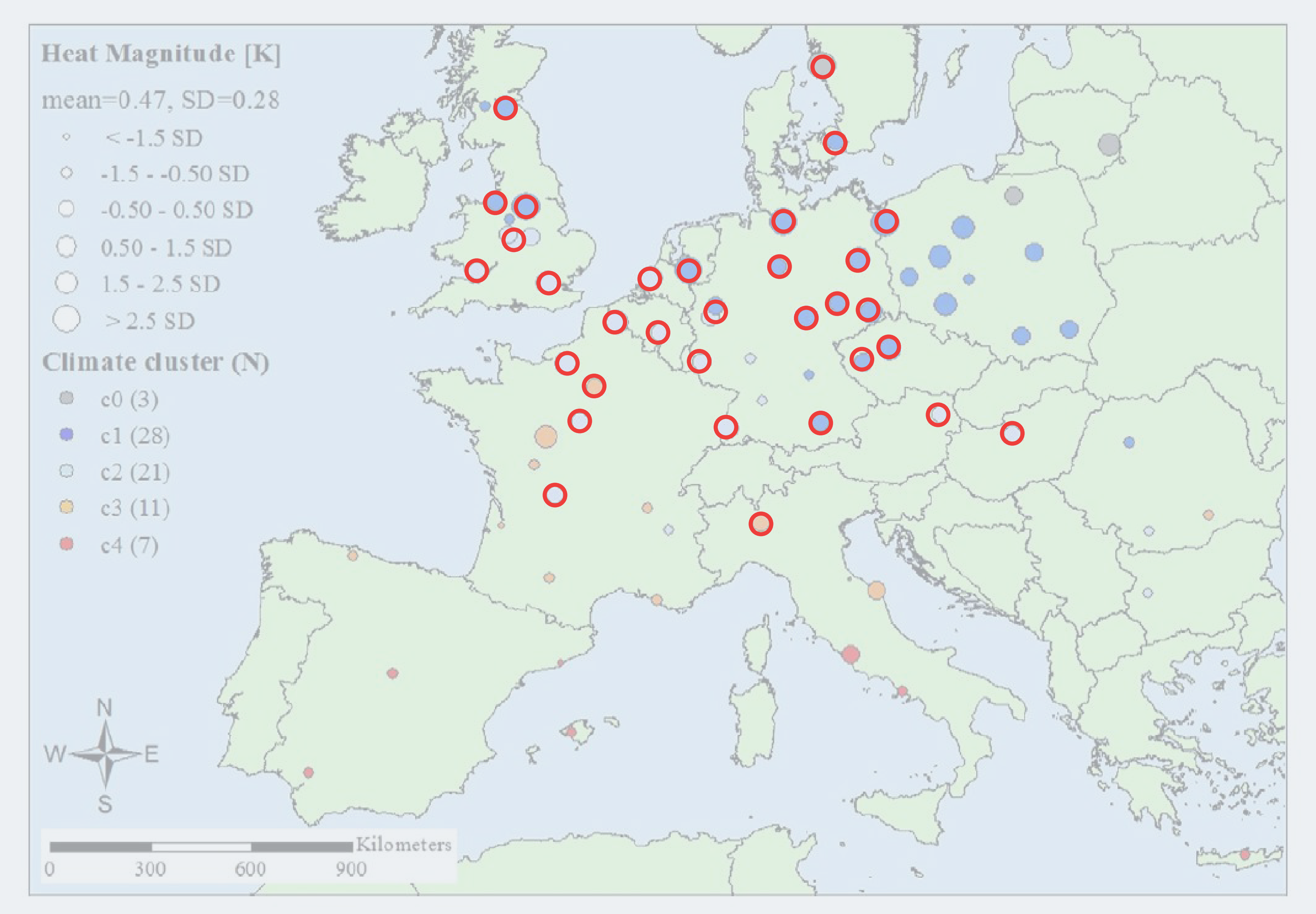
Urban Conditions:



Heat Magnitude
cooler climates are more vulnerable

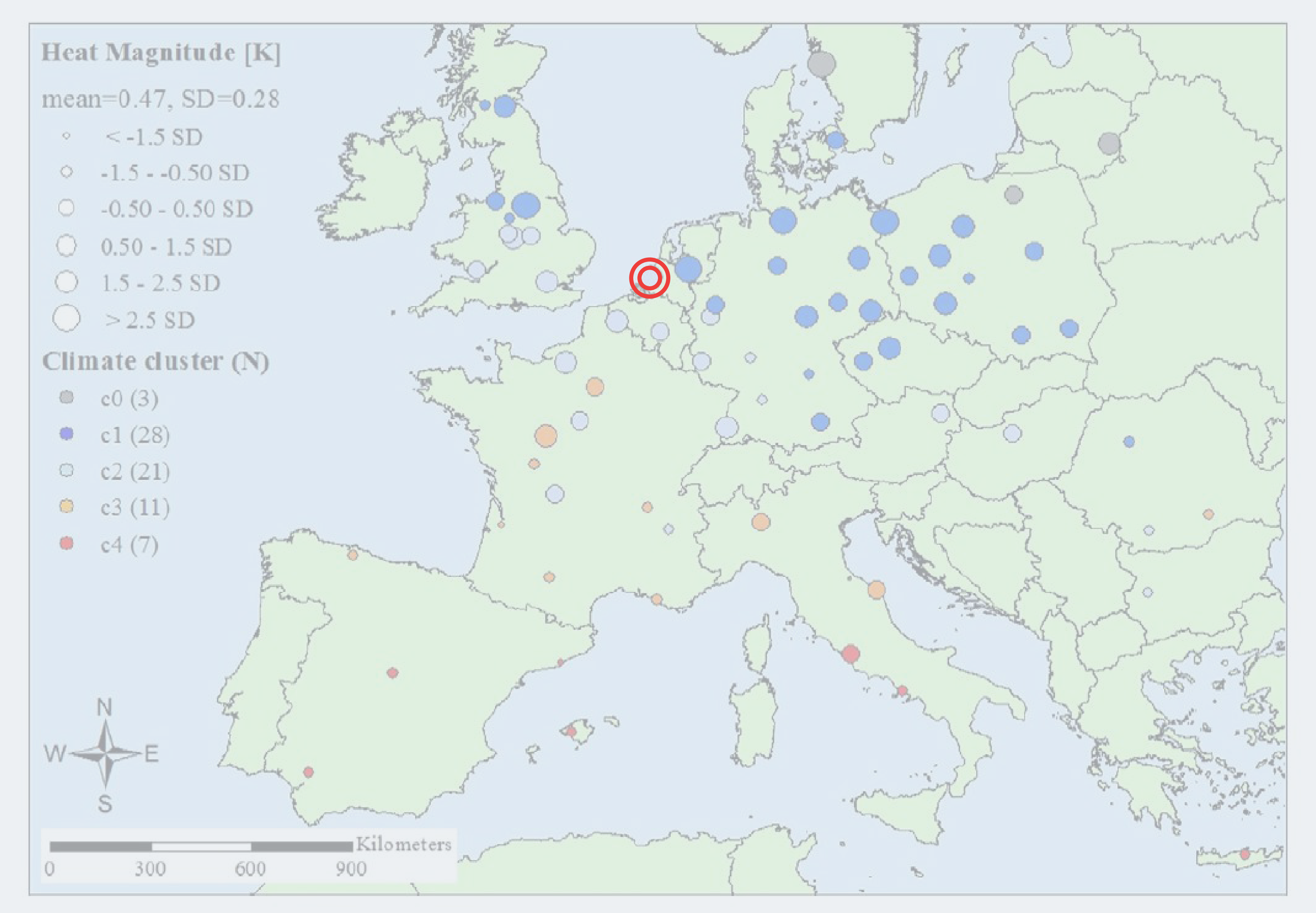
Heat waves and urban heat islands in Europe: A review of relevant drivers

Potential Sites:



Potential Application
UHI, Humidity and Hardiness

Location:



Rotterdam
Potential Application

Rotterdam:

Hotterdam

How space is making Rotterdam warmer, how this affects the health of its inhabitants, and what can be done about it.

TU Delft, Architecture and the Built Environment
Frank van der Hoeven
Alexander Wandl

Hotterdam. How space is making Rotterdam warmer, how this affects the health of its inhabitants, and what can be done about it

Urban Climate 23 (2018) 342–351

Contents lists available at ScienceDirect

Urban Climate

journal homepage: http://www.elsevier.com/locate/uclim

Reasons to adapt to urban heat (in the Netherlands)

E.J. (Lisette) Klok *, J. (Jeroen) Kluck

Amsterdam University of Applied Sciences, Urban Technology, Weesperzijde 190, 1097 DZ Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 30 May 2016
Received in revised form 12 September 2016
Accepted 21 October 2016

Keywords:
Urban heat
Climate adaptation
Urban vulnerability
Urban heat island effects
Urban governance

ABSTRACT

The future will be warmer with more tropical days, heat stress and related impacts for the healthy and liveable city. This is clear from many scientific studies and papers. Yet many local governments in the Netherlands claim to have insufficient understanding of the importance of these impacts in order to make the necessary step to climate adaptation and to take practical actions to manage the risks associated with rising heat levels. They struggle with defining the urgency of heat stress and finding good arguments for the need to adapt urban environments to rising temperatures. In order to provide urban professionals with reasons to adapt their urban environments to heat, we analyzed the potential impacts of urban heat from international policy reports and scientific literature. We summarized the impacts in a mind map. This map visualizes the large number and variety of heat-related risks. They can be subdivided into risks for health, open space, liveability, water and infrastructure networks. We believe that this mind map provides useful insight into the reasons to take heat adaptation actions. It can also be a helpful visual for urban professionals in outlining the reasons to take action for heat adaptation.

1. Introduction

Climate scenarios project more warm days and an increase in the frequency of heat waves in the Netherlands (KNMI, 2015) and Europe (Russo et al., 2015; Meehl and Tebaldi, 2004). This poses serious risks on human health, and has adverse consequences for productivity and infrastructure networks (e.g. EEA, 2012; Chapman et al., 2013). Urban areas will be particularly vulnerable to heat waves and hot days because of the urban heat island effect (Oke, 1982).

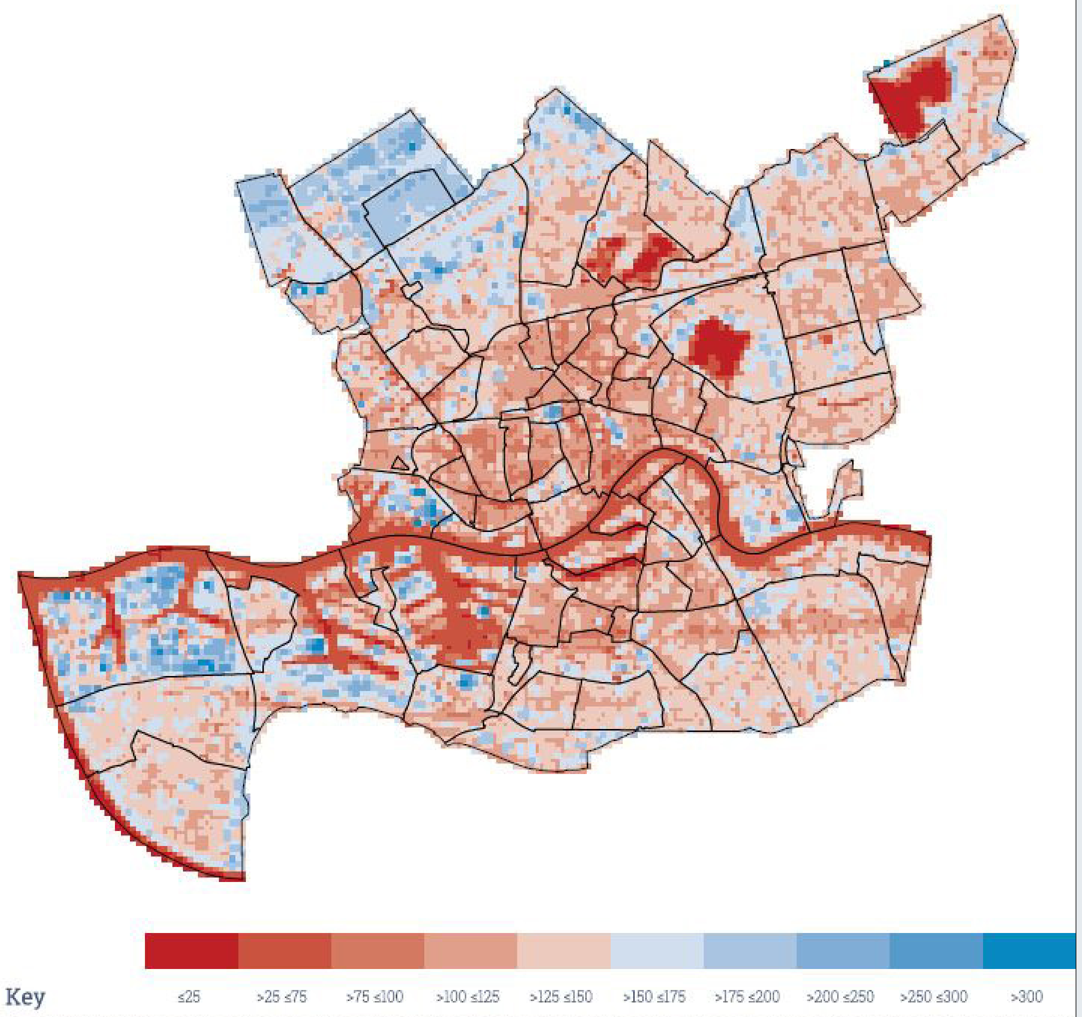
---

[*] Corresponding author.
E-mail addresses: ej.klok@hva.nl (E.J.(L.) Klok), j.kluck@hva.nl (J.(J.) Kluck)

http://dx.doi.org/10.1016/j.uclim.2016.10.005
2212-0955/© 2016 Elsevier B.V. All rights reserved.

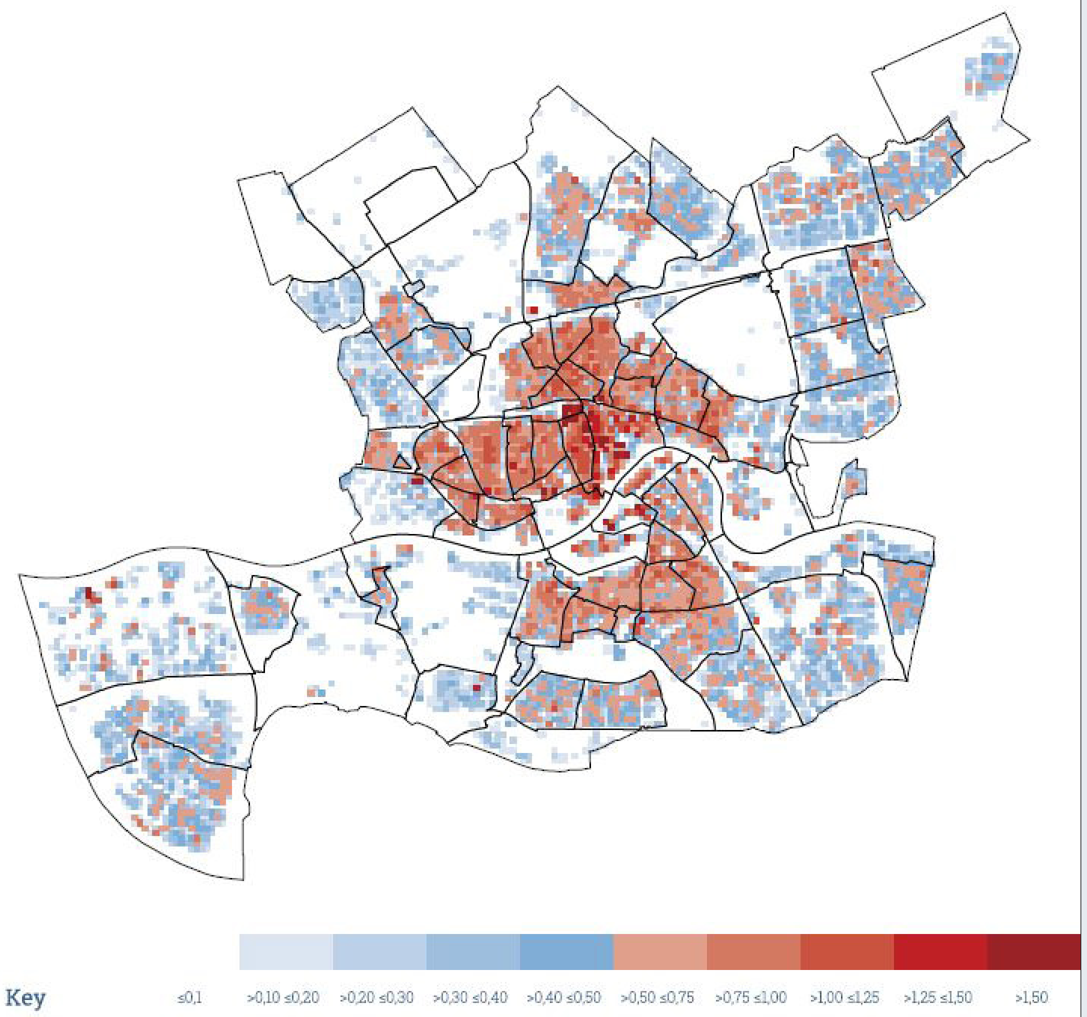
Reasons to adapt to urban heat (in the Netherlands)

Rotterdam:



Contents Albedo is an indicator that expresses the degree to which buildings, streets and the ground reflect solar radiation. In general, a high albedo value means that buildings and cities heat up less quickly.

Surface Albedo

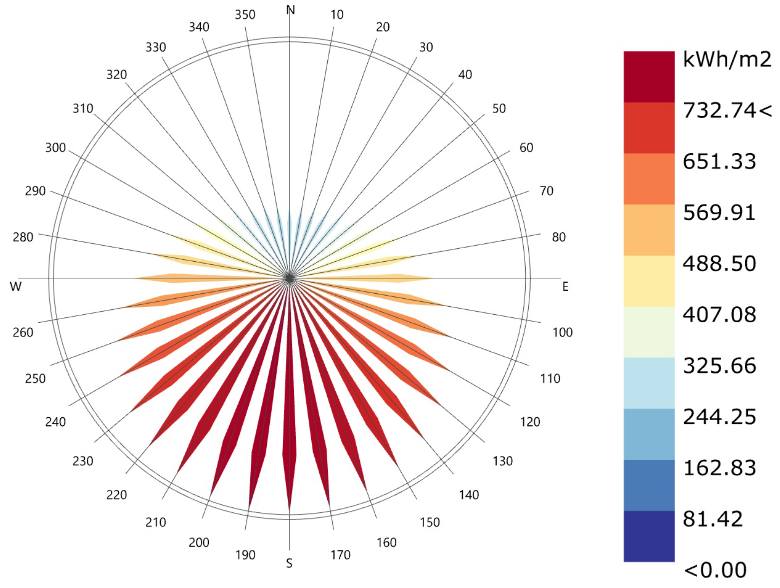


Contents The building envelope determines the degree to which a building is exposed to the sun and the sky. In the daytime, the building envelope determines how much solar radiation is received. At night, it determines how much heat is given off.

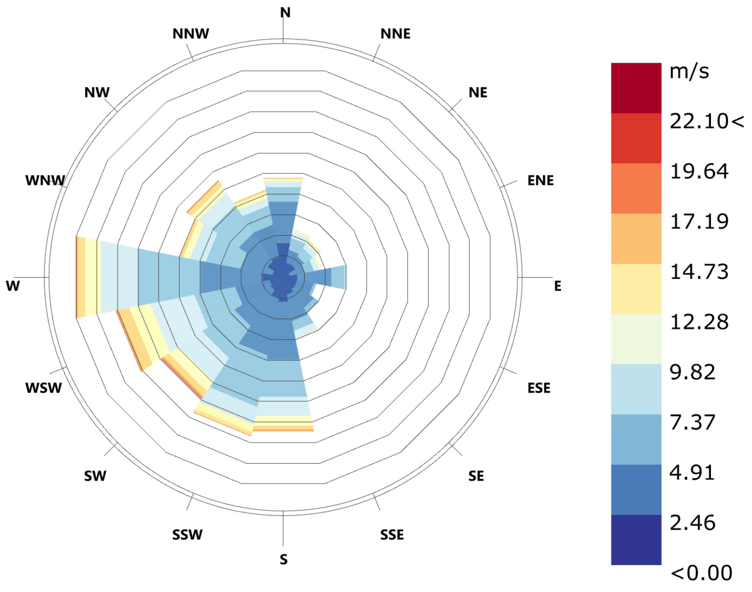
Building Envelope

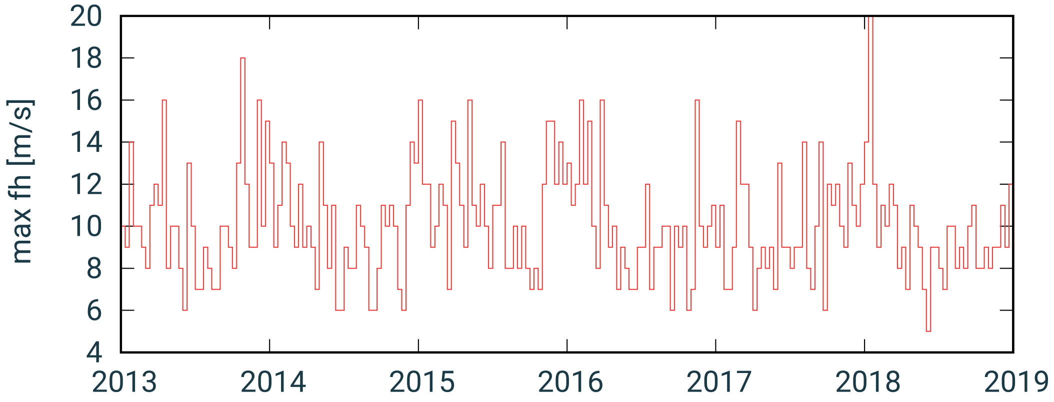
Site Weather Data:

Radiation Rose

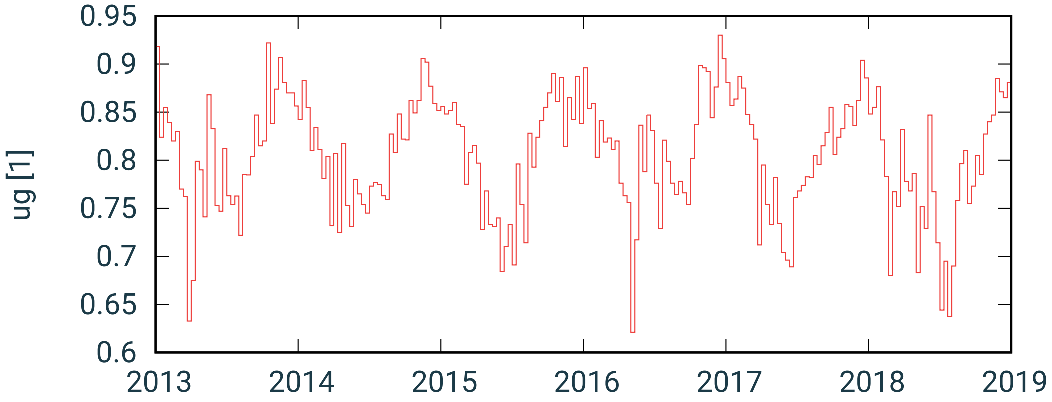


Wind-rose Rotterdam



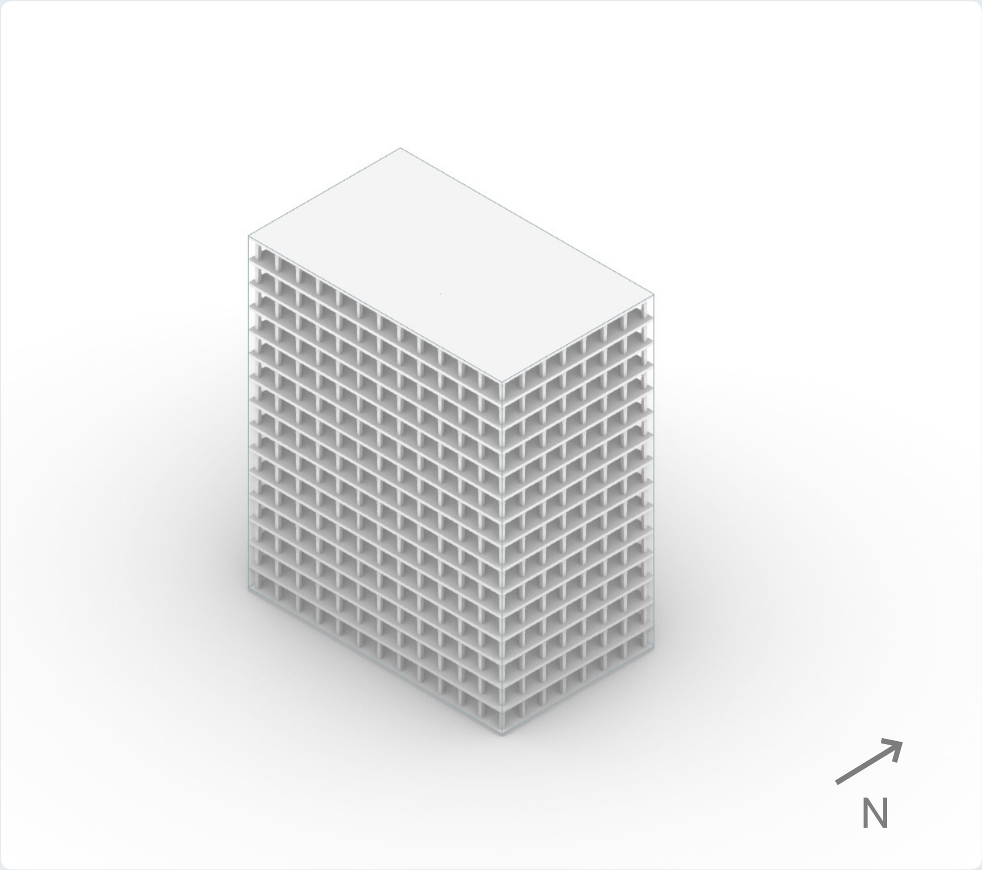


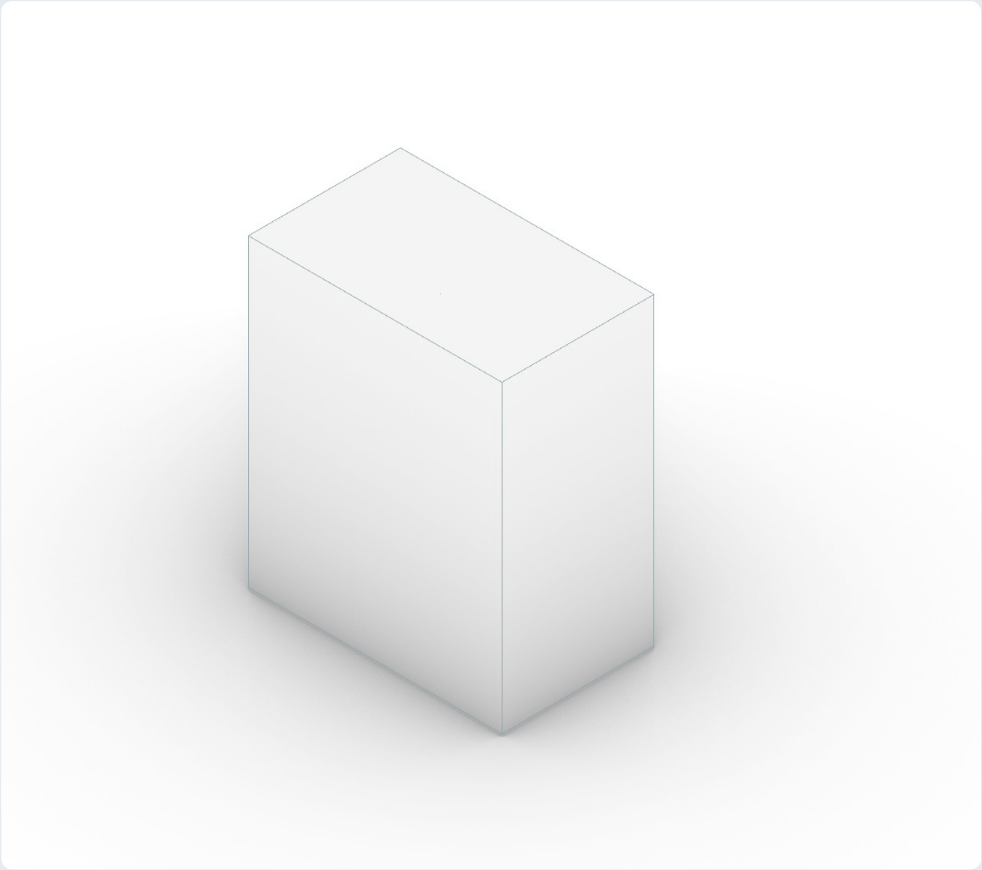
Average Max Windspeed: Rotterdam



Average Relative Humidity: Rotterdam

Case Building:





A simple massing of a building was created to simulated the basic dimensions of an average mid to high rise building ranging from 10 to 30 stories high. The building’s footprint also takes a typical rectangular shape, measuring 50 meters by 30 meters. For simulations a simple mass was used in place of a more complex geometry.

Bioreceptive Material

Potential Material:

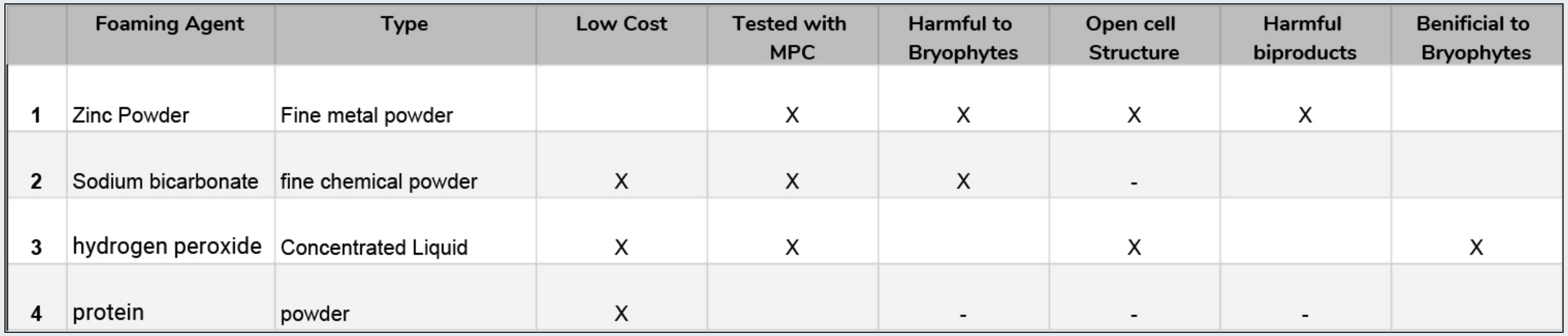
Foamed MPC Concrete

- **Control Porosity**
- **Consistent Pore size**
- **Homogeneous Material**
- **Can be cast and formed**

Preparation and properties of magnesium phosphate cement foam concrete with H2O2 as foaming agent.

Foaming Agents:

Commonly used foaming agents:
surfactant, protein, synthetic, sodium carbonate, metal powders
(zinc, alumina) and hydrogen peroxide



	Foaming Agent	Type	Low Cost	Tested with MPC	Harmful to Bryophytes	Open cell Structure	Harmful biproducts	Benificial to Bryophytes
1	Zinc Powder	Fine metal powder		X	X	X	X	
2	Sodium bicarbonate	fine chemical powder	X	X	X	-		
3	hydrogen peroxide	Concentrated Liquid	X	X		X		X
4	protein	powder	X		-	-	-	

Preparation and properties of magnesium phosphate cement foam concrete with H2O2 as foaming agent.

Hydrogen Peroxide
+
MPC

Foaming Reaction:
$H_2O_2 = H_2O + O$

Mix	Material	dead-burnt magnesia (MgO)	ammonium dihydrogen phosphate (ADP)	borax (B)	calcium stearate (CS)	manganese dioxide (MnO_2)	water (H_2O)	hydrogen peroxide (H_2O_2)	Sandstone or granite
		Percentage of Total Mixture							
1	MPC - Foamed - Low	61.1%	15.3%	7.3%	0.2%	1.5%	11.8%	2.8%	
2	MPC - Foamed - Mid	62.6%	15.7%	7.5%	0.2%	1.6%	10.7%	1.8%	
3	MPC - Foamed - High	62.7%	15.7%	7.5%	0.2%	1.9%	10.8%	1.2%	
		kg for sample speciemens (3)							
1	MPC - Foamed - Low	0.43992	0.11016	0.05256	0.00144	0.0108	0.08496	0.02016	
2	MPC - Foamed - Mid	0.67608	0.16956	0.081	0.00216	0.01728	0.11556	0.01944	
3	MPC - Foamed - High	0.90288	0.22608	0.108	0.00288	0.02736	0.15552	0.01728	
kg		2.019	0.506	0.242	0.006	0.055	0.356	0.057	
(+15%) kg		**2.322**	**0.582**	**0.278**	**0.007**	**0.064**	**0.409**	**0.065**	
Control Sample		.35	.085			.015	.1		.45
		0.756	0.1836	0	0	0.0324	0.216	0	0.972
Total kg		**3.078**	**0.765**	**0.278**	**0.007**	**0.096**	**0.625**	**0.065**	**0.972**

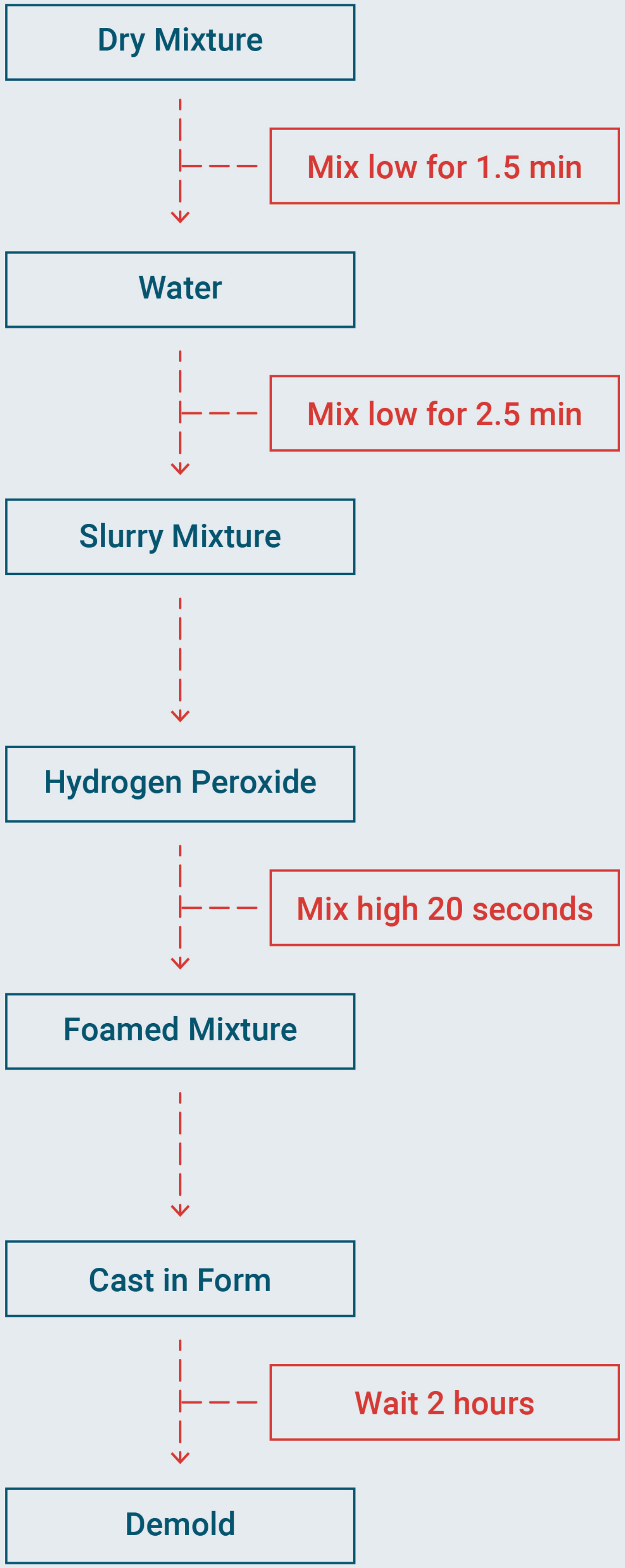
	Speciemen Dimensions	Length cm	Width cm	Height cm	Volume m^3	Number of samples	Total Volume m^3
	Flat Panel	12	20	2.5	0.0006	3	0.0018

	Material	Dry Density kg/m^3	kg
1	MPC - Foamed - Low	400	0.72
2	MPC - Foamed - Mid	600	1.08
3	MPC - Foamed - High	800	1.44
	control	1200	2.16

Mix	Material	dead-burnt magnesia (MgO)	ammonium dihydrogen phosphate (ADP)	borax (B)	calcium stearate (CS)	manganese dioxide (MnO2)	water (H2O)	hydrogen peroxide (H2O2)	Sandstone or granite
		Percentage of Total Mixture							
1	MPC - Foamed - Low	61.1%	15.3%	7.3%	0.2%	1.5%	11.8%	2.8%	
2	MPC - Foamed - Mid	62.6%	15.7%	7.5%	0.2%	1.6%	10.7%	1.8%	
3	MPC - Foamed - High	62.7%	15.7%	7.5%	0.2%	1.9%	10.8%	1.2%	
		kg for sample speciemens (3)							
1	MPC - Foamed - Low	0.43992	0.11016	0.05256	0.00144	0.0108	0.08496	0.02016	
2	MPC - Foamed - Mid	0.67608	0.16956	0.081	0.00216	0.01728	0.11556	0.01944	
3	MPC - Foamed - High	0.90288	0.22608	0.108	0.00288	0.02736	0.15552	0.01728	
kg		2.019	0.506	0.242	0.006	0.055	0.356	0.057	
(+15%) kg		**2.322**	**0.582**	**0.278**	**0.007**	**0.064**	**0.409**	**0.065**	
Control Sample		.35	.085			.015	.1		.45
		0.756	0.1836	0	0	0.0324	0.216	0	0.972
Total kg		**3.078**	**0.765**	**0.278**	**0.007**	**0.096**	**0.625**	**0.065**	**0.972**

	Speciemen Dimensions	Length cm	Width cm	Height cm	Volume m^3	Number of samples	Total Volume m^3
	Flat Panel	12	20	2.5	0.0006	3	0.0018

	Material	Dry Density kg/m^3	kg
1	MPC - Foamed - Low	400	0.72
2	MPC - Foamed - Mid	600	1.08
3	MPC - Foamed - High	800	1.44
	control	1200	2.16



Dry Mixture
Mix low for 1.5 min
Water
Mix low for 2.5 min
Slurry Mixture
Hydrogen Peroxide
Mix high 20 seconds
Foamed Mixture
Cast in Form
Wait 2 hours
Demold

Bryophytes

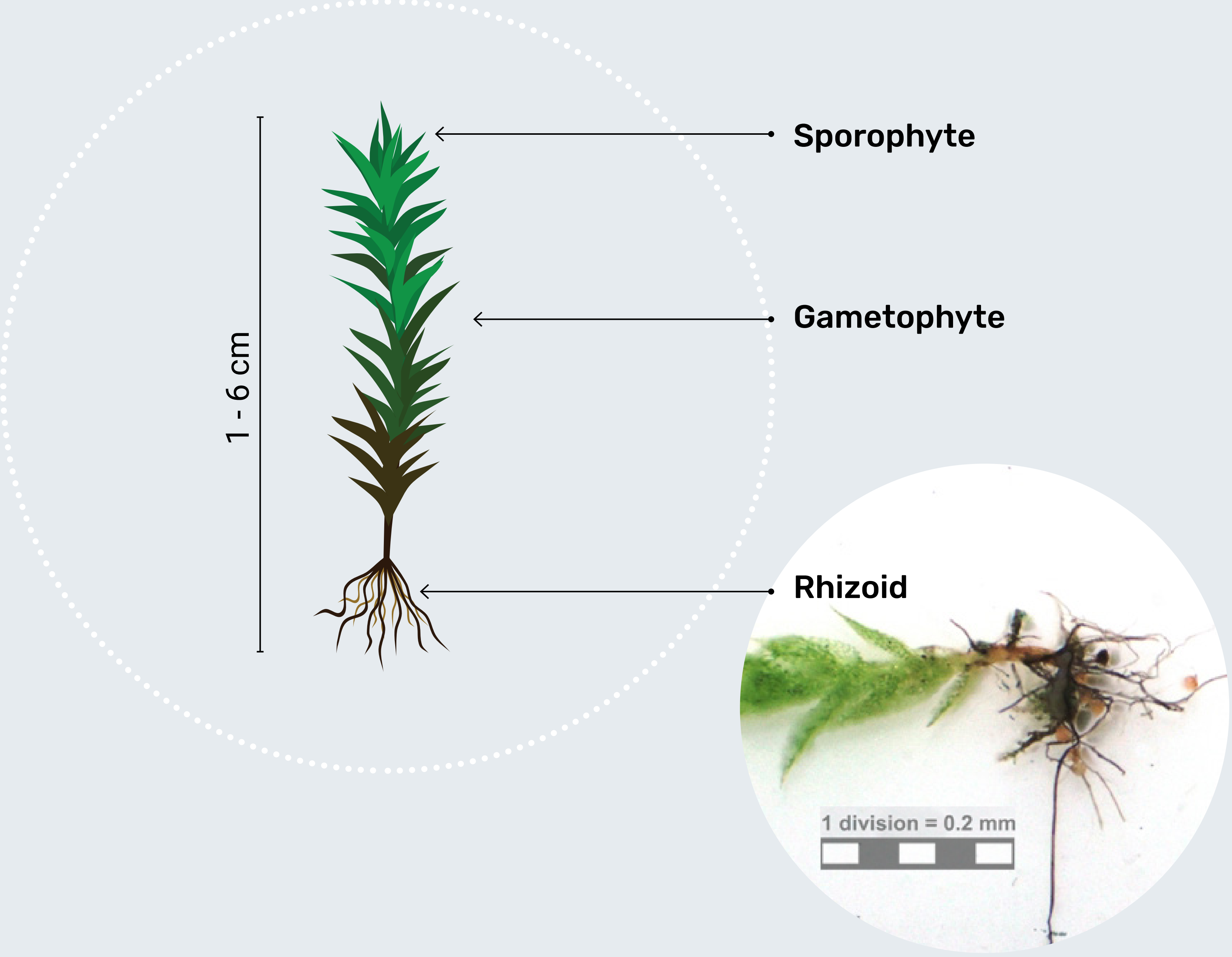

Liverwort
Moss


Moss
Liverwort

Why Moss?

Benefits:

- Compact height
- Dense form
- 90% photosynthetic cells
- Air purification
- No soil required
- Gain nutrients from air/water
- No seeding
- Resilient to extreme weather
- Low maintenance
- Acoustics
- Biodiversity
- Fire resistant
- High water retention



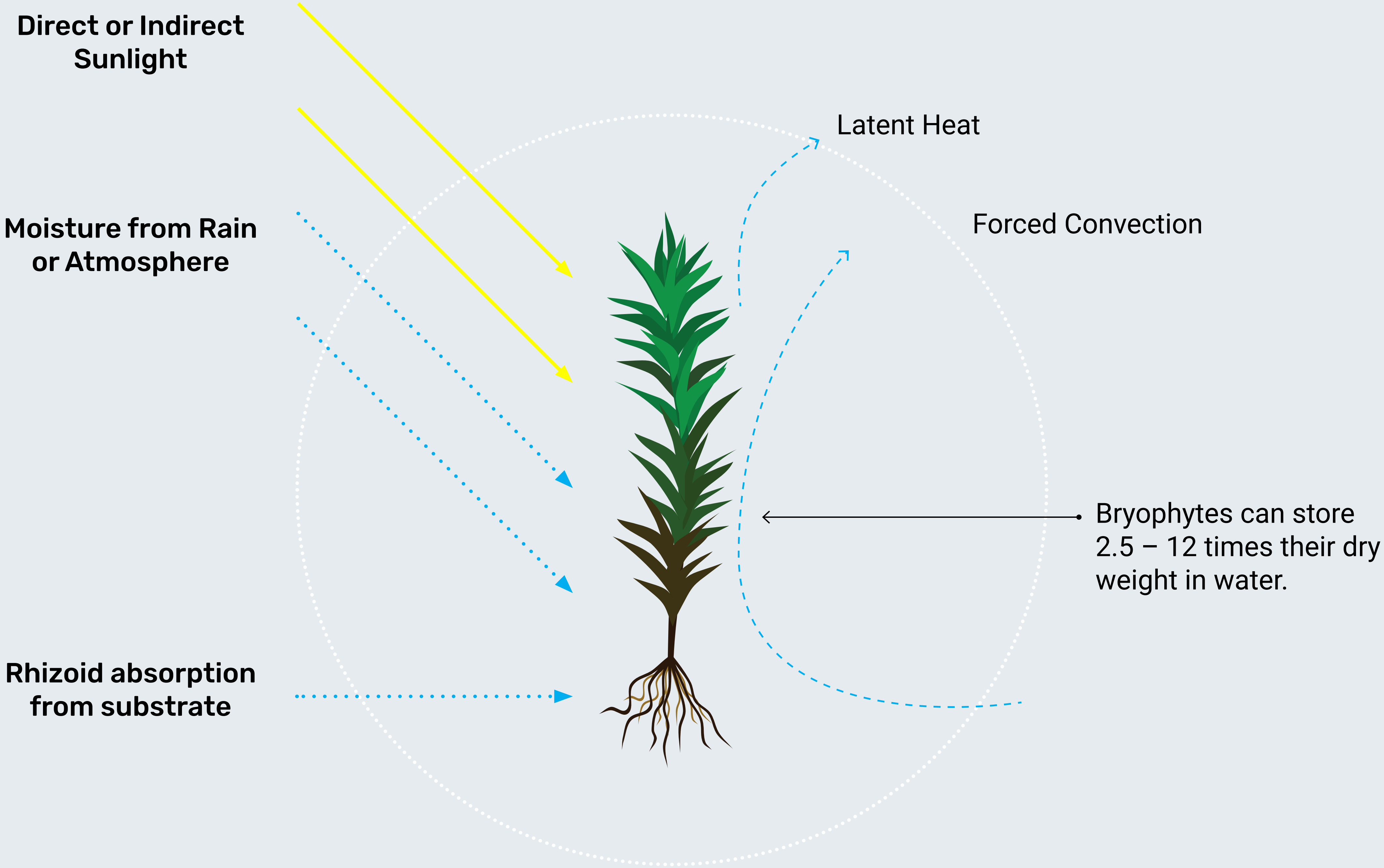
1 - 6 cm

Sporophyte

Gametophyte

Rhizoid

http://www.greatfen.org.uk/wildlife/plants/bryophytes



Bryophytes can store 2.5 – 12 times their dry weight in water.

Bryophytes transfer water from the lower sections to the upper tips of the plant where it then evaporates and cools the surrounding air (Glime 2017).

Limitations:

High levels of metal exposure:

- Copper
- Zinc
- Lead

These an other metals can cause mosses to die back. So mosses are tolerant to some of these metals.

Low moisture and High temps:

Prolonged exposure to dry environments can put the bryophyte into dormancy. This may not kill the moss but causes browning. Likewise, extreme cold can trigger dormancy as well.

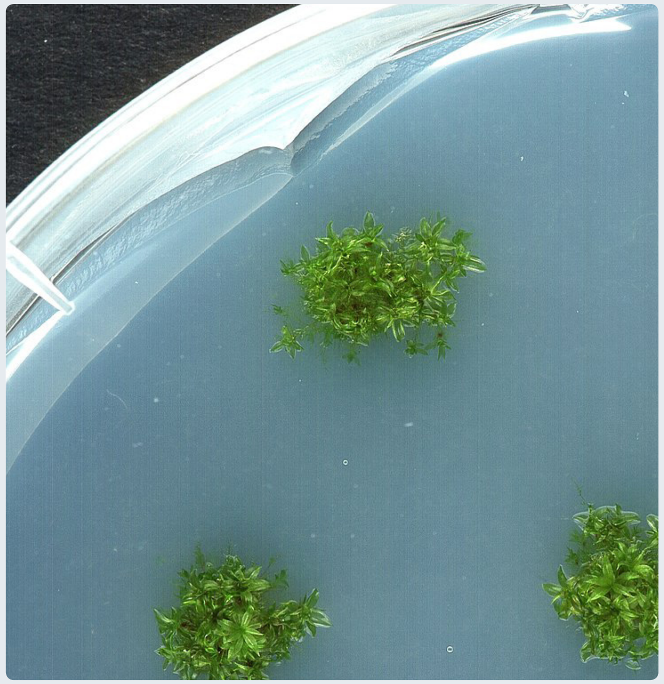
Irrigation with hard tap water or urban rainwater can kill off moss when high concentrations of chlorine, oil and metals are found.

Moss Species Selection:

Moss	pH	Type	Region	Potential Moss	Observation Notes
Aloina ambigua	8	Vertical	Northern Europe and UK	☑	mosses cultured on tufa
Anomodon viticulosus	8	Vertical	Northern Europe and UK	☑	moss that grows on the alkaline mortar of walls.
Barbula unguiculata,	7	Urban Roof	Northern Europe and UK	☑	roof dweller in Sweden.
Brachythecium laetum	-	Urban Roof	UK	☐	partly shaded roofs in West Virginia
Brachythecium rutabulum	8	Vertical	Northern Europe and UK	☑	moss that grows on tufa
Bryum argenteum	7	Urban Pavement	Northern Europe and UK	☑	moss that grows inbetween pavers
Bryum capillare	7	Vertical	Northern Europe and UK	☑	moss that grows on the mortar of walls.
Ctenidium molluscum	8	Vertical	Northern Europe and UK	☑	moss that grows on the alkaline mortar of walls.
Didymodon tophaceus	8	Vertical	Northern Europe and UK	☑	with the CaCO3 deposits at the base. tufa, travertine
Encalypta streptocarpa	9	Vertical	Northern Europe and UK	☑	moss that grows on the alkaline mortar of walls.
Entodon seductrix	-	Urban Roof	UK	☐	moss roof, tolerant of sun
Funaria hygrometrica	6	Urban Roof	Northern Europe and UK	☐	low nutrients suitable for roofs
Grimmia decipiens	-	Urban Roof	Uk	☐	roof tiles of old churches in the UK.
Grimmia ovalis	5	Urban Roof	Northern Europe and UK	☐	grows on hand-made clay roof tiles in Germany
Grimmia pulvinata	8	Urban Pavement	Northern Europe and UK	☑	Pioneer moss, grows in cushions
Grimmia trichophylla	3	Urban Roof	Northern Europe and UK	☐	roof tiles of old churches in the UK.
Hedwigia ciliata	3	Urban Roof	Northern Europe and UK	☐	moss roof, tolerant of sun
Hypnum cupressiforme	-	Vertical	UK	☐	colonizer of stone walls
Mnium hornum	3	Vertical	Northern Europe and UK	☐	colonizer of stone walls
Plagiomnium cuspidatum	7	Urban Roof	Northern Europe and UK	☑	moss roof, tolerant of sun
Platygyrium repens	6	Urban Roof	Northern Europe and UK	☐	moss roof, tolerant of sun
Polytrichastrum formosum	-	Vertical	Northern Europe and UK	☐	colonizer of stone walls
Racomitrium fasciculare	2	Urban Roof	Northern Europe and UK	☐	roof tiles of old churches in the UK.
Racomitrium heterostichum	2	Urban Roof	Northern Europe and UK	☐	roof tiles of old churches in the UK.
Rhytidiadelphus squarrosus	5	Vertical	Northern Europe and UK	☐	wetter north-facing portions of roofs
Thamnobryum alopecurum	7	Vertical	Northern Europe and UK	☑	moss that grows on the mortar of walls.
Zygodon viridissimus	7	Vertical	Northern Europe and UK	☑	moss that grows on the mortar of walls.

Dutch Bryological and Lichenological Society (2019)

Moss Biofilm:

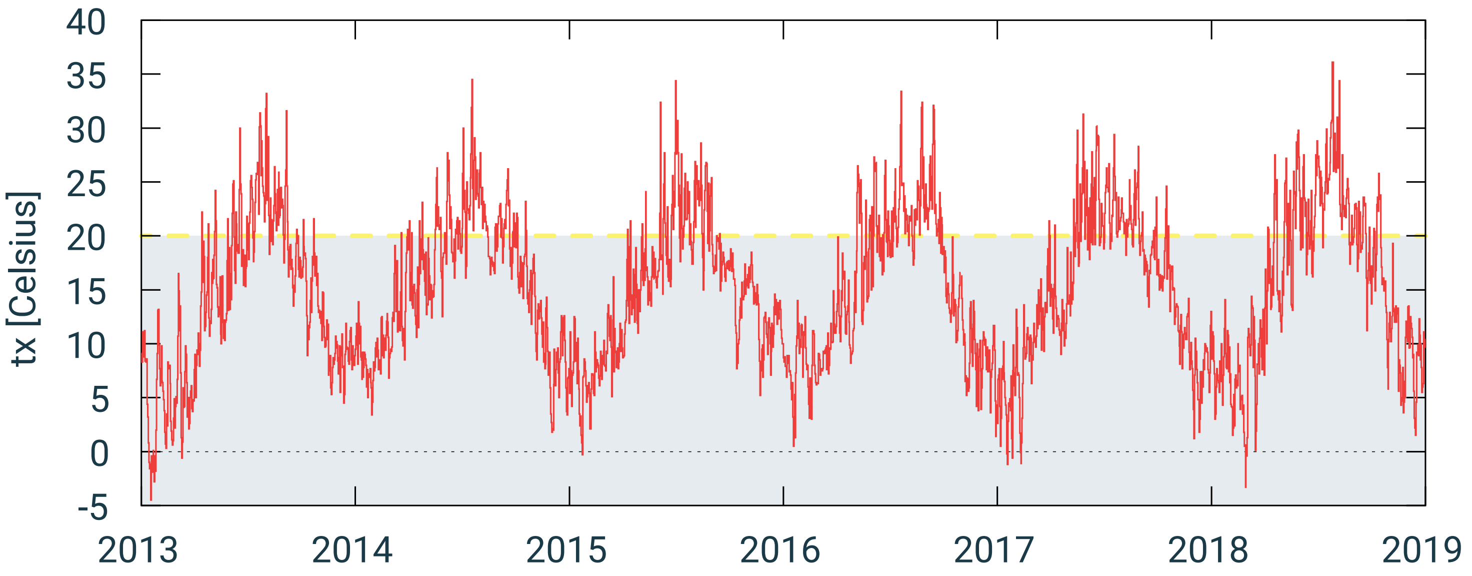


Gelling agent:
A gel mixture was developed as a potential biofilm. The mixture consists of the following materials:

- Agar powder or other horticulture gelling agents
- Distilled water
- NPK nutrient solution (to promote rapid growth)
- Blended moss or moss spores

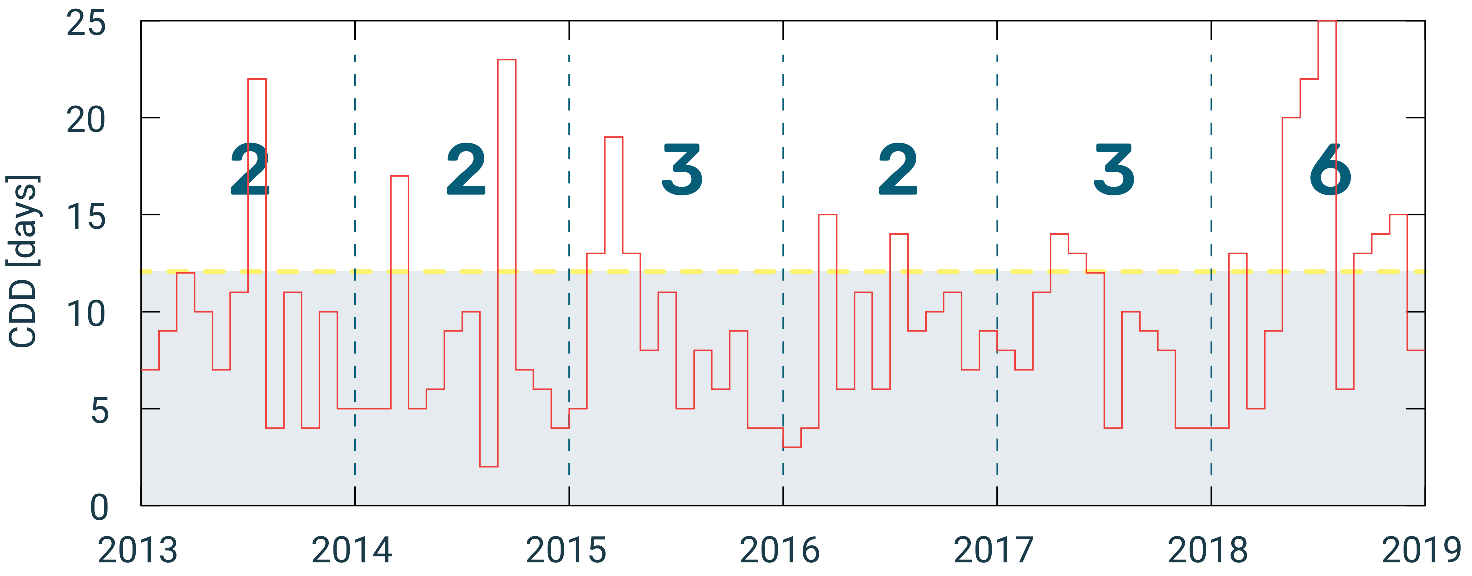
Moss Dessication Rate:

Peak Daily Temperature



Rotterdam - Dataset - Climate Explorer - KNMI 2019

Consecutive Dry Days (< 1mm)



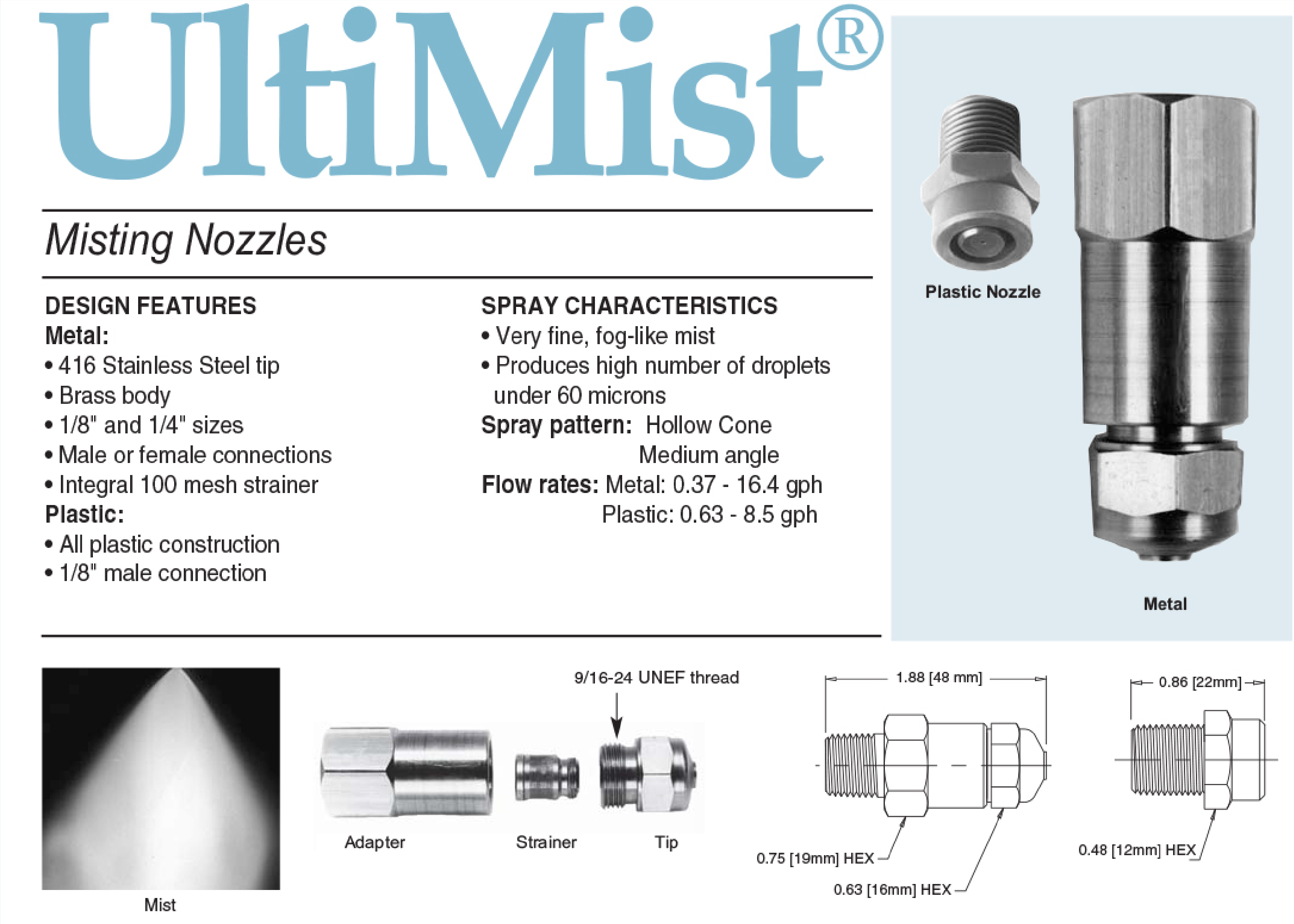
Rotterdam - Dataset - Climate Explorer - KNMI 2019

Rotterdam Climatic data from KNMI.

Above: Maximum Daily Temperature.

Bellow: Consecutive Dry Days and number of occurrences a year exceeding 12 consecutive days.

Misting System:



UltiMist®

Misting Nozzles

DESIGN FEATURES

Metal:

- 416 Stainless Steel tip
- Brass body
- 1/8" and 1/4" sizes
- Male or female connections
- Integral 100 mesh strainer

Plastic:

- All plastic construction
- 1/8" male connection

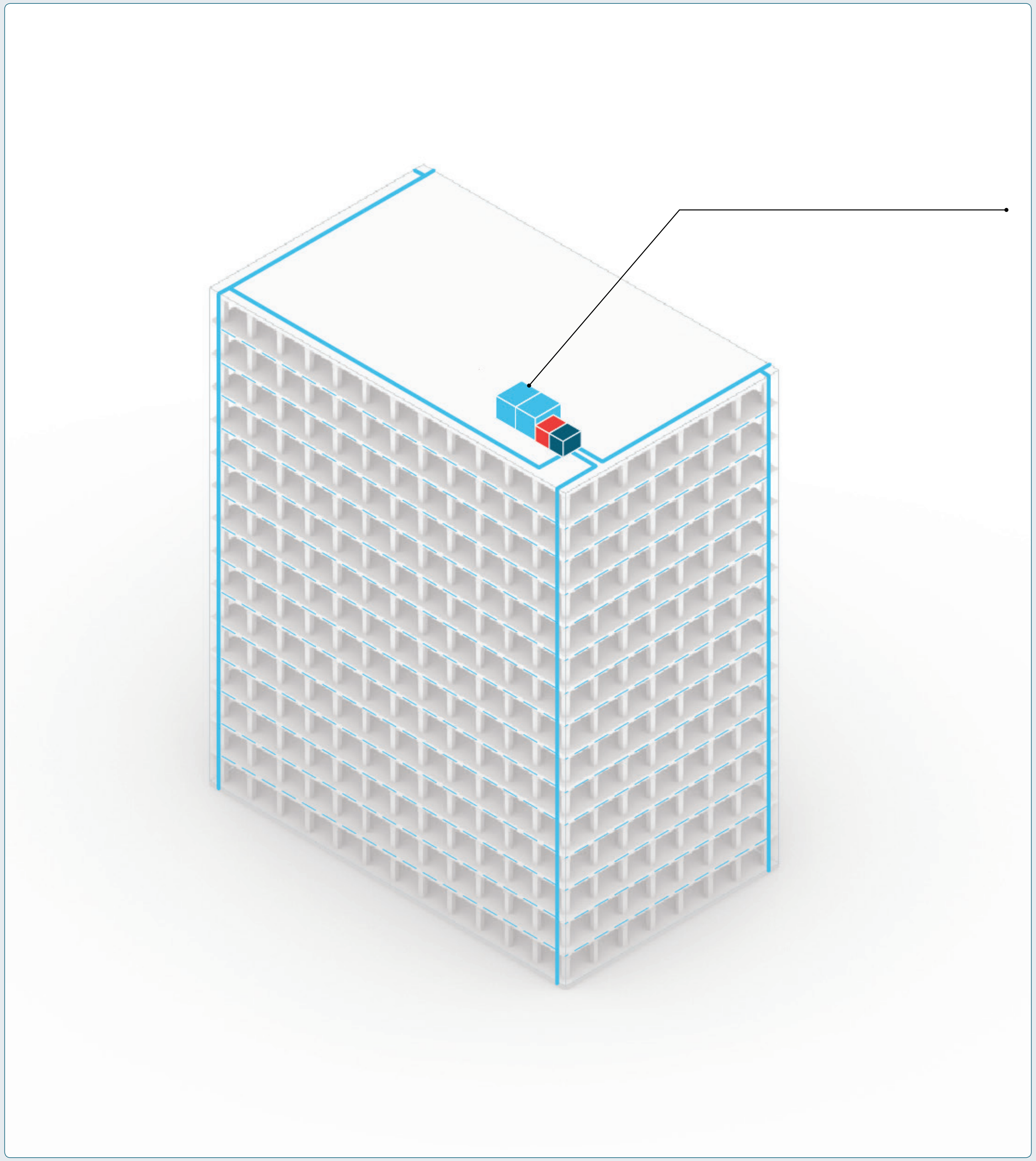
SPRAY CHARACTERISTICS

- Very fine, fog-like mist
- Produces high number of droplets under 60 microns

Spray pattern: Hollow Cone
Medium angle

Flow rates: Metal: 0.37 - 16.4 gph
Plastic: 0.63 - 8.5 gph

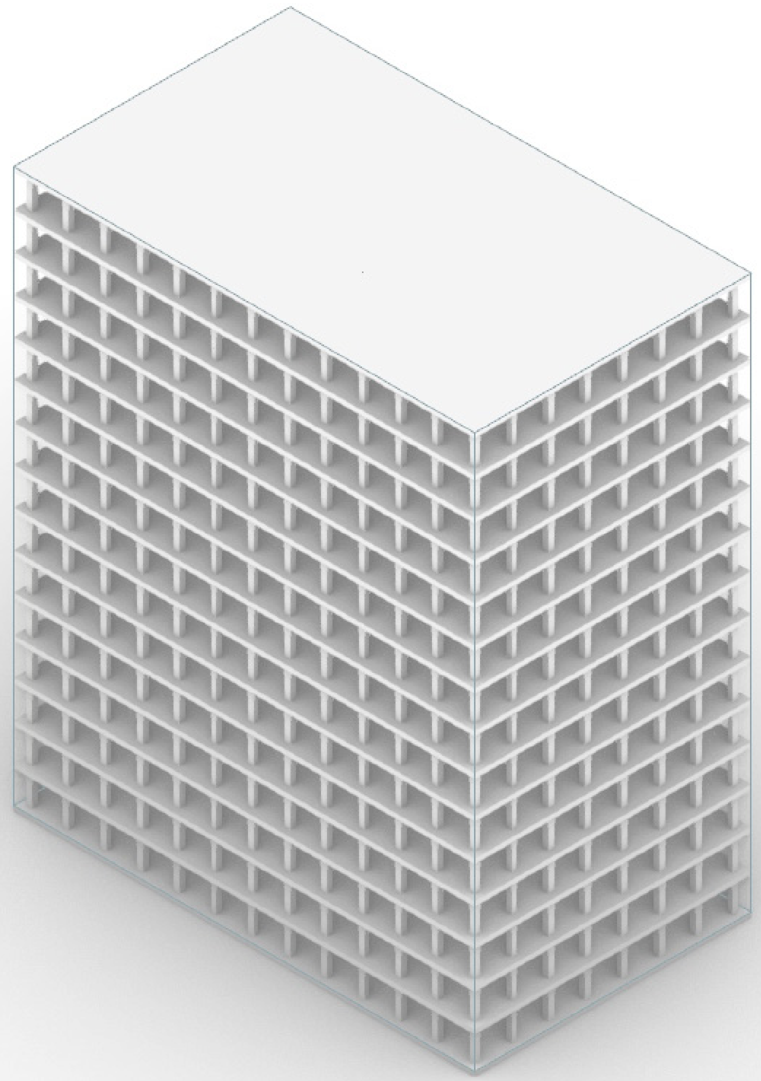
Irrigation Network:



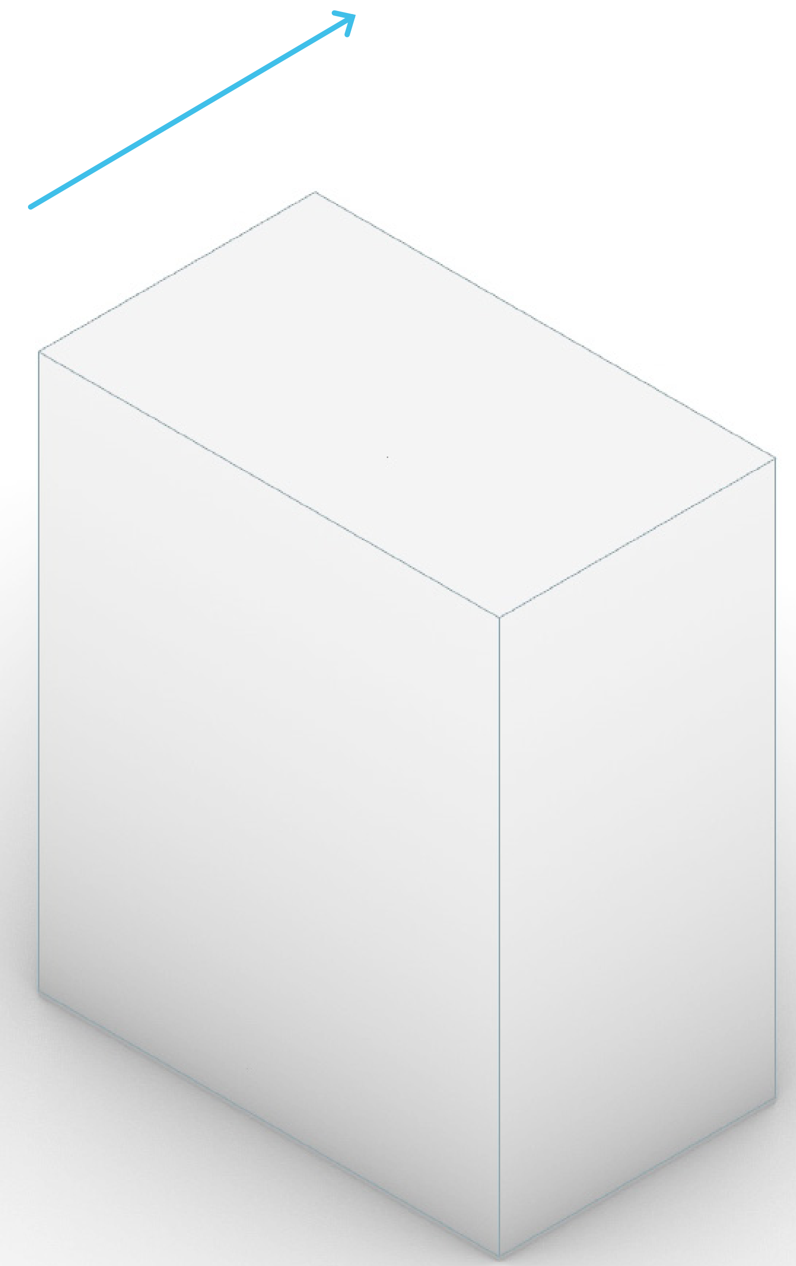
Water storage, Pumps, Nutrient system and weather monitoring

CFD Facade Wind

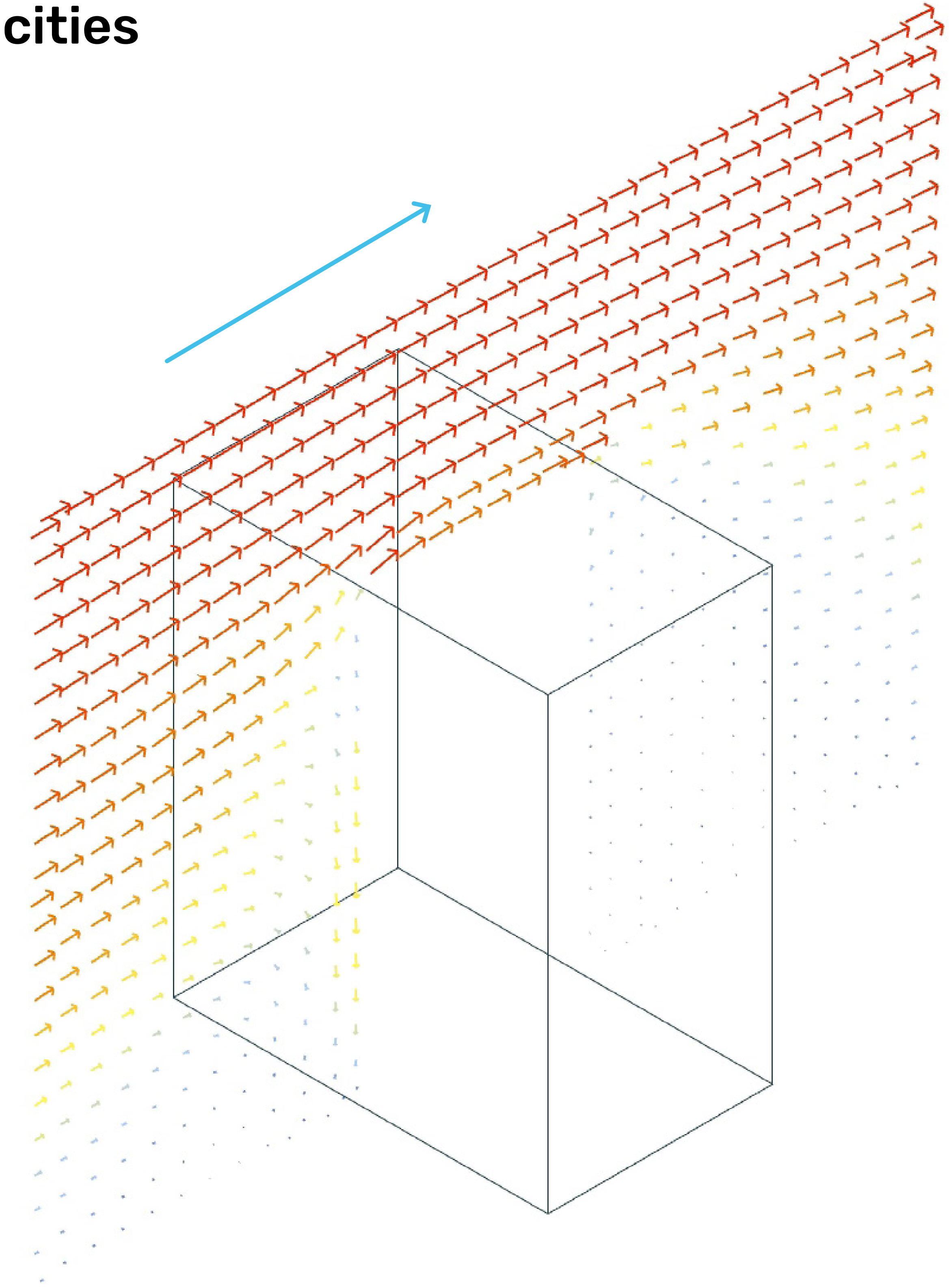
CFD Analysis:



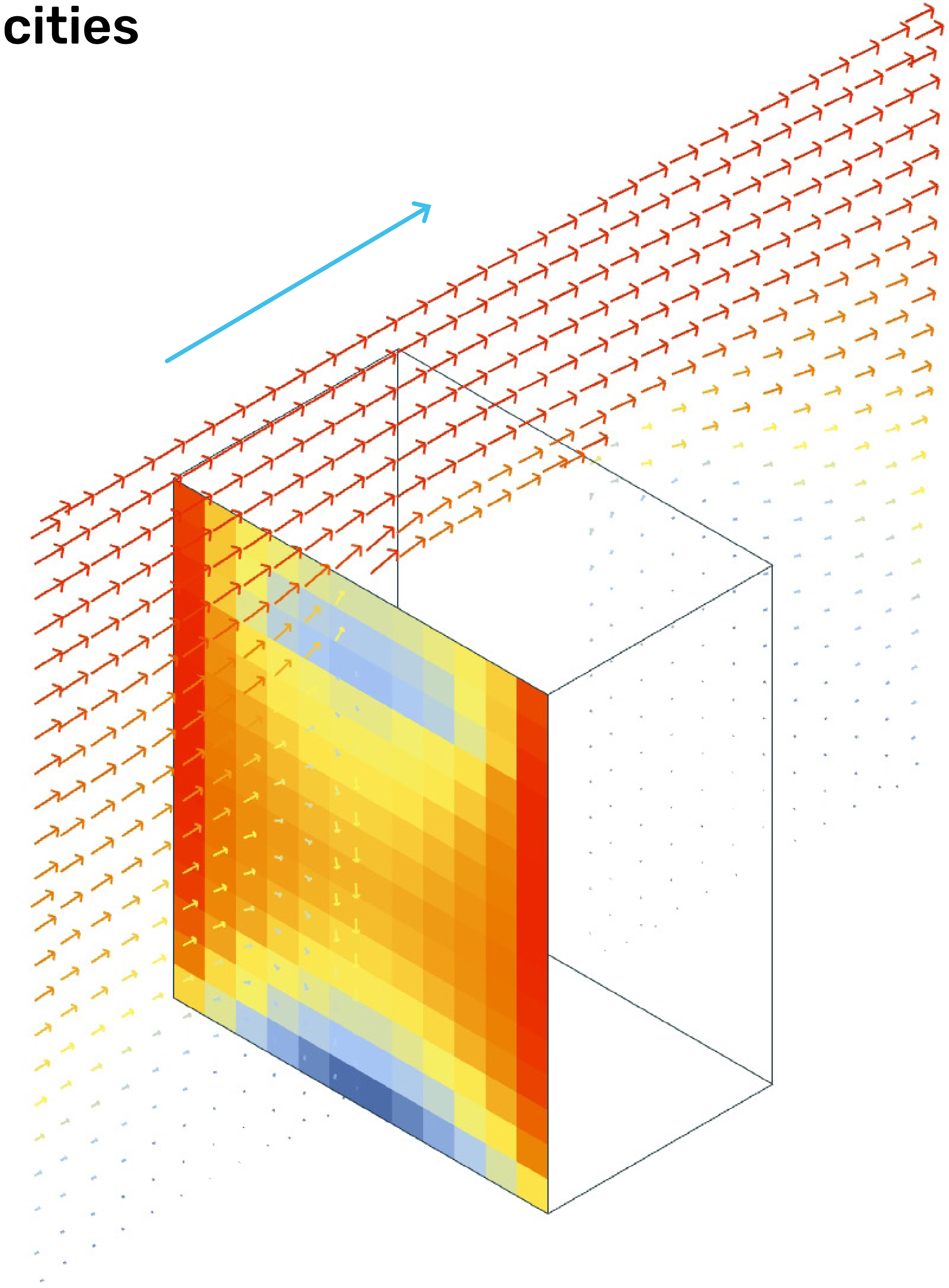
Simulation Massing



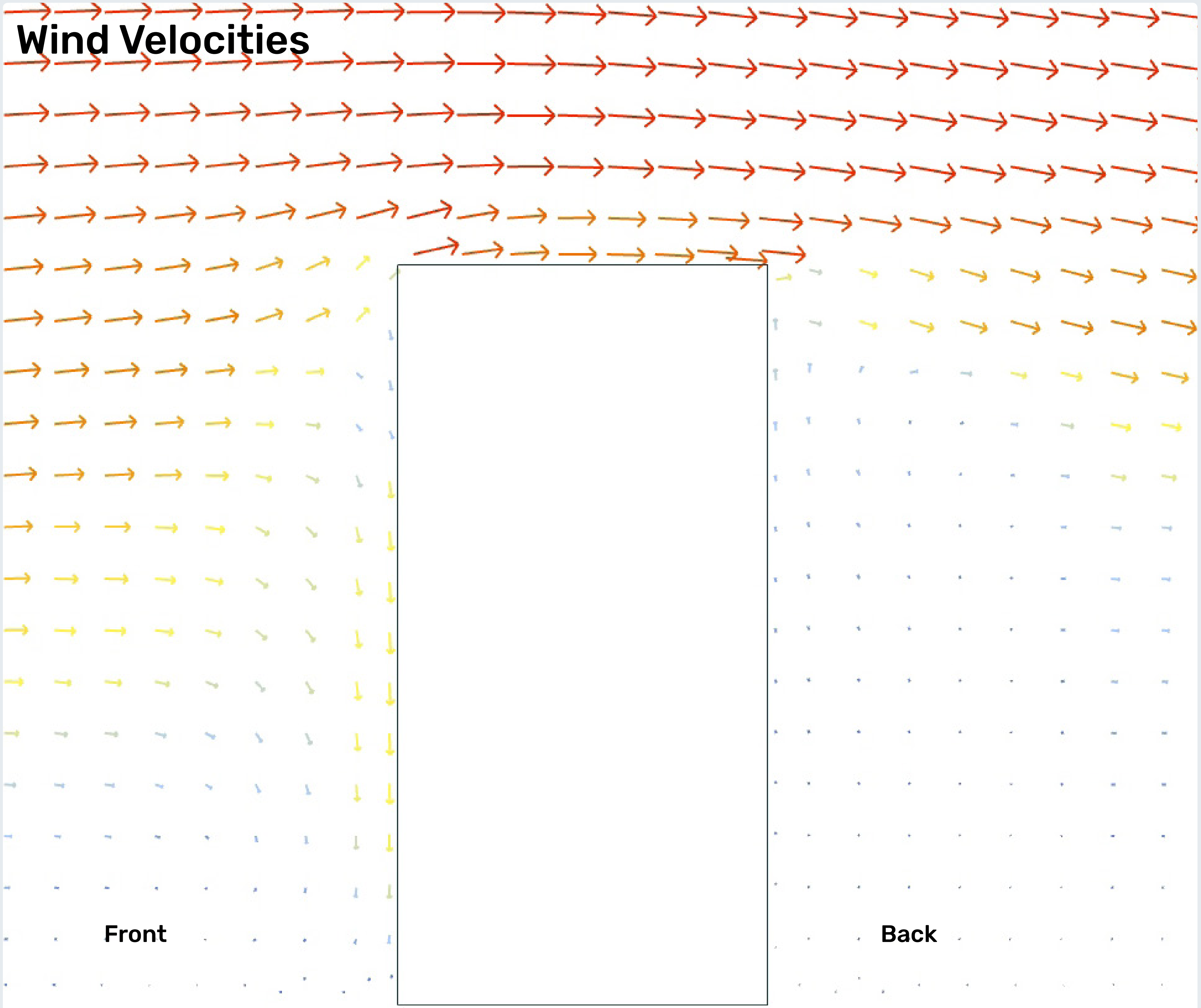
Wind Velocities



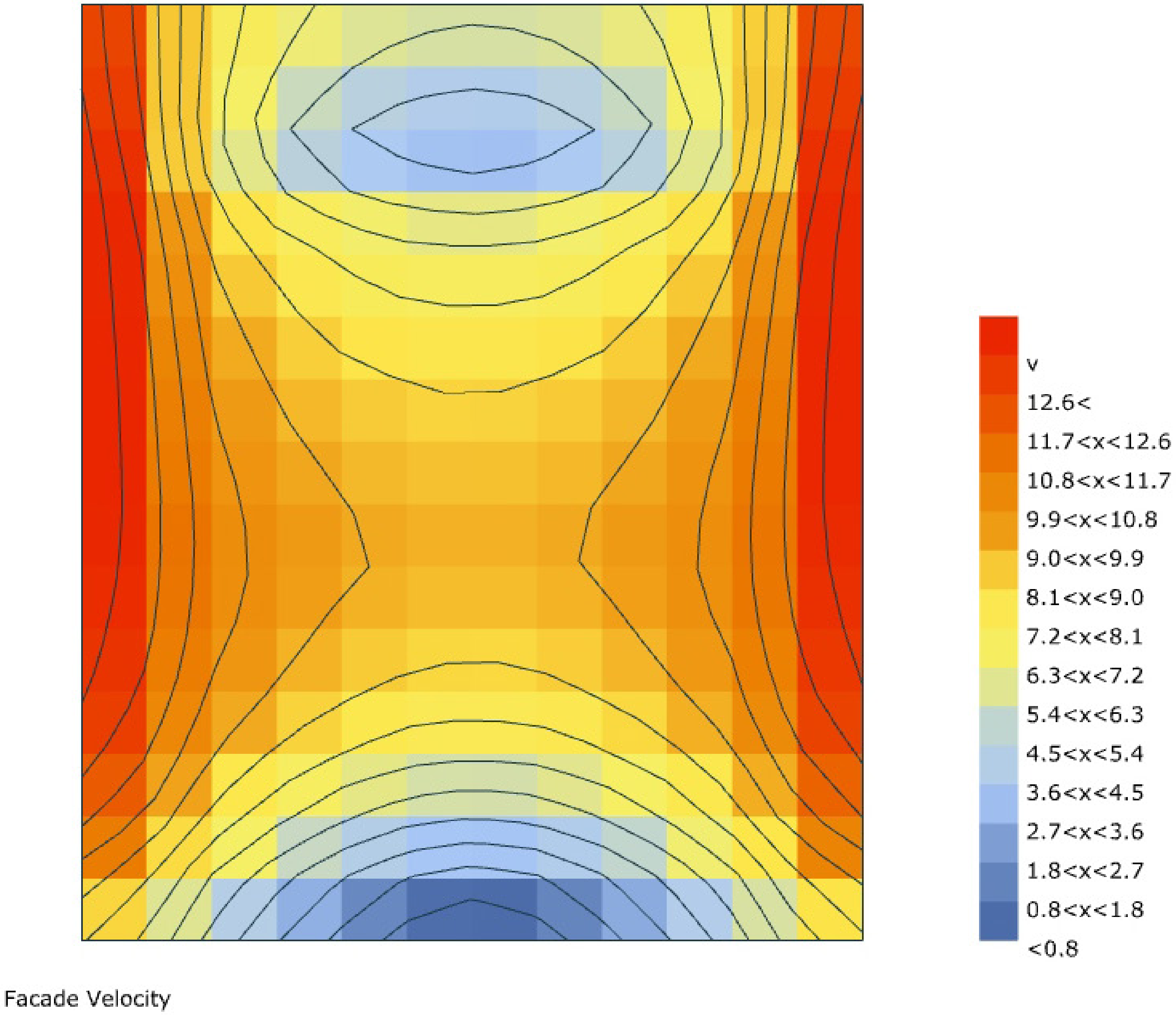
Wind Velocities



Wind Velocities

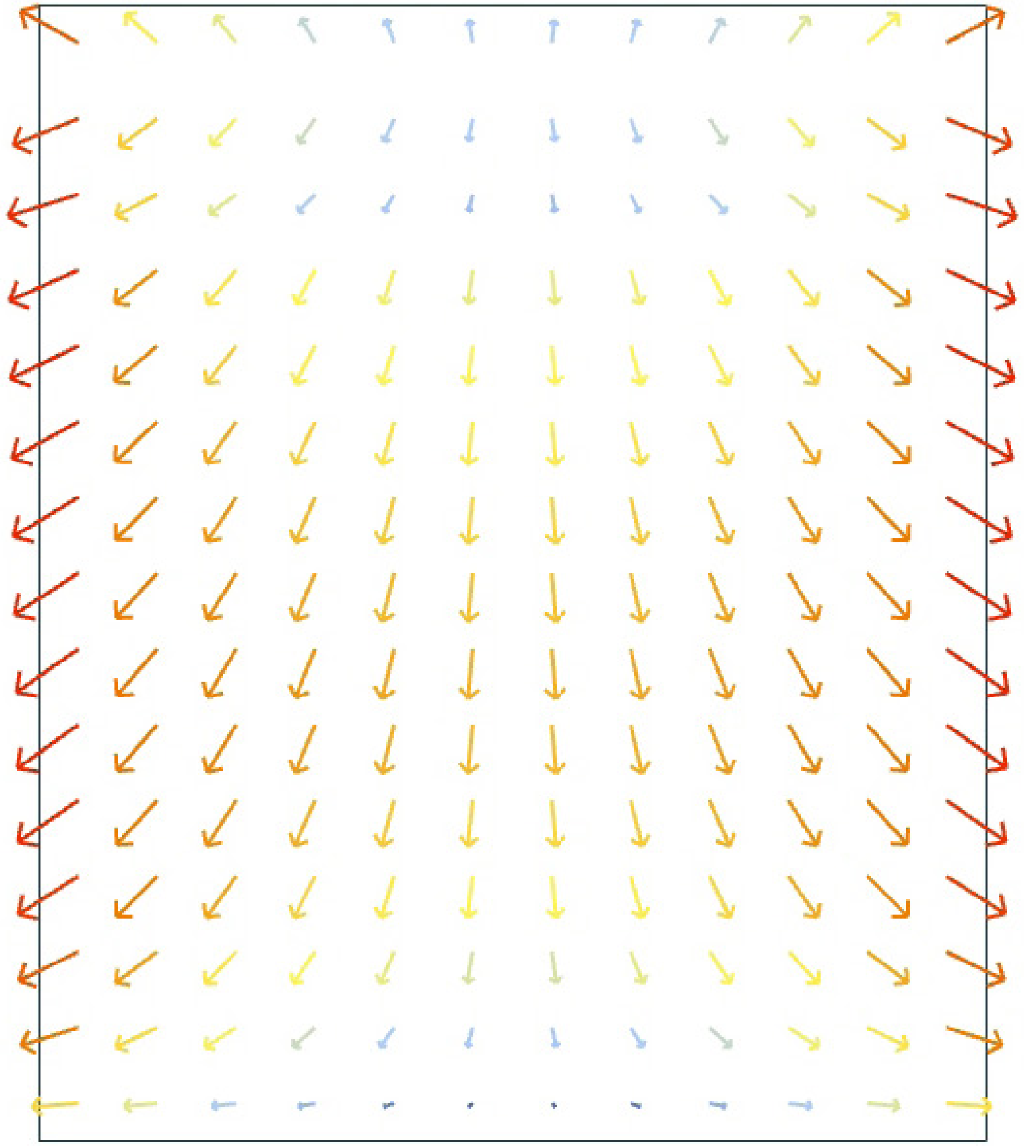


Facade Velocities



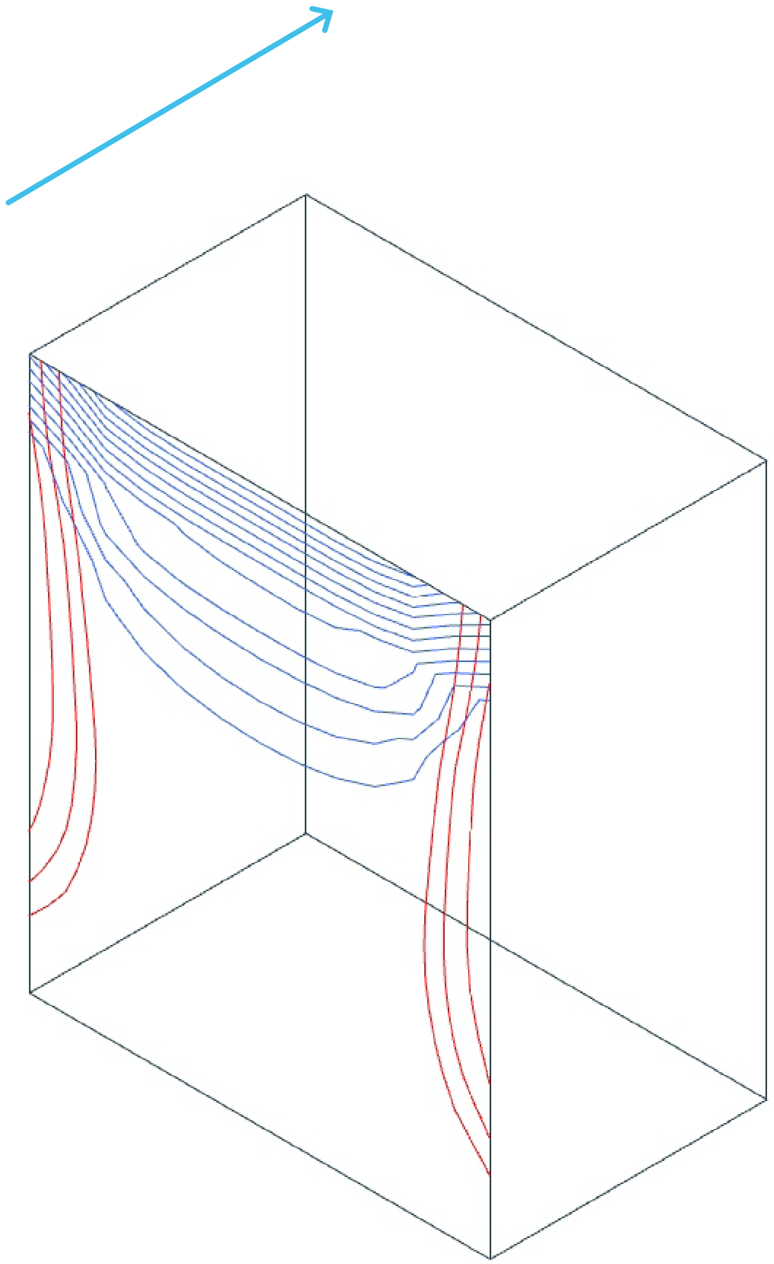
Front Face

Facade Velocities

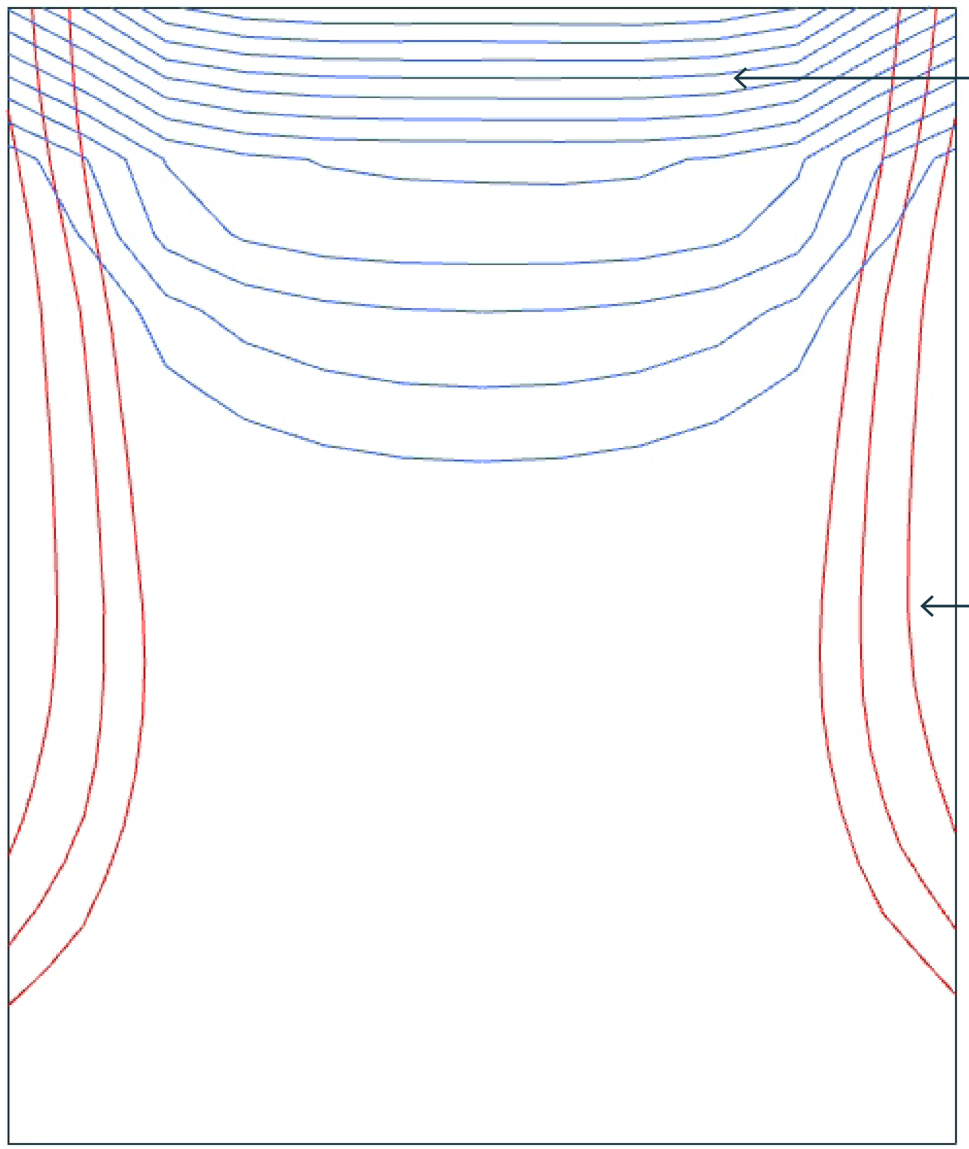


Front Face

Velocity & Pressure



Velocity & Pressure

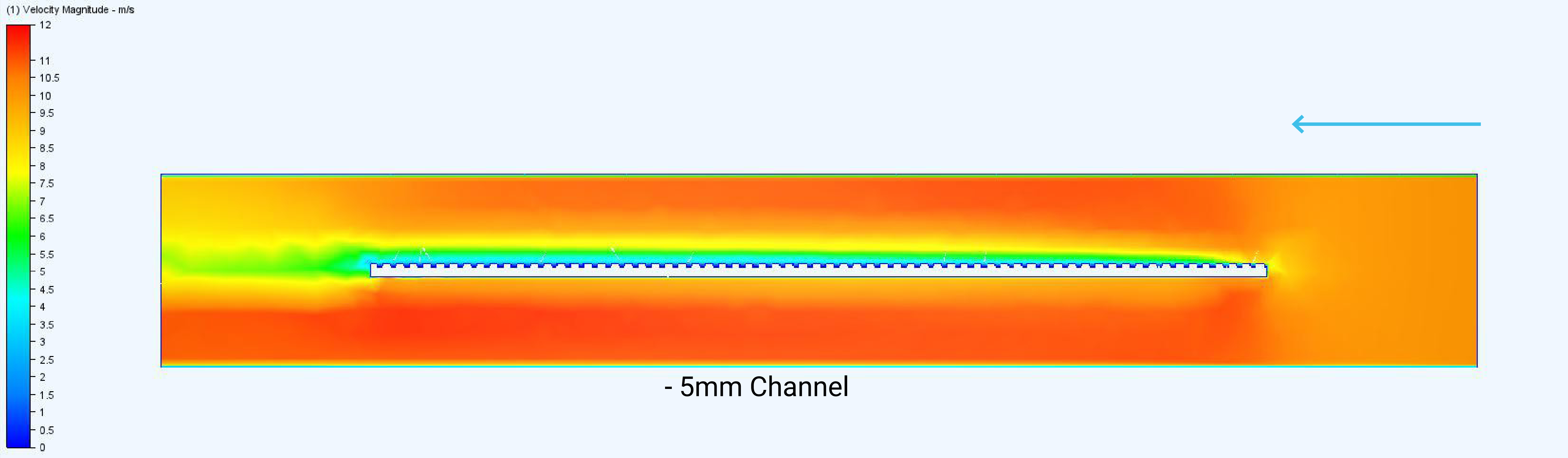


High Pressure

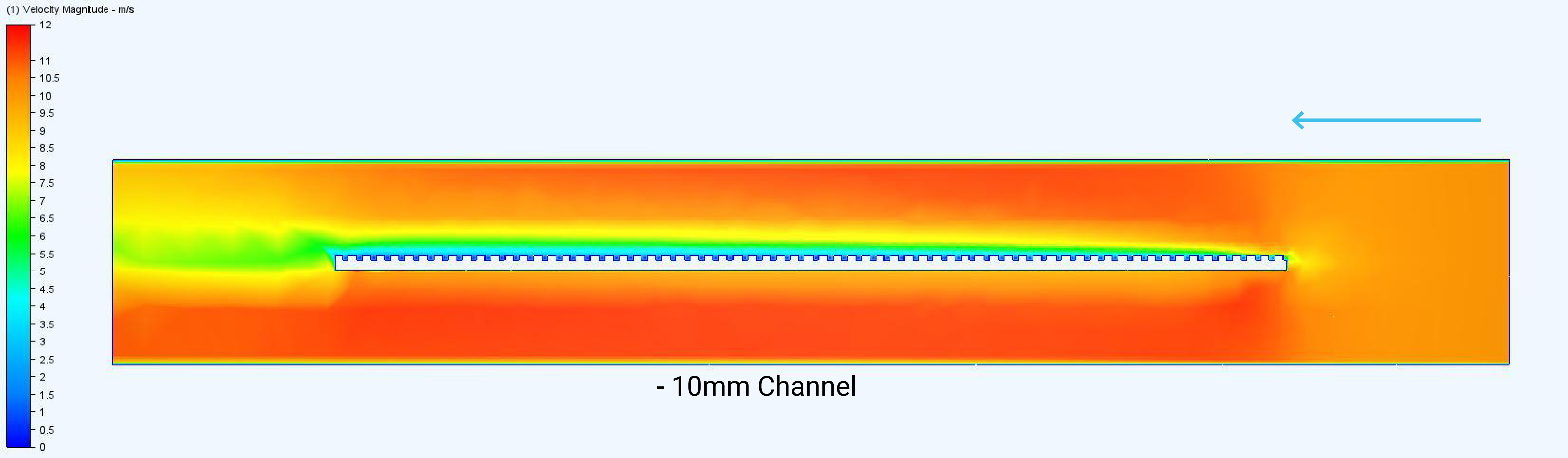
High Velocity

Front Face

Determine depth of grooves

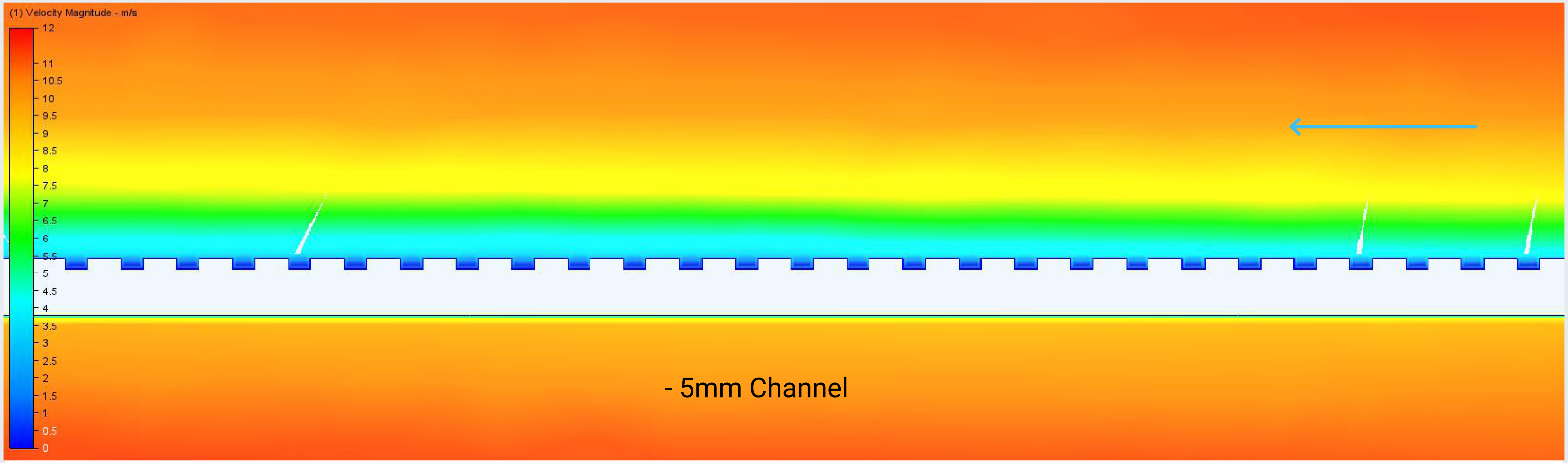


- 5mm Channel

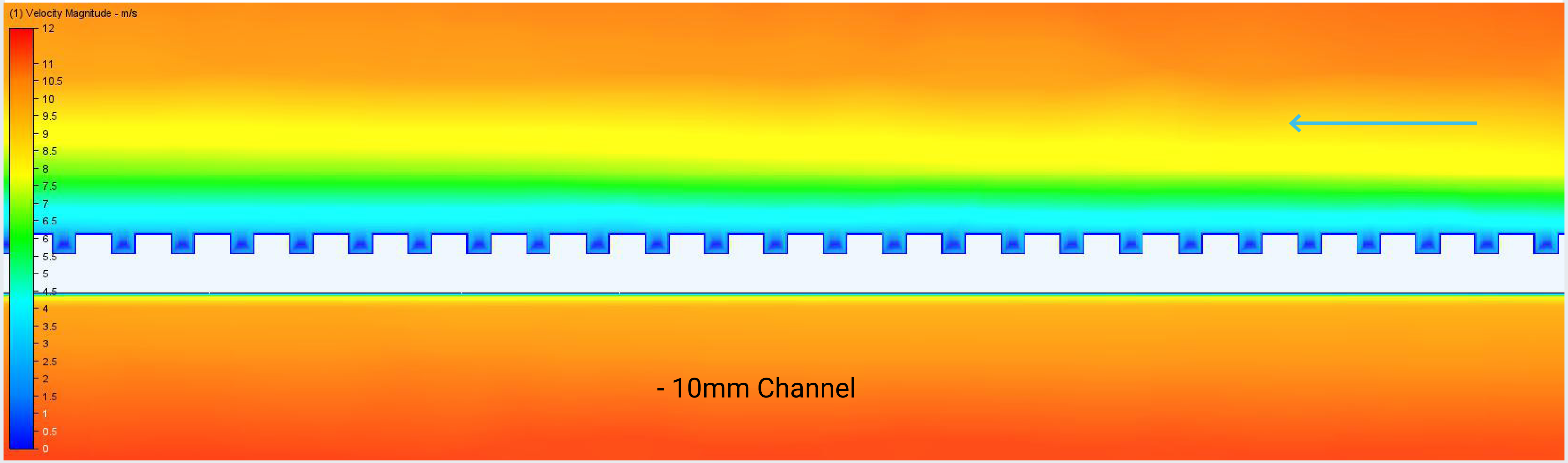


- 10mm Channel

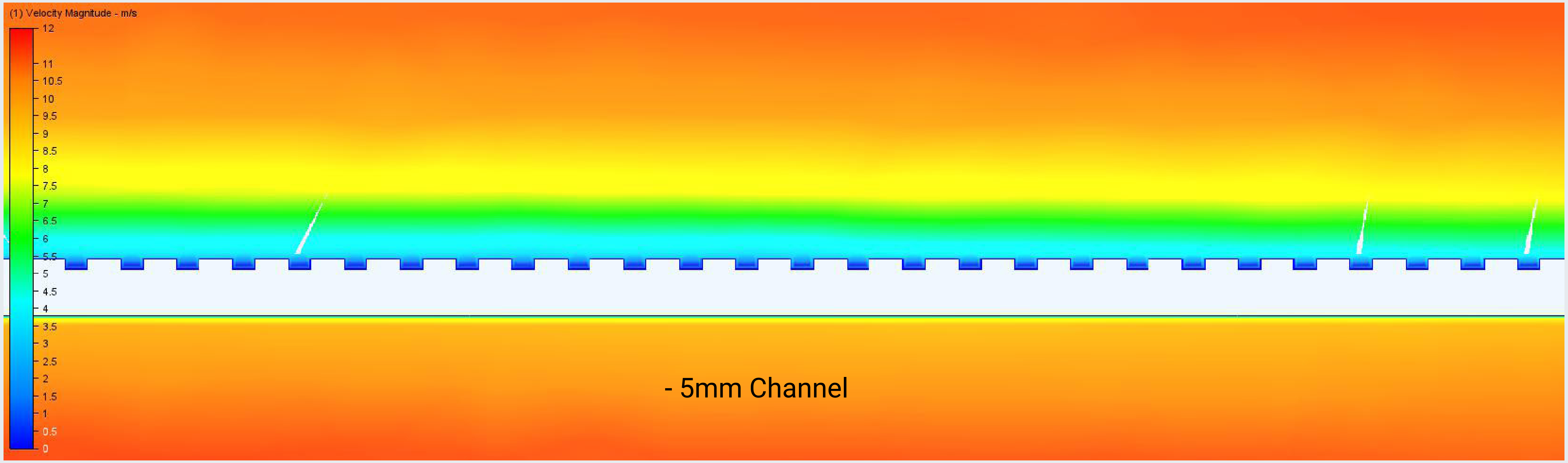
Determine depth of grooves



- 5mm Channel



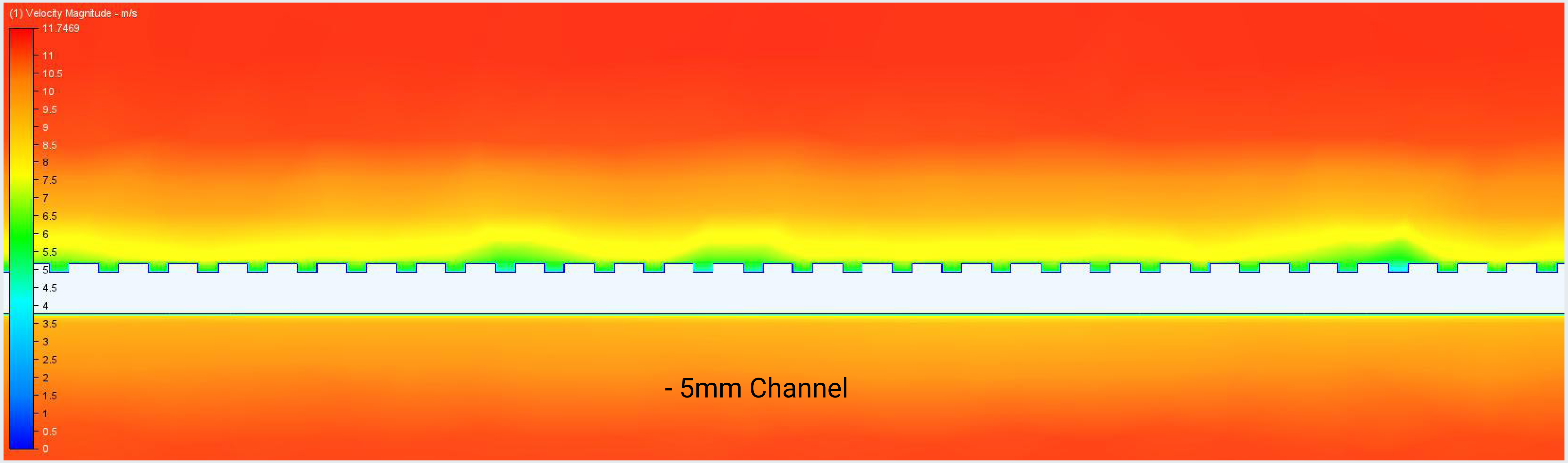
- 10mm Channel



- 5mm Channel

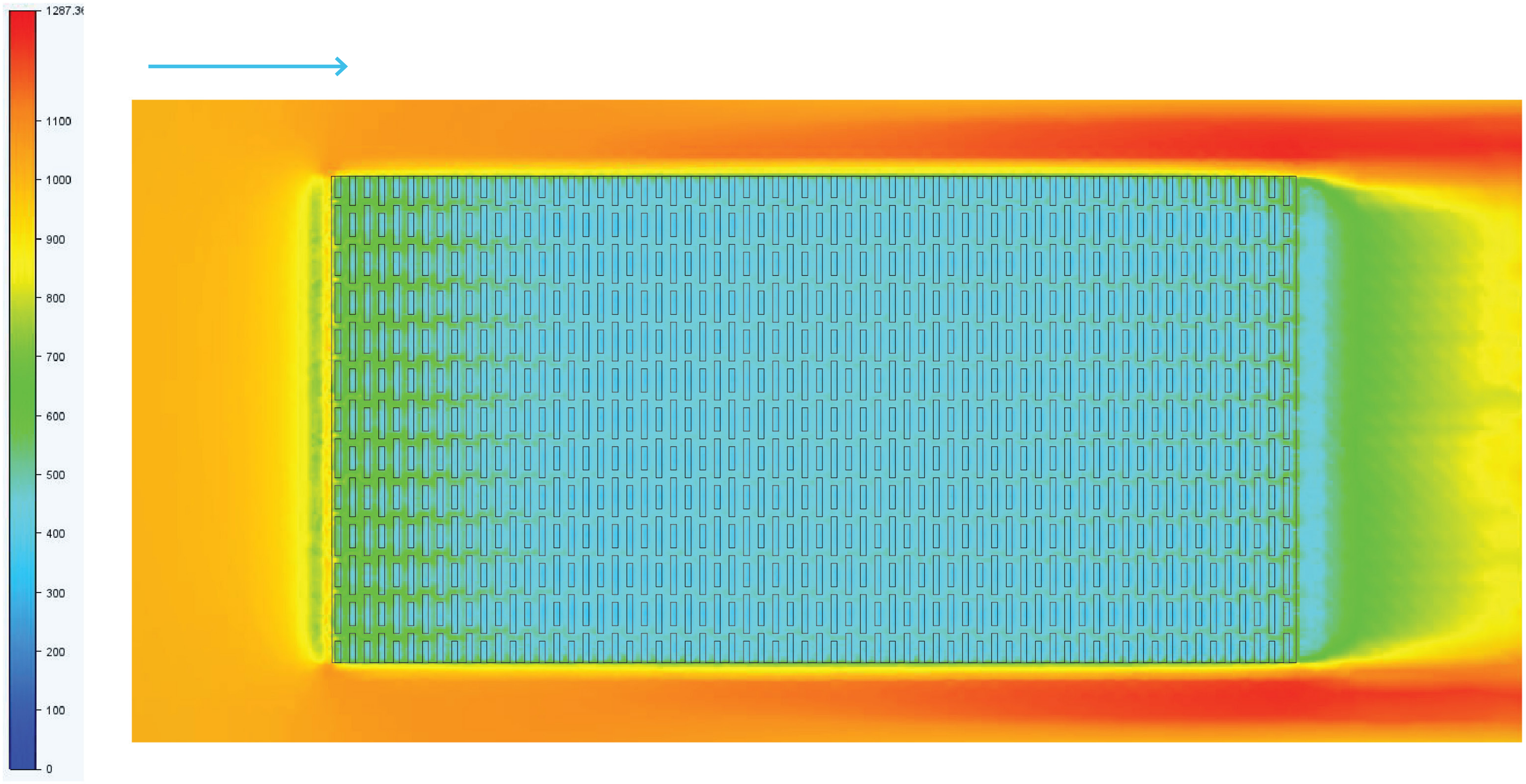
- Deep enough to be seen
- Deep enough to protect establishment

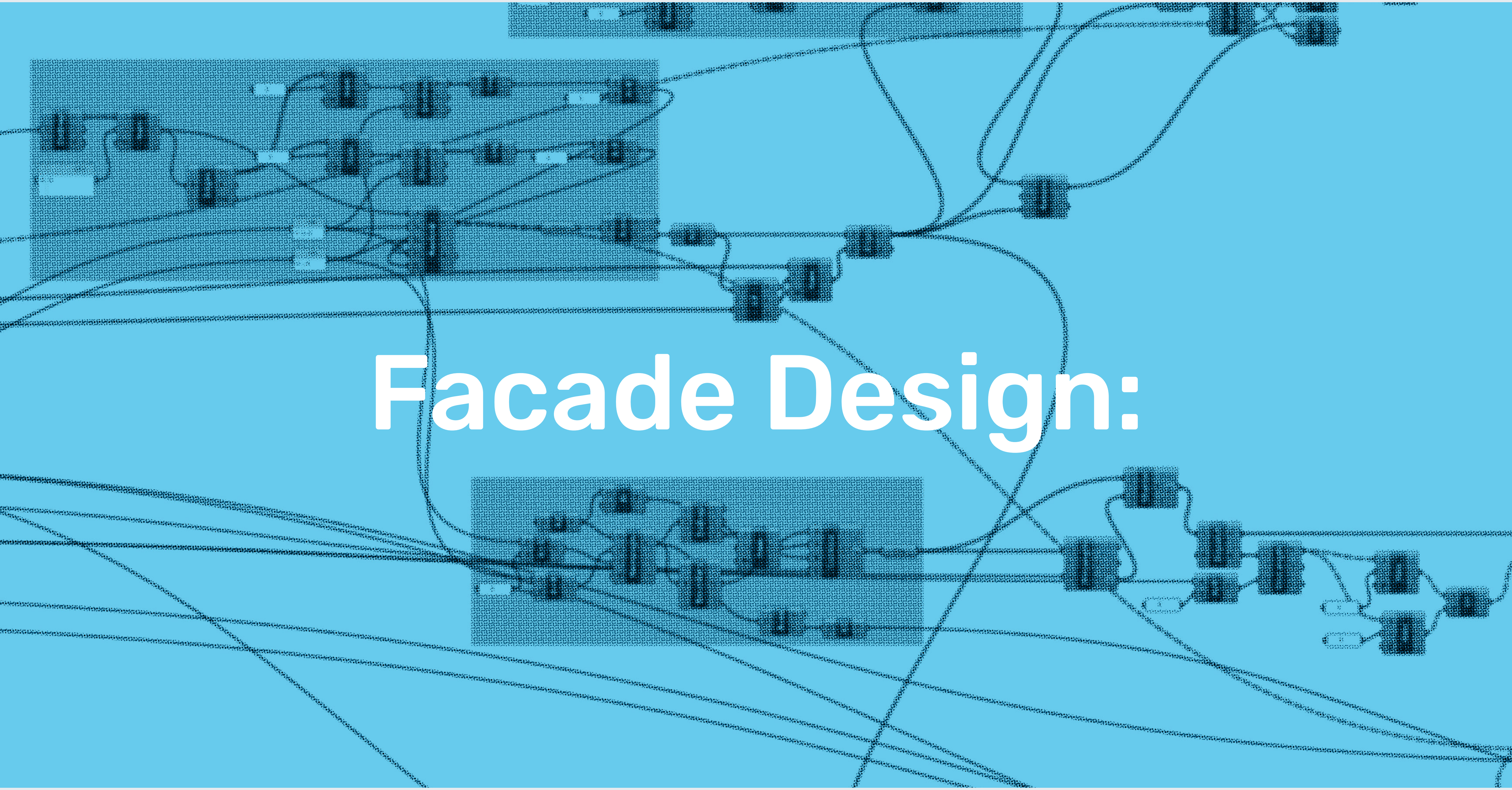
Worse case:
Parallel Wind Direction



- 5mm Channel

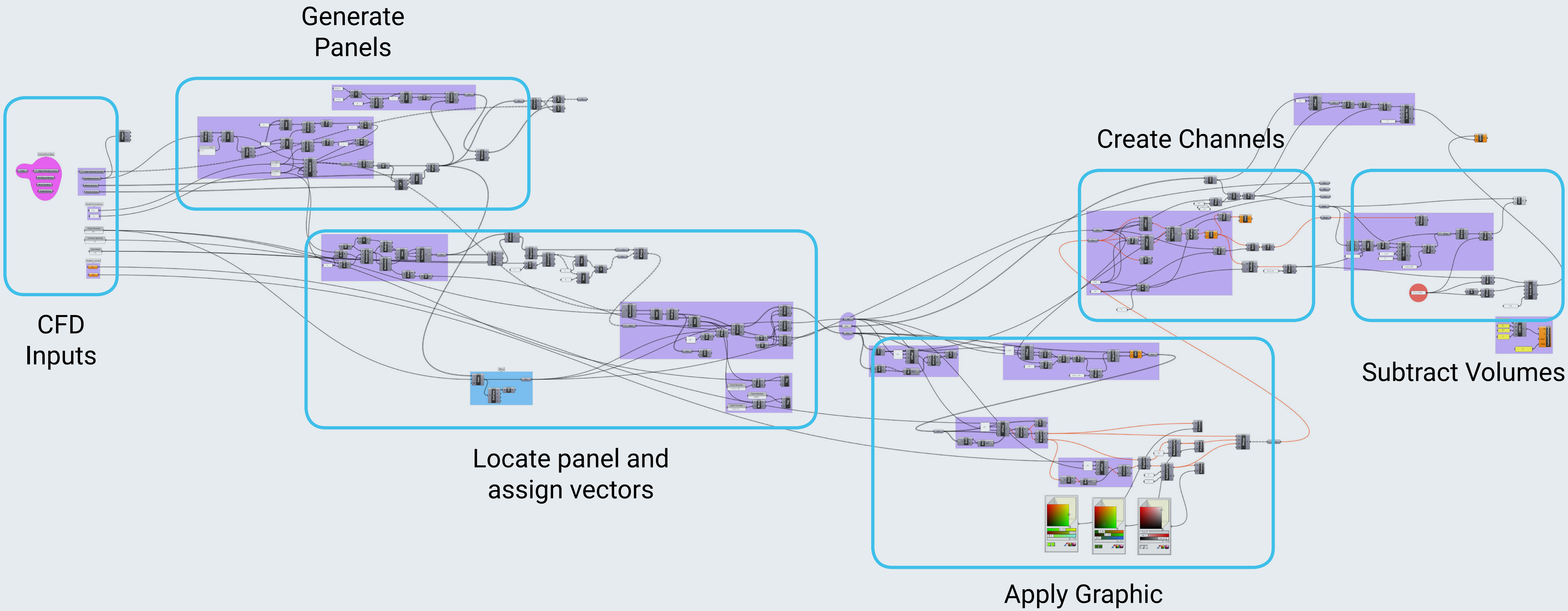
Turbulence Above Front of Surface





Facade Design:

Grasshopper Script: Parametric Panel Geometry


Generate Panels

CFD Inputs

Locate panel and assign vectors

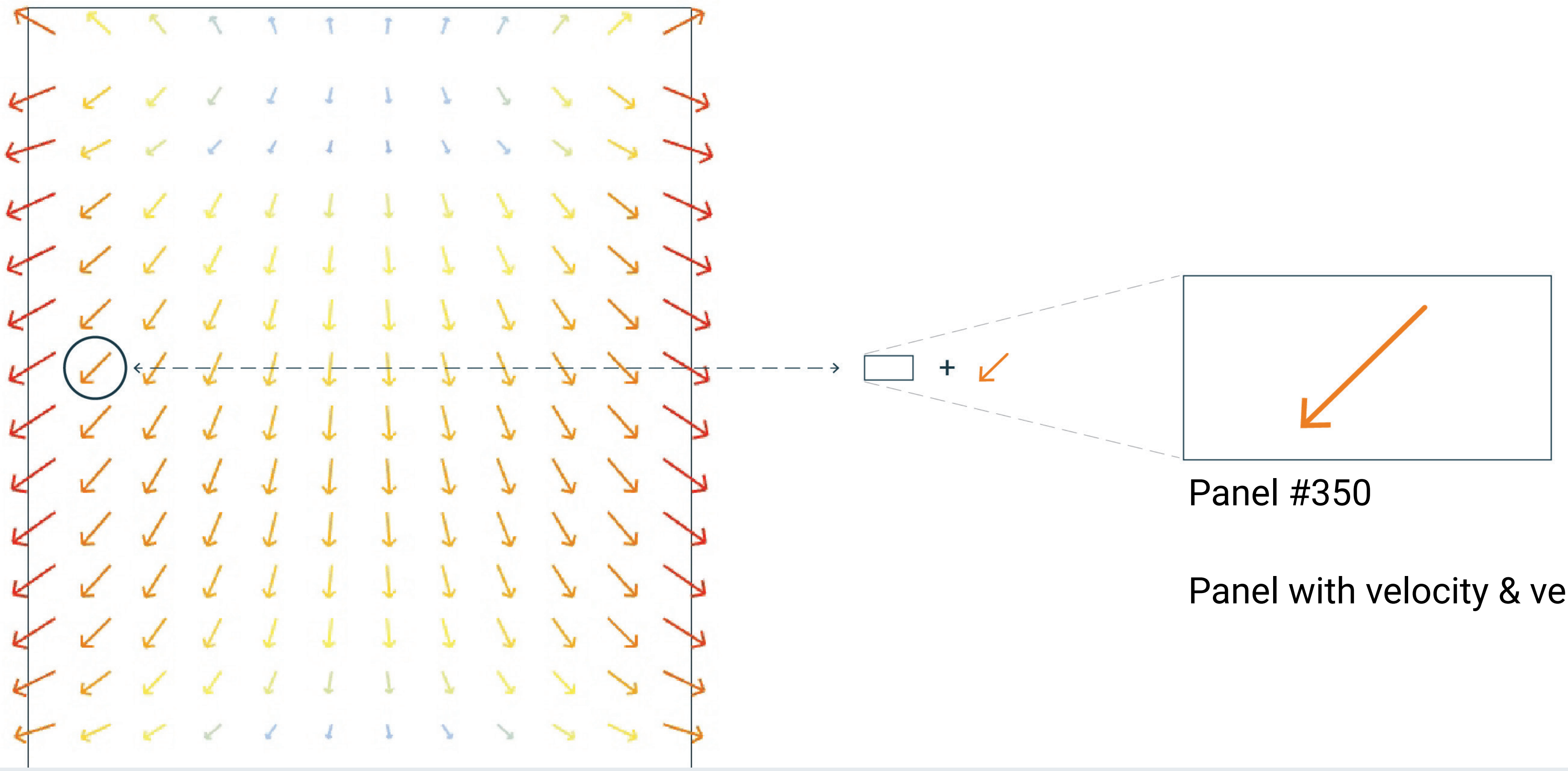
Create Channels

Subtract Volumes

Apply Graphic

Prob Vector and Assign to Facade Panel

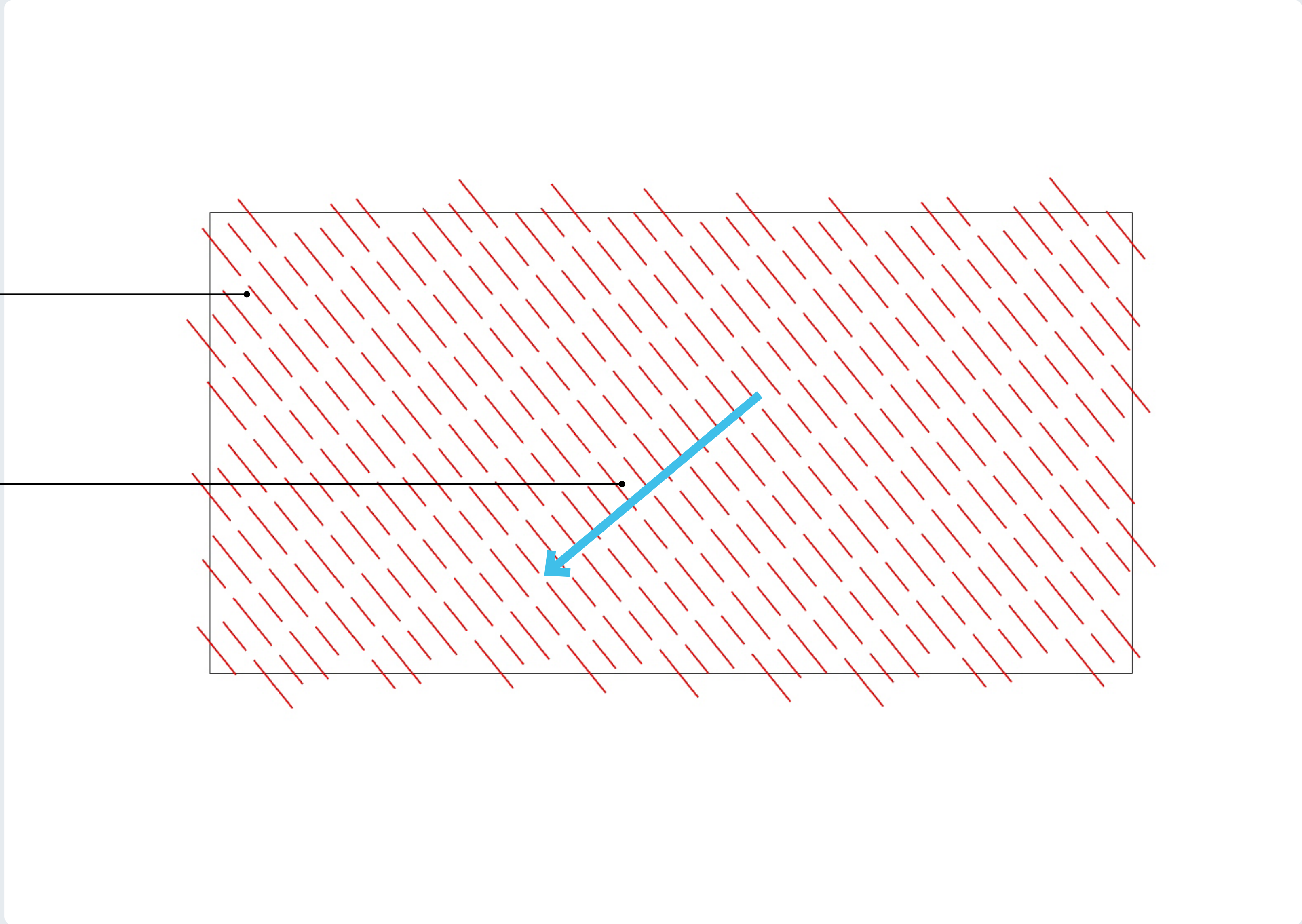
Location of panel:



Panel #350

Panel with velocity & vector

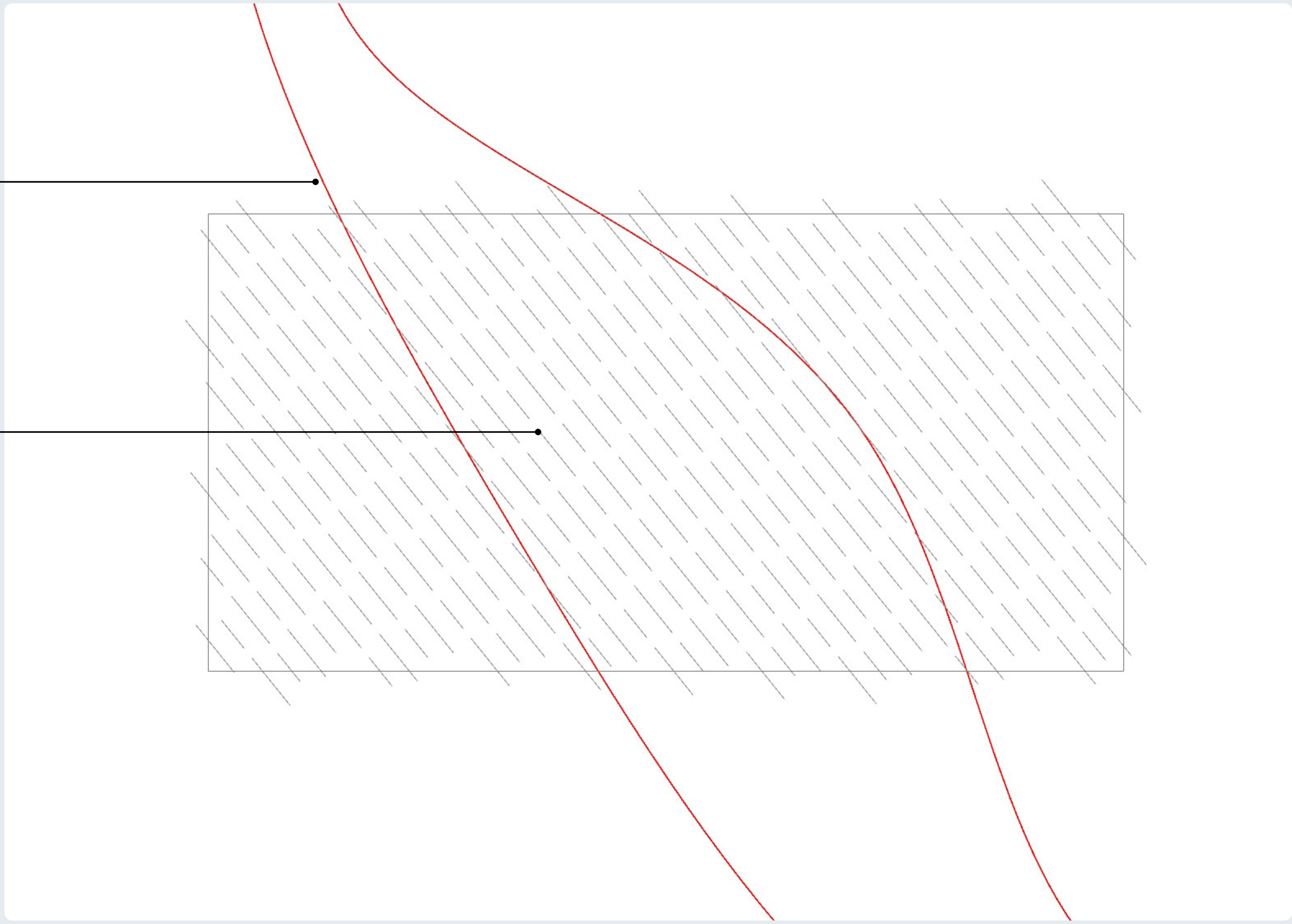
1.



Apply pattern

Align perpendicular to vector

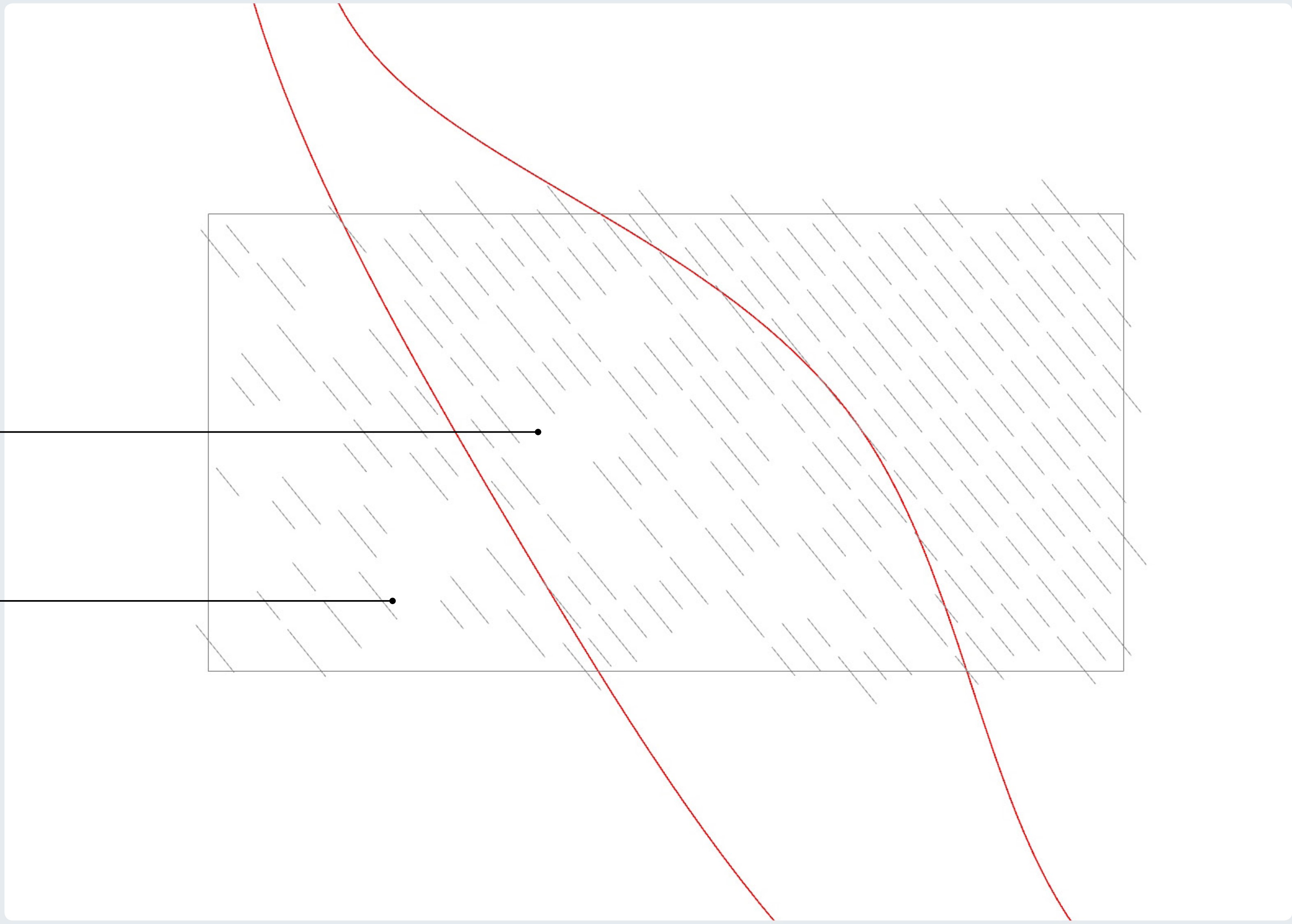
2.



Apply graphic

Assign value to regions

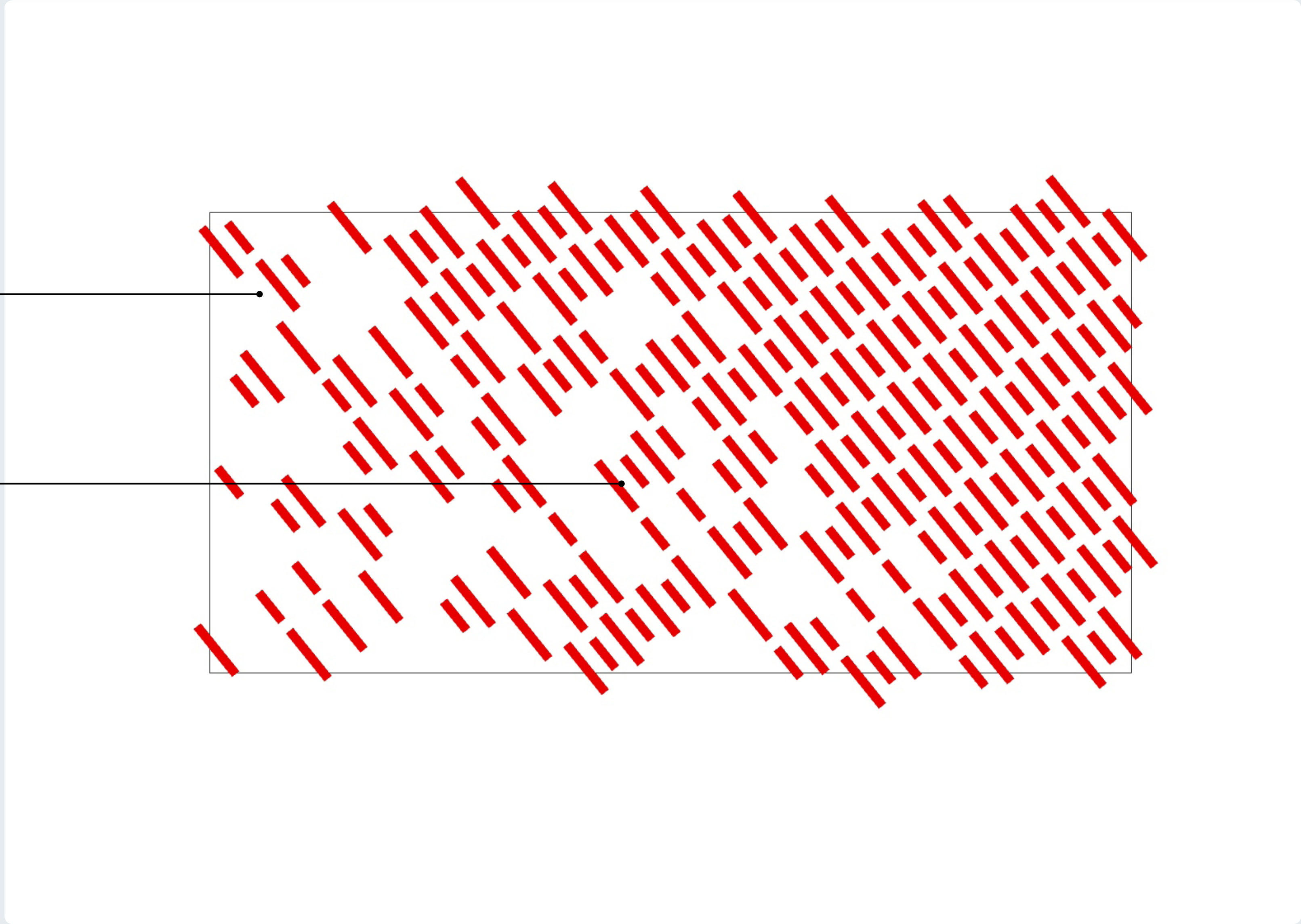
3.



Assign value to regions

Control density

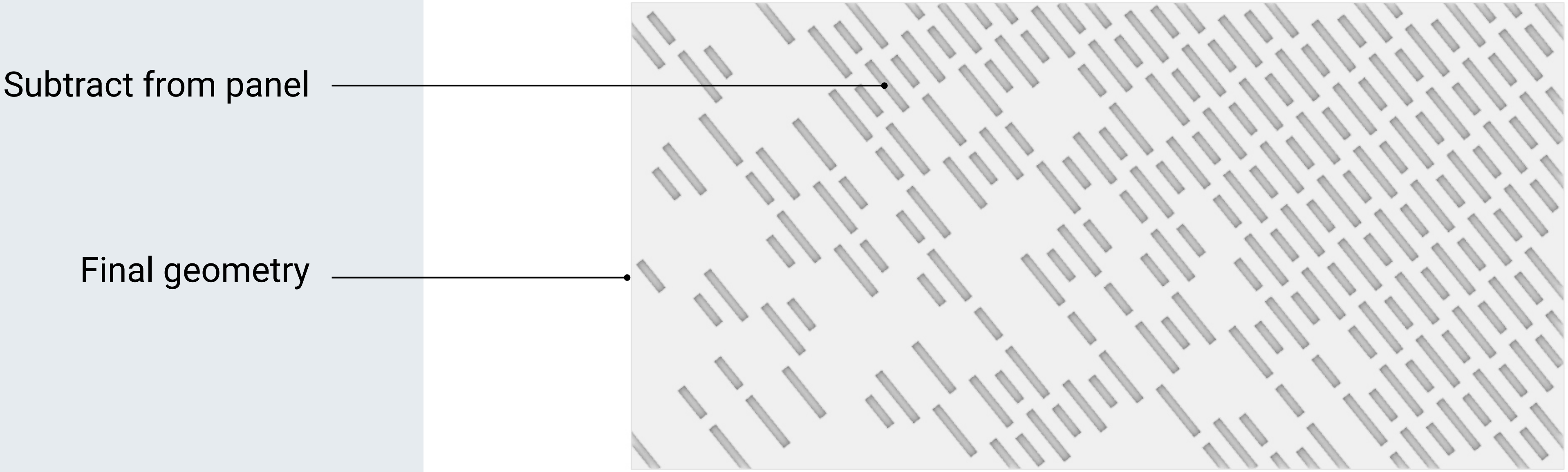
4.



Offset to create channel width

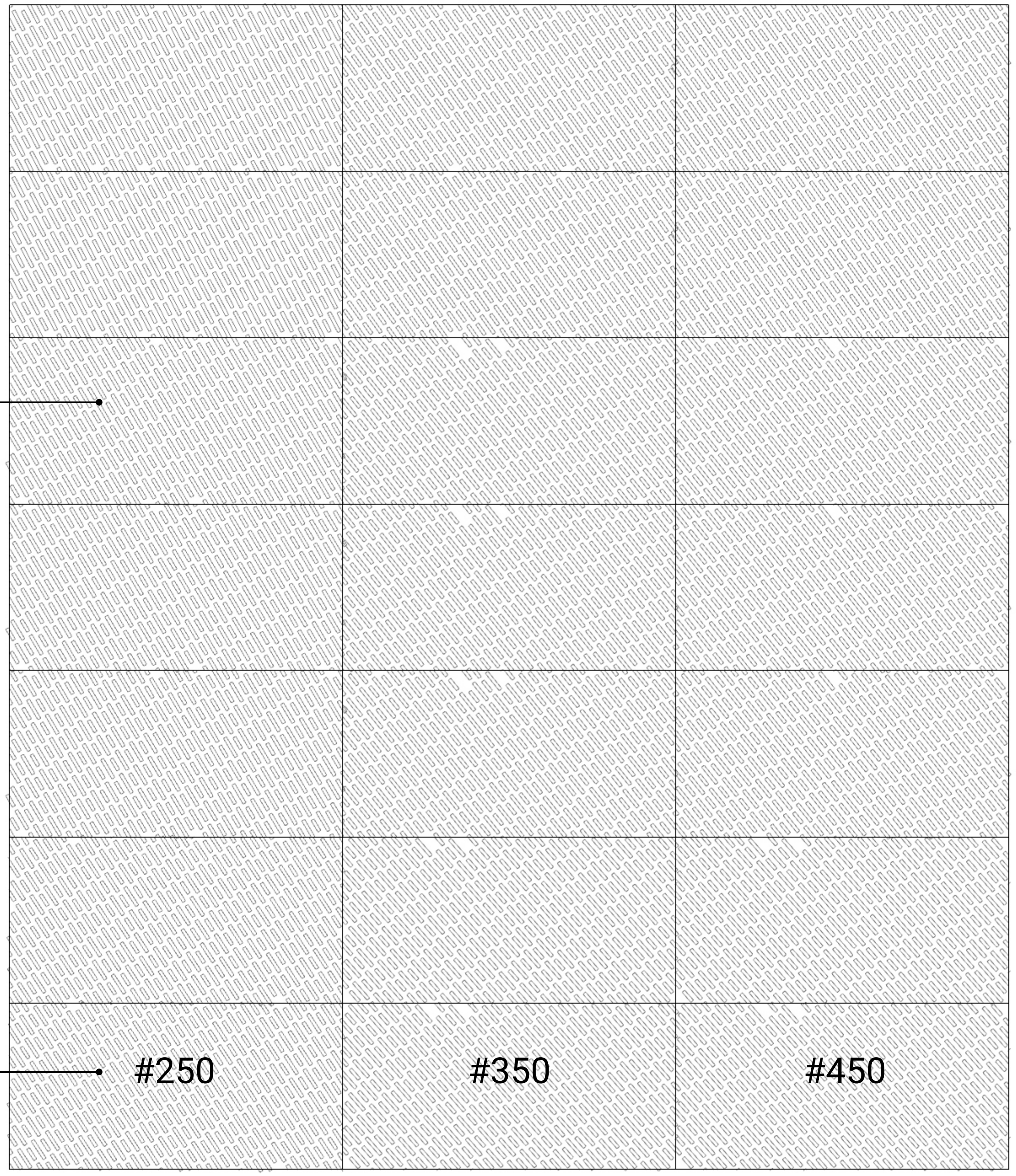
Assign depth

5.


Subtract from panel

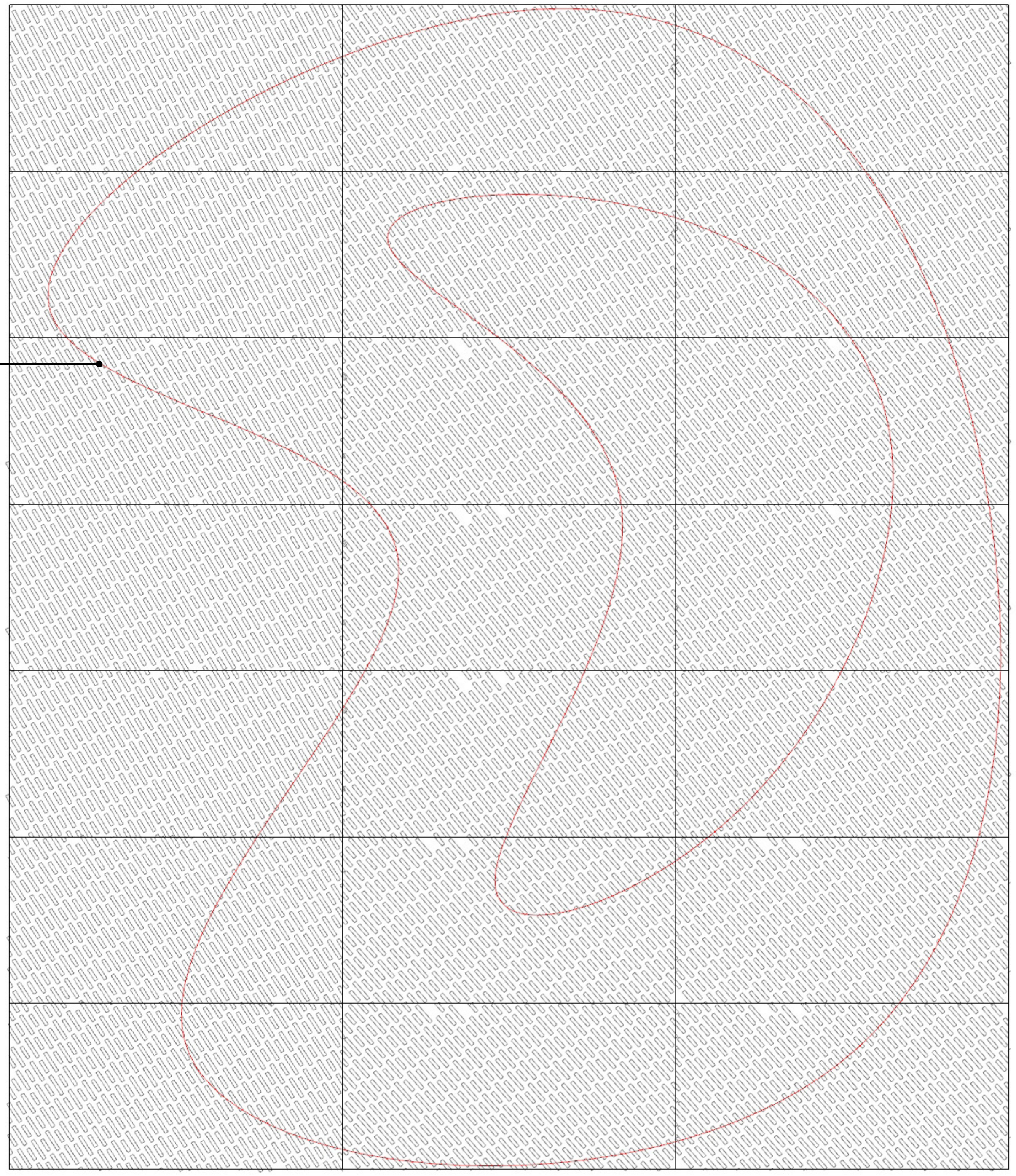
Final geometry

Facade Graphics

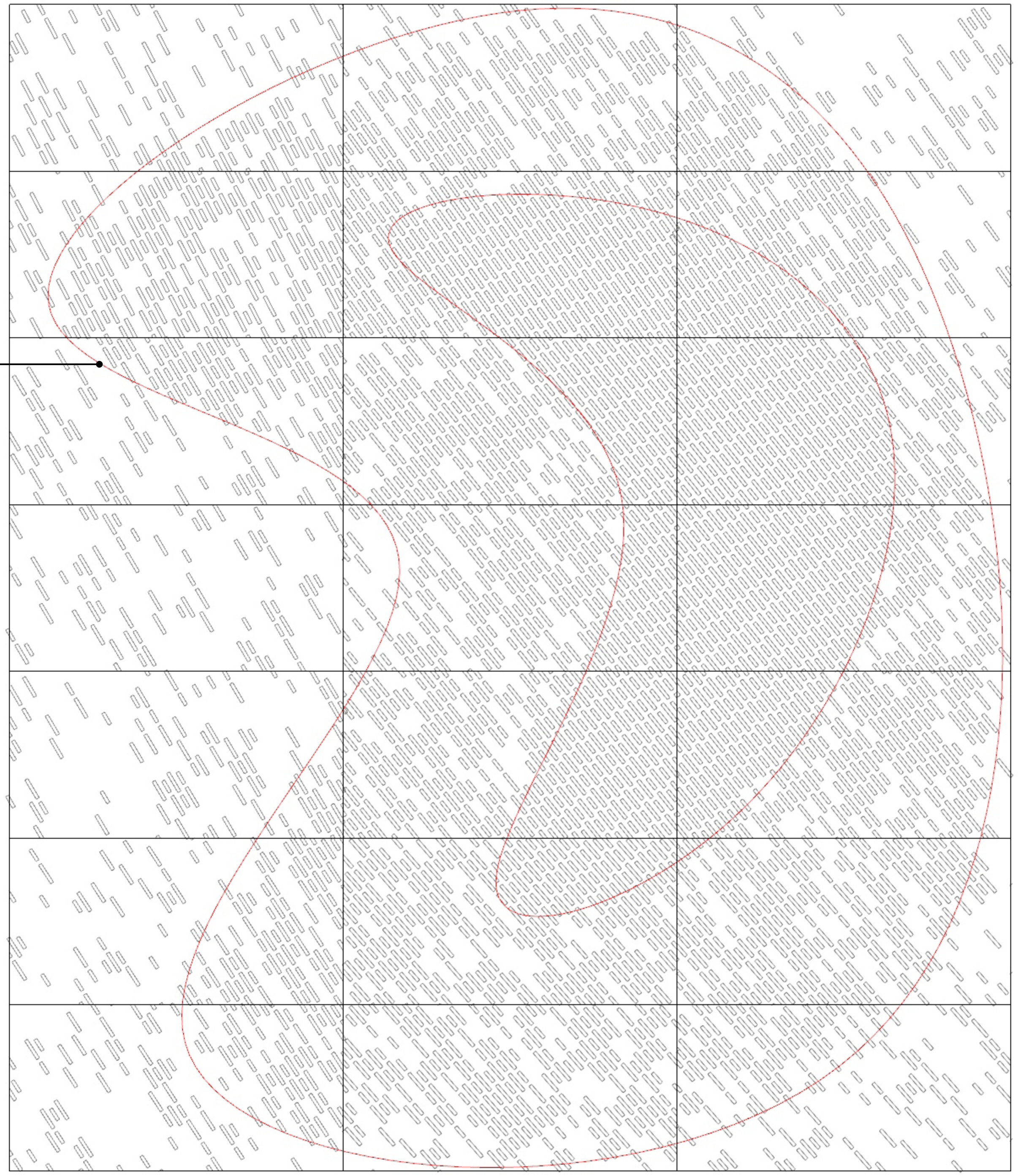


Facade Panel w/channels

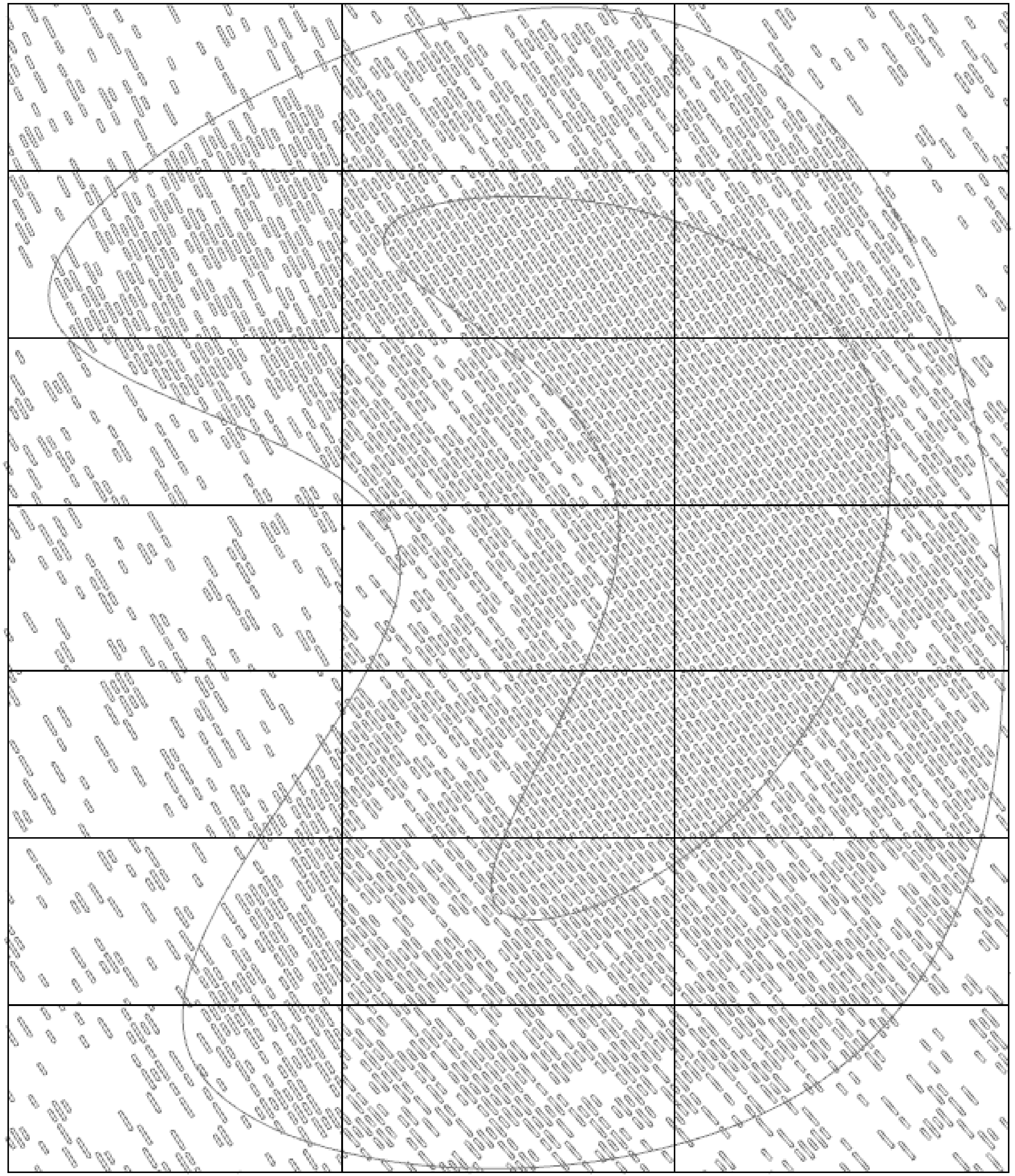
Numbering assigned



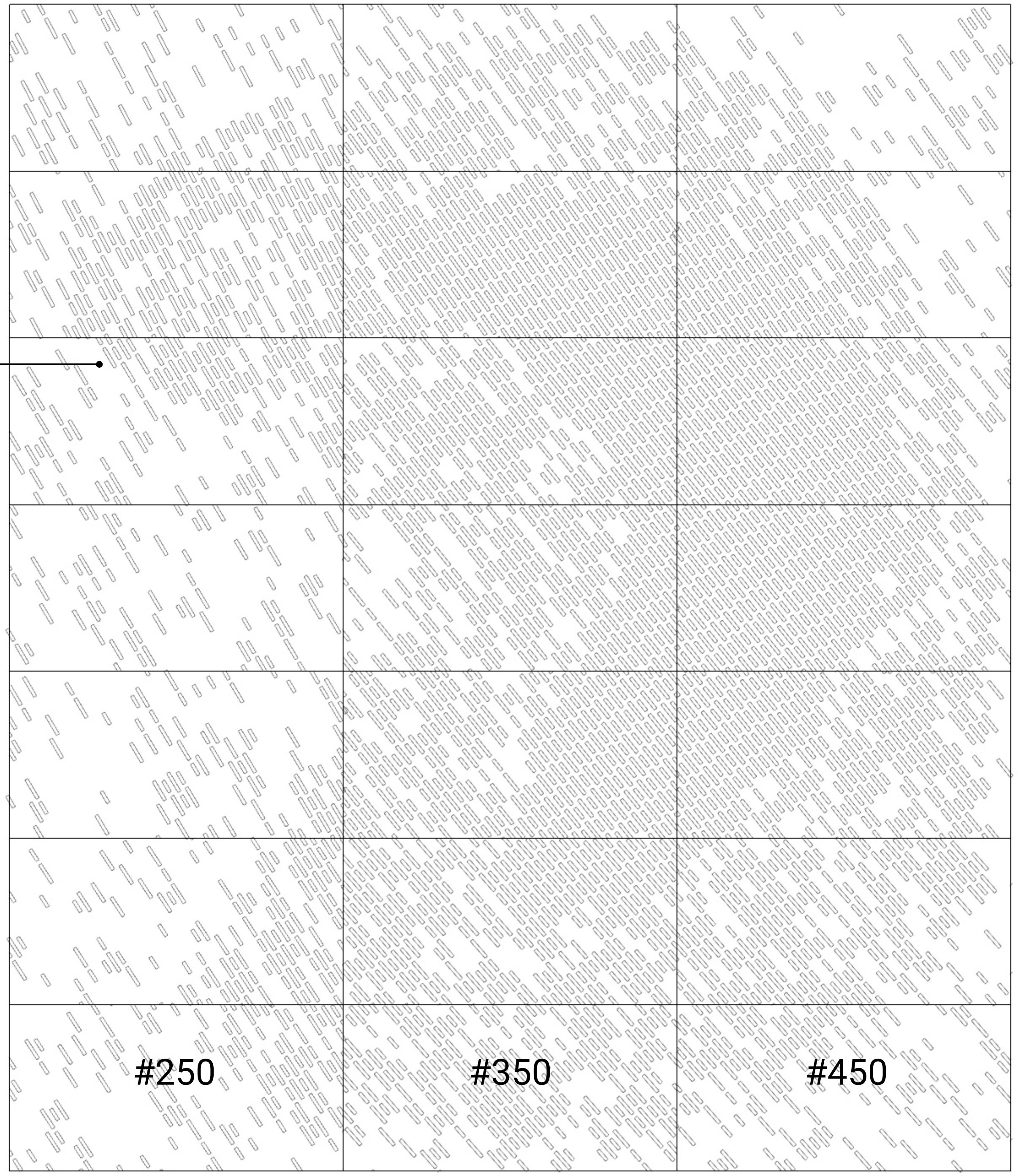
Apply Boundary Regions



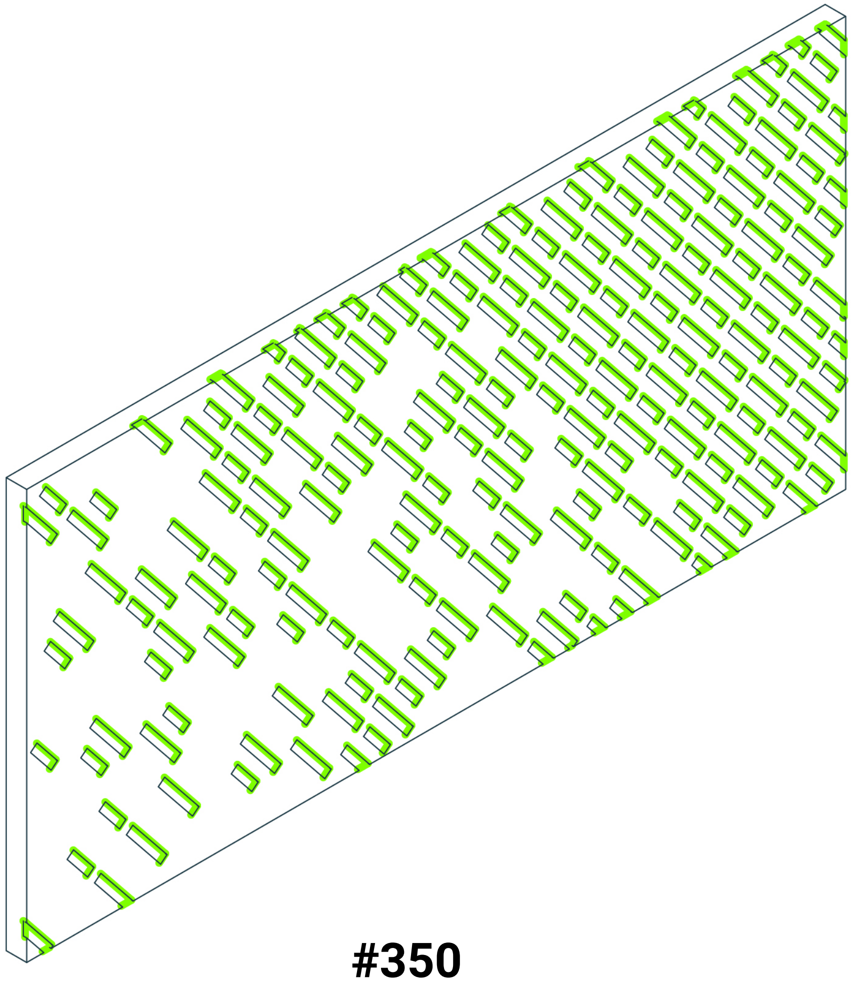
Assign Density to Regions



Reassign to Panels

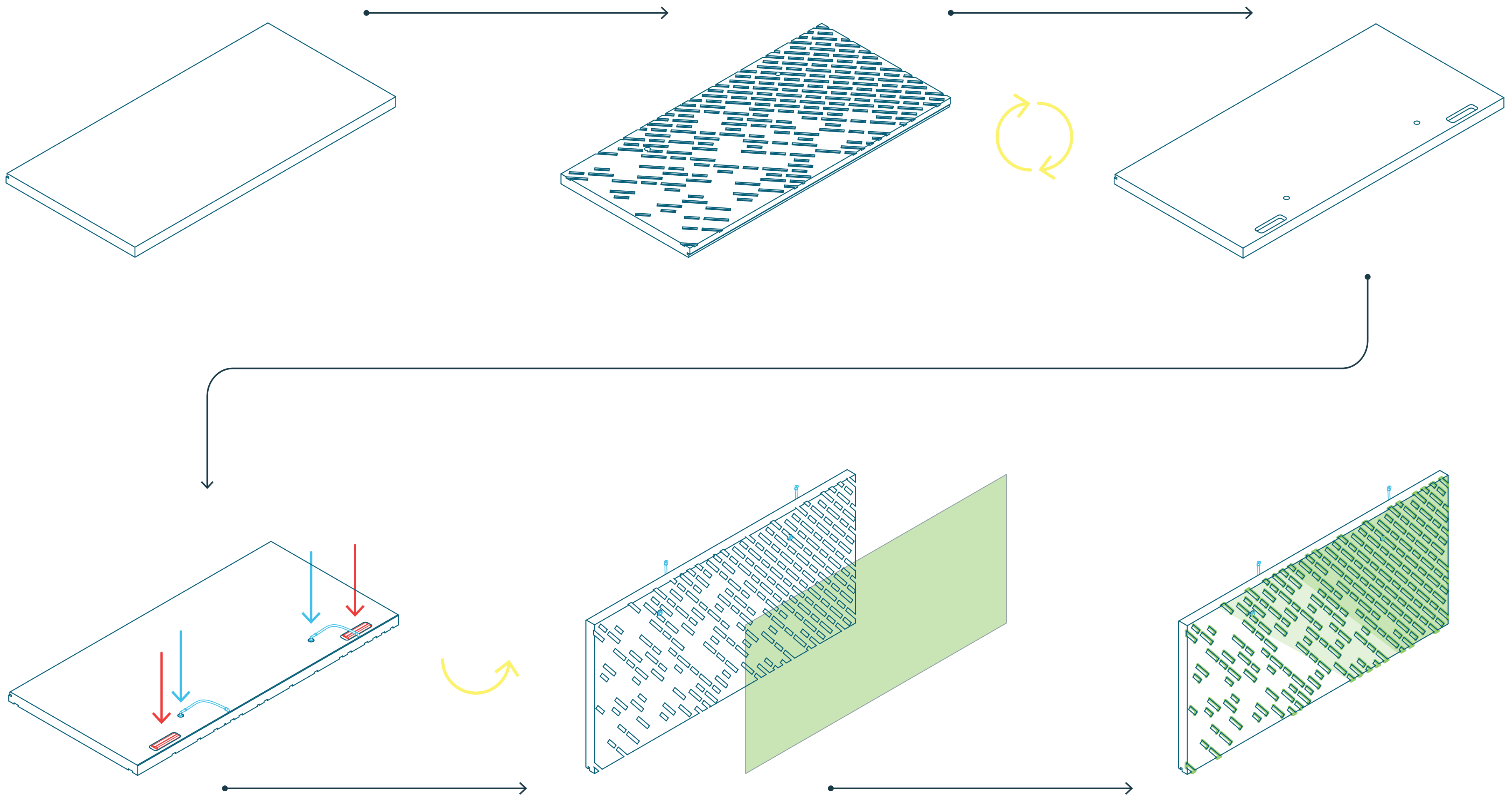


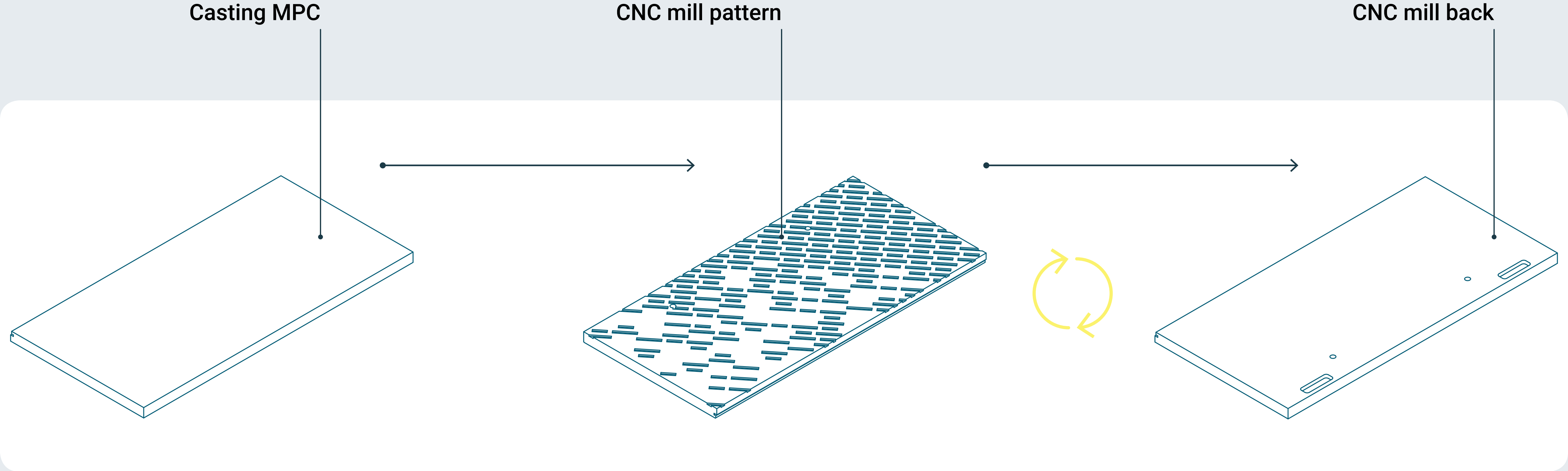
Digital Representation



#350

Panel Production Process:

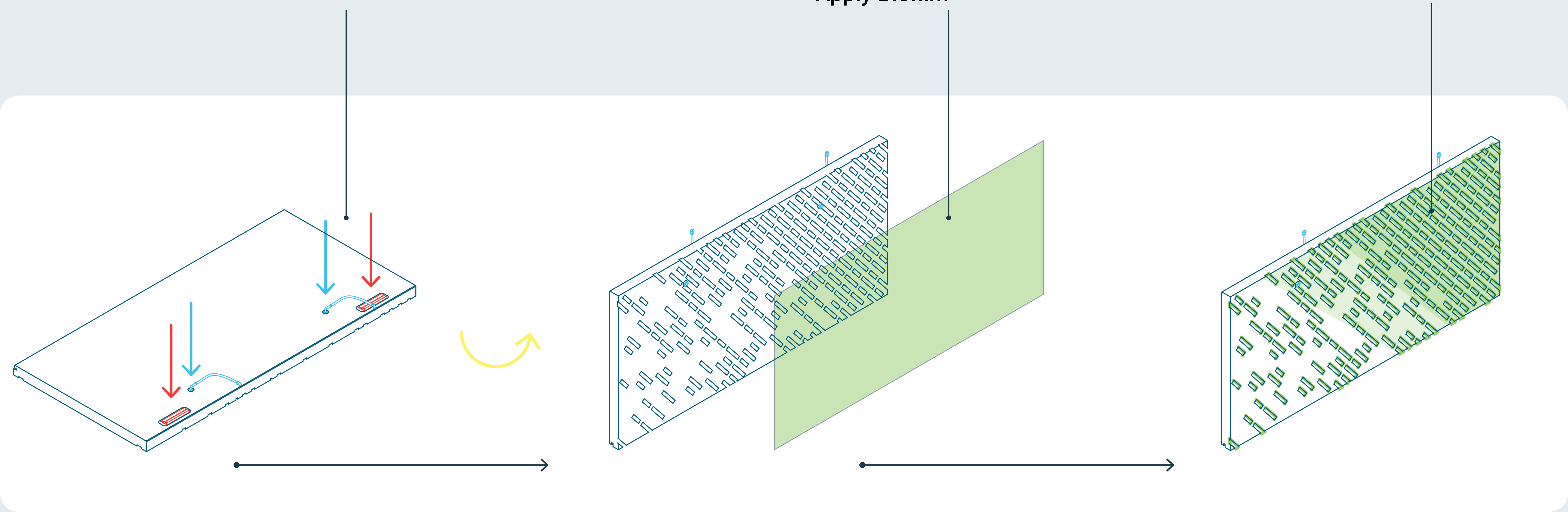




Casting MPC

CNC mill pattern

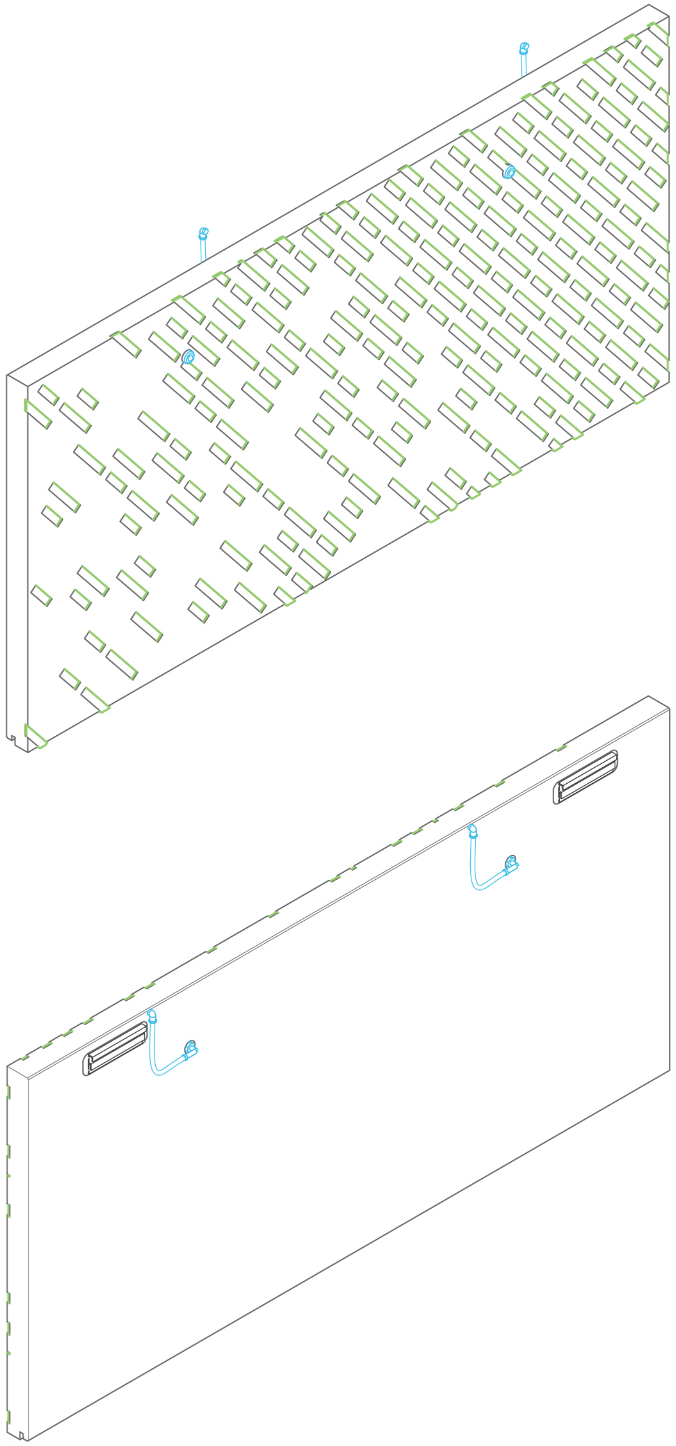
CNC mill back



Insert mounting bracket
& Misters

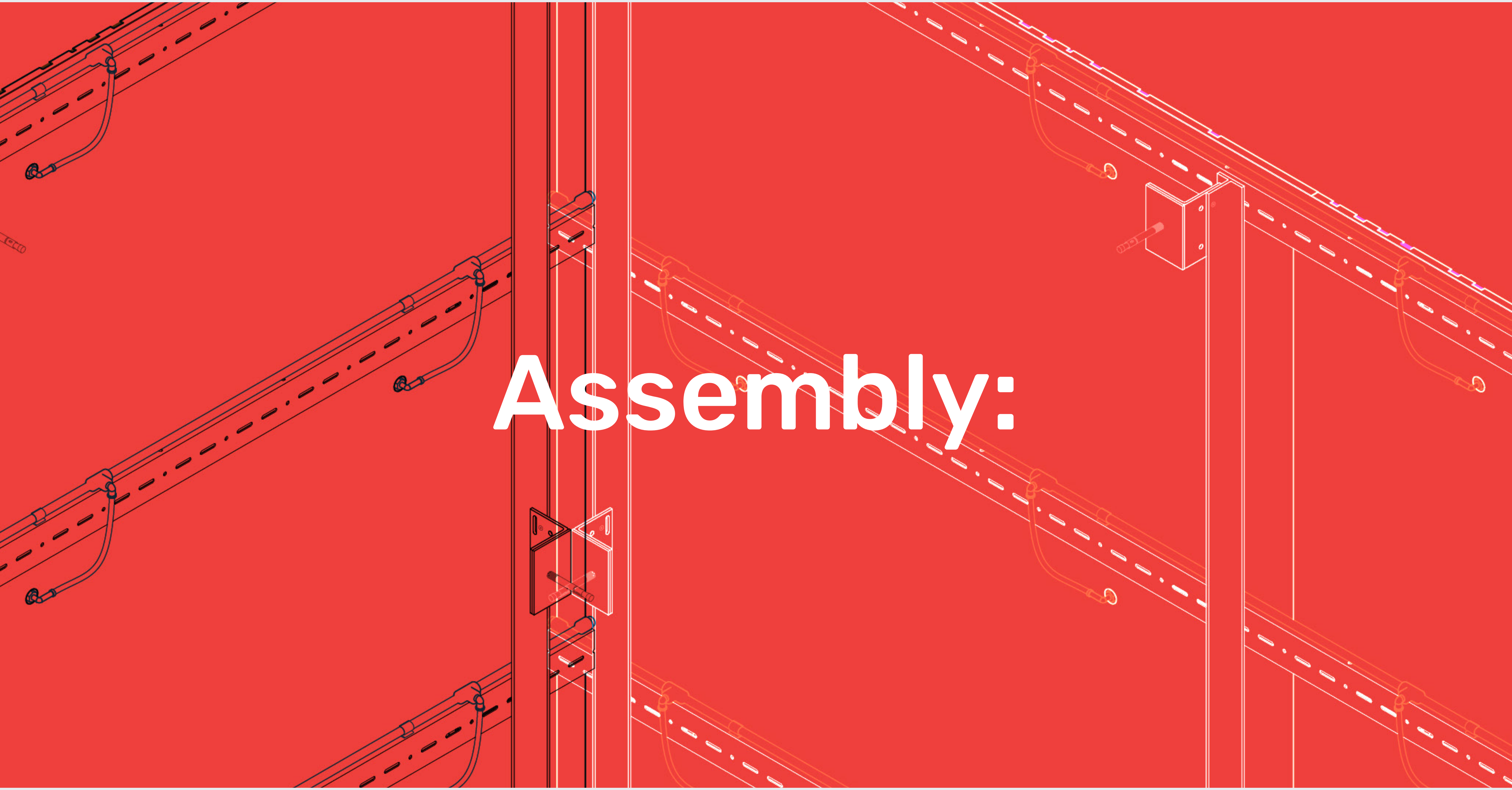
Apply Biofilm

Leave until established



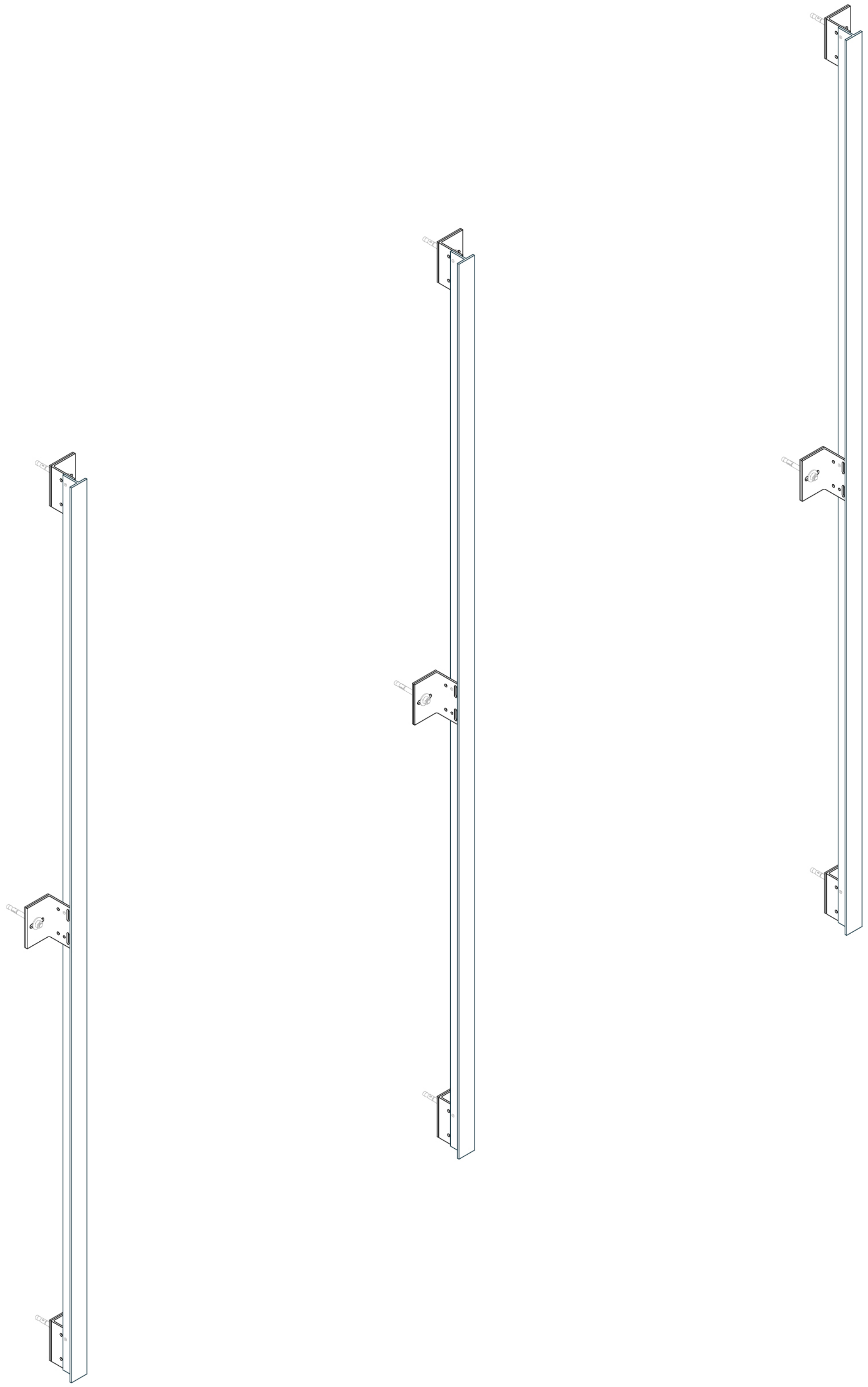
FACADE PANEL - FRONT AND BACK

SCALE: 1-10

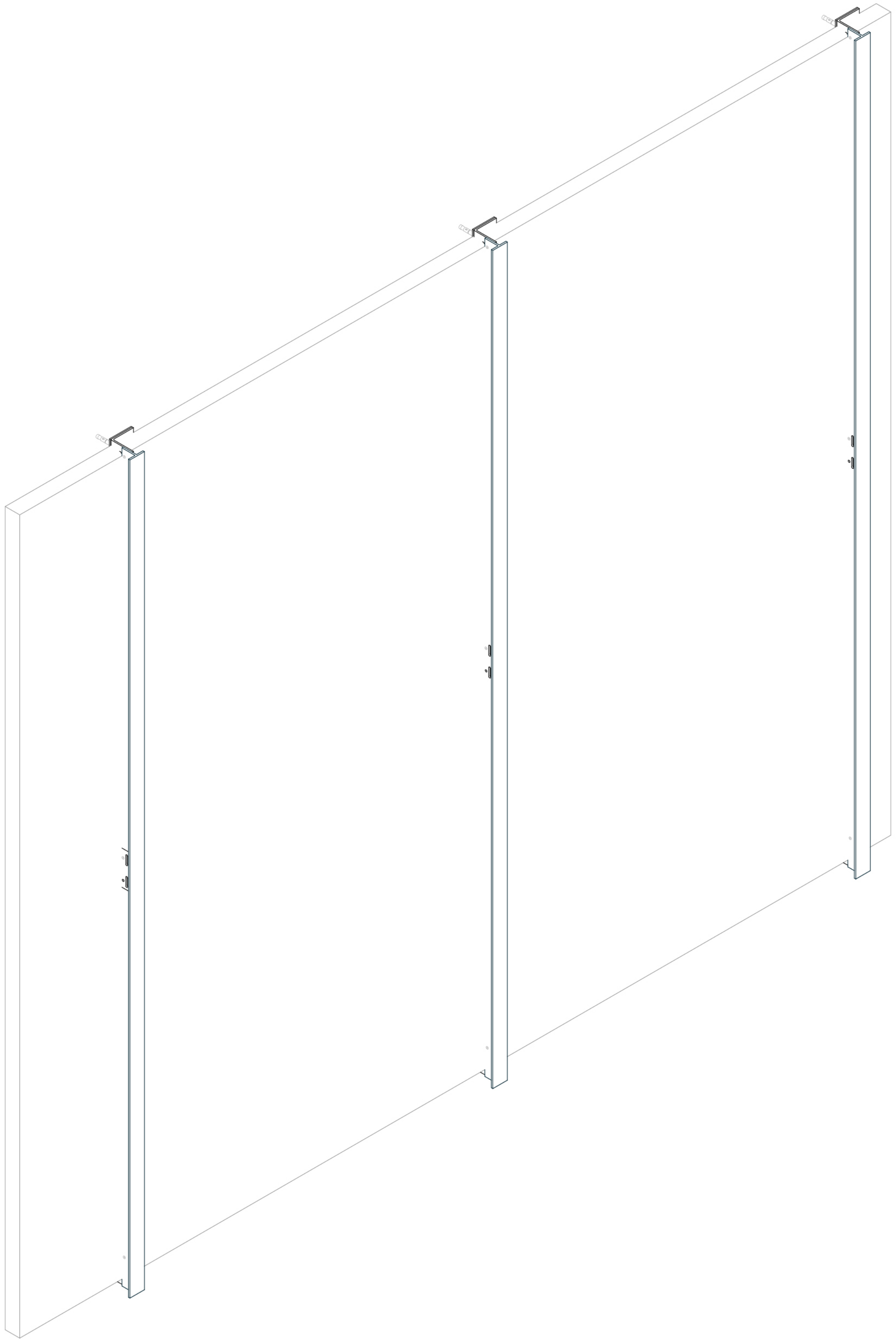


Assembly:

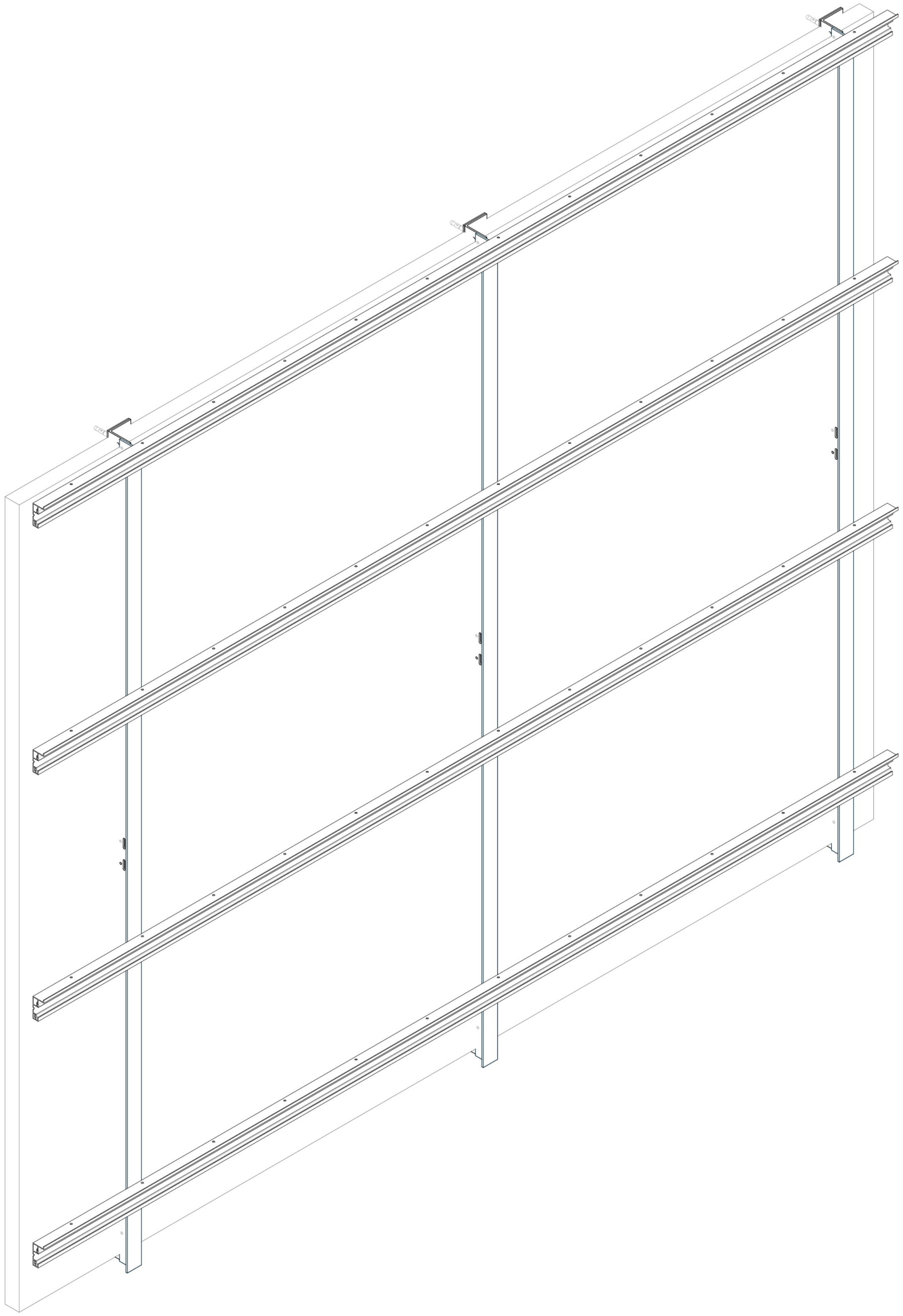
Facade Structure:



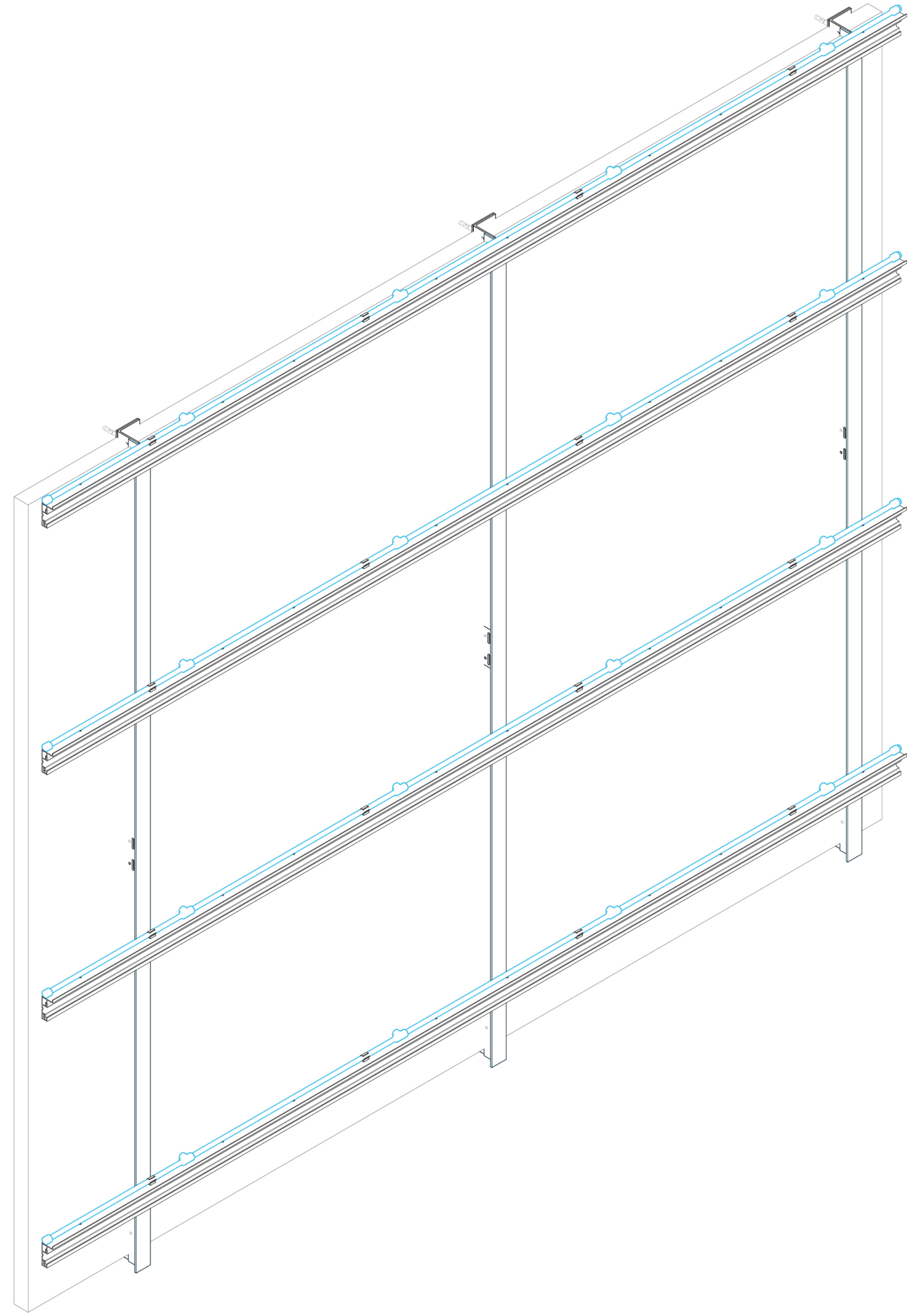
Facade Structure:



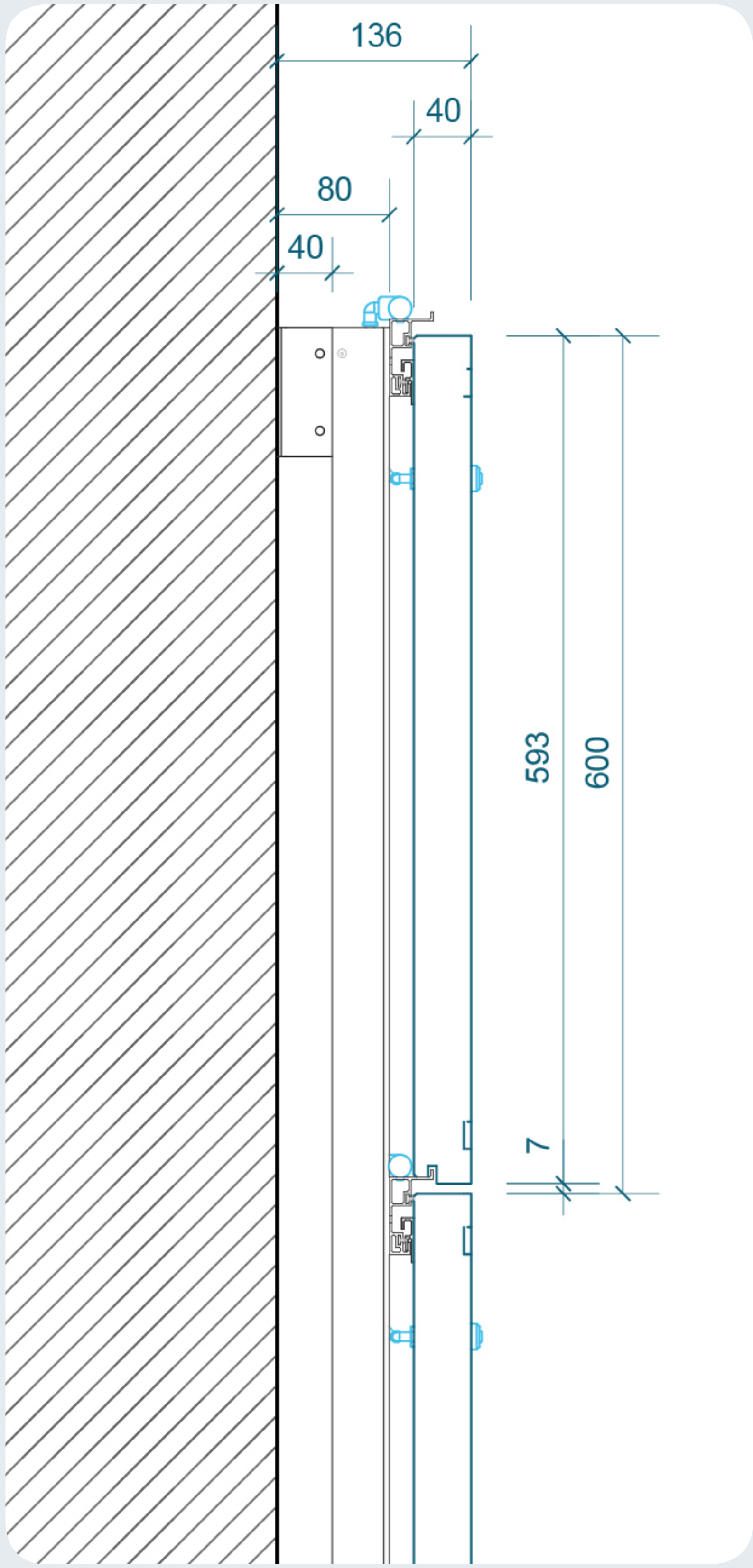
Facade Structure:

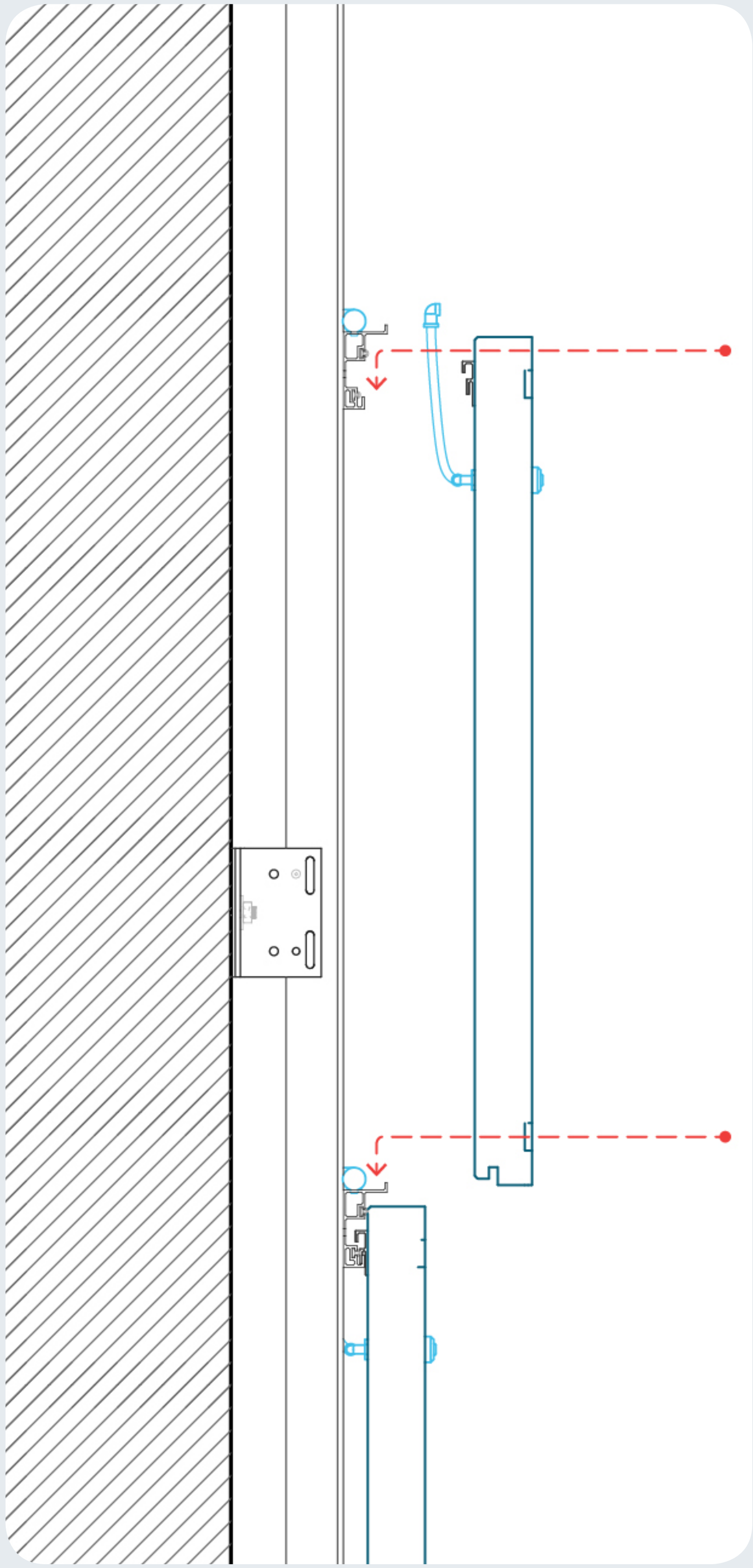


Facade Structure + Irrigation:

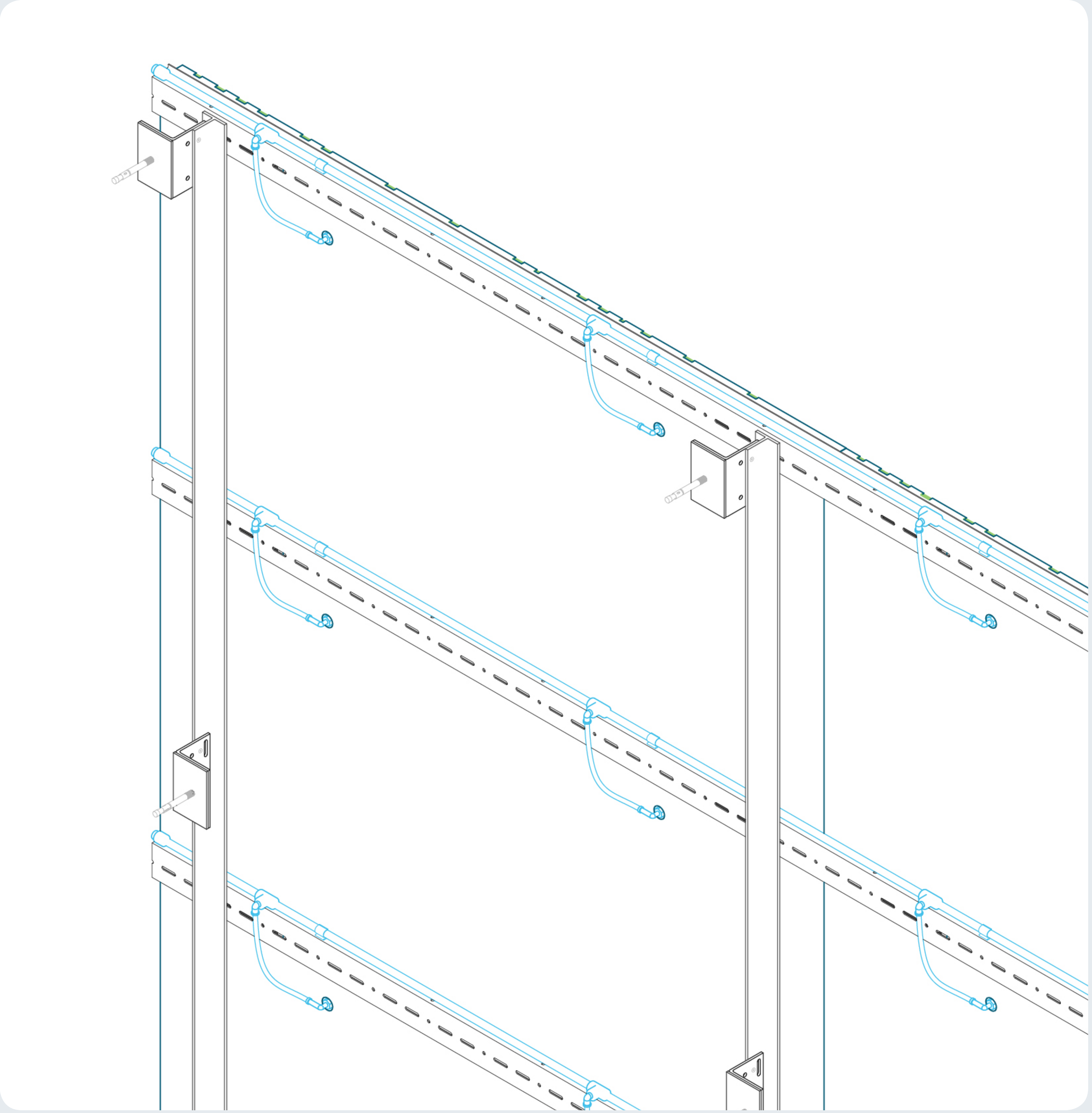


Panel Mounting to Structure:

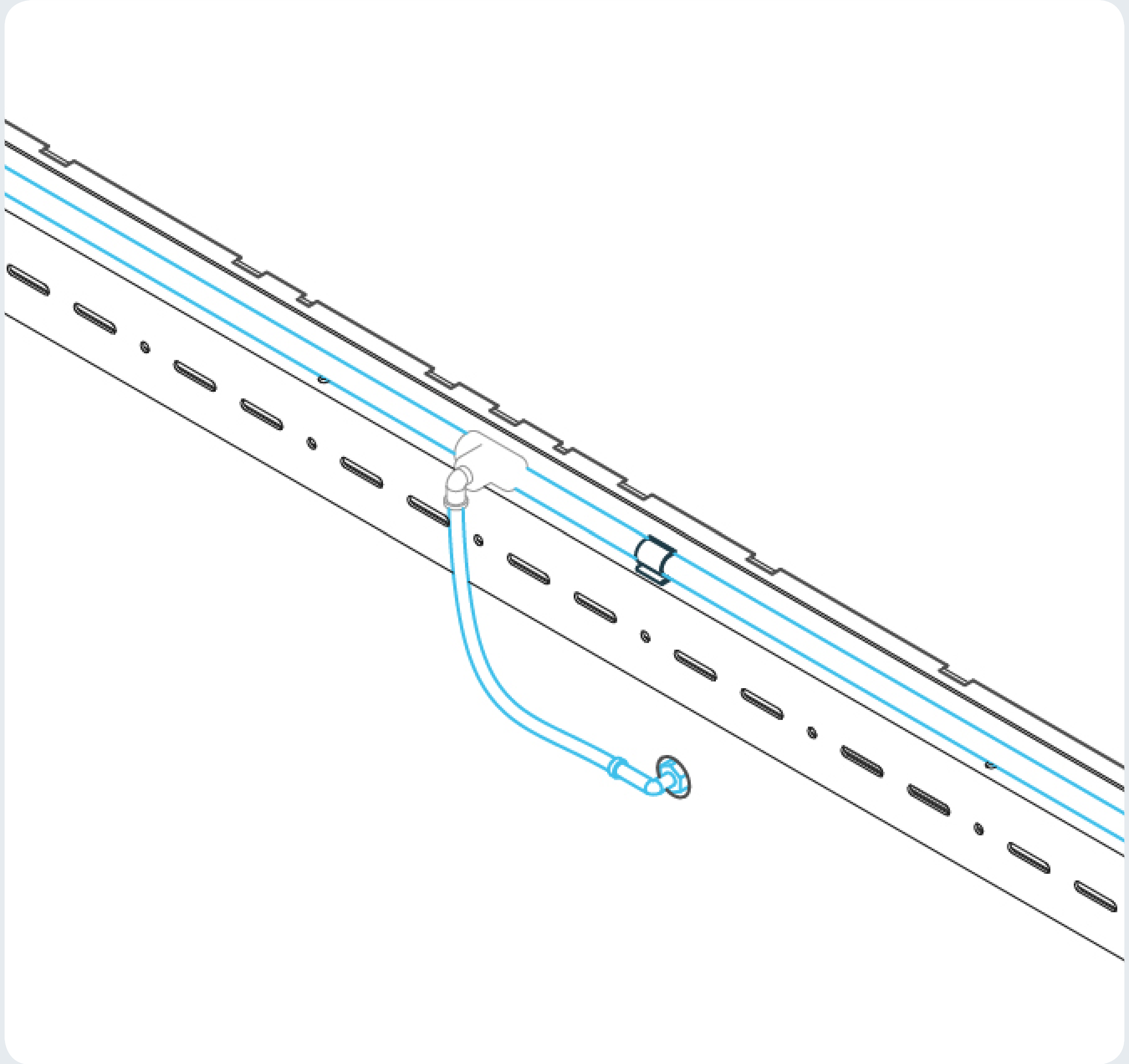




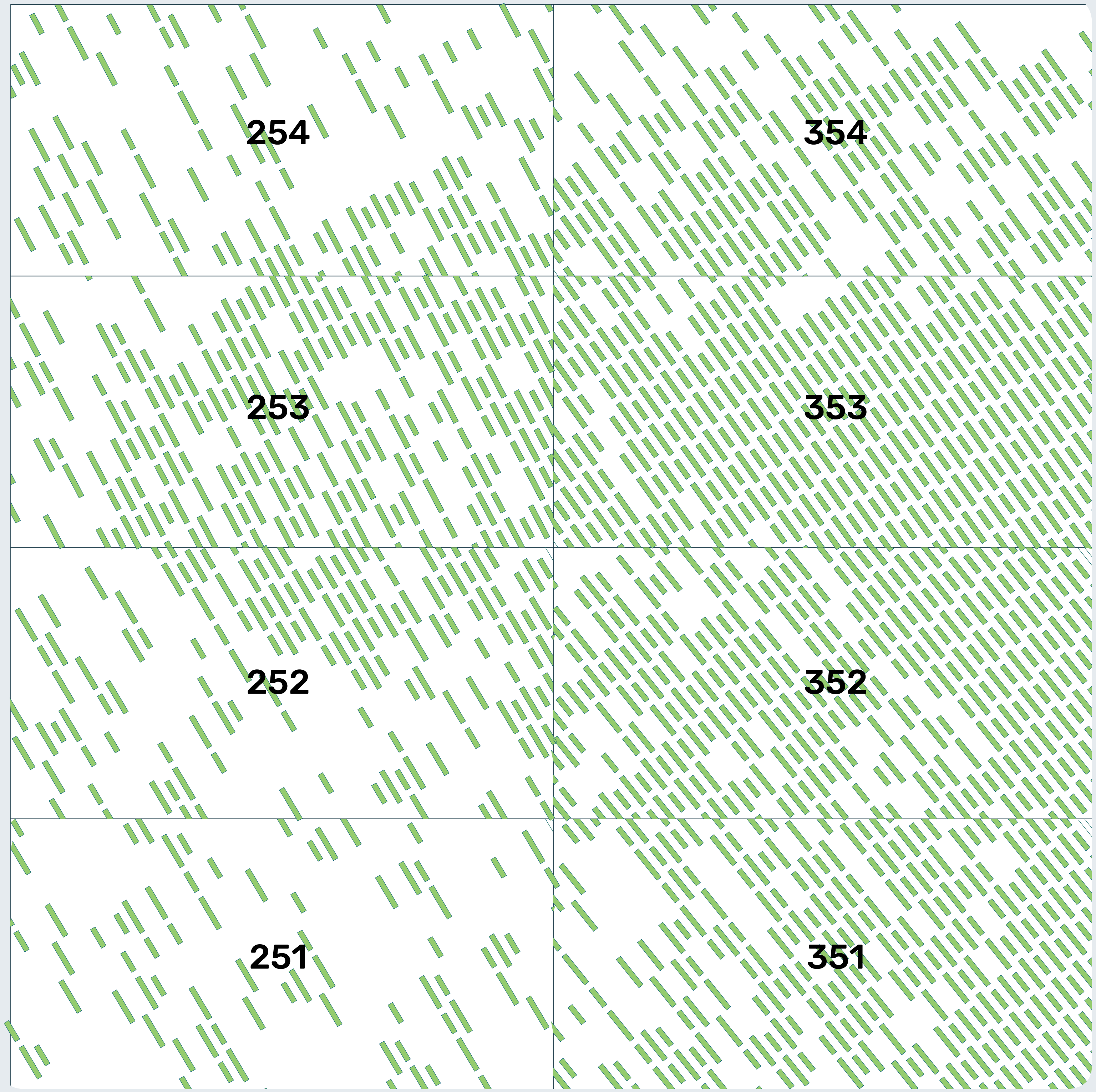
Irrigation Connection-Back:



Irrigation Connection:



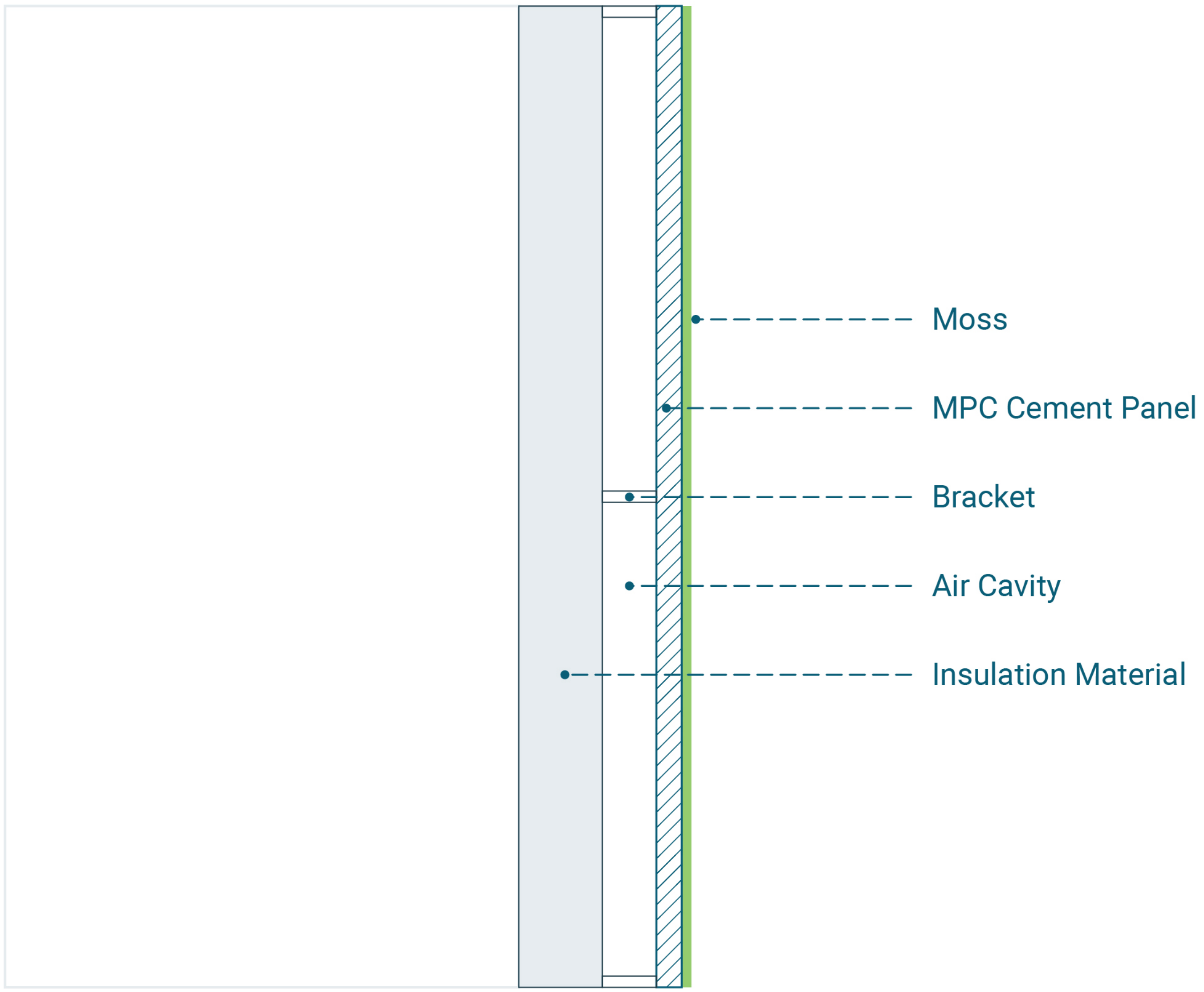
Panel Organization:



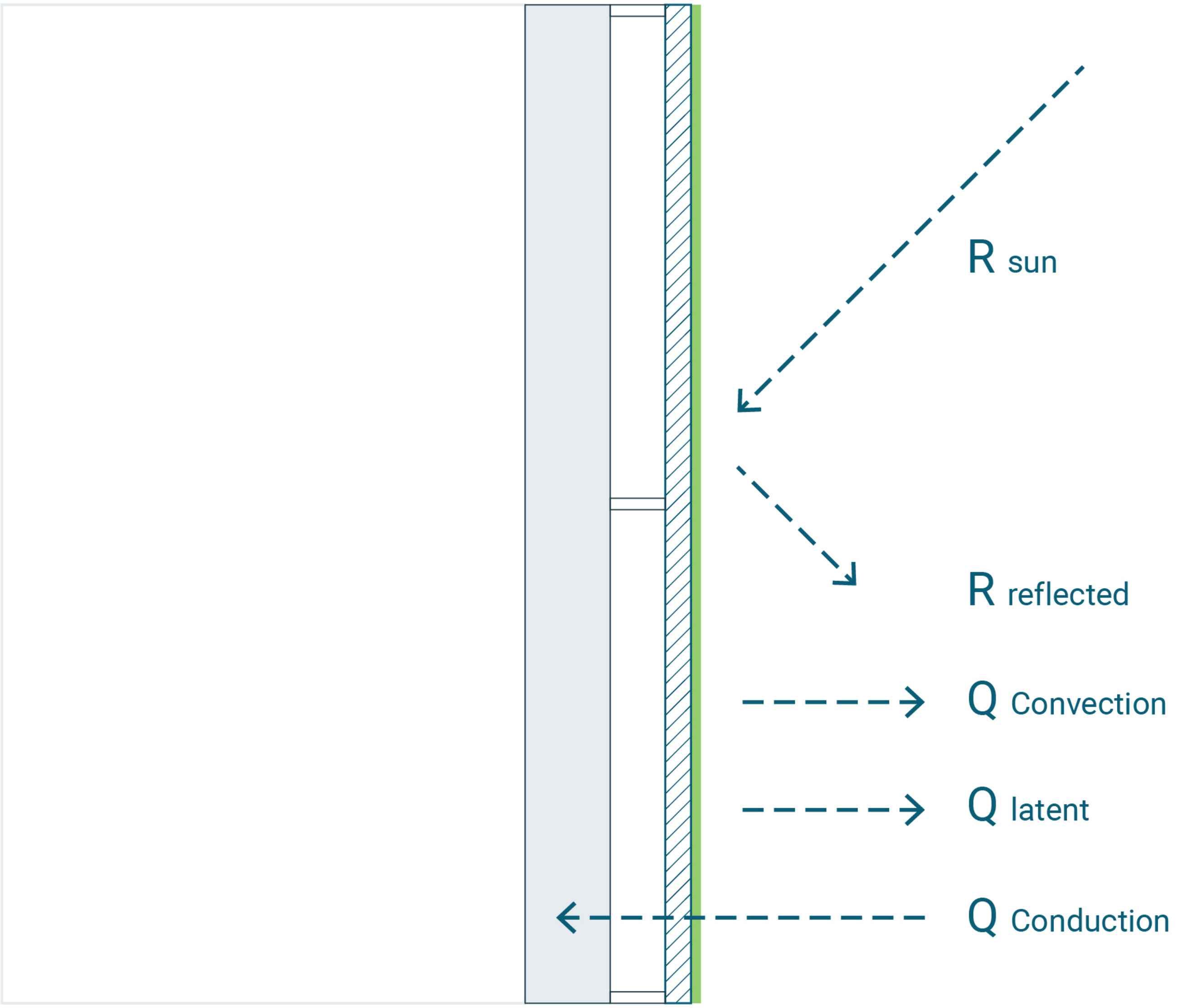
Facade Panels:

Evaluation

Material Layers



Schematic



Equations:

$$Q_{sun} = Q_{convection} + Q_{conduction} + Q_{latent}$$

$$Gr = \frac{g\beta\left(T_s - T_\infty\right)L^3}{v^2}$$

$$Re = \frac{U_{average}L}{v}$$

$$Q_{latent} = \frac{el}{tA}$$

$$Q_{convection} = h\left(T_s - T_\infty\right)$$

$$Q_{conduction} = \frac{\Delta T}{r_T}$$

Equations:

$$Q_{sun} = Q_{convection} + Q_{conduction} + Q_{latent}$$

$$Gr = \frac{g\beta\left(T_s - T_\infty\right)L^3}{v^2}$$

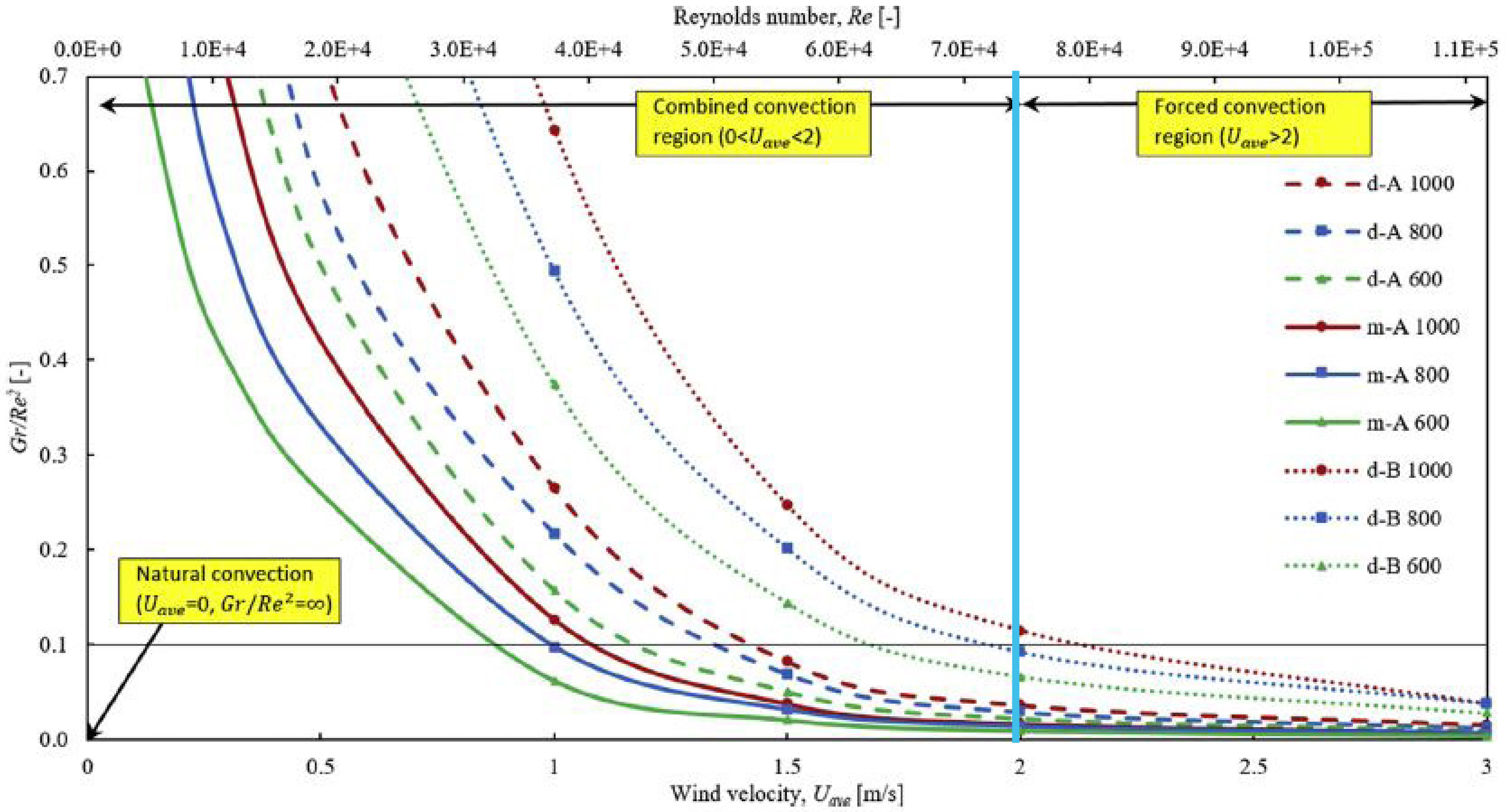
$$Re = \frac{U_{average}\,L}{v}$$

Used to generate a ratio to determine turbulence and a state of forced convection

$$Q_{latent} = \frac{el}{tA}$$

$$Q_{convection} = h\left(T_s - T_\infty\right)$$

$$Q_{conduction} = \frac{\Delta T}{r_T}$$



Ratio of Reynolds number and Grashof number to determine convection of moss. Katoh, Katsurayama, Koganei and Mizunuma (2018).

Equations:

$$Q_{sun} = Q_{convection} + Q_{conduction} + Q_{latent}$$

$$Gr = \frac{g\beta\left(T_s - T_\infty\right)L^3}{v^2}$$

$$Re = \frac{U_{average}\,L}{v}$$

$$Q_{latent} = \frac{el}{tA}$$

$$\boxed{Q_{convection} = h\left(T_s - T_\infty\right)}$$

Ratio influences the convection heat transfer coefficient (h)

$$Q_{conduction} = \frac{\Delta T}{r_T}$$

MPC Panel	**44.8° c**	at 1 m/s air flow
MPC Panel w/Moss	**40.1° c**	
MPC Panel w/Moss	**33.5° c**	above 2 m/s air flow forced convection

44.8° c

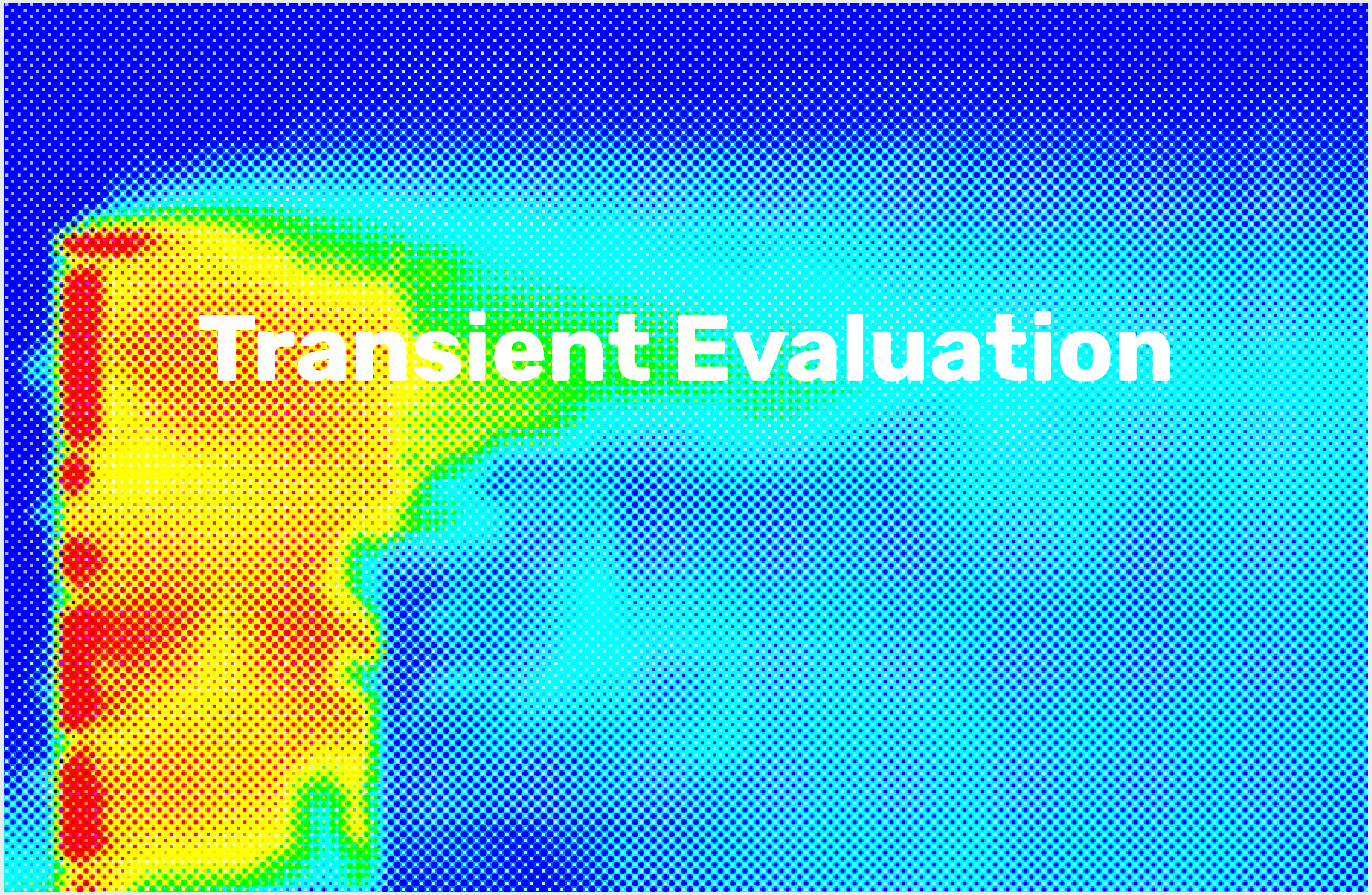
≈ 4.7° c reduction in surface temperatures, assuming 5mm surface of moss coverage

40.1° c

33.5° c

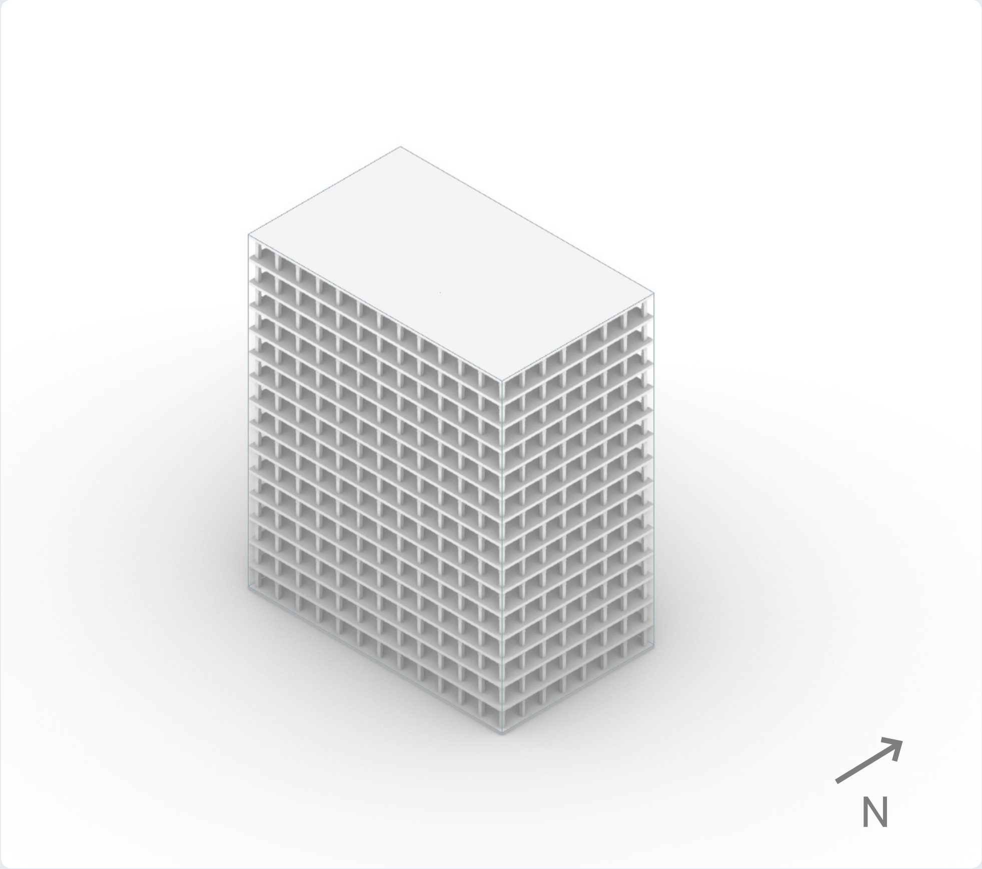
Additional ≈ 6.6° c reduction in surface temperatures, under forced convection

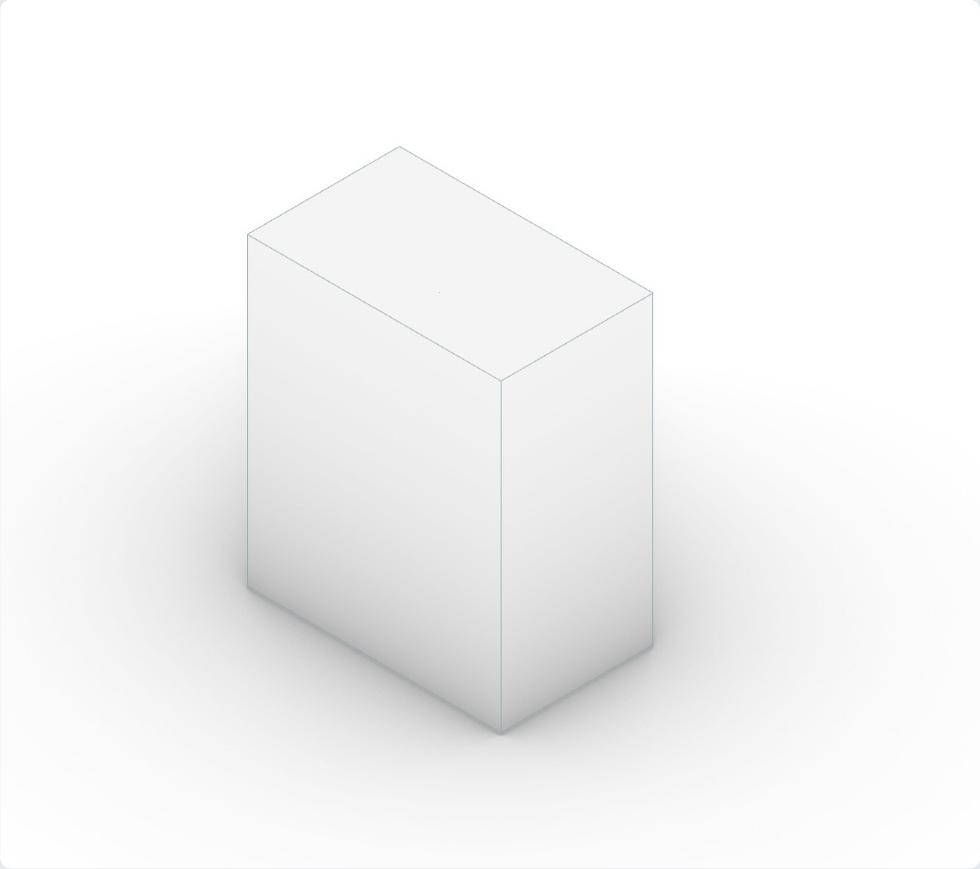
*Air flow is not a constant or predictable variable



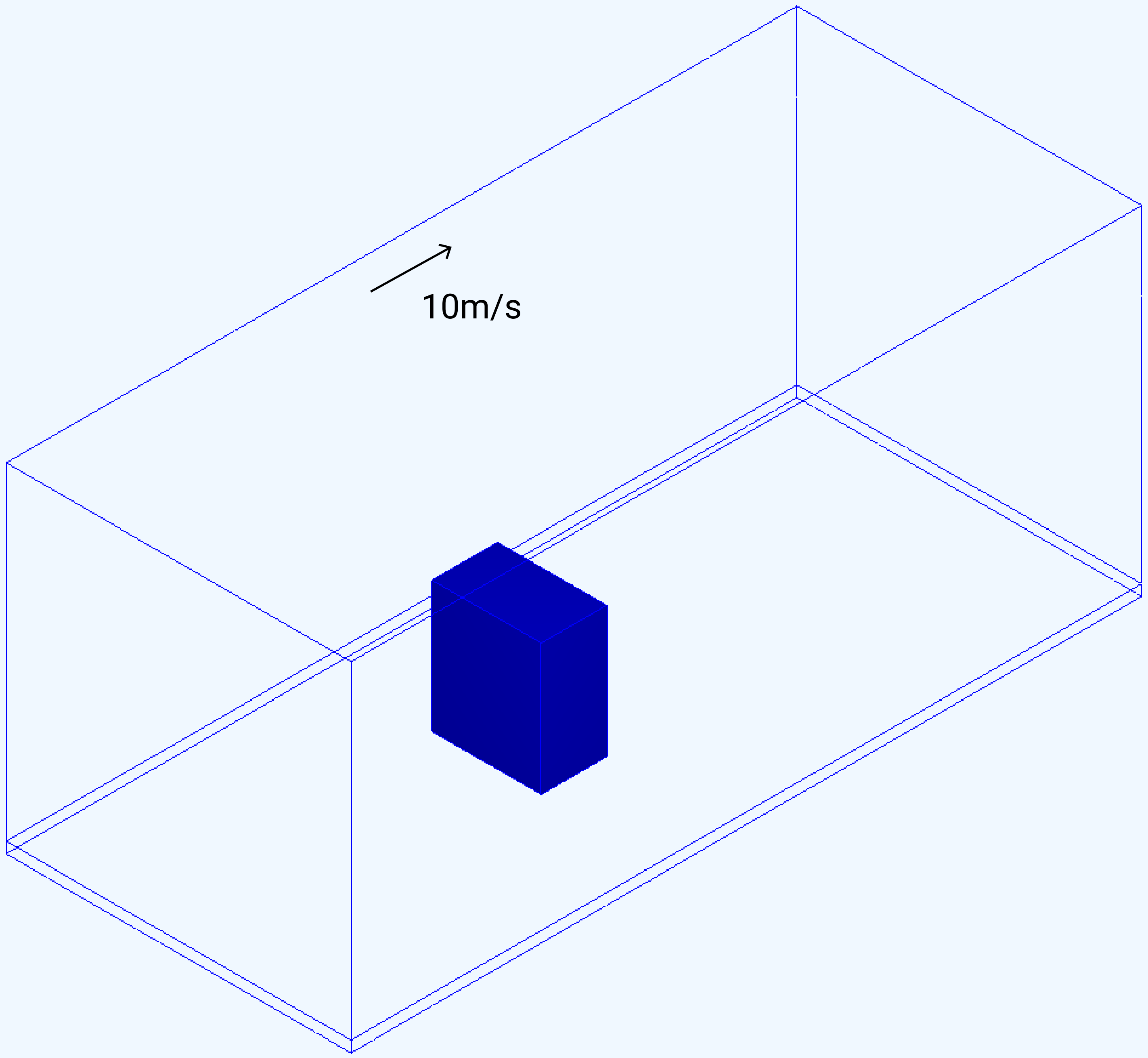
Transient Evaluation

CFD Case Building:

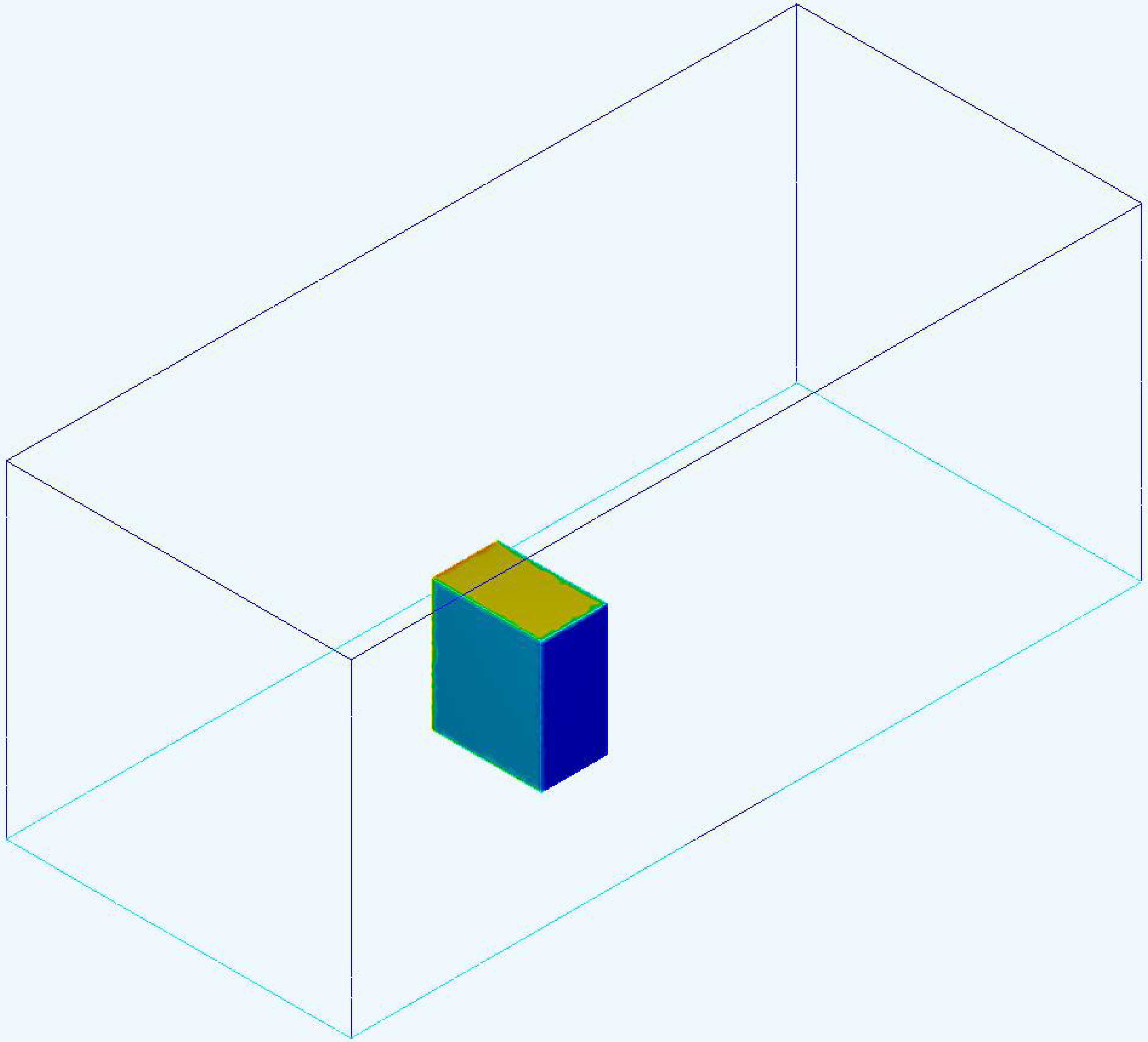




Setup:

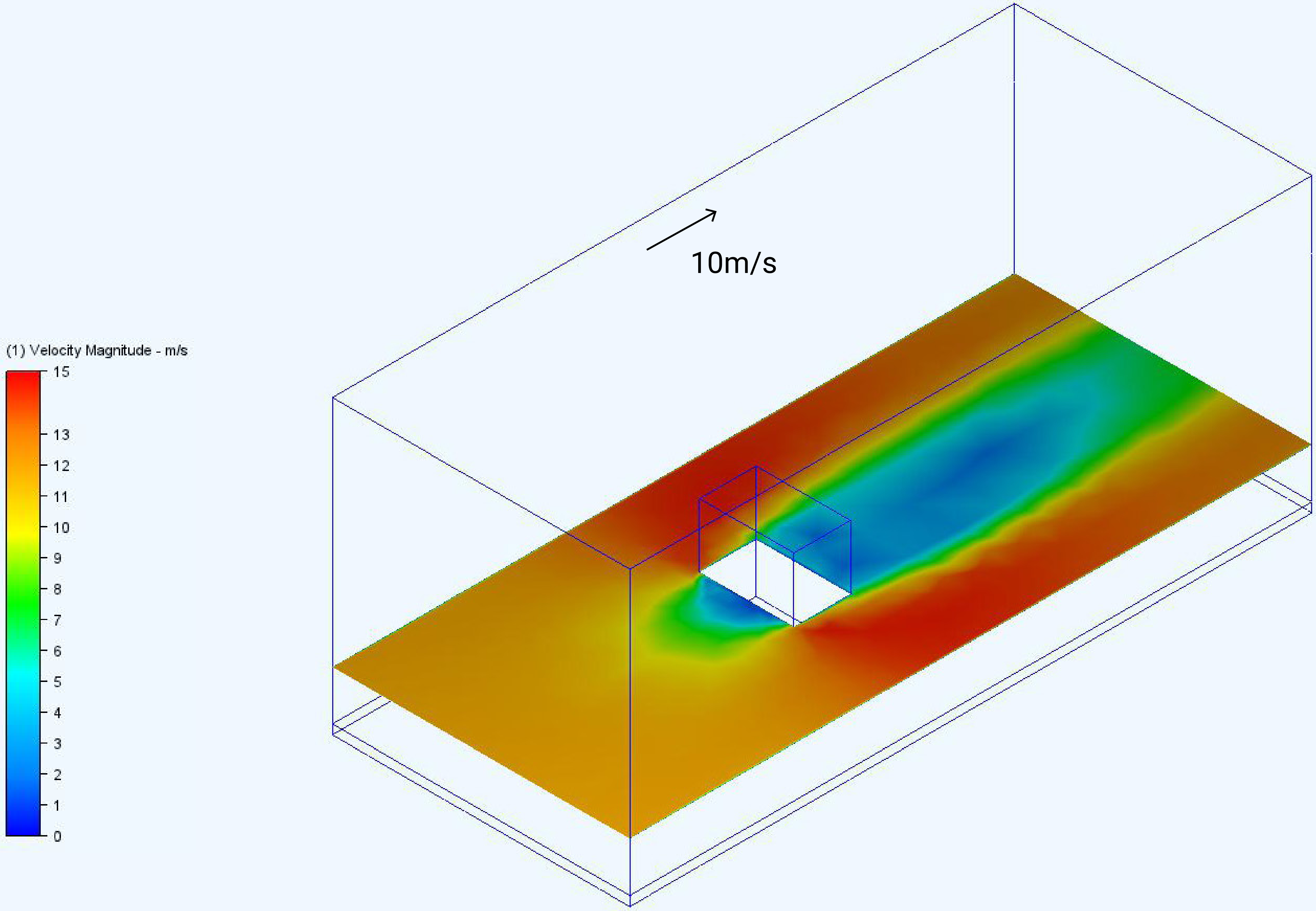


Solar Heat Flux

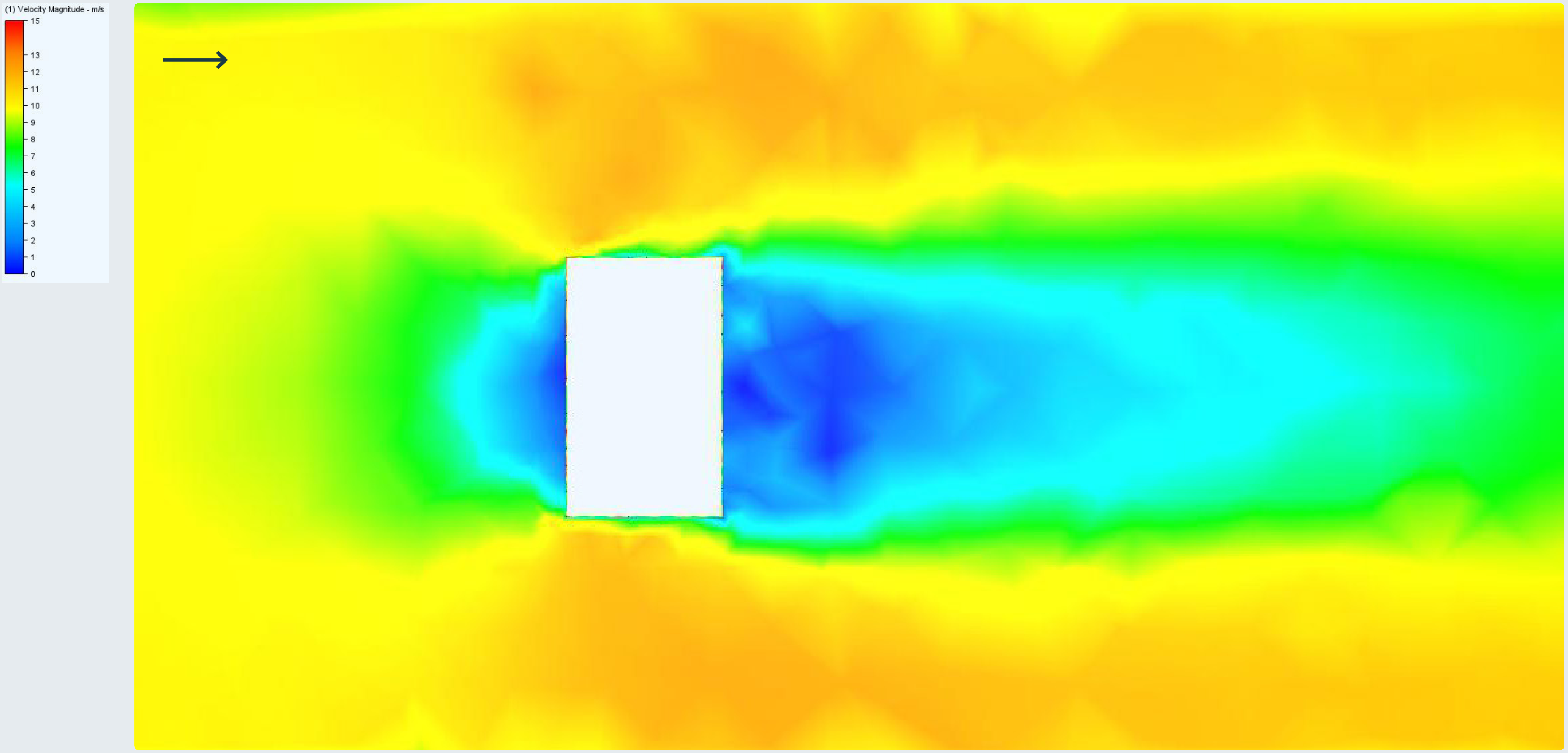


13:00

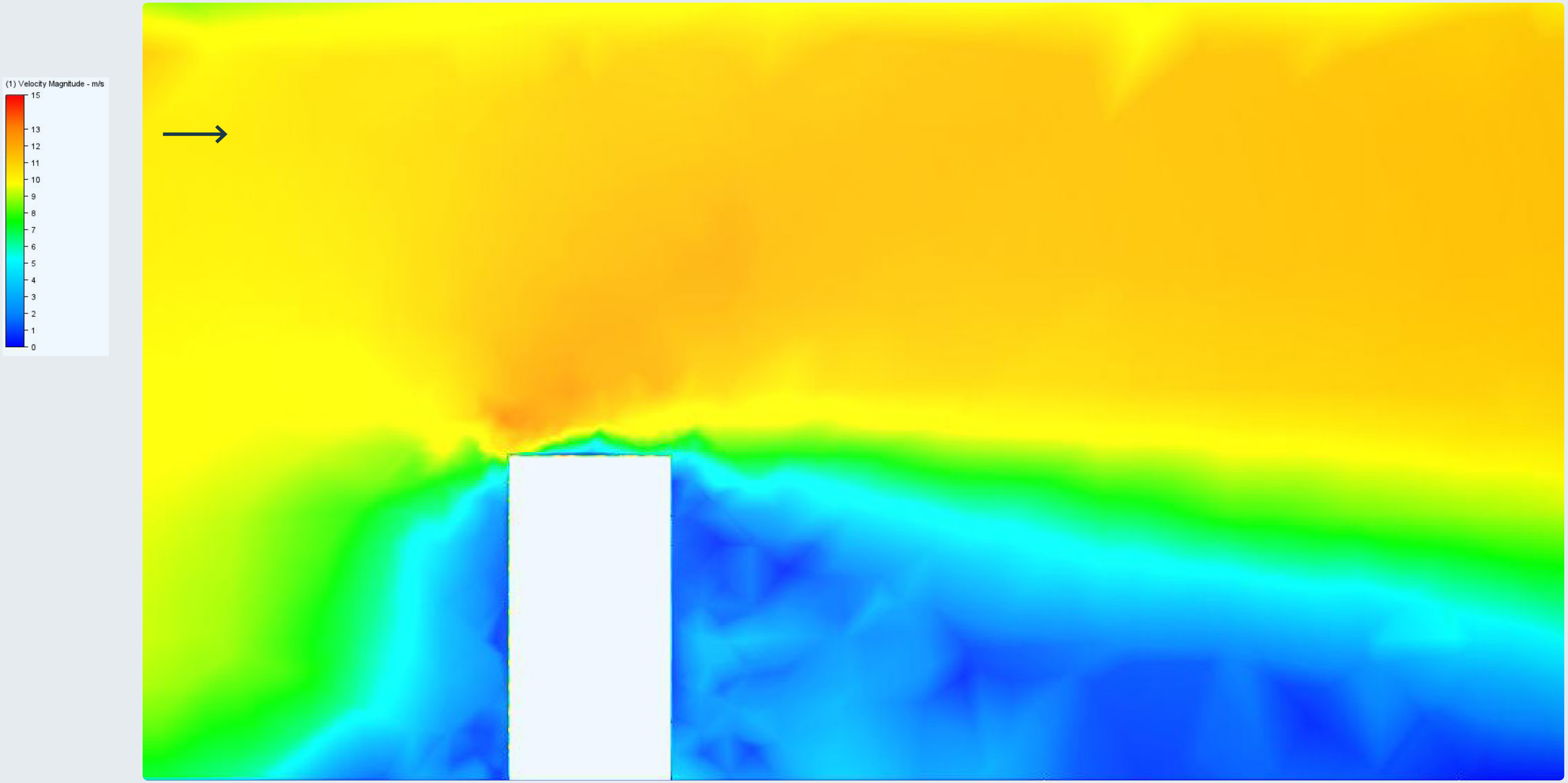
Steady State Air Flow



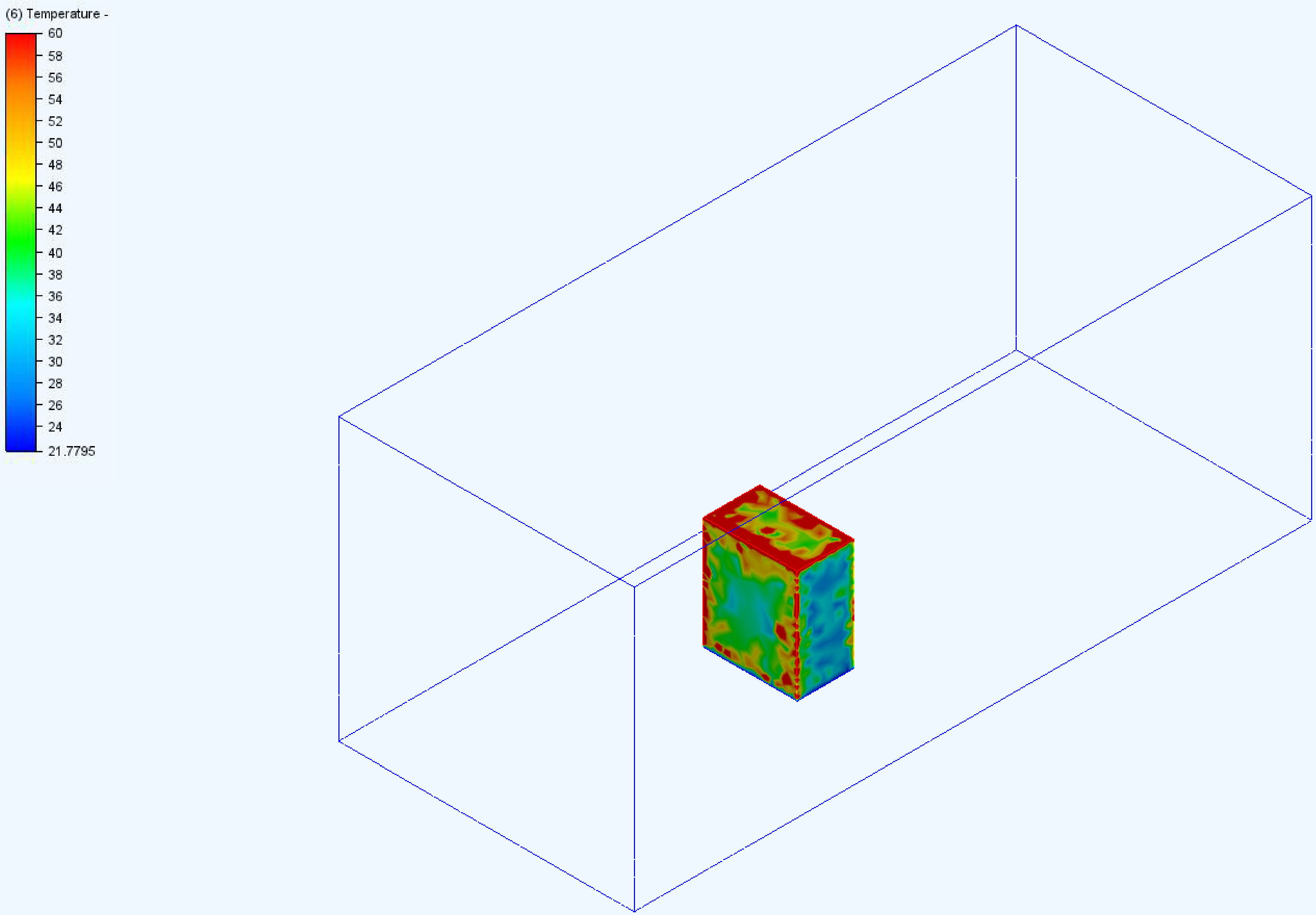
Steady State Air Flow: Top



Steady State Air Flow: Side

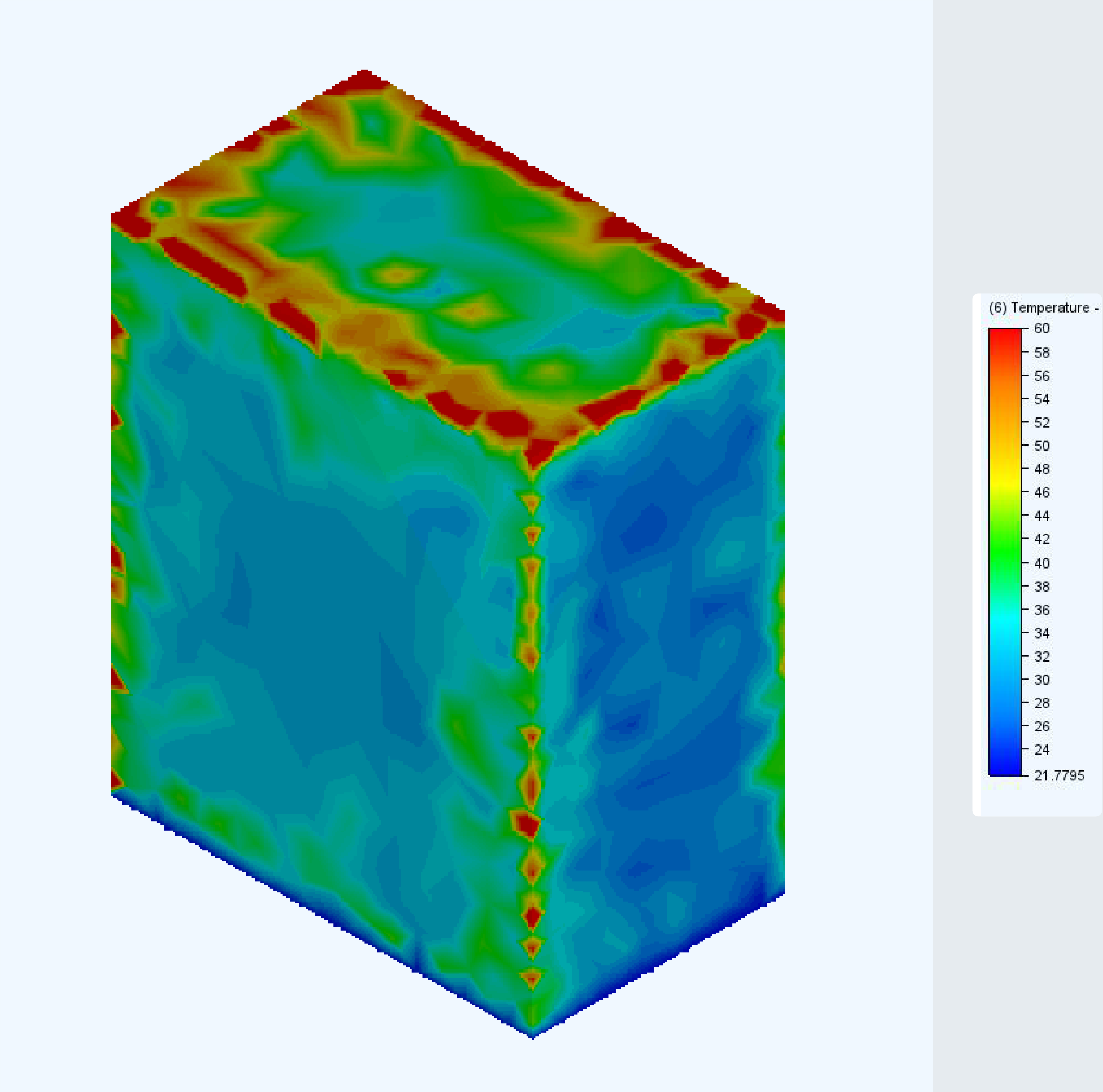


Surface Temperatures

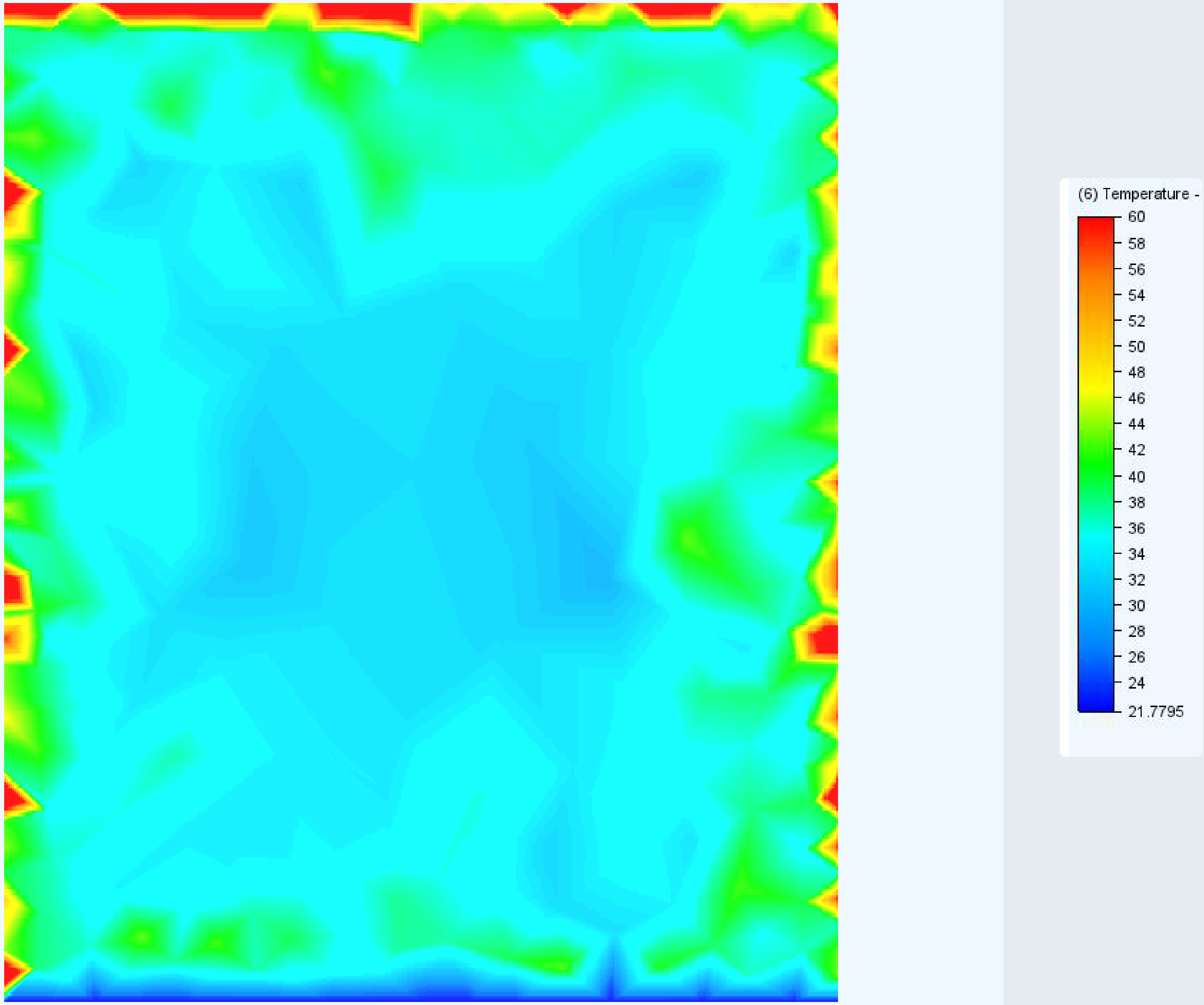


Ambient air: 25° c

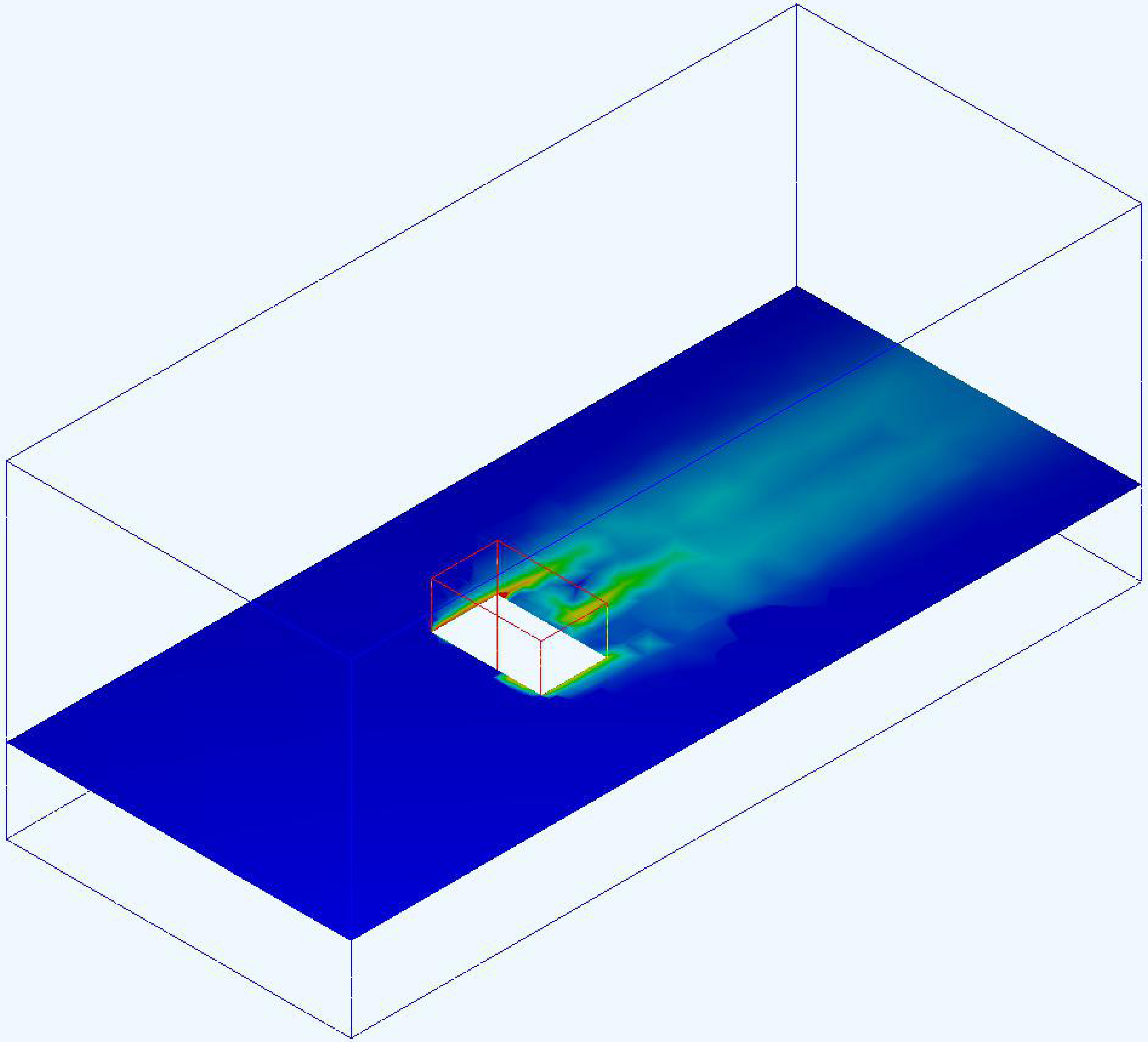
Surface Temperatures



Surface Temperatures: Front

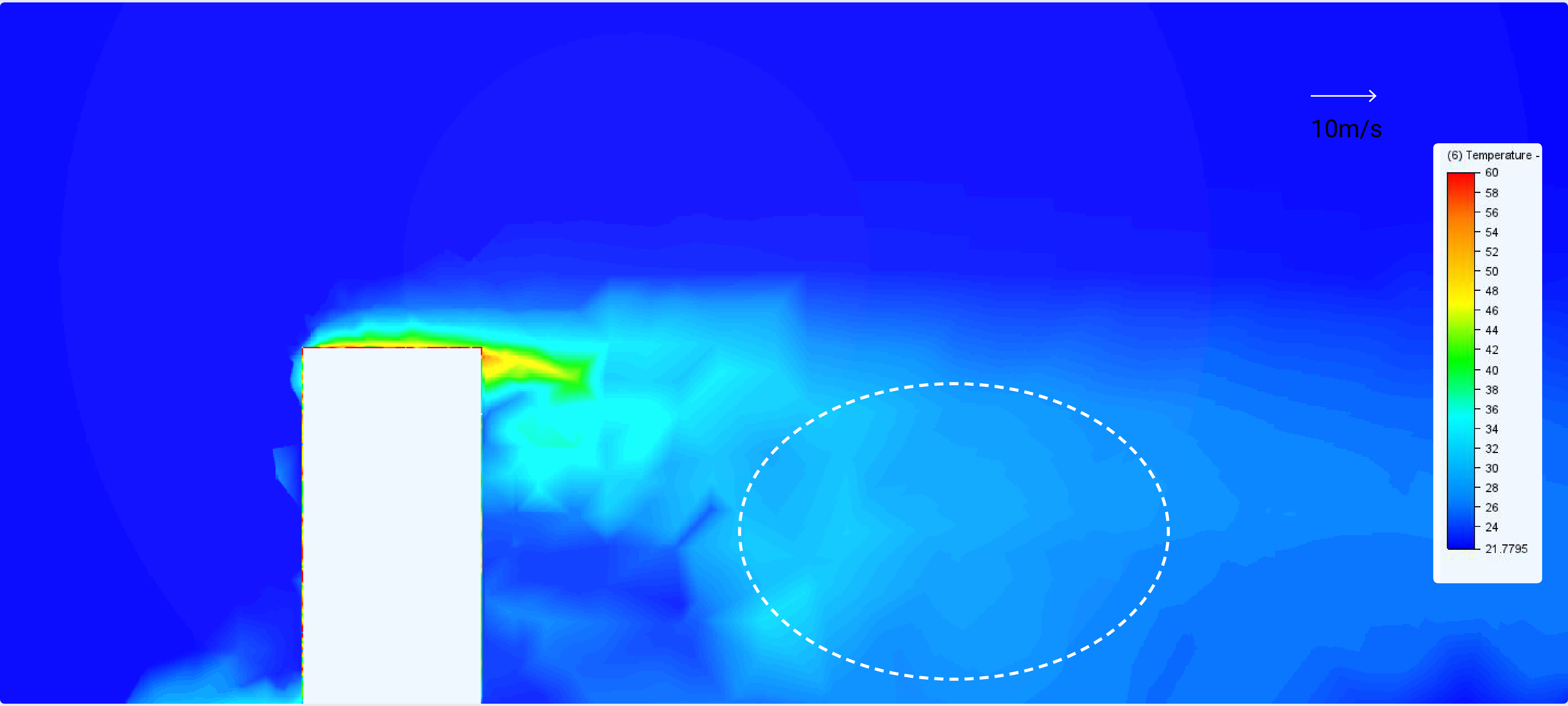


Transient Heat Transfer

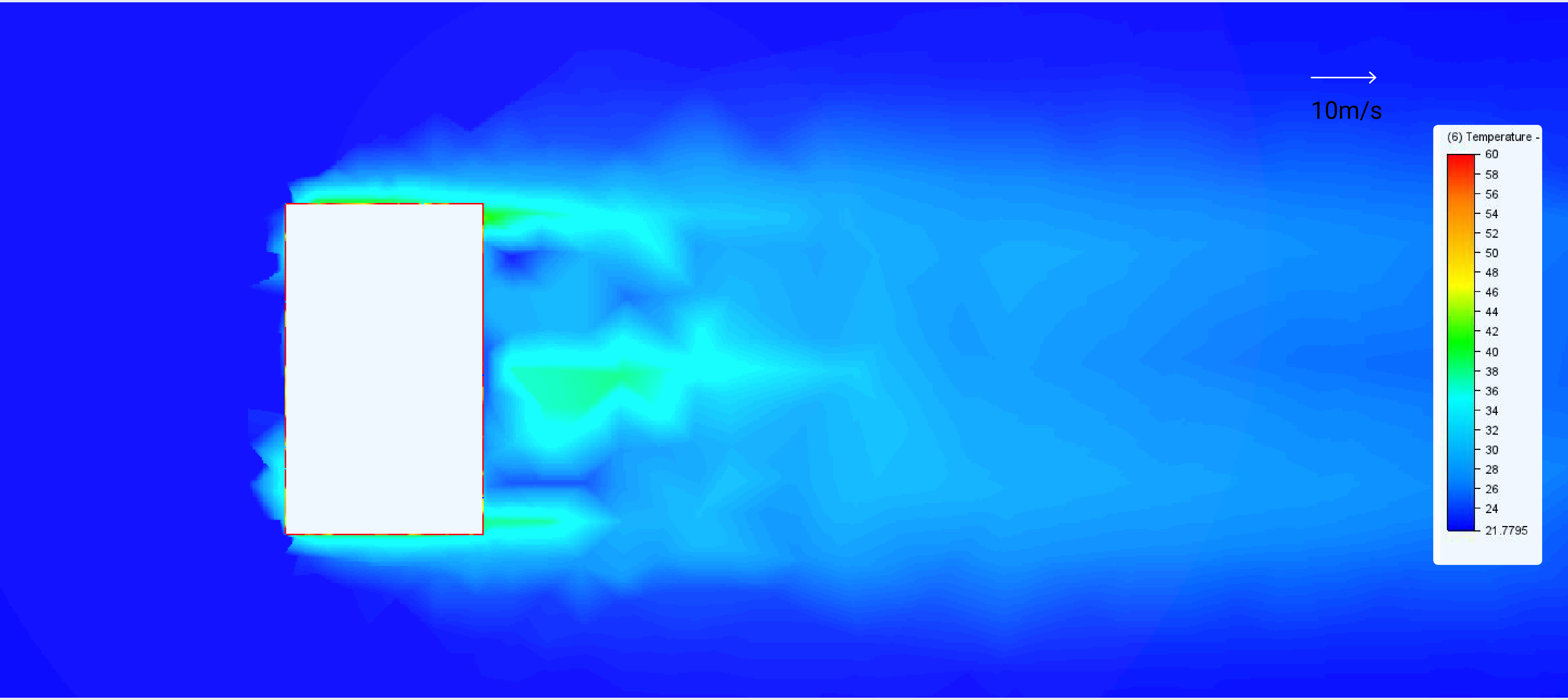


Ambient air: 25° c

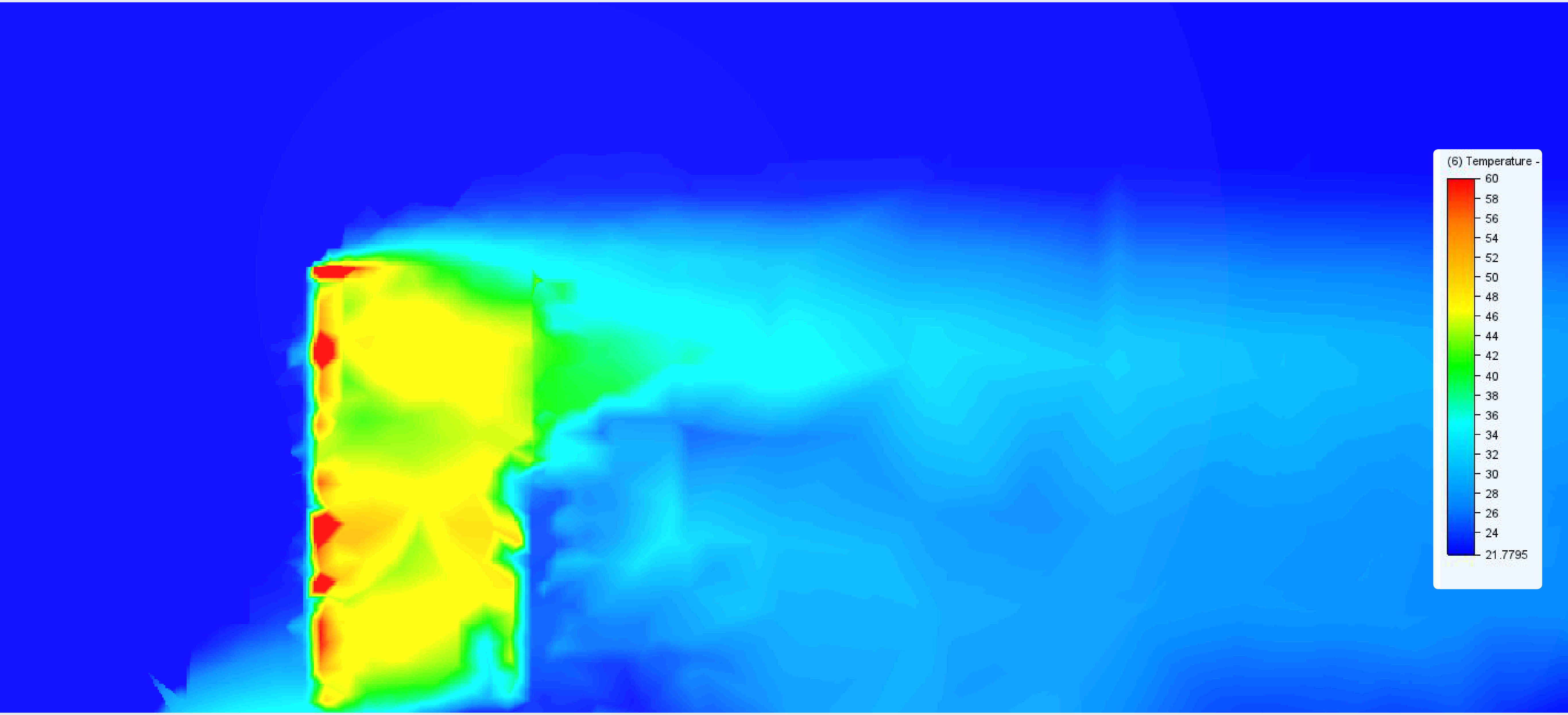
Transient Heat Transfer to Ambient Air



Transient Heat Transfer to Ambient Air



Transient Heat Transfer to Ambient Air



Assuming a window to wall ratio of 50% with the remaining being a bioreceptive material

Ambient air can be reduced:

2.35° c

Assuming forced convection on 70% of the surface.

Surface Temp. can be reduced:

4.6° c

Summary:

This benefit is highly dependent on air velocity and assumes there is surface moisture to be evaporated.

Empirical Research should be conducted using prototype materials under urban conditions.

Discussion:

Temperature is just one potential benefit to the application of bioreceptive materials. It is should be considered an added benefit to the facade rather than the main reason to implement.

This is a new concept that is still in its infancy and many aspects can be developed further:

- Air Quality
- Irrigation system
- Material Prototyping
- Rainwater retention
- Species Selection
- Optimal Porosity

Within Reach

Literature

Cruz, M., & Beckett, R. (2016). Bioreceptive design: a novel approach to biodigital materiality. Cambridge University Press.

Delta Programme (2015). Working on the Delta. The Decisions to Keep the Netherlands Safe and Liveable. Publication of the Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs (https://english.deltacommissaris.nl/documents/publications/2014/09/16/delta-programme-2015).

Dutch Bryological and Lichenological Society. (2019). Retrieved from https://www.blwg.nl/mossen/mossen/mossen.aspx

Glime, J. (2017). Bryophyte Ecology [Ebook]. Michigan Technological University and the International Association of Bryologists.

Goryainova, Z., Vuković, G., Urošević, M., Vergel, K., Ostrovnaya, T., Frontasyeva, M., & Zechmeister, H. (2016). Assessment of vertical element distribution in street canyons using the moss Sphagnum girgensohnii: A case study in Belgrade and Moscow cities. Atmospheric Pollution Research, 7(4), 690-697. doi: 10.1016/j.apr.2016.02.013

Guillitte, O. (1995). Bioreceptivity: a new concept for building ecology studies. Science Of The Total Environment, 167(1-3), 215-220. doi: 10.1016/0048-9697(95)04582-l

Gulotta, D., Villa, F., Cappitelli, F., & Toniolo, L. (2018). Biofilm colonization of metamorphic lithotypes of a renaissance cathedral exposed to urban atmosphere. Science Of The Total Environment, 639, 1480-1490. doi: 10.1016/j.scitotenv.2018.05.277

Hoeven, F. D., van der & Wandl, A. (2015) Hotterdam. How space is making Rotterdam warmer, how this affects the health of its inhabitants, and what can be done about it. Delft, the Netherlands: TU Delft.

Huang, Y., Zheng, Y., Li, J., Liao, Q., Fu, Q., & Xia, A. et al. (2018). Enhancing microalgae biofilm formation and growth by fabricating microgrooves onto the substrate surface. Bioresource Technology, 261, 36-43. doi: 10.1016/j.biortech.2018.03.139

K., M., Katoh, Y., Katsurayama, H., Koganei, M., & Mizunuma, M. (2018). Effects of convection heat transfer on Sunagoke moss green roof: A laboratory study. Energy And Buildings, 158, 1417-1428. doi: 10.1016/j.enbuild.2017.11.043

Klok, E., & Kluck, J. (2018). Reasons to adapt to urban heat (in the Netherlands). Urban Climate, 23, 342-351. doi: 10.1016/j.uclim.2016.10.005

Manso, S., De Muynck, W., Segura, I., Aguado, A., Steppe, K., Boon, N., & De Belie, N. (2014). Bioreceptivity evaluation of cementitious materials designed to stimulate biological growth. Science Of The Total Environment, 481, 232-241. doi: 10.1016/j.scitotenv.2014.02.059

Manso, S., Mestres, G., Ginebra, M., De Belie, N., Segura, I., & Aguado, A. (2014). Development of a low pH cementitious material to enlarge bioreceptivity. Construction And Building Materials, 54, 485-495. doi: 10.1016/j.conbuildmat.2014.01.001

Miller, A., Sanmartín, P., Pereira-Pardo, L., Dionísio, A., Saiz-Jimenez, C., Macedo, M., & Prieto, B. (2012). Bioreceptivity of building stones: A review. Science Of The Total Environment, 426, 1-12. doi: 10.1016/j.scitotenv.2012.03.026

Ottelé, M. (2011). The Green Building Envelope. TU Delft: Technische Universiteit Delft.

Reski, R. (2018). Quantitative moss cell biology. Current Opinion In Plant Biology, 46, 39-47. doi: 10.1016/j.pbi.2018.07.005

Safikhani, T., Abdullah, A., Ossen, D., & Baharvand, M. (2014). A review of energy characteristic of vertical greenery systems. Renewable And Sustainable Energy Reviews, 40, 450-462. doi: 10.1016/j.rser.2014.07.166

Sujetovienė, G., & Galinytė, V. (2016). Effects of the urban environmental conditions on the physiology of lichen and moss. Atmospheric Pollution Research, 7(4), 611-618. doi: 10.1016/j.apr.2016.02.009

Udawattha, C., Galkanda, H., Ariyarathne, I., Jayasinghe, G., & Halwatura, R. (2018). Mold growth and moss growth on tropical walls. Building And Environment, 137, 268-279. doi: 10.1016/j.buildenv.2018.04.018

Ward, K., Lauf, S., Kleinschmit, B., & Endlicher, W. (2016). Heat waves and urban heat islands in Europe: A review of relevant drivers. Science Of The Total Environment, 569-570, 527-539. doi: 10.1016/j.scitotenv.2016.06.119