VEGETATIVE ROOF PERFORMANCE DURING SUMMER – CRITICAL ANALYSIS OF THE IRRIGATION EFFECT

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Outline

1. INTRODUCTION
2. VEGETATIVE ROOFS
3. EXPERIMENTAL VEGETATIVE ROOF MONITORING
4. PERFORMANCE IN SUMMER CONDITIONS
5. VEGETATIVE ROOF MODELING
6. CONCLUSIONS

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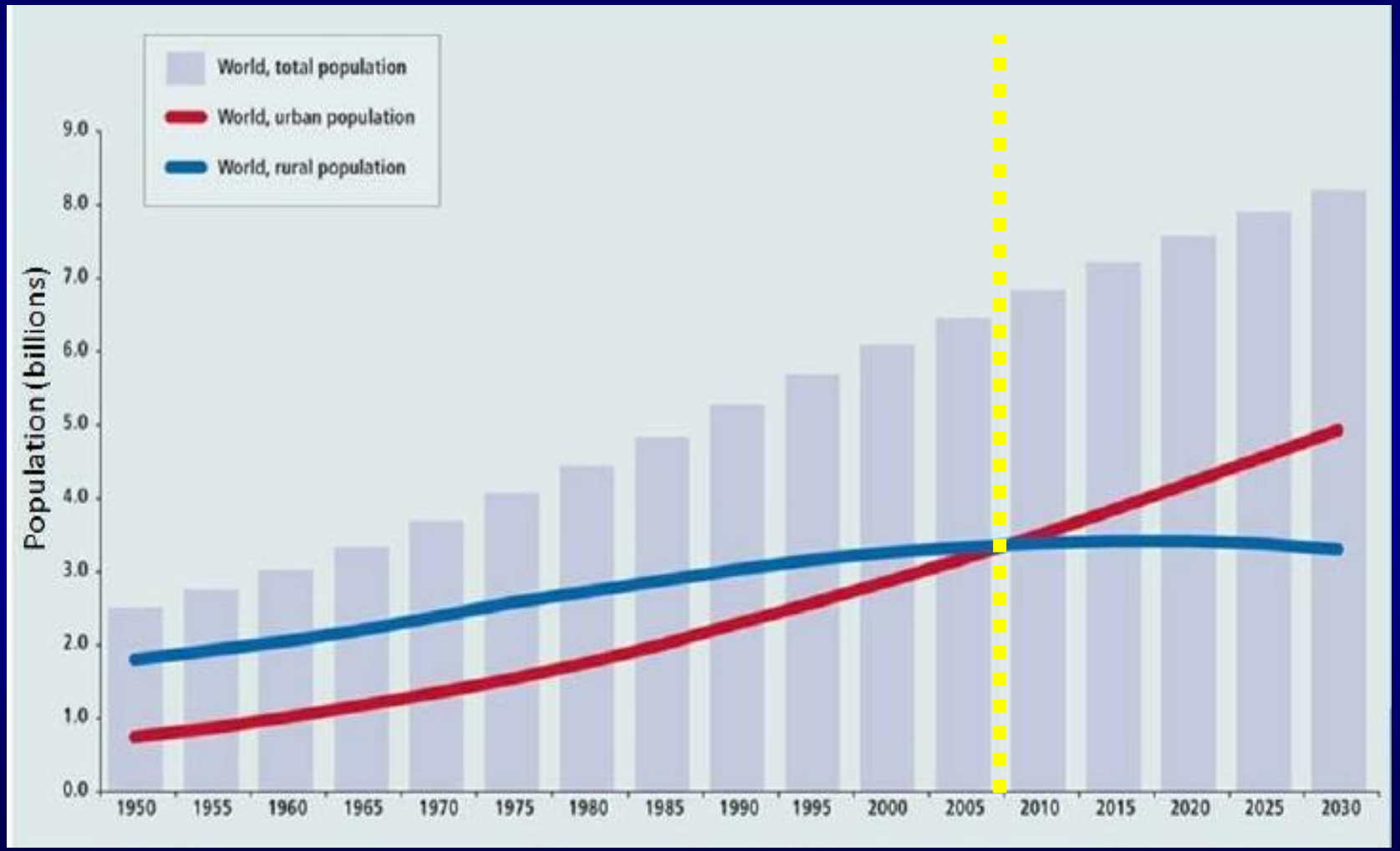
1.

INTRODUCTION

Urban and Rural world population

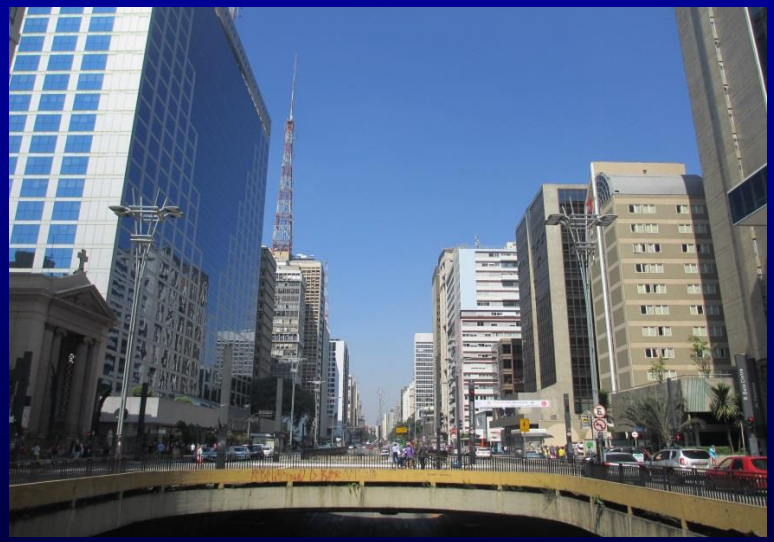
1950-2030



World Urbanization Prospects , UN

World urbanization prospects for 2050

Changes in the urban environment



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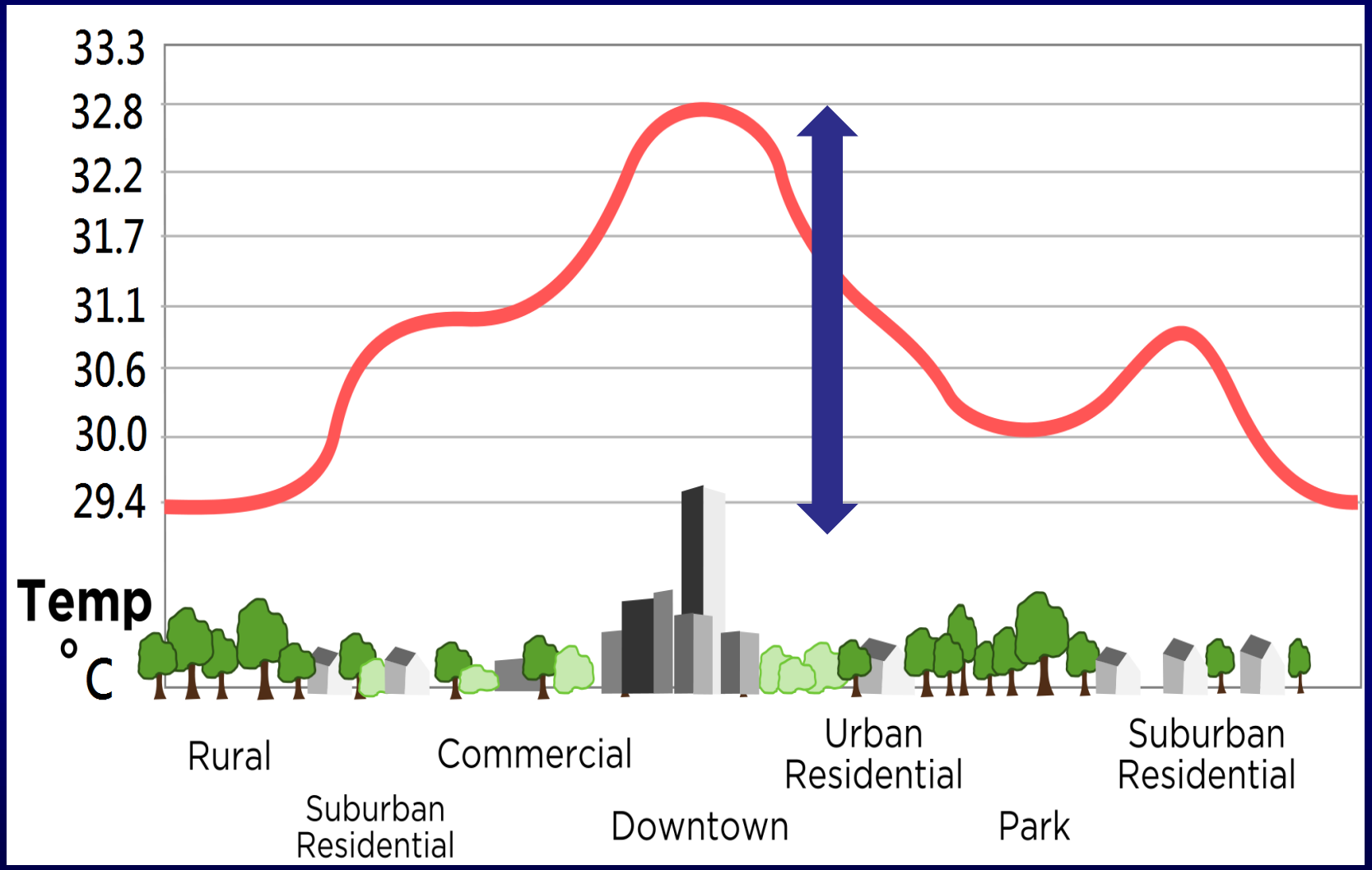
Urban heat island - up to 6ºC difference



EPA


ORAG-HAUS
ORAG-HAUS

Evapotranspirative cooling and roof shadding

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2.

VEGETATIVE ROOFS

Vegetative Roof Examples

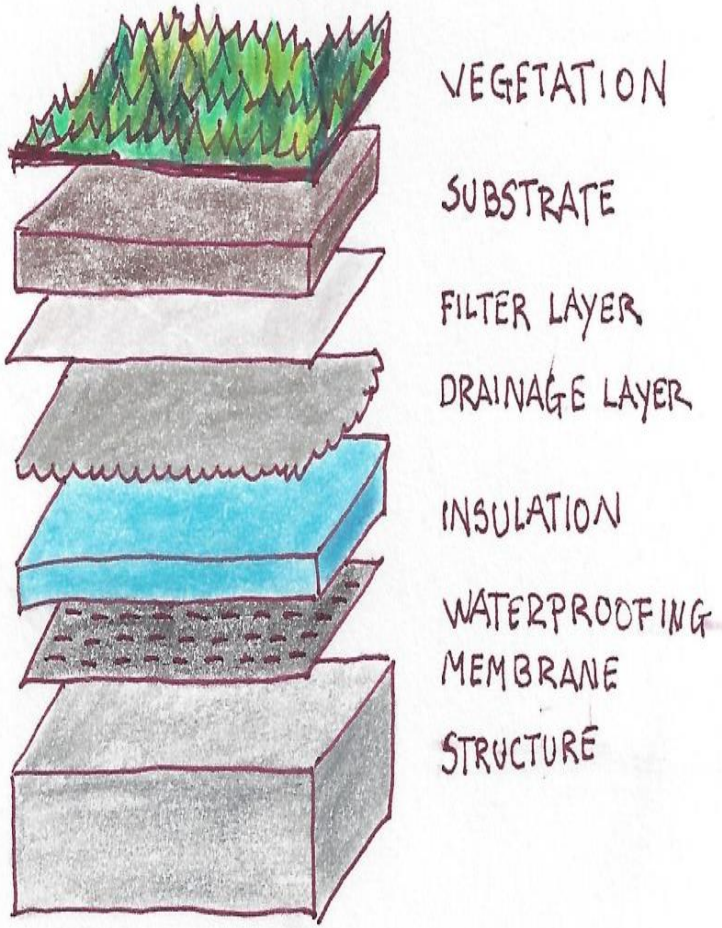
Commercial Building – Porto [Porto 24]

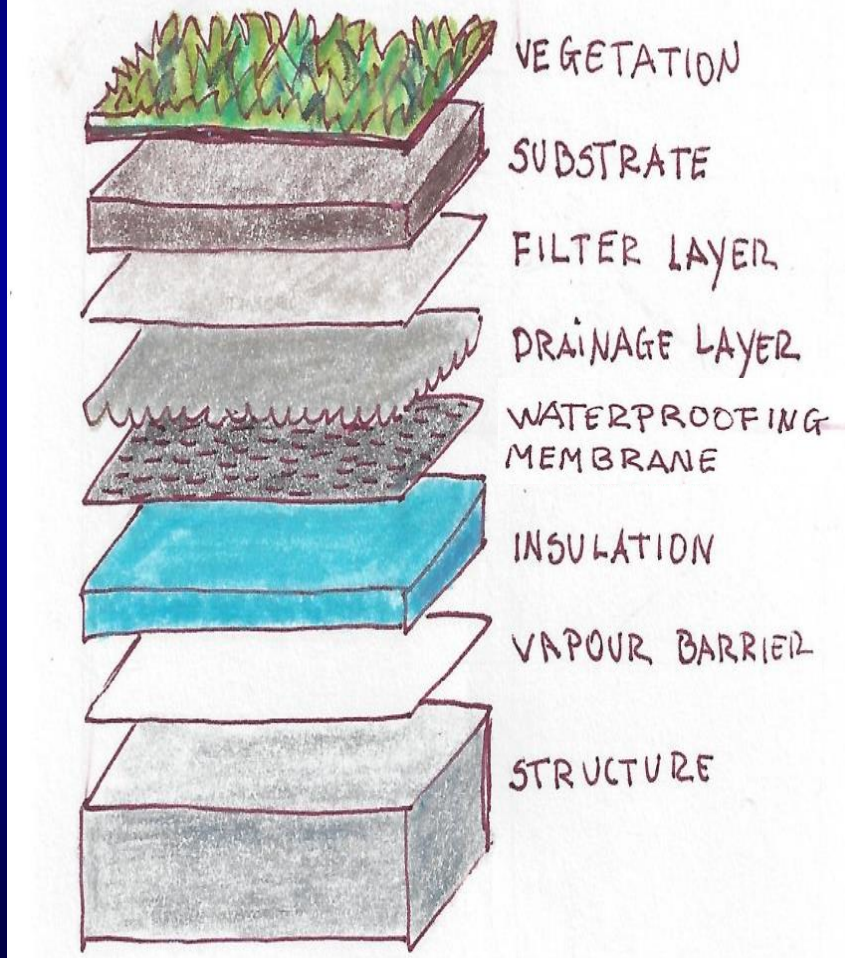
Trindade Subway Station - Porto

Services Building - Copenhagen

Market - Porto

Vegetative Roof Assembly





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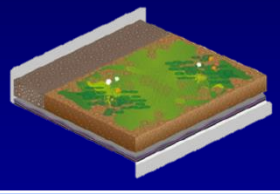
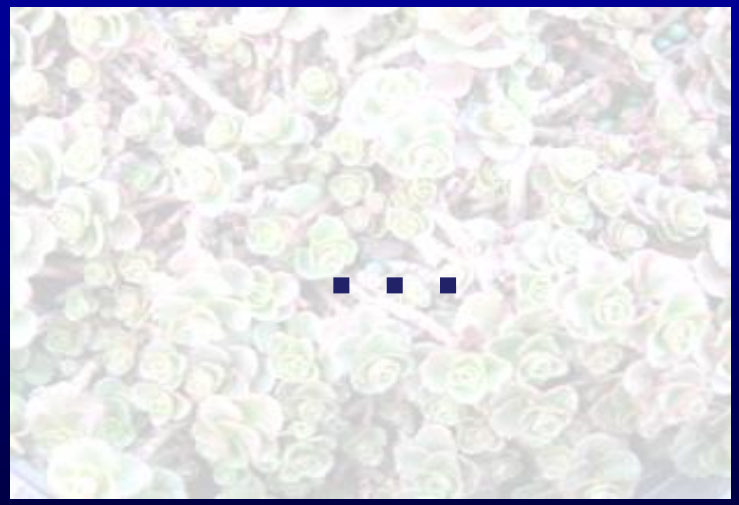
Vegetative Roof Classification



	Extensive	Intensive
Substrate thickness	up to 200 mm	from 200 mm
Weight	60 - 150 kg/m^2	180 - 500 kg/m^2
Plants diversity	limited	high
	mosses sedums succulents herbs grasses	perennials lawn shrubs trees
Construction structure	usually structure reinforcement not required	usually reinforced structure is required
Irrigation	usually not required	usually required
Maintenance	low	high
Accessibility	usually inaccessible	usually accessible

Vegetative Roof

walkable plants



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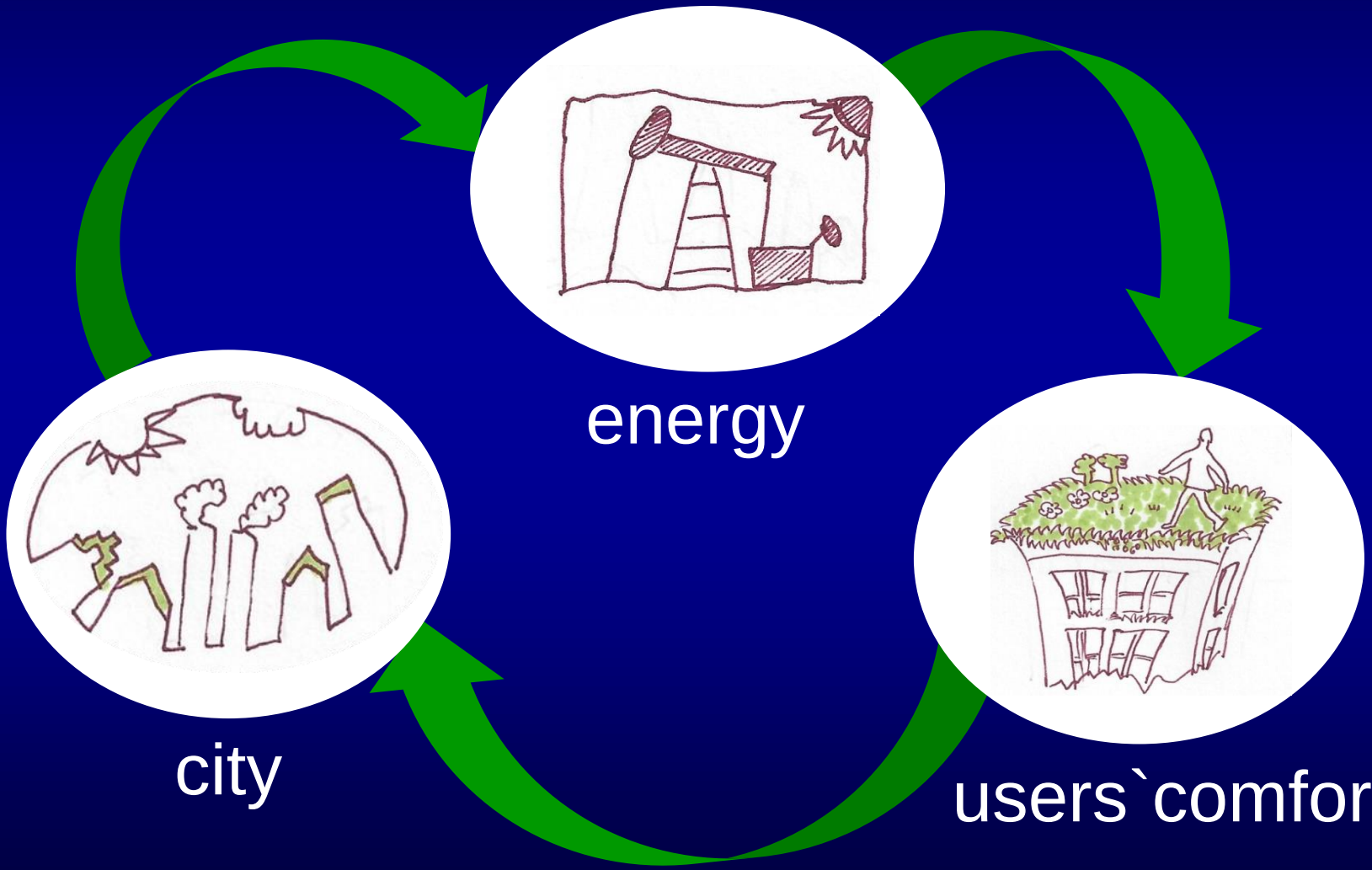
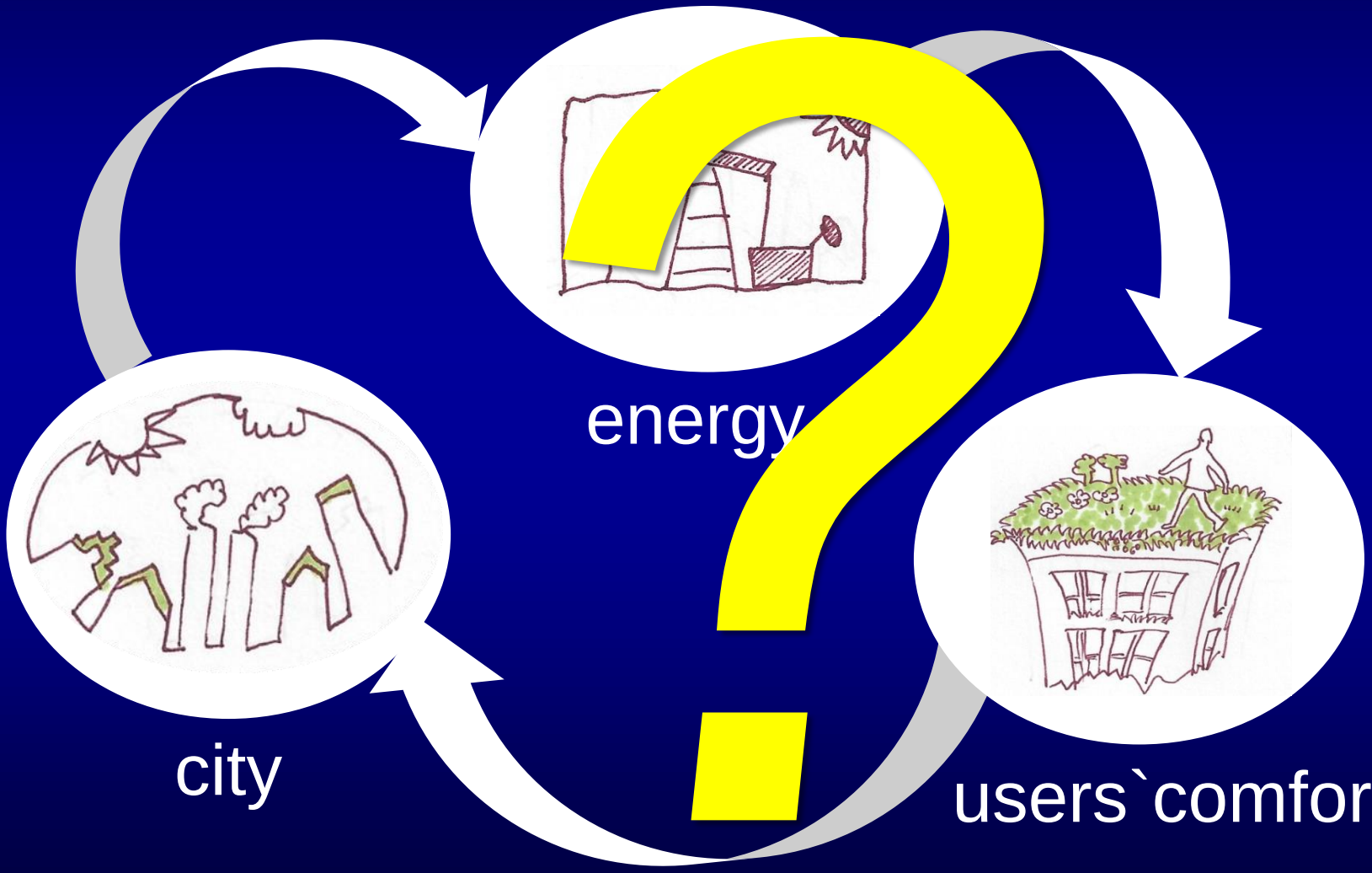
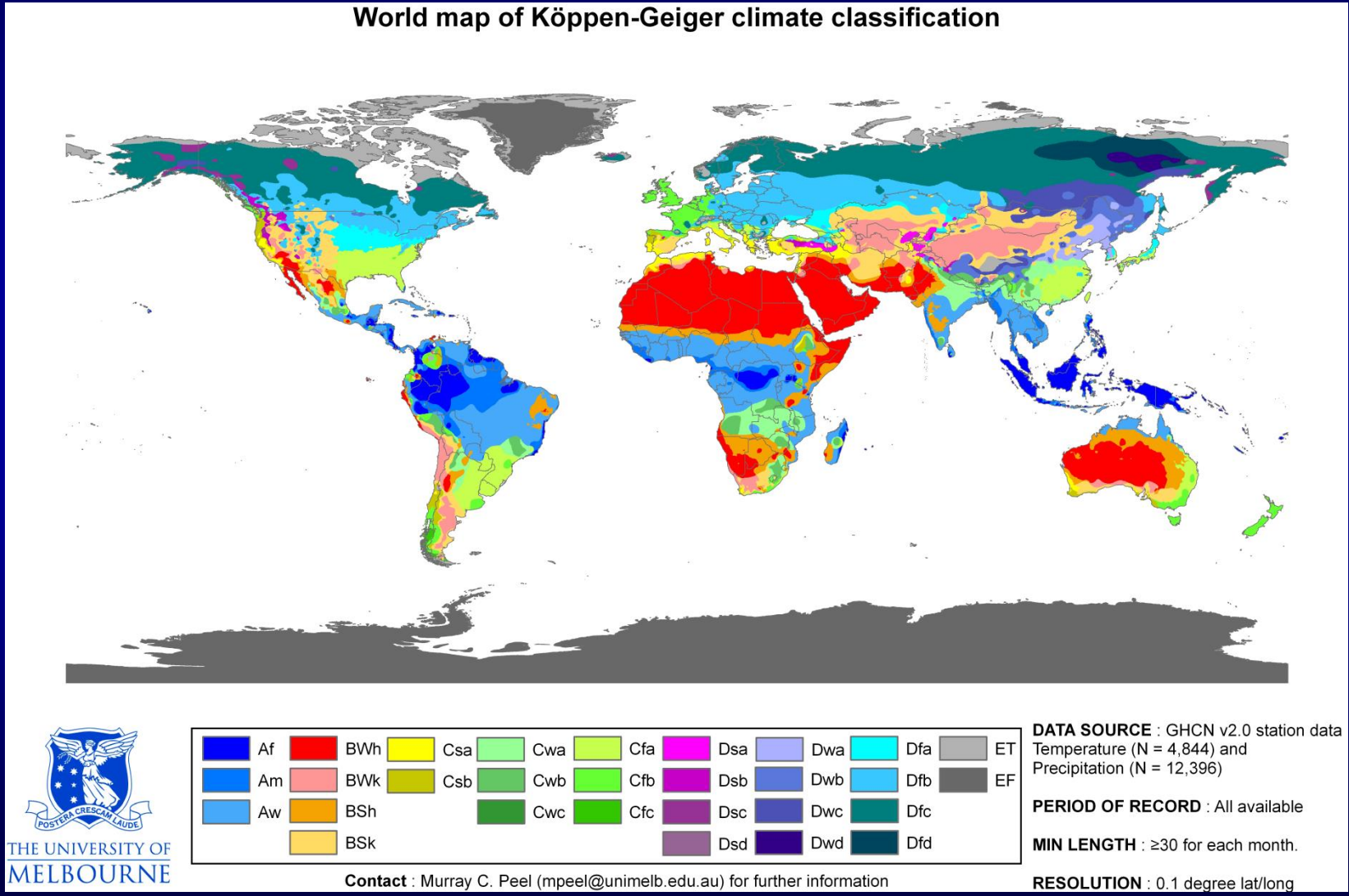
Vegetative Roof Impacts



Uncertainty ...



Environment conditions constraints



Murray C Peel

Additional water supply

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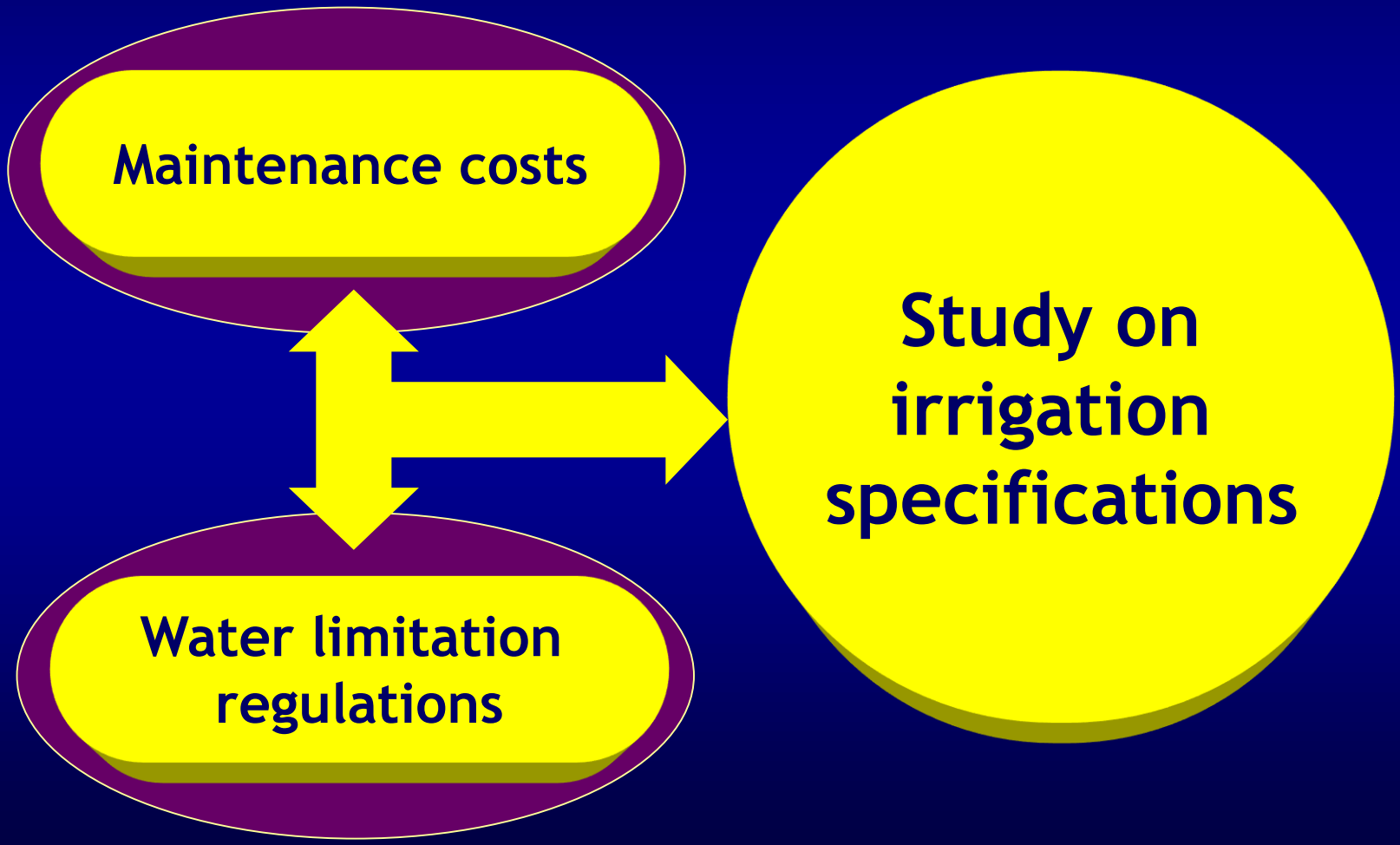
Energy Resource Center

…plant survival and performance enhancement



Questions

What is the effect of irrigation on roof performance during summer?

Are there numerical simulations tools available to study irrigation scenarios?

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3.

EXPERIMENTAL VEGETATIVE ROOF MONITORING

Climate

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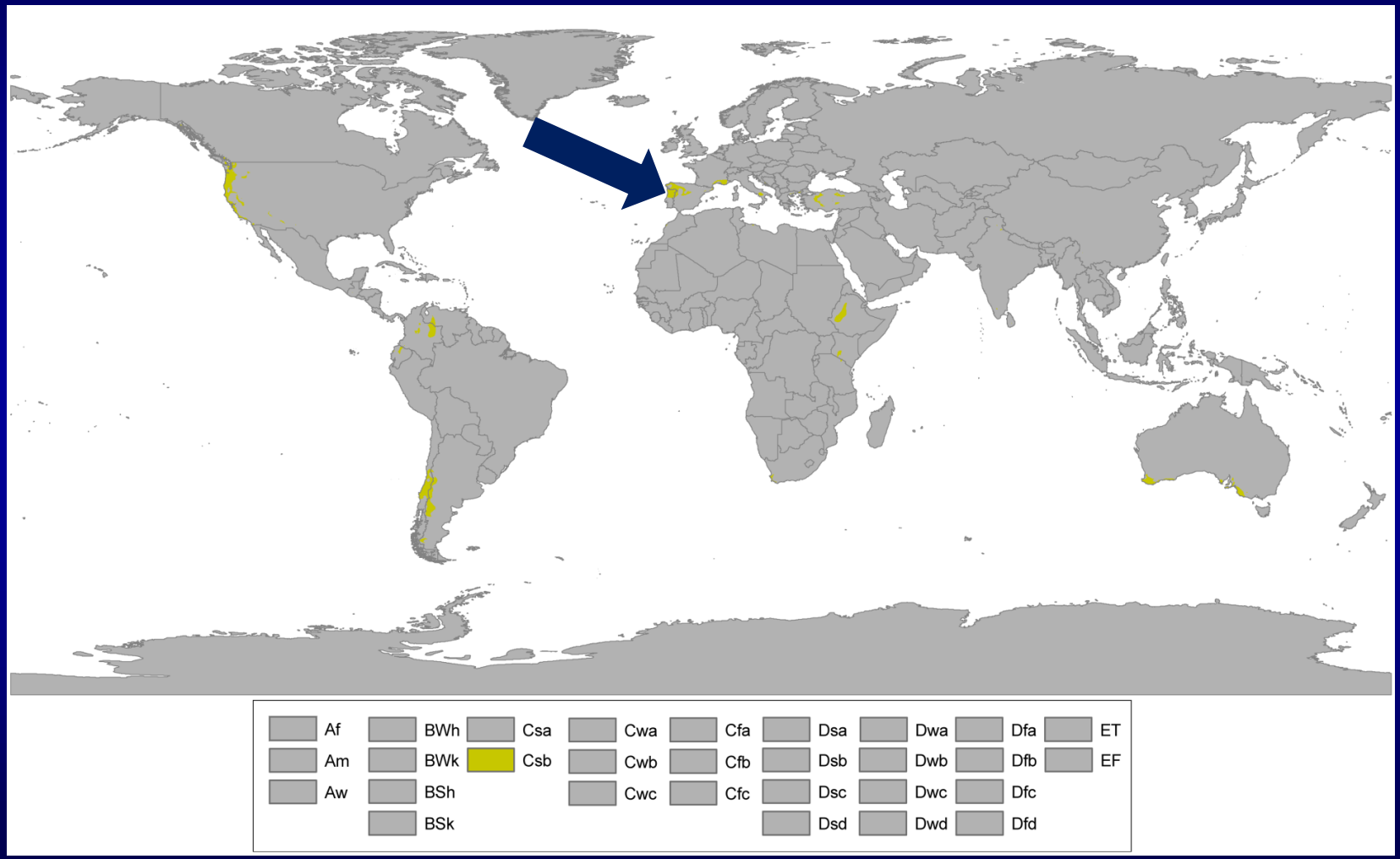
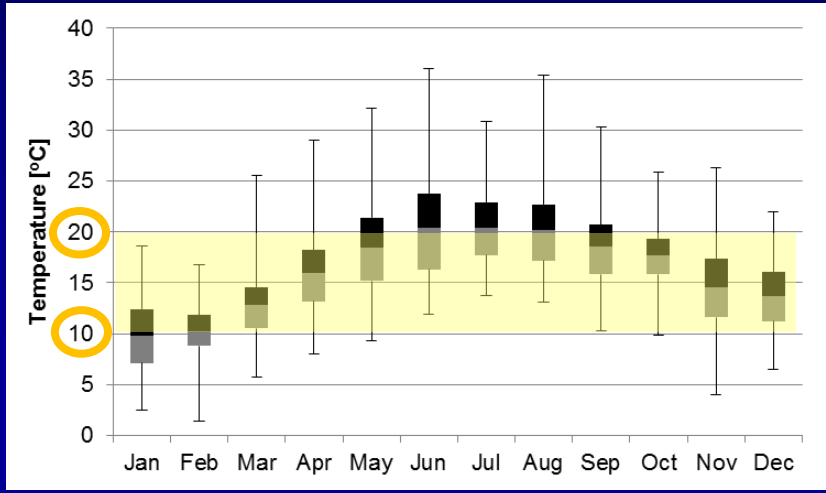
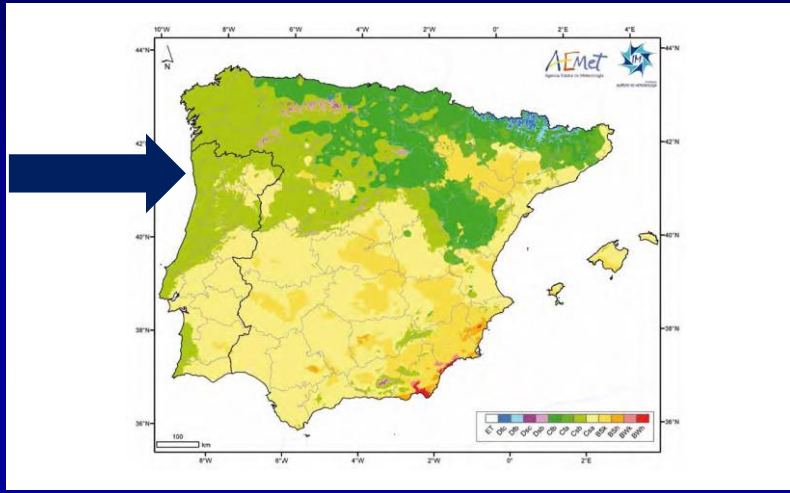
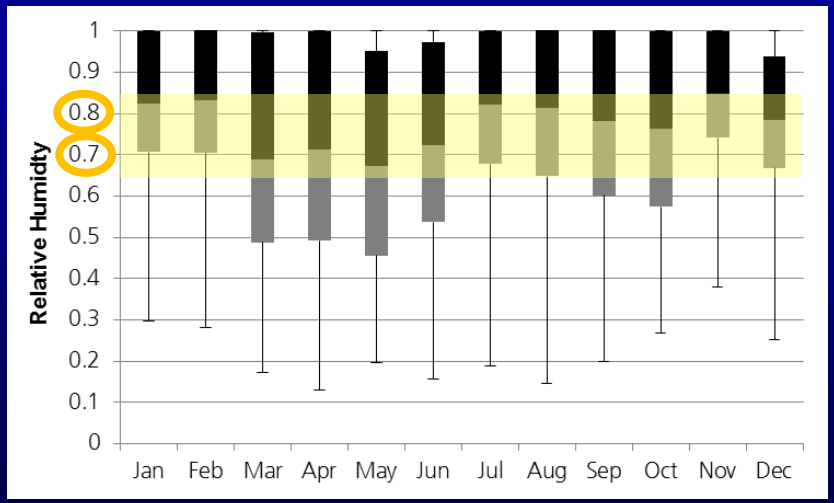
Atlantic/Mediterranean climate

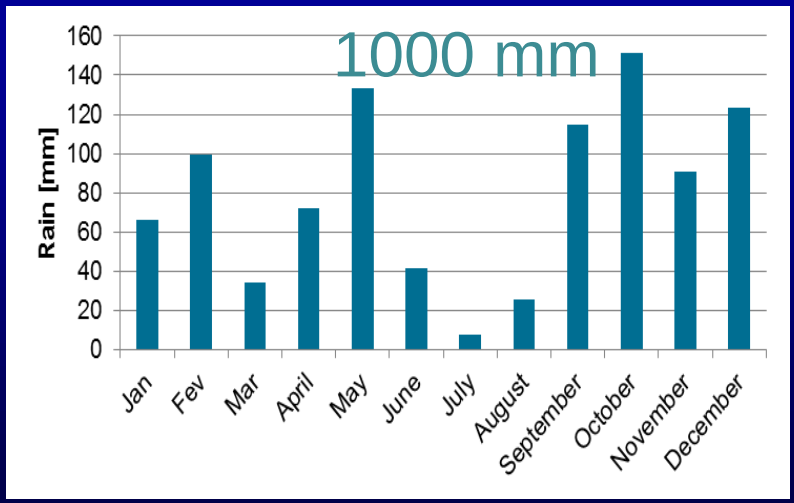


Porto Climate

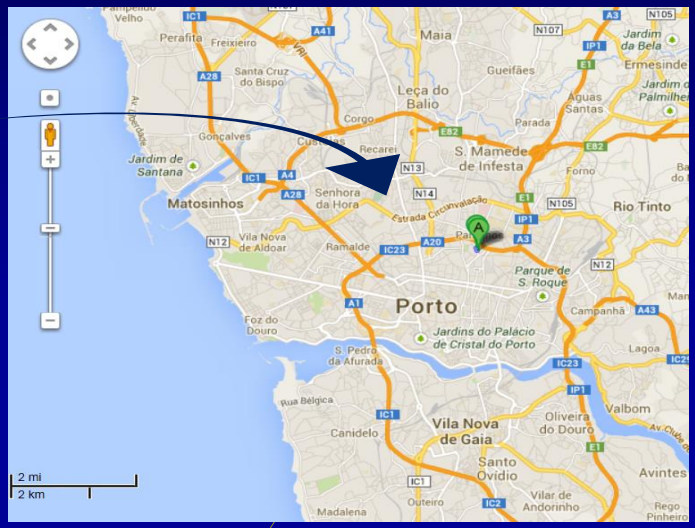








Setup Location



General overview

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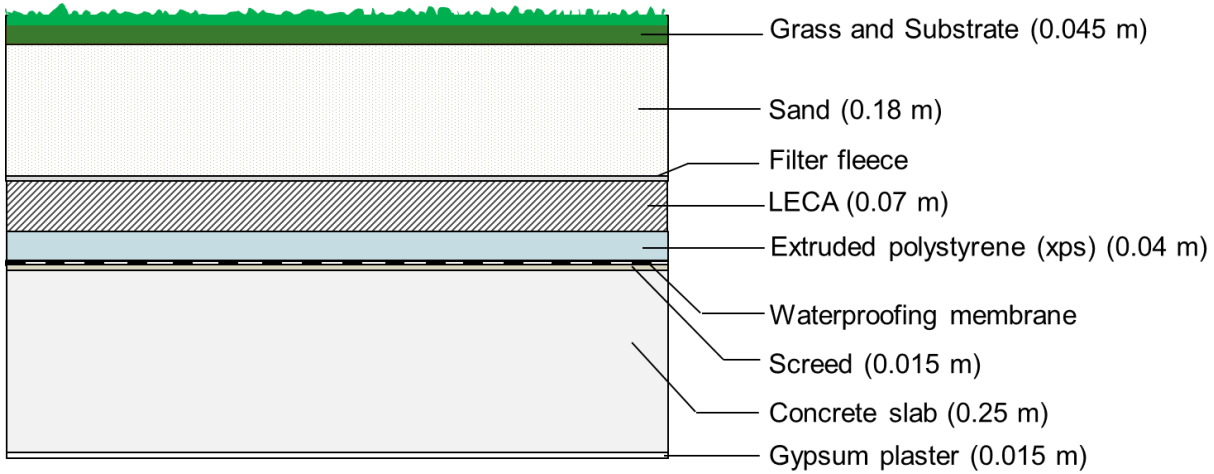
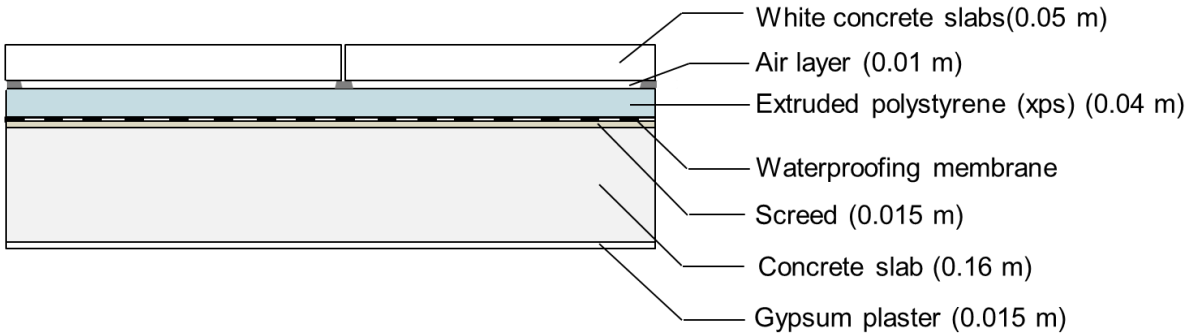
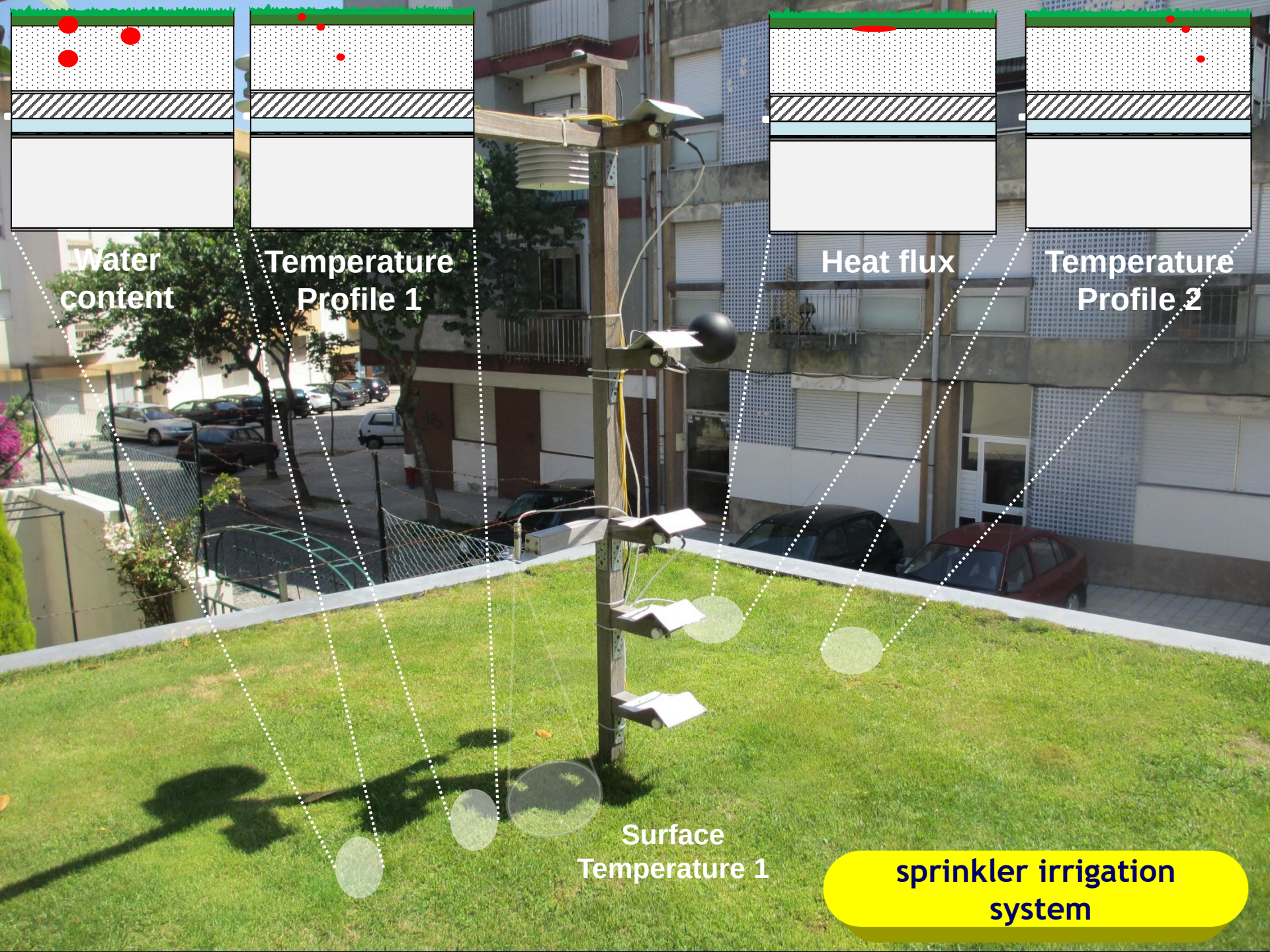
Roofs composition

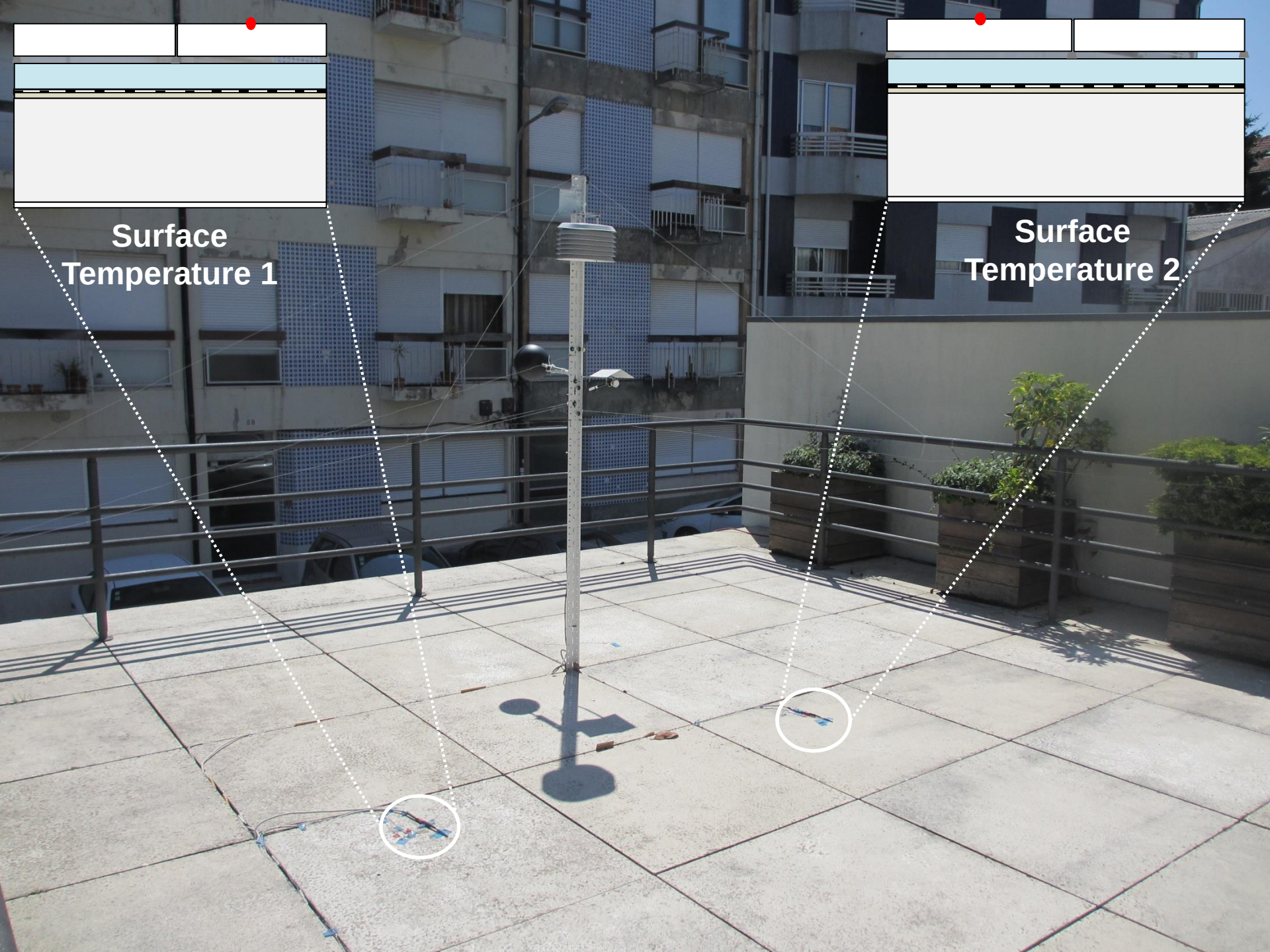


Vegetative Roof



Traditional Roof


Water content
Temperature Profile 1
Heat flux
Temperature Profile 2
Surface Temperature 1
sprinkler irrigation system


Surface
Temperature 1
Surface
Temperature 2

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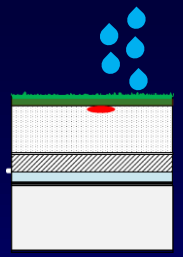
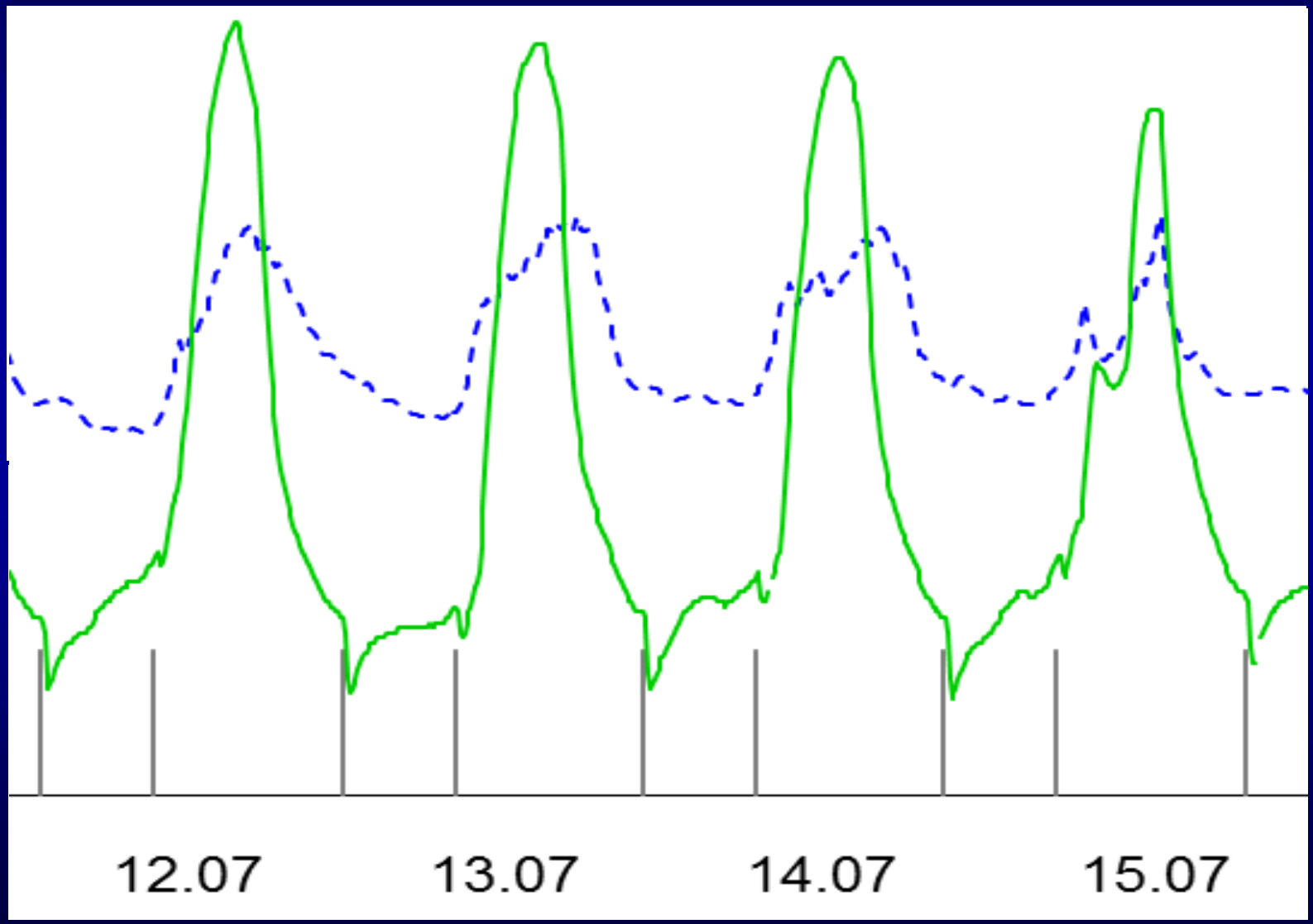
PERFORMANCE IN SUMMER CONDITIONS

Impact of irrigation on heat fluxes

6.3 l/m²





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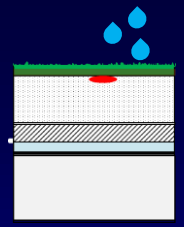
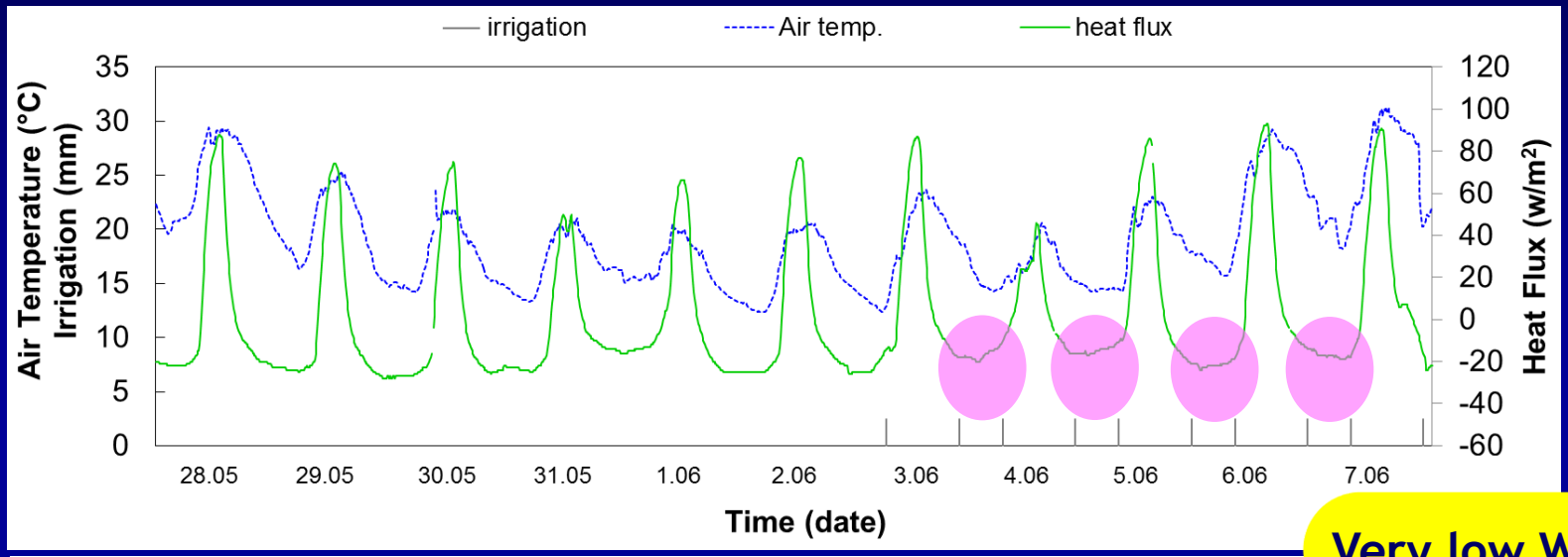
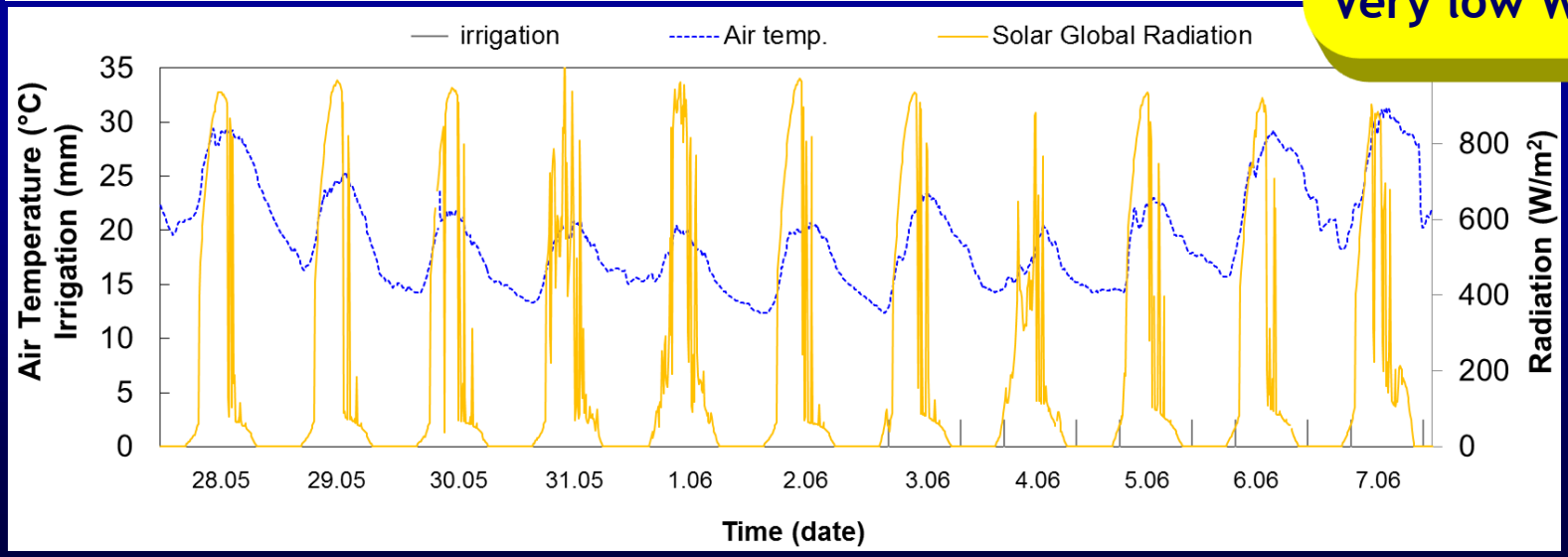
Impact of irrigation on heat fluxes

2.5 l/m²



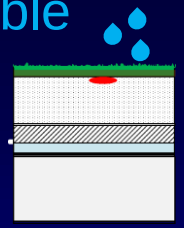


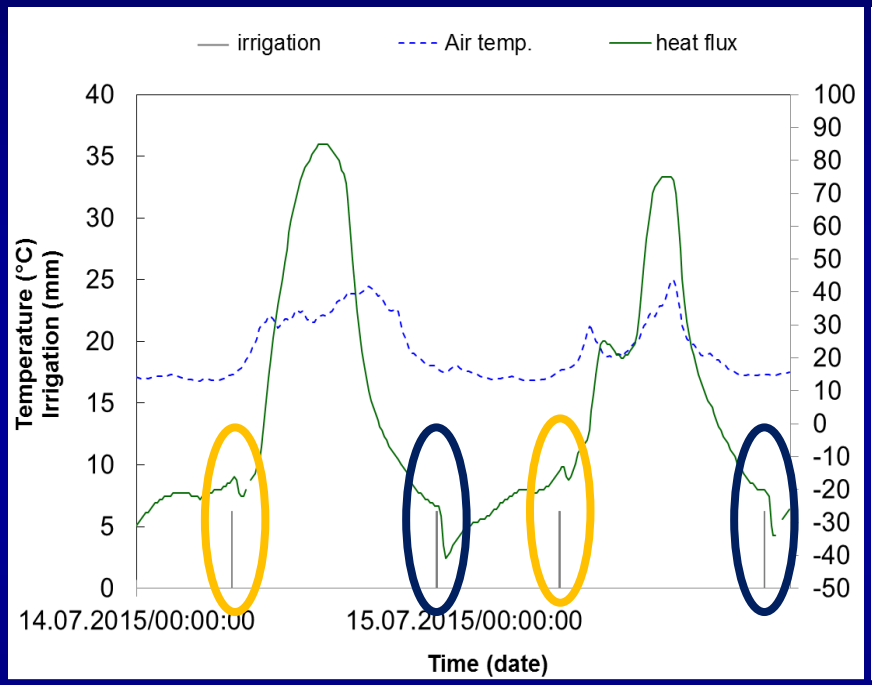
Very low WC

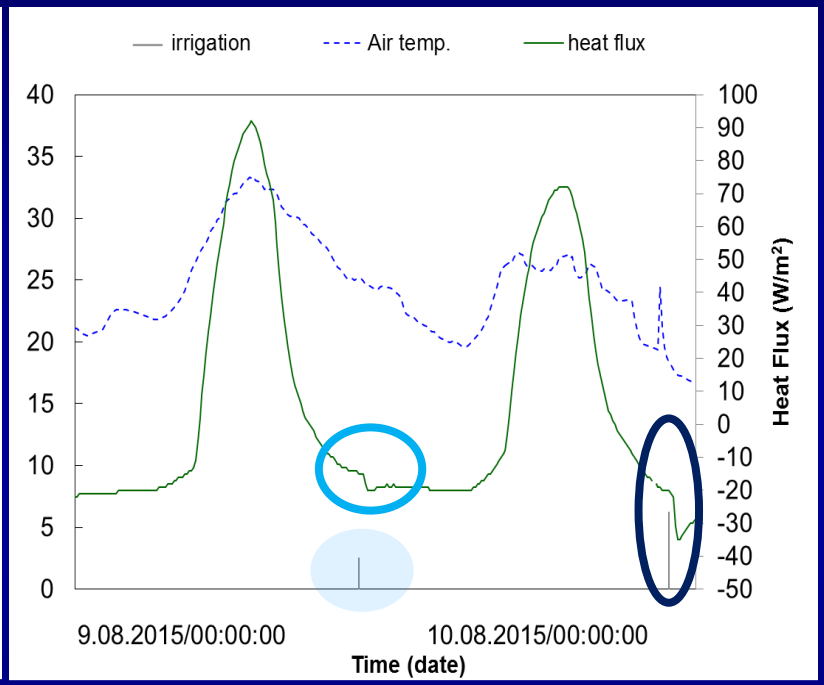


Impact of irrigation on heat fluxes - different amounts

variable

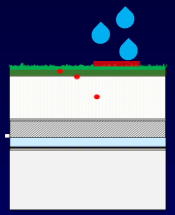


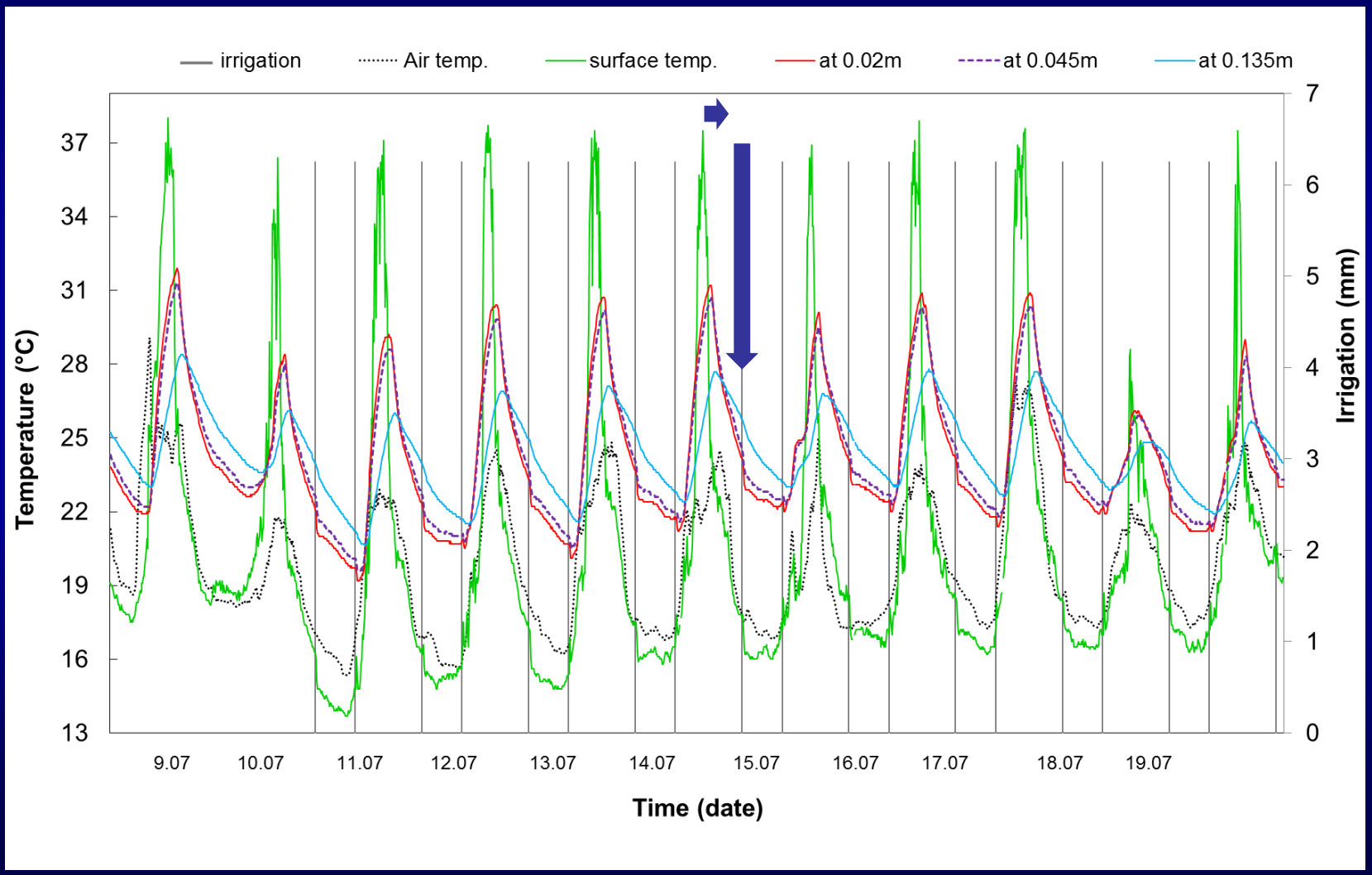




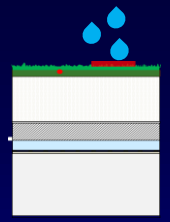
daily schedule
air temperature
solar radiation
magnitude and evolution of the fluxes

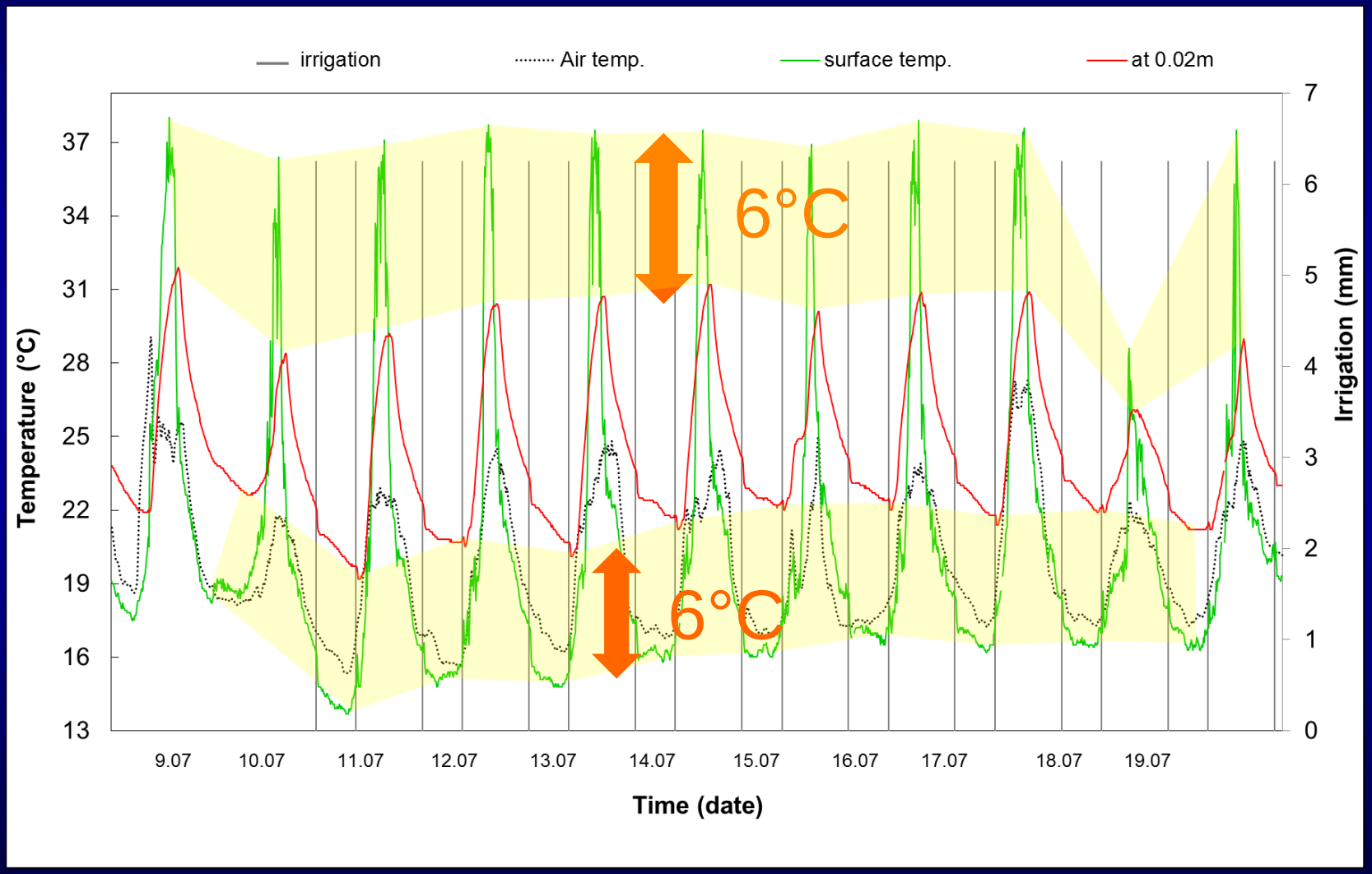
Impact of irrigation on surface/near surface temperatures





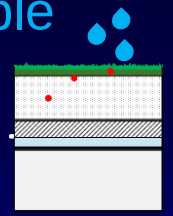
Impact of irrigation on surface/near surface temperatures

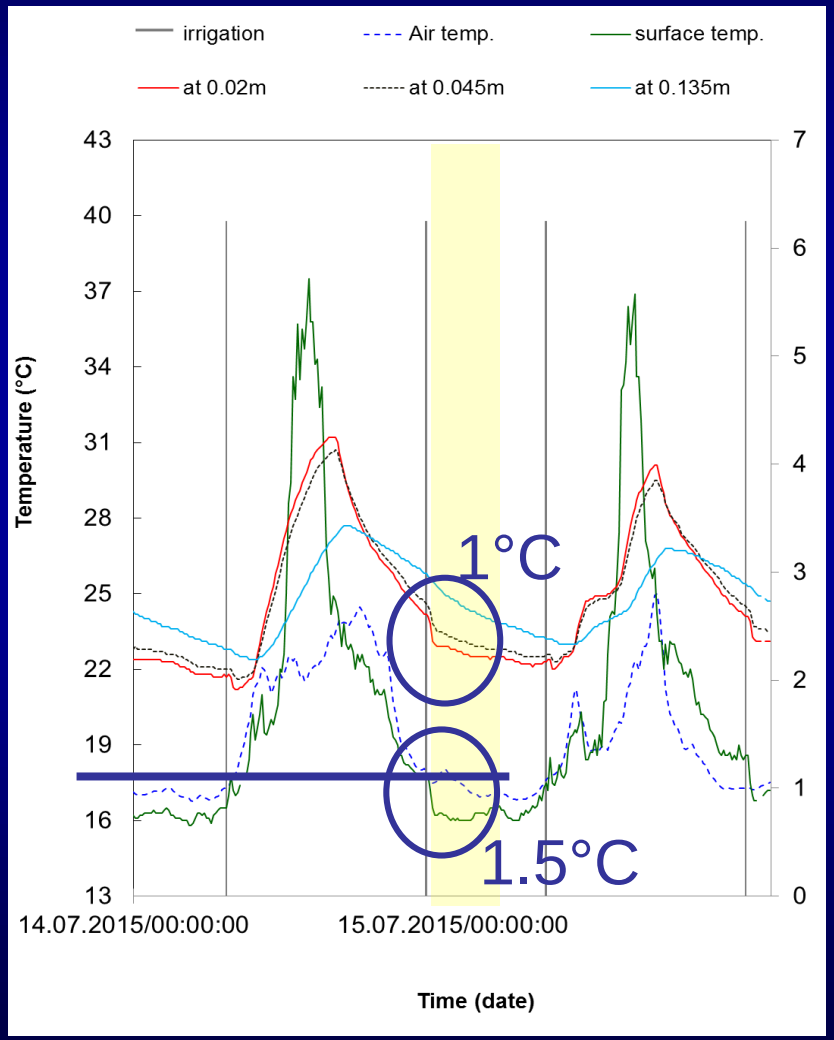


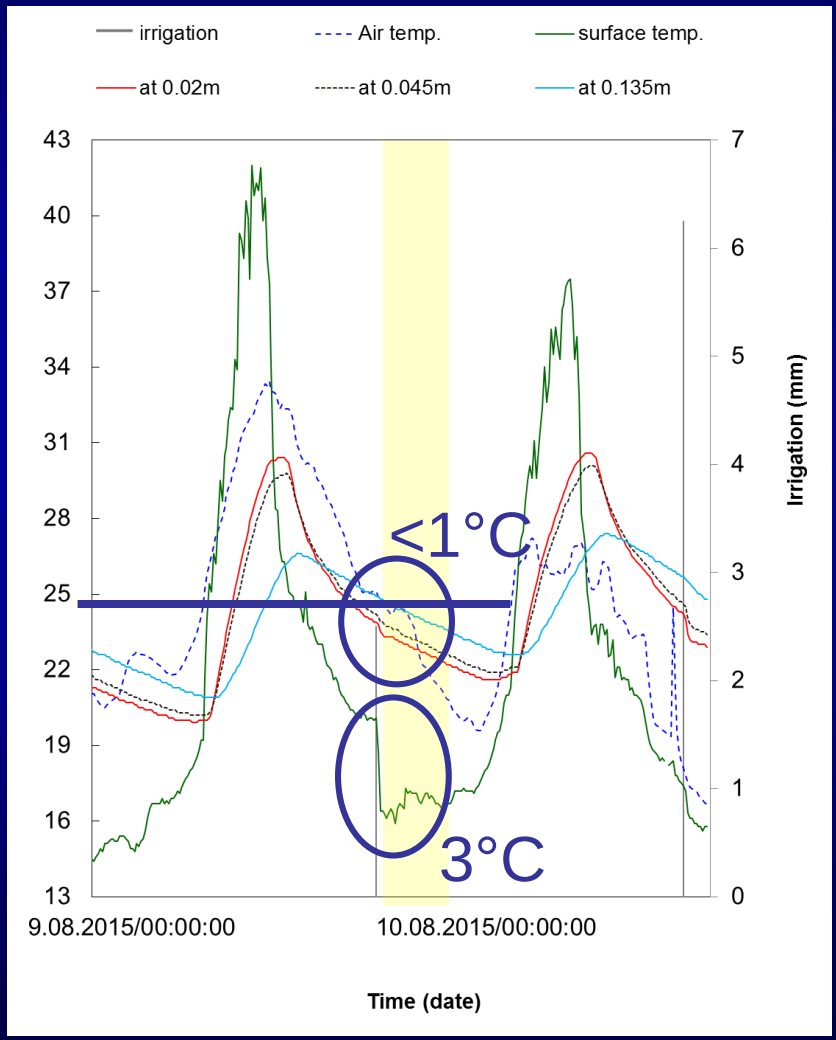


Impact of irrigation detailed analysis

variable







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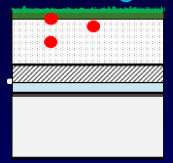
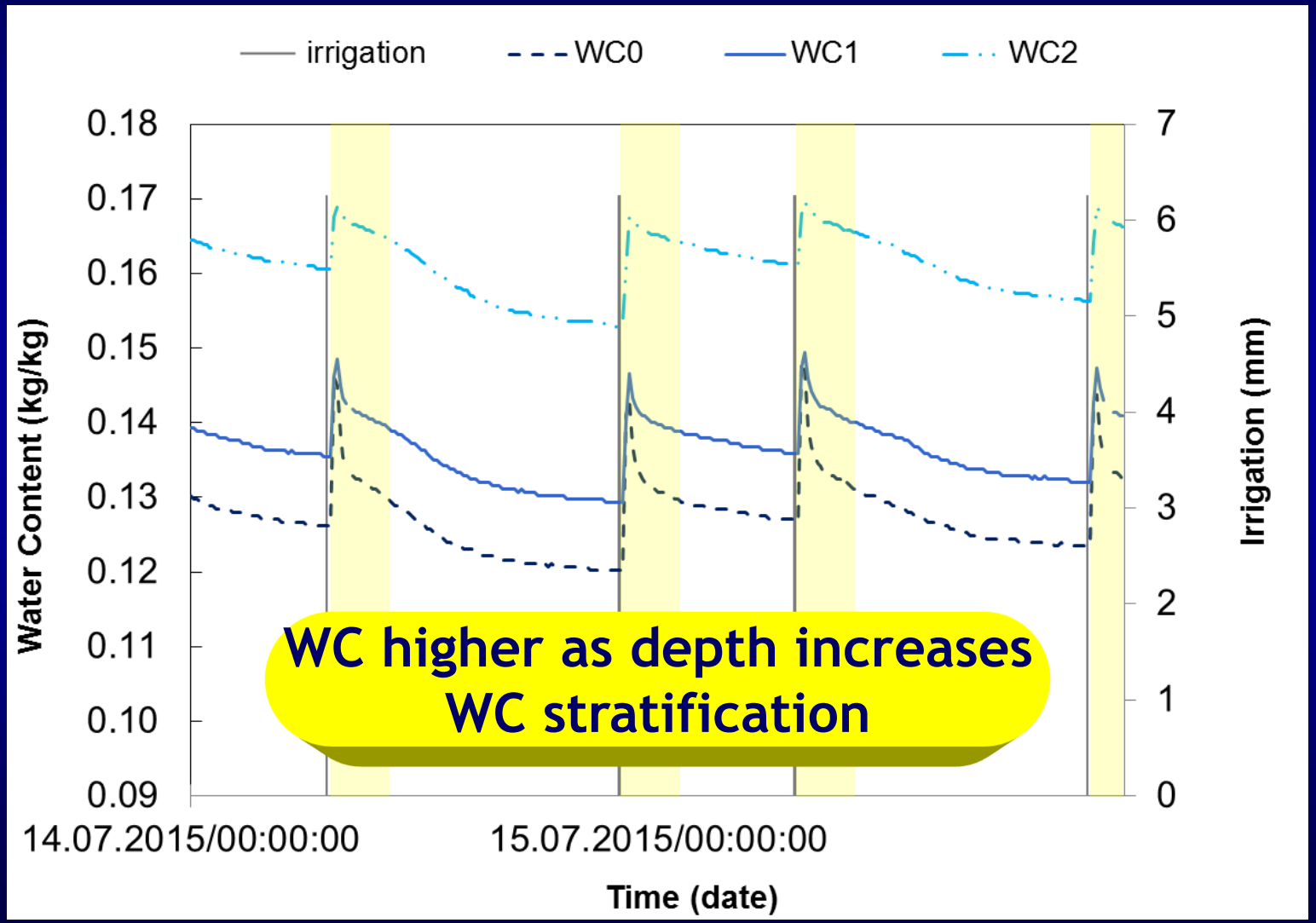
8am and 11pm

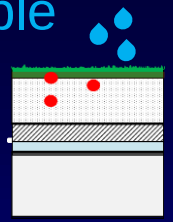


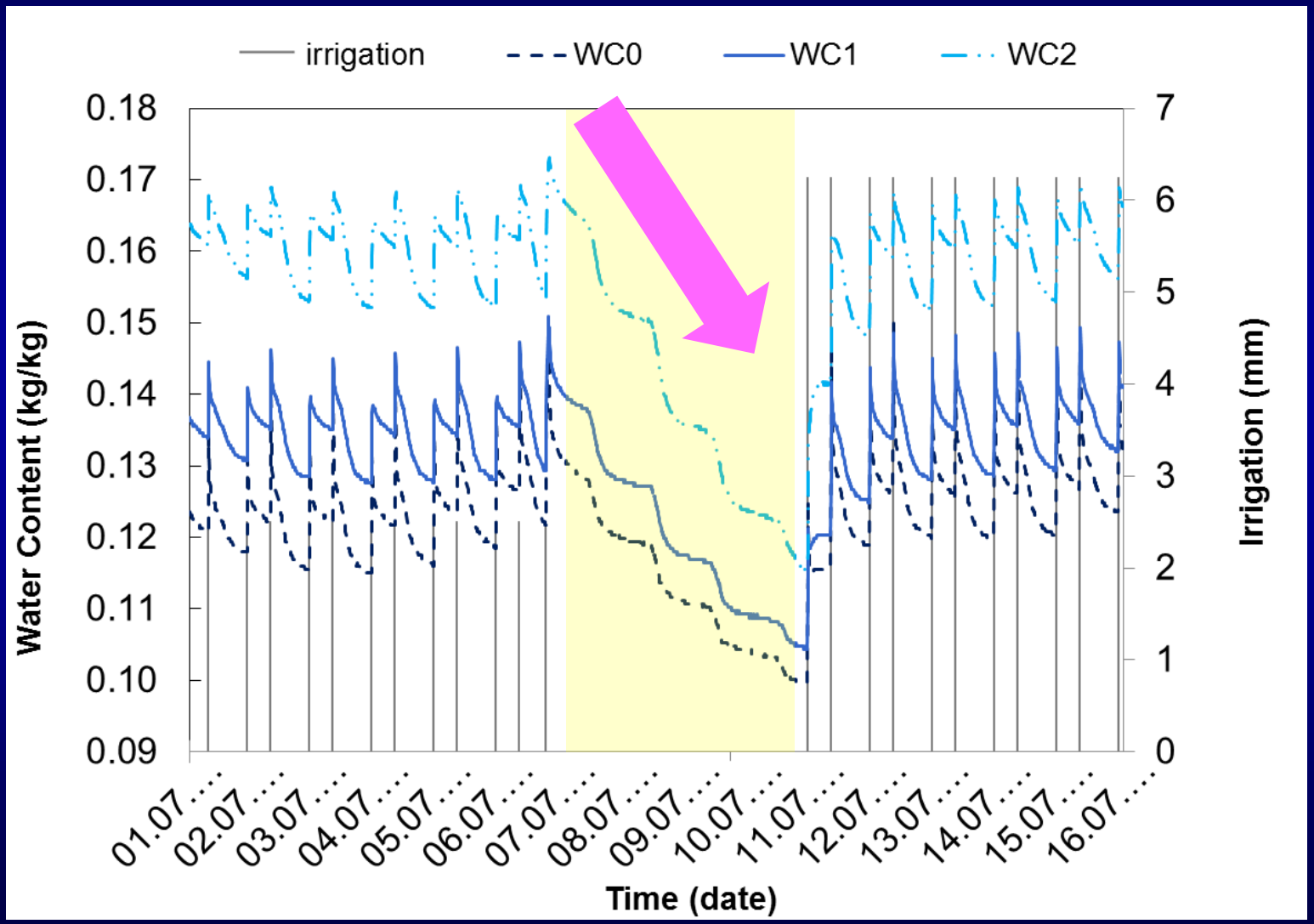
Water Content evolution



Water Content
- absence of water supply

variable





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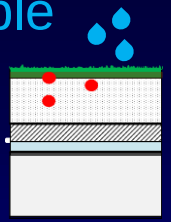
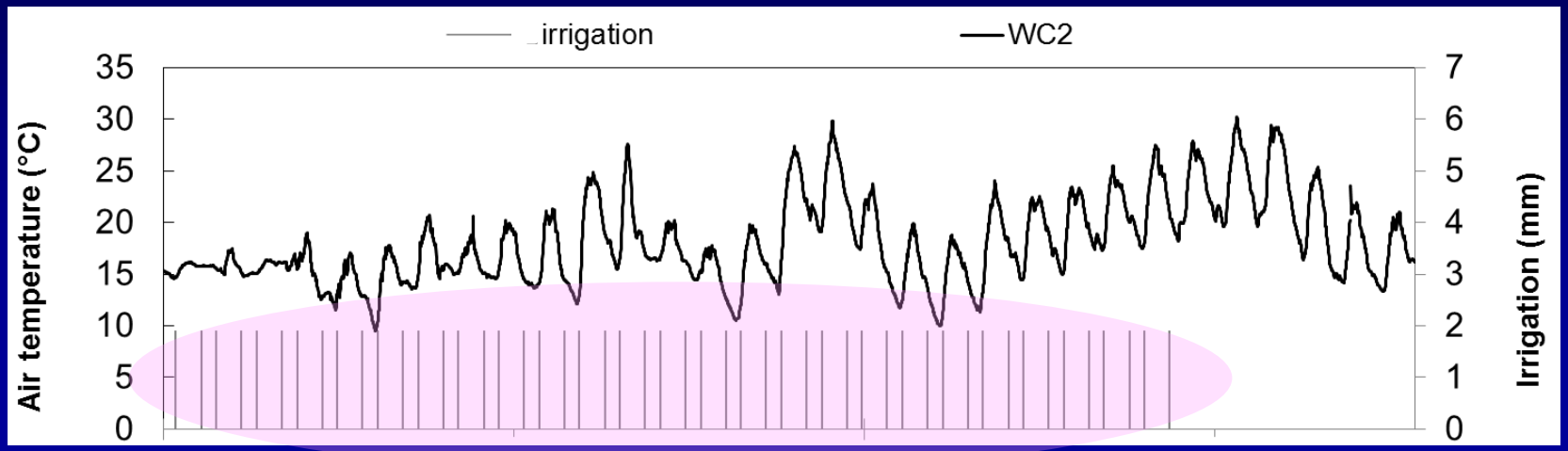
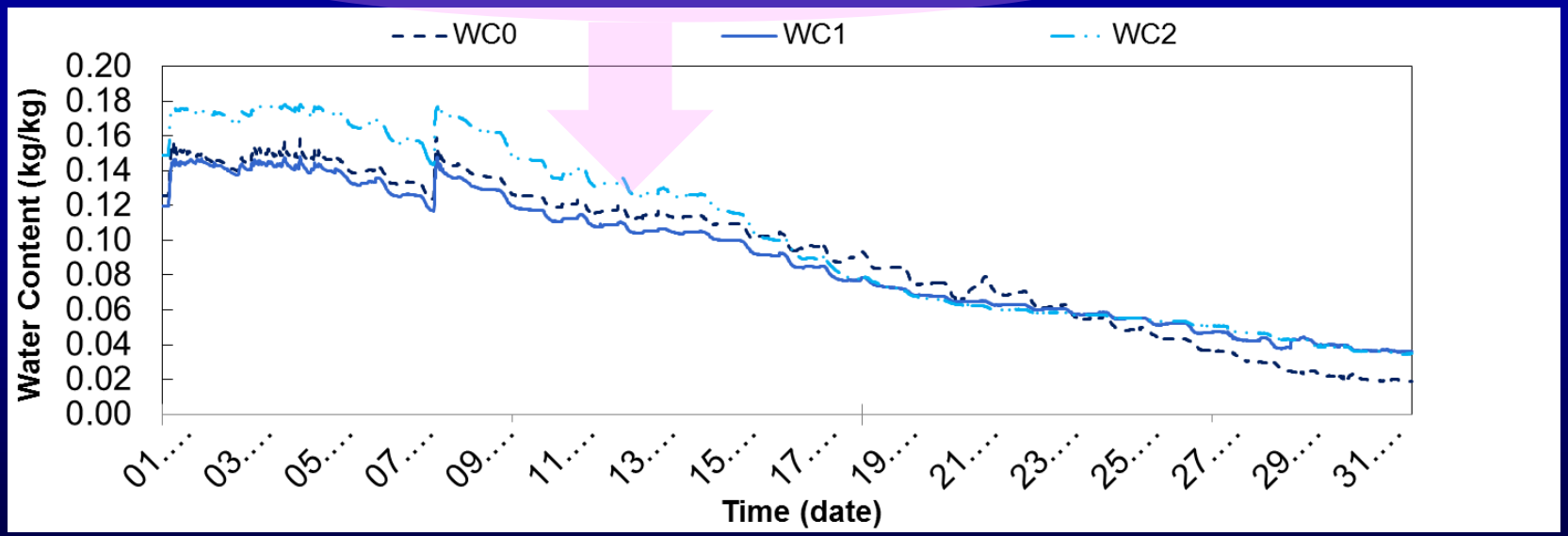
Water Content - which amount?

variable







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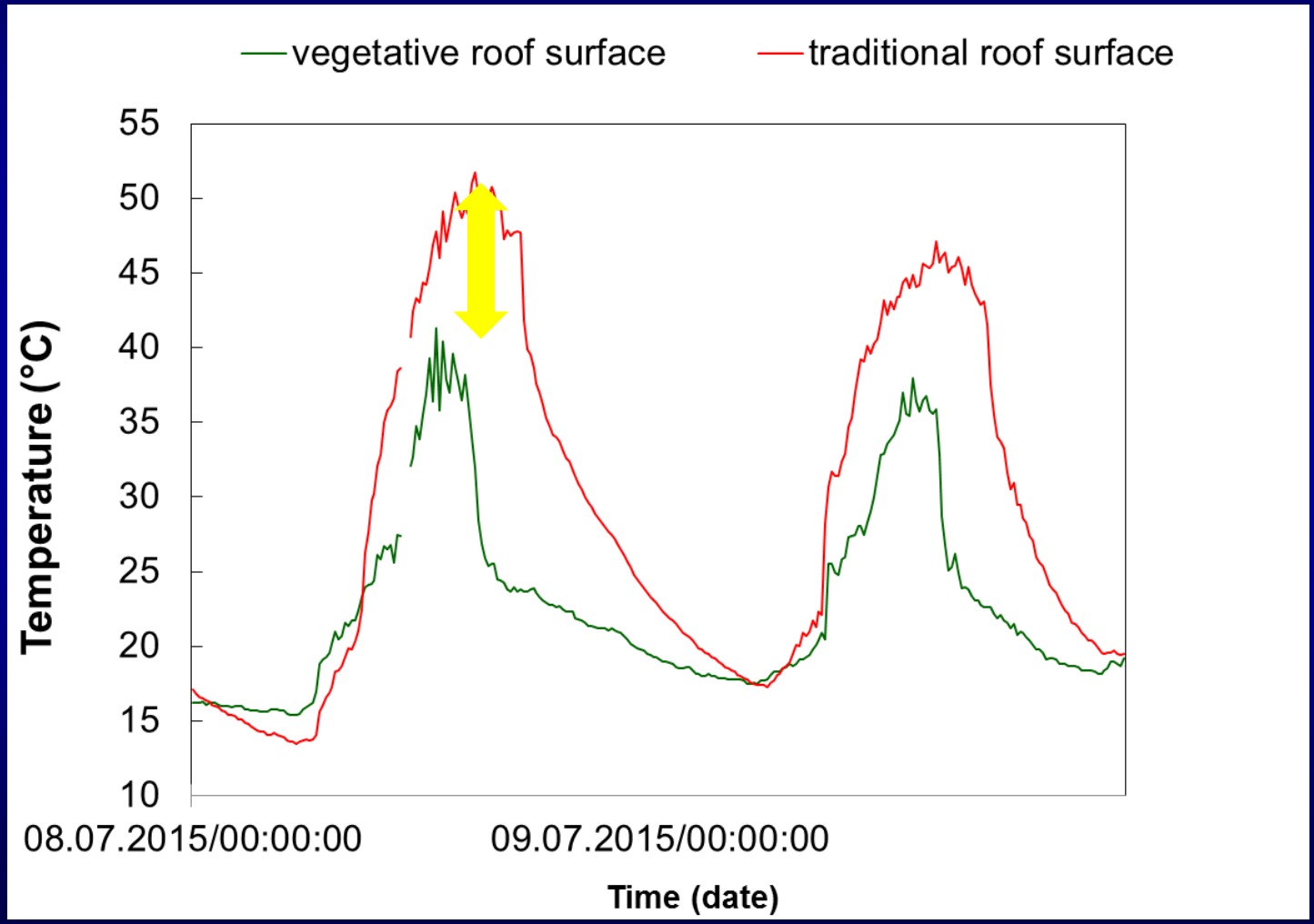
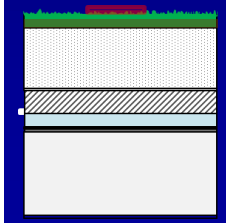
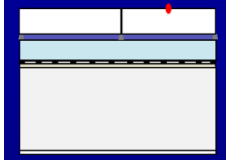
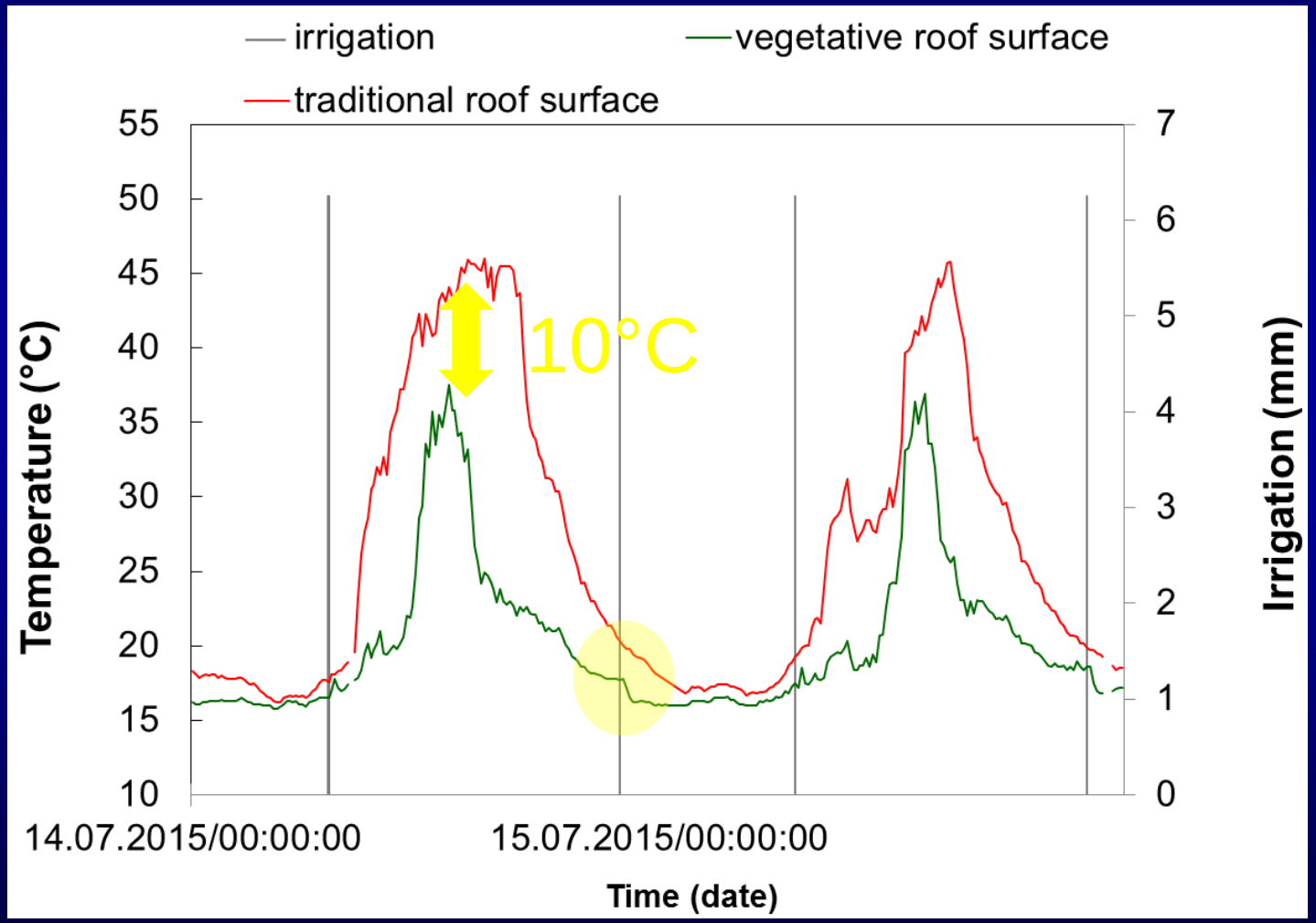
Traditional vs Vegetative Roof summer days

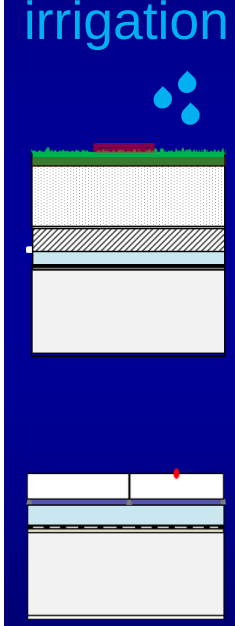




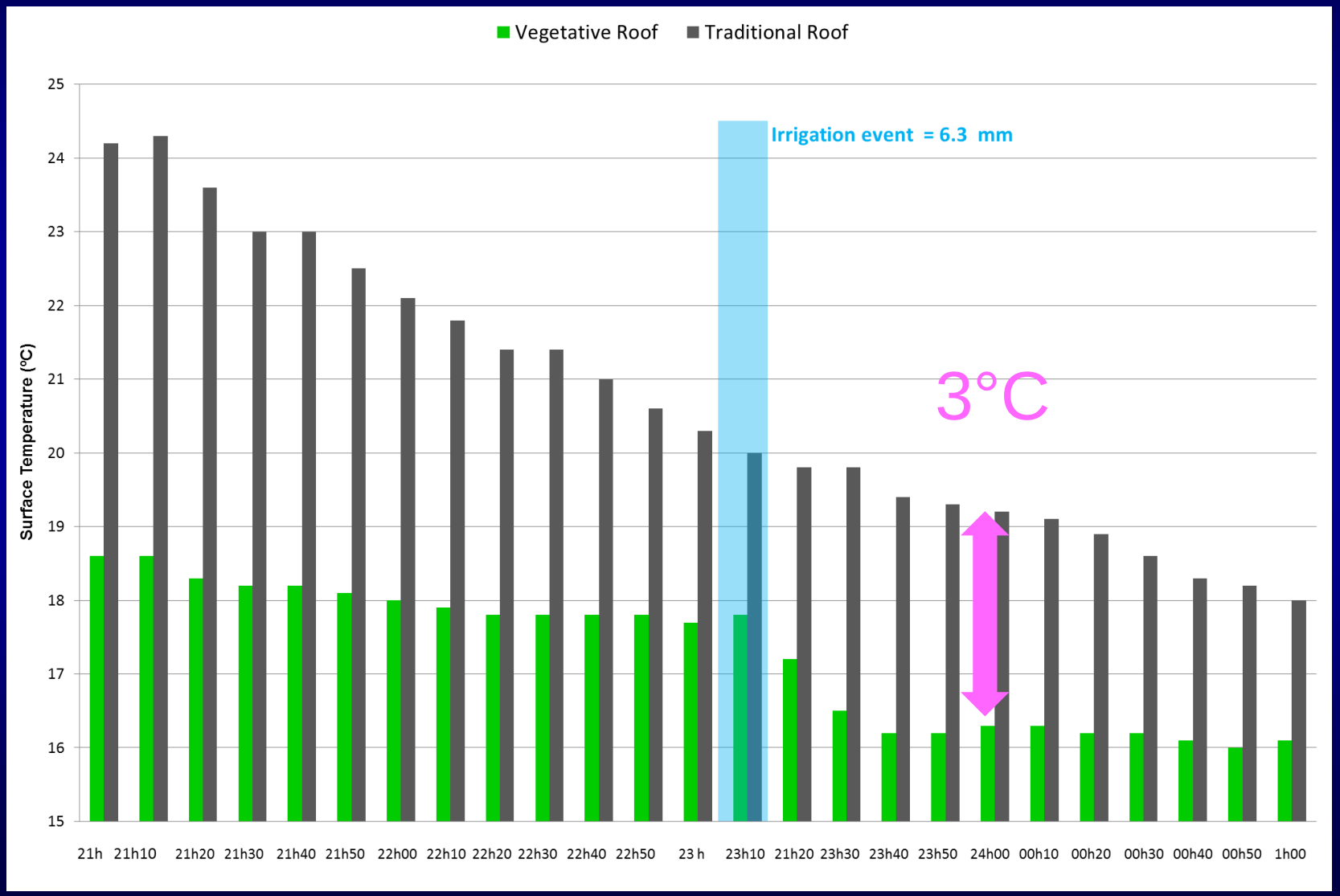


Traditional vs Vegetative Roof
summer days





Traditional vs Vegetative Roof night irrigation event



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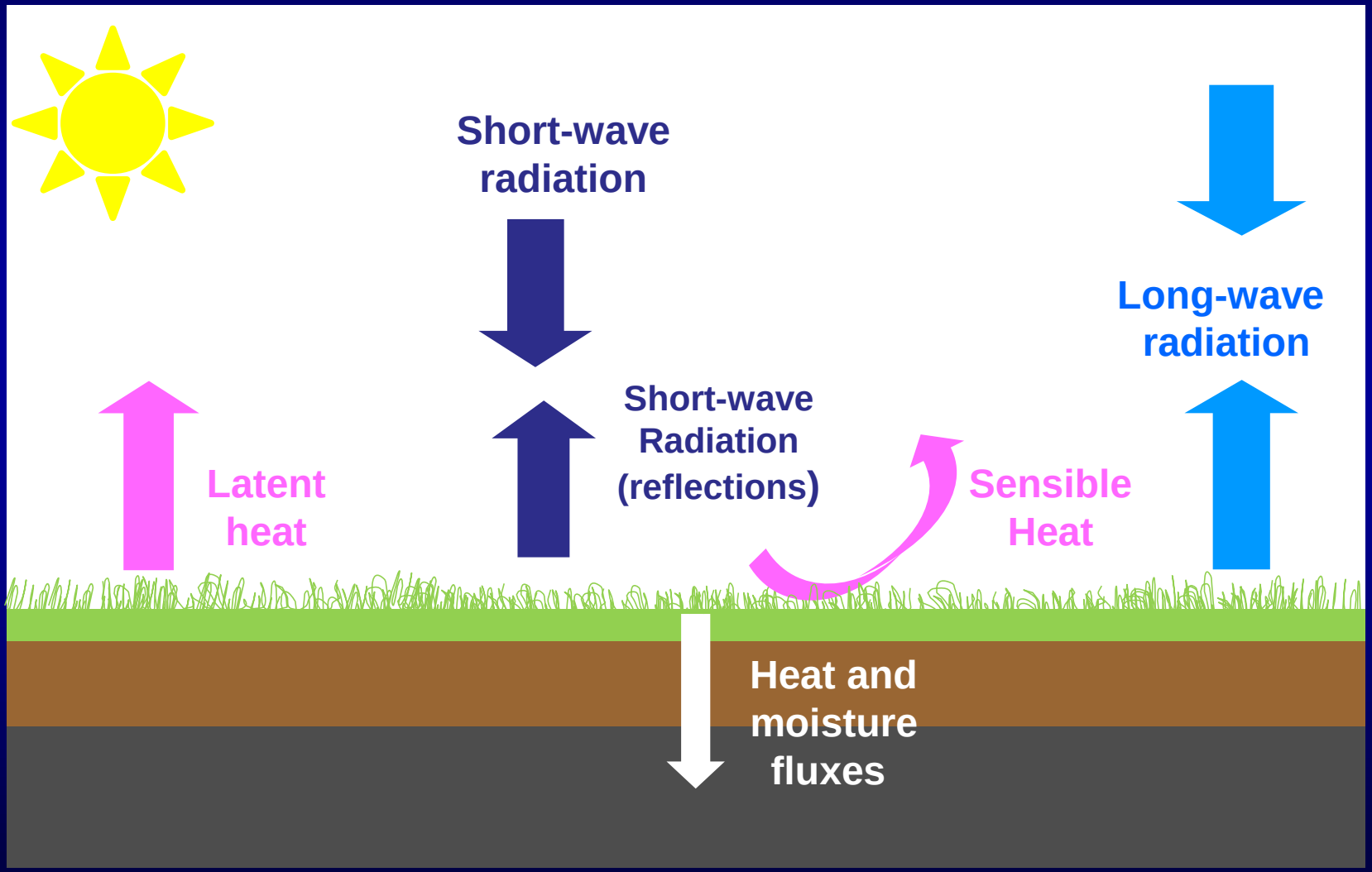
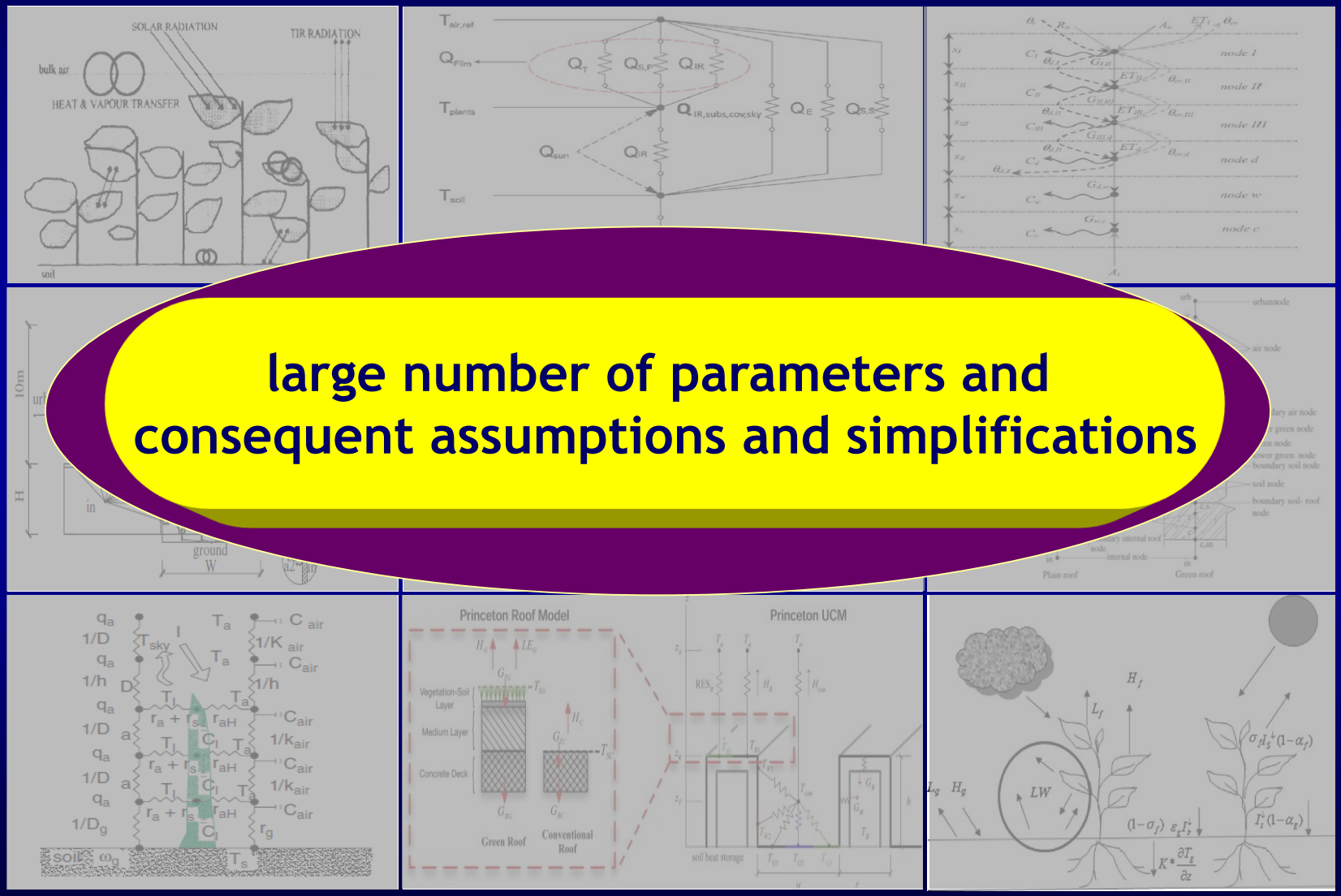
5.

VEGETATIVE ROOF MODELING

Vegetative roof simplified energy balance



Vegetative Roof Models



large number of parameters and consequent assumptions and simplifications

Authors	Dimension		Scale		Model		Hydrological Model		Support				Substrate				Vegetation				Drainage Layer				Waterproofing membrane		Air stratification
	1D	2D	Building	City	Coupled				Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		
					Yes	No	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	
Künzel 1995	x		x			x	x			x		x		x	x		x		x			x	x			x	
Del Barrio 1988	x		x			x	x			x				x		x		x		x							
Lazzarin et al. 2005	x		x		x		x		x				x		x		x		x		x		x		x		
Kumar and Kaushik 2005	x		x		x		x			x				x		x		x		x							
Alexandri and Jones 2007	x			x		x	x			x		x		x		x		x		x							X
Sailor 2008	x		x		x		x						x		x			x		x							
Palla et al. 2008	x		x			x		x						x		x											
Feng et al. 2010	x		x			x							x				x		x								
He and Jim 2010	x			x		x												x									X
Sailor and Hagos 2011						x							x		x												
Ouldboukhitine et al. 2011	x		x			x		x						x		x		x		x							
Jaffal et al 2012	x		x		x								x		x		x		x								
Tabares-Velasco and Srebric 2012	x		x		x		x						x		x			x		x							
Djedjig et al. 2012	x		x		x			x						x		x		x		x							
Munck et al. 2013		x		x	x			x	x				x		x		x		x		x		x				
Sun et al. 2013	x		x		x			x		x		x		x		x		x		x							
Olivieri et al. 2013	x		x			x							x				x										

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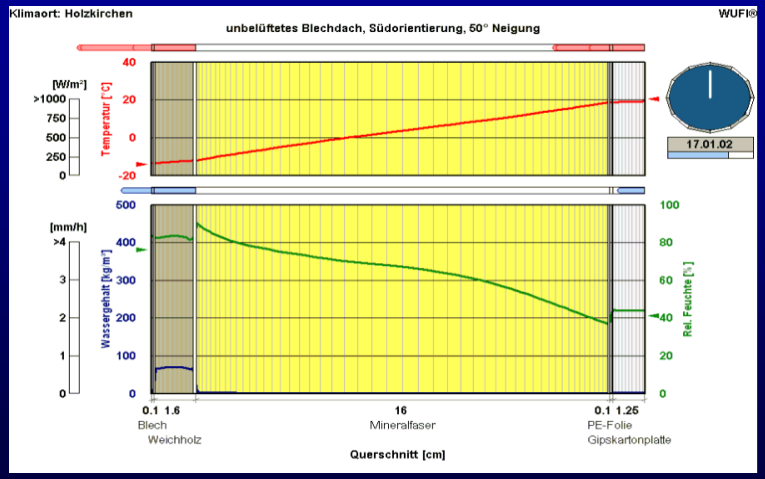
Major modeling limitations

Hydrological balance

Properties



Authors	Dimension		Scale		Model		Hydrological Model		Support				Substrate				Vegetation				Drainage Layer				Waterproofing membrane		Air stratification
	1D	2D	Building	City	Coupled				Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		Mass Transf.		Heat Transf.		
					Yes	No	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	
Künzel 1995	x		x			x	x			x		x		x	x		x		x			x	x			x	
Del Barrio 1988	x		x			x	x			x				x		x		x		x							
Lazzarin et al. 2005	x		x		x		X		x				x		x		x		x		x		x		x		
Kumar and Kaushik 2005	x		x		x		x			x				x		x		x		x							
Alexandri and Jones 2007	x			x		x	x			x		x		x		x		x		x							X
Sailor 2008	x		x		x		x						x		x			x		x							
Palla et al. 2008	x		x			x		x						x		x											
Feng et al. 2010	x		x			x							x				x		x								
He and Jim 2010	x			x		x																					X
Sailor and Hagos 2011						x																					
Ouldboukhitine et al. 2011	x		x			x		x																			
Jaffal et al 2012	x		x		x																						
Tabares-Velasco and Srebric 2012	x		x		x		x																				
Djedjig et al. 2012	x		x		x			x																			
Munck et al. 2013		x		x	x			x	x				x		x		x		x		x		x				
Sun et al. 2013	x		x		x			x		x		x		x		x		x		x							
Olivieri et al. 2013	x		x			x							x				x										

approximation errors due to water content distribution

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	1D	2D	Building	City	Coupled				Heat Transf.	Mass Transf.	Heat Transf.	Mass Transf.	Heat Transf.	Mass Transf.	Heat Transf.	Mass Transf.	Heat Transf.	Mass Transf.	Heat Transf.	Mass Transf.	Heat Transf.		
					Yes	No	S	C	S	C	S	C	S	C	S	C	S	C	S	C	S	C	
Künzel 1995	x		x			x	x			x		x		x	x		x		x		x	x			x	
Del Barrio 1988	x		x			x	x			x				x		x		x		x						
Lazzarin et al. 2005	x		x		x		X		x				x		x		x		x		x		x		x	
Kumar and Kaushik 2005	x		x		x		x			x				x		x		x		x						
Alexandri and Jones 2007	x			x		x	x			x		x		x		x		x		x						X
Sailor 2008	x		x		x		x						x		x			x		x						
Palla et al. 2008	x		x			x		x						x		x										
Feng et al. 2010	x		x			x																				
He and Jim 2010	x			x		x																				
Sailor and Hagos 2011						x																				
Ouldboukhitine et al. 2011	x		x			x		x																		
Jaffal et al 2012	x		x		x								x													
Tabares-Velasco and Srebric 2012	x		x		x		x						x		x			x		x						
Djedjig et al. 2012	x		x		x			x						x		x		x		x						
Munck et al. 2013		x		x	x			x	x				x		x		x		x		x		x			
Sun et al. 2013	x		x		x			x		x		x		x		x		x		x						
Olivieri et al. 2013	x		x			x							x				x									

knowledge of complex parameters difficult to quantify

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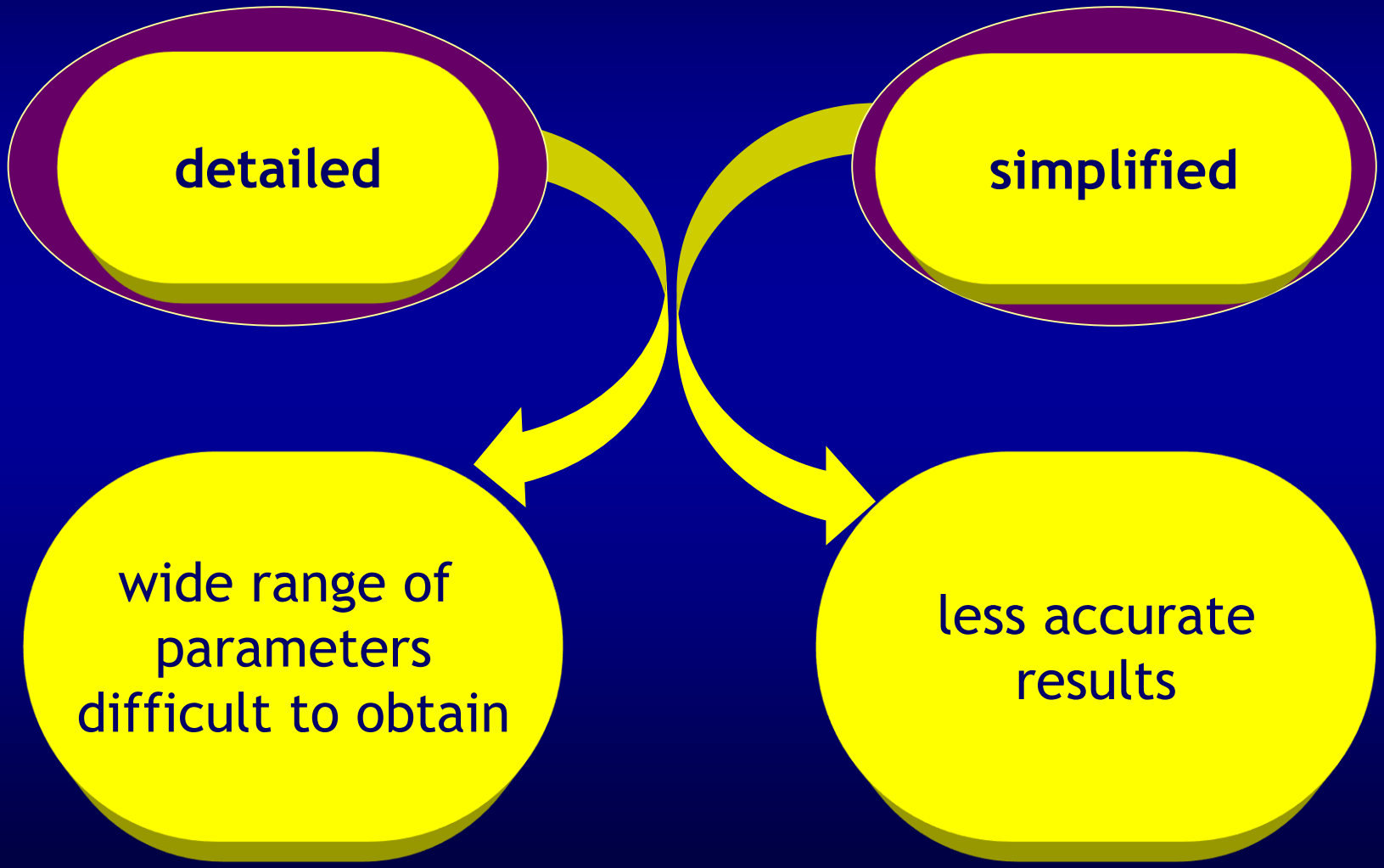
Modeling approach



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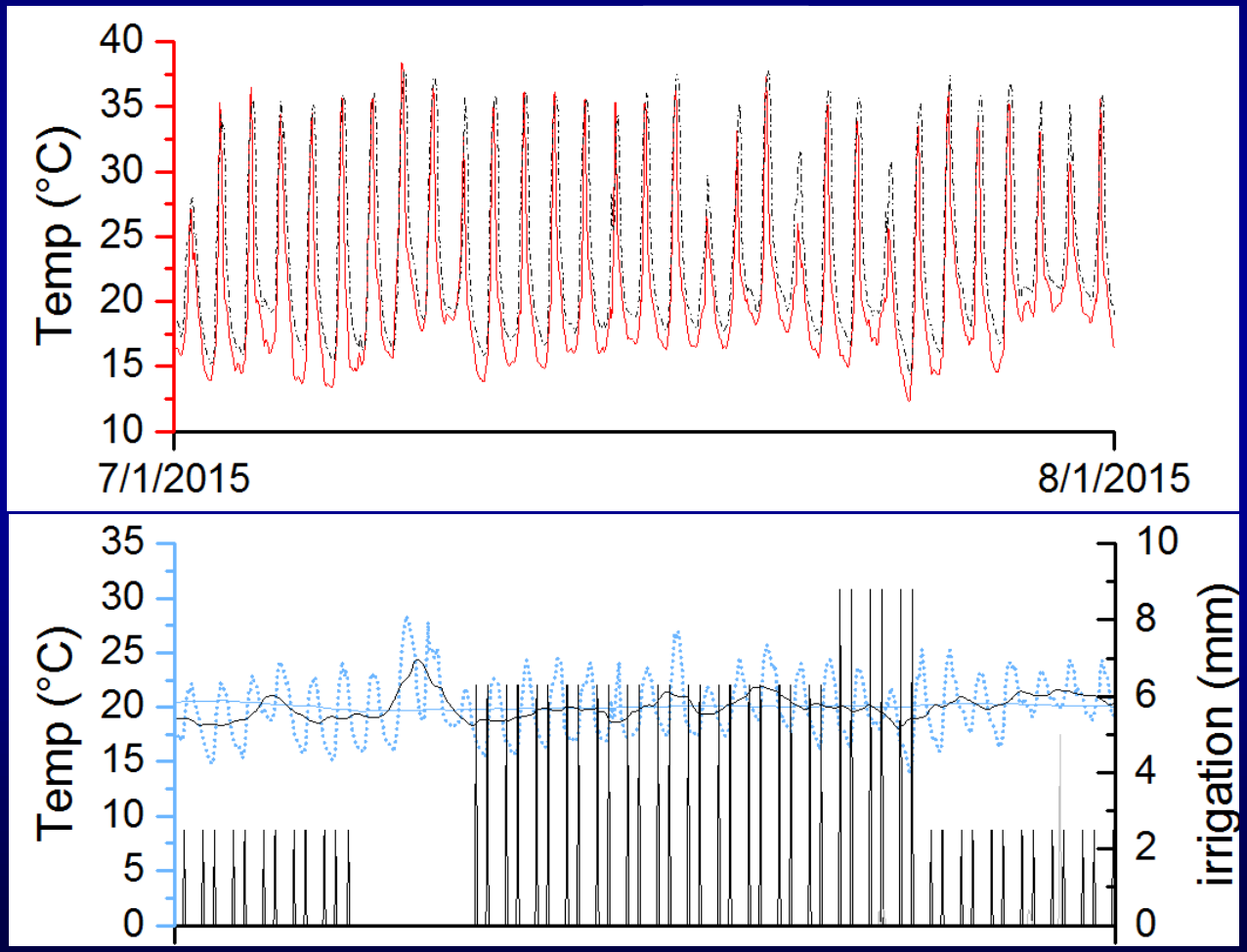
Measurements vs Simulations

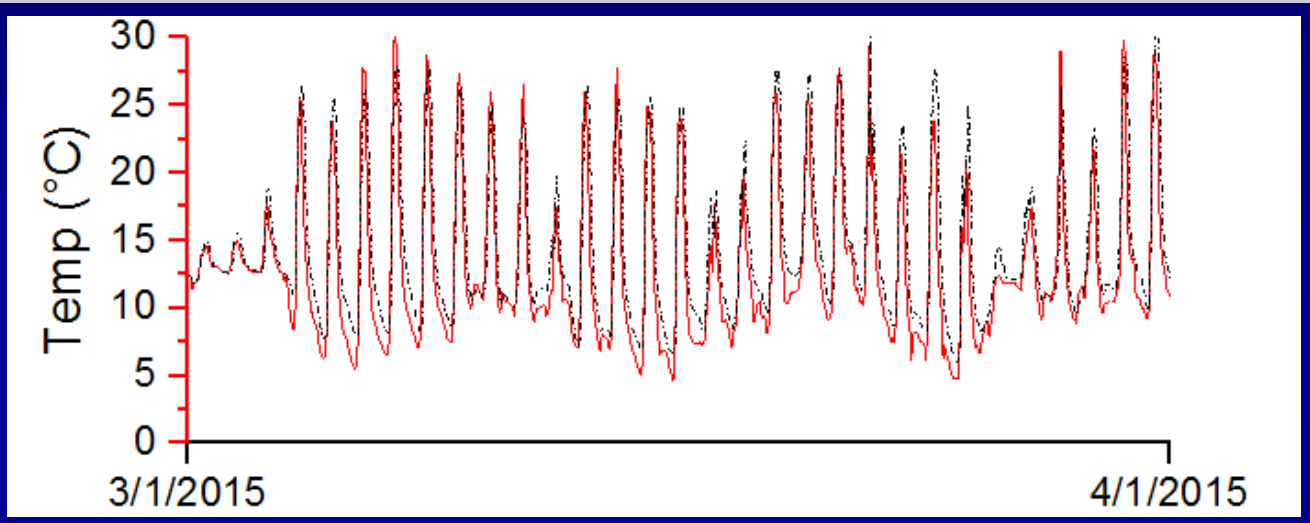
Measured vs simulated - surface temperatures

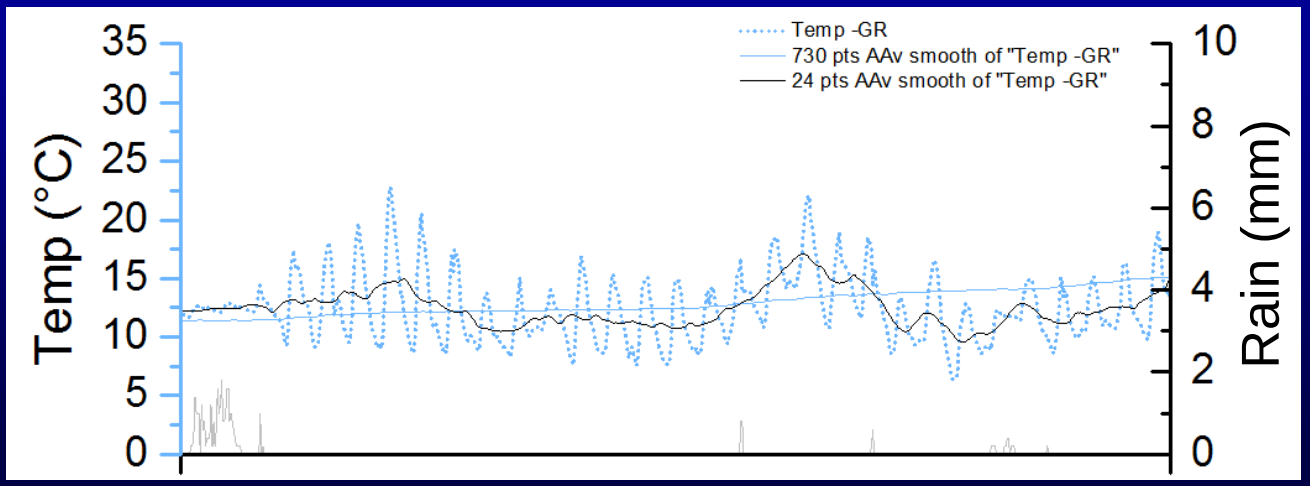
with irrigation



Measured vs simulated - surface temperatures

with rain events





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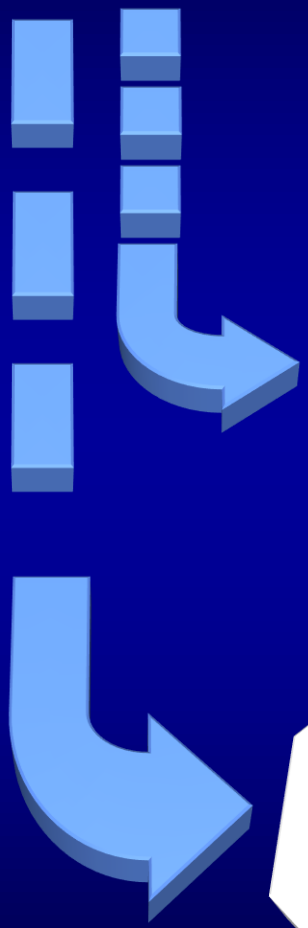
6.

CONCLUSIONS

CONCLUSIONS



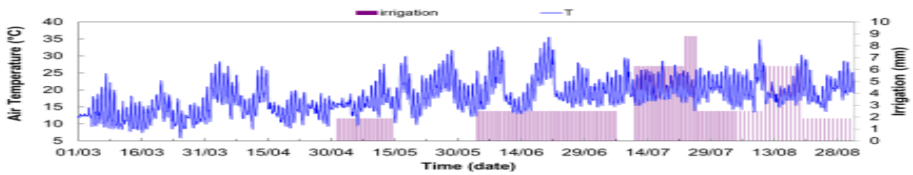
Vegetative roofs are designed to depend primarily on precipitation, but we need to consider vegetation species and climatic conditions

Maximization of water efficiency is imperative: to reduce water waste, costs and enhance roof performance during summer

CONCLUSIONS

Simulation tool validated to test different irrigation scenarios

irrigation scenarios



Irrigation impacts positively on heat fluxes and surface temperatures

Thank you for your attention