Investigation of the effect of sealed surfaces on local climate and thermal stress

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Questions

- Do high reflecting concrete surfaces have the potential to reduce the thermal heat stress and to improve the local urban climate?

- How is the agreement between the measured and the calculated surface temperatures and main energy balance components above different types of sealed surfaces?

- Introduction
- Methods
    - Location of measurements and instrumentation
    - Modelling
- Results (preliminary)
    - Measurements
    - Model simulations
- Conclusion

INTRODUCTION

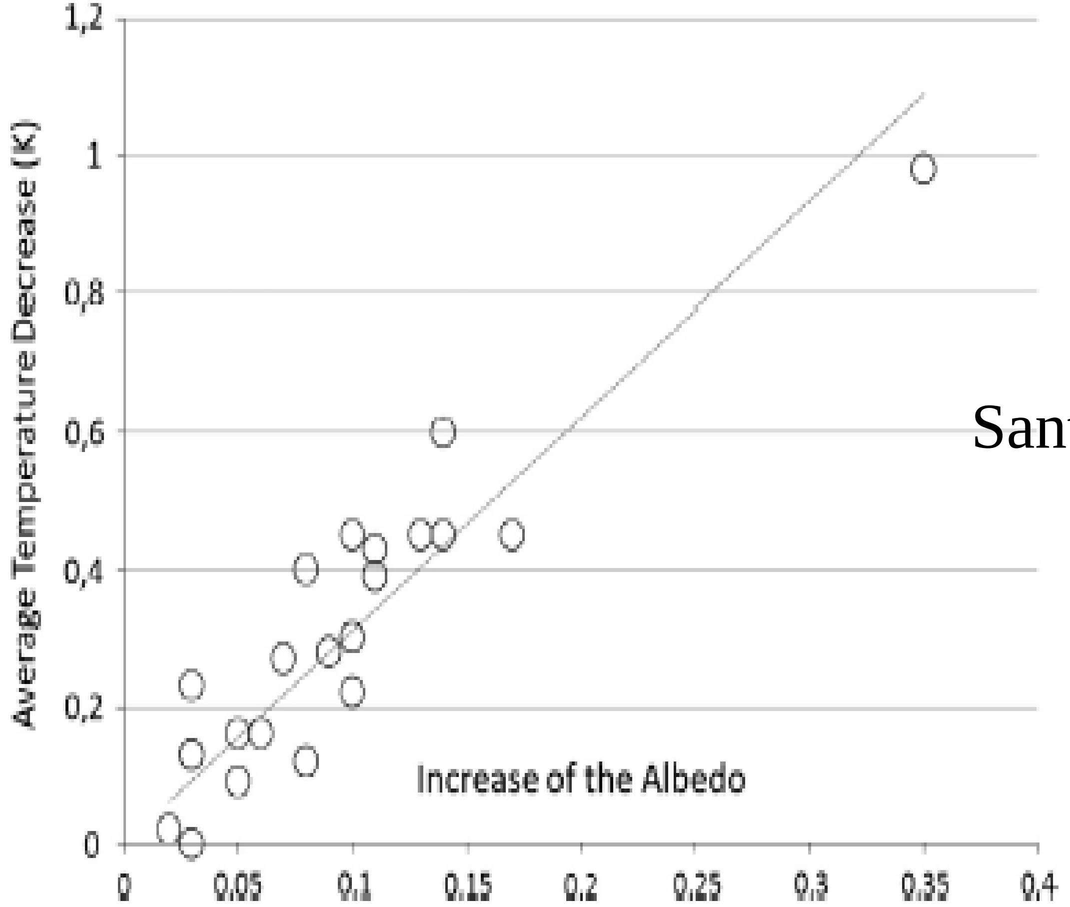
Several studies showed that an increase in albedo may lead to a reduction in air temperature (e.g. Synnefa et al.(2011); Akbari et al. (2012))

Akbari et al (2012) showed that an albedo increase of 0.01 may lead to a long term cooling effect of 3×10^{-15} K (for a 1 m^2 surface)

•Influence of albedo on the average temperature of a city

ATD = 3.11 ALBIN

ALBIN =increase of albedo, ATD = decrease in temperature



Santamouris, 2014

Fig. 1. Correlation between the possible albedo change and the corresponding decrease of the average ambient temperature in urban areas.

Methods:

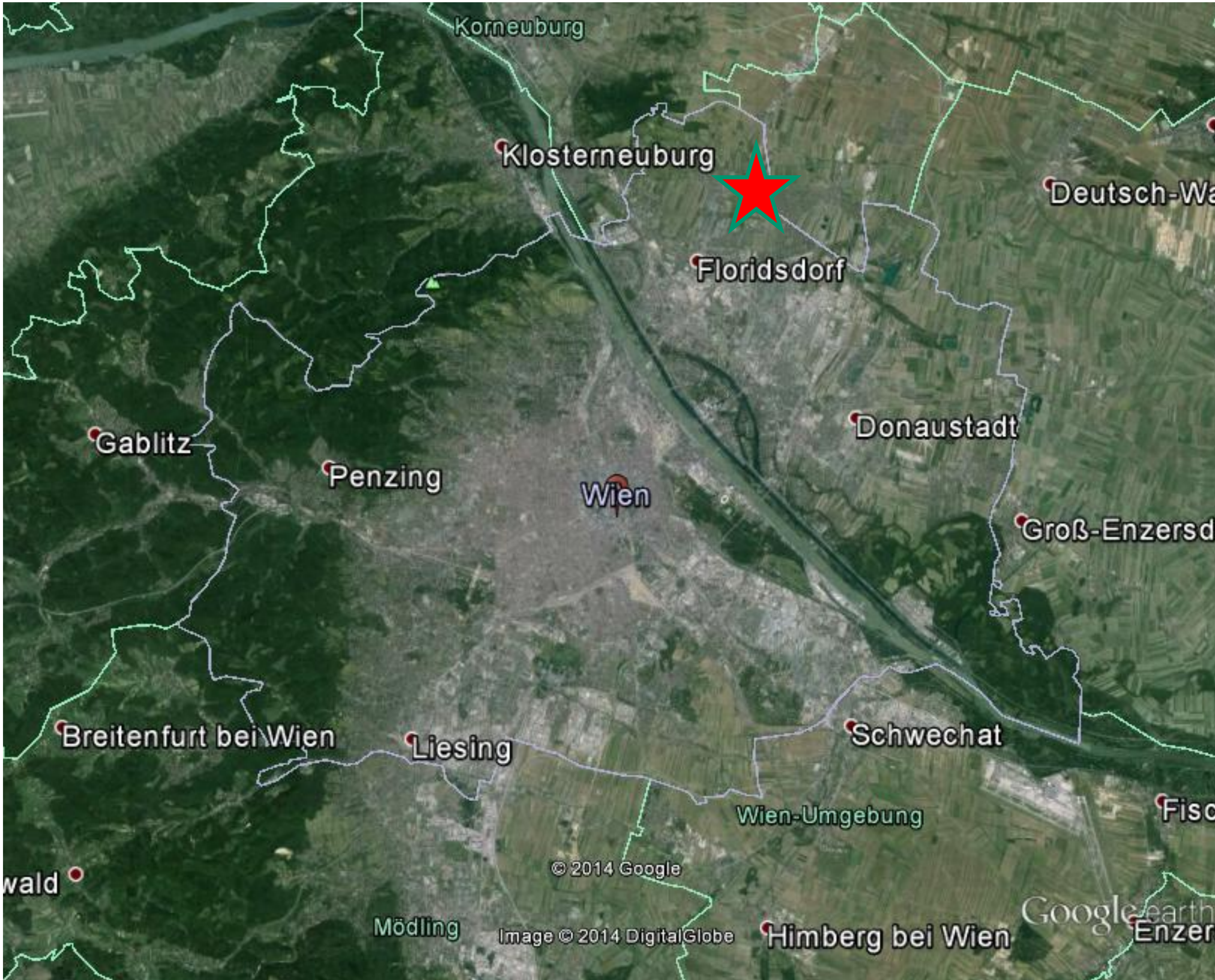
- Experimental Investigations

Measurements of albedo, radiation balance, surface and air temperature of various sealed surfaces

- Model simulations for chosen city districs of Vienna and for typical urban canyon

Simulations with models Envi-Met and TEB

Experimental investigations: location of measurements


Korneuburg
Klosterneuburg
Floridsdorf
Deutsch-Wa
Gablitz
Penzing
Wien
Donaustadt
Groß-Enzersdo
Breitenfurt bei Wien
Liesing
Schwechat
Wien-Umgebung
Fisch
wald
© 2014 Google
Mödling
Image © 2014 DigitalGlobe
Himberg bei Wien
Google earth
Enzers


© 2014 Google
Google earth

MEASUREMENTS

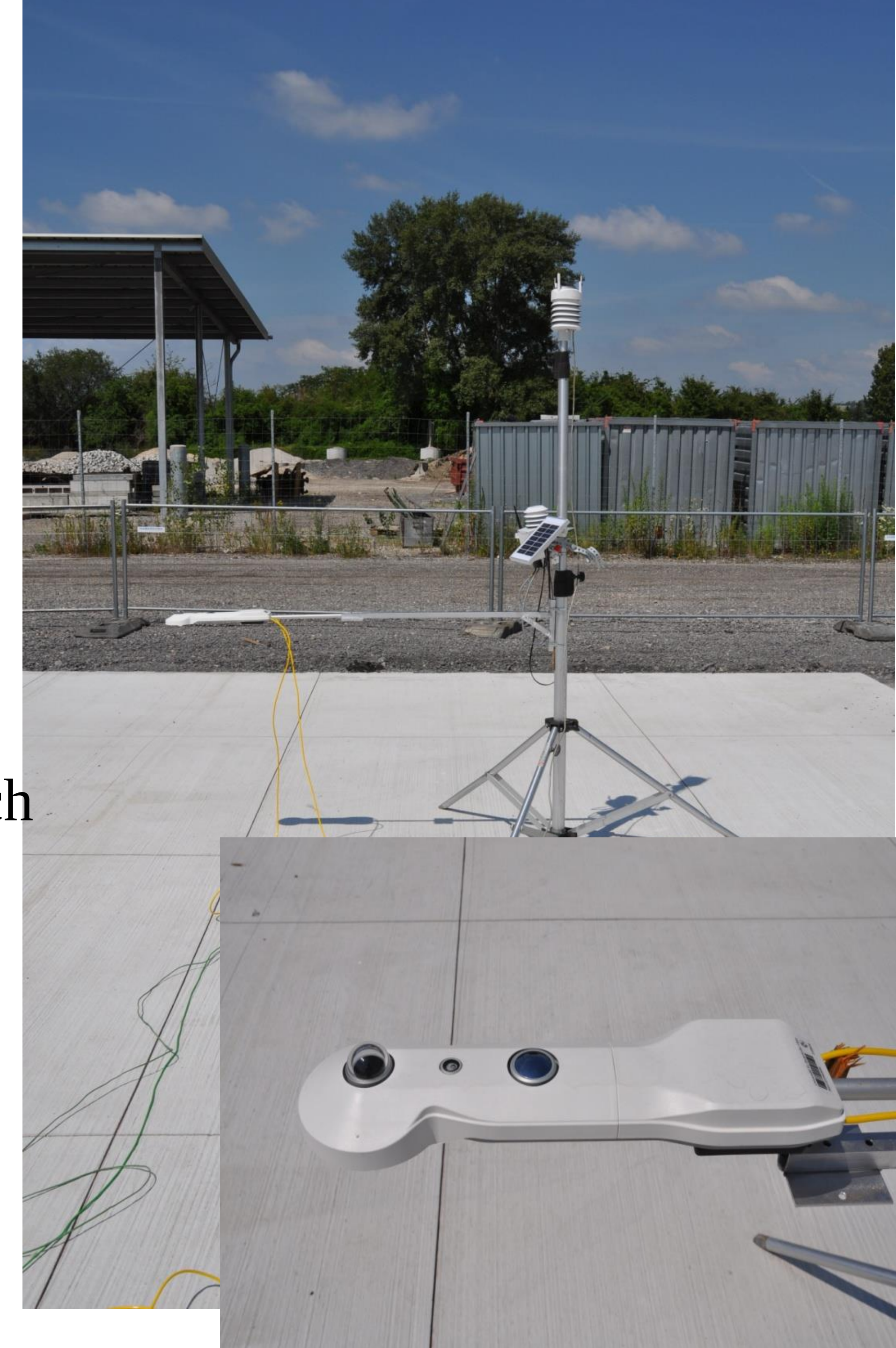
Measurement campaign (17.7.2014)

Measurements with a mobile system

- Measurements of the short wave and longwave radiation balance above each surface

- Measurement of the albedo of each surface

- Measurement of surface temperature with thermal camera



Routine measurements

Measurement period: 18. July 2014 - 10. October 2014

- of incident shortwave and longwave radiation
- of reflected shortwave radiation and emitted longwave above each surface
- of temperature of the 6 surfaces with thermal IR sensors and with thermoelements
- of the air temperature in 10 cm height above each surface
- of air temperature and humidity in 2 m height at one point
- of wind speed and direction
- of vertical ground temperature profile

Modelling

Modelling of urban energy balance and of meteorological components using

- the micro scale urban energy balance model Envi Met (http://www.envi-met.com)

and

- the topo scale urban town energy balance (TEB) model (Masson, 2000)

Introduction

Methods

Location of measurements and instrumentation

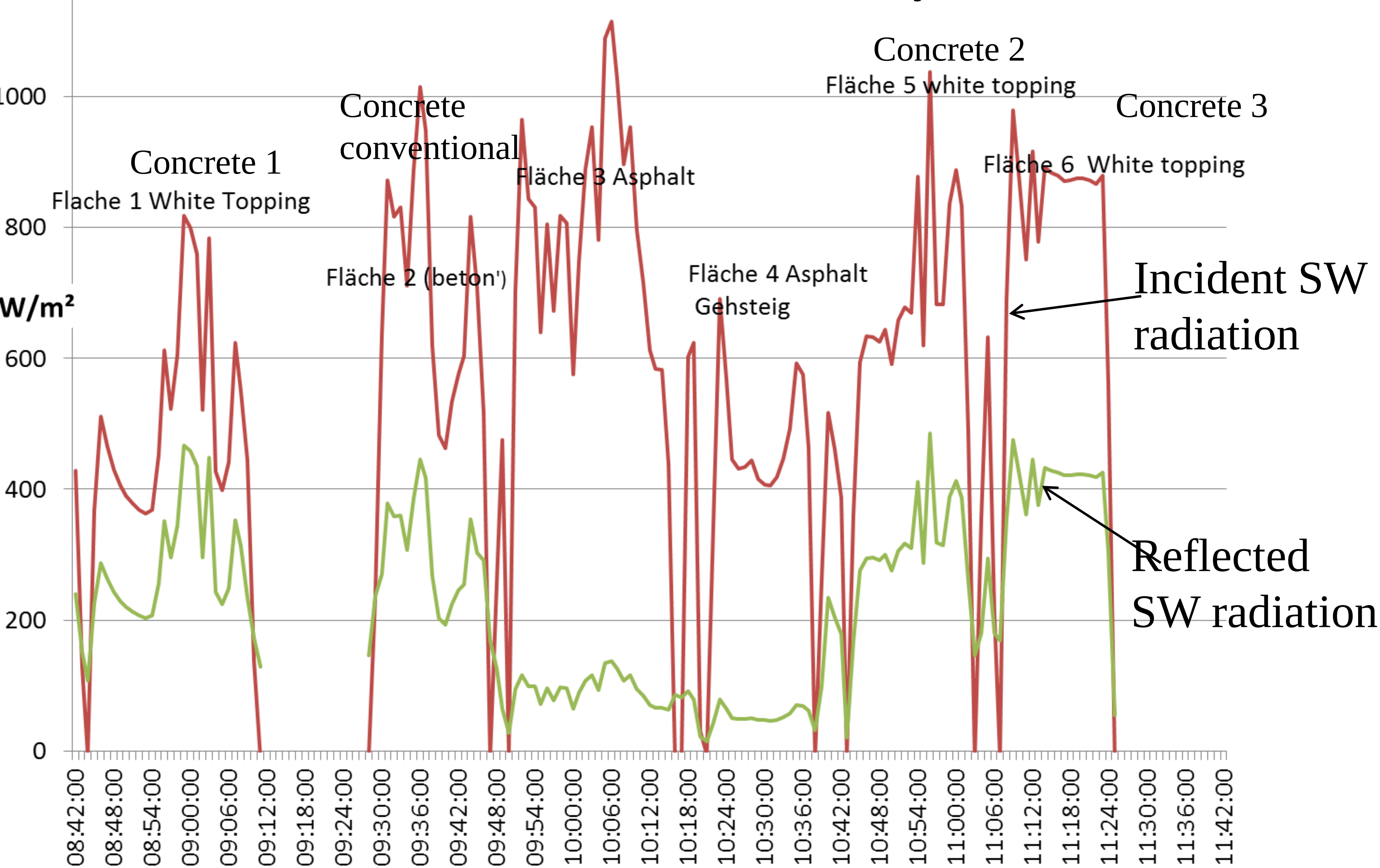
Results (preliminary)

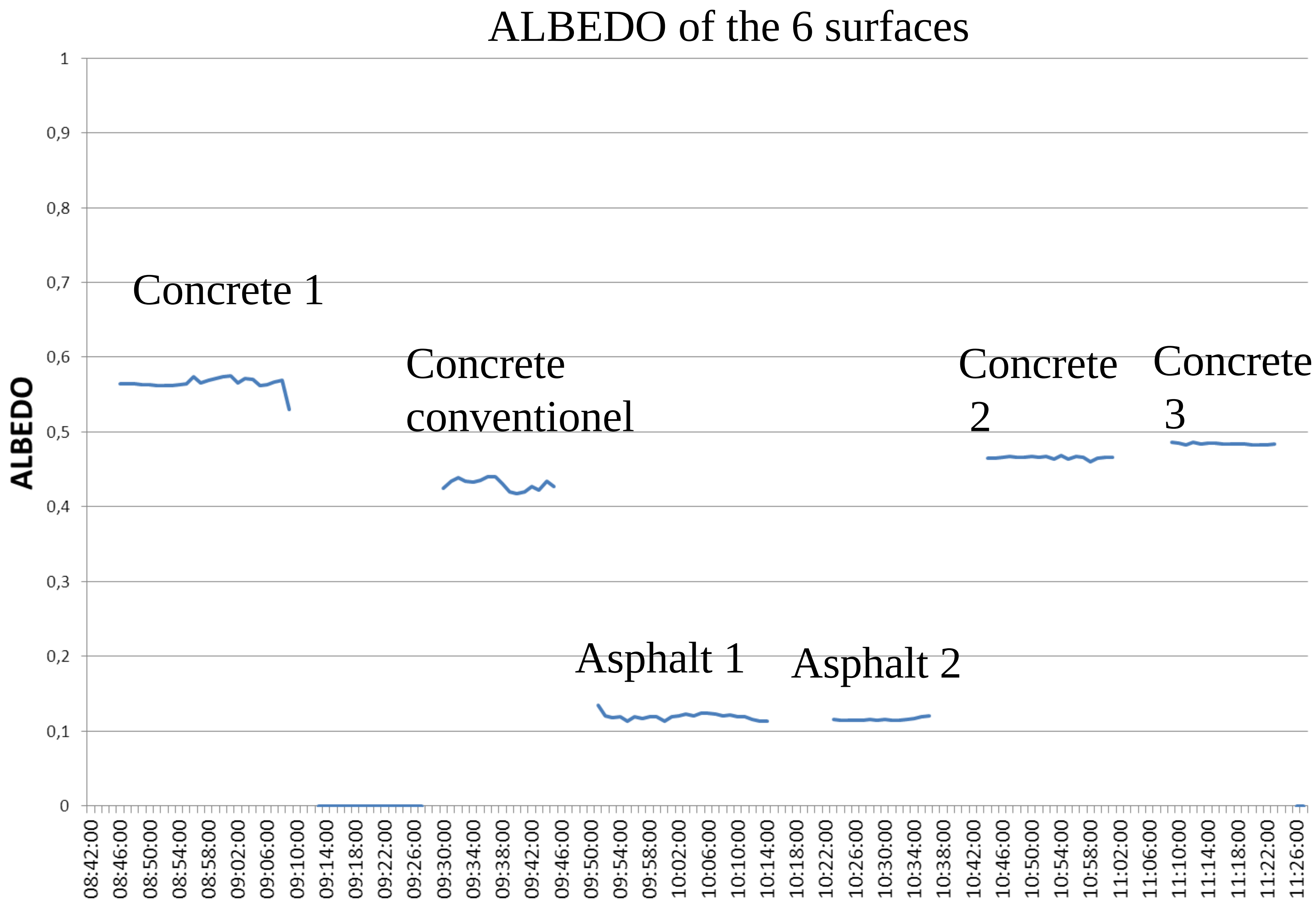
→ Measurements

Model simulations

Conclusion

Measurement of incident and reflected shortwave (SW) radiation with the mobile measurement system 17.7.2014

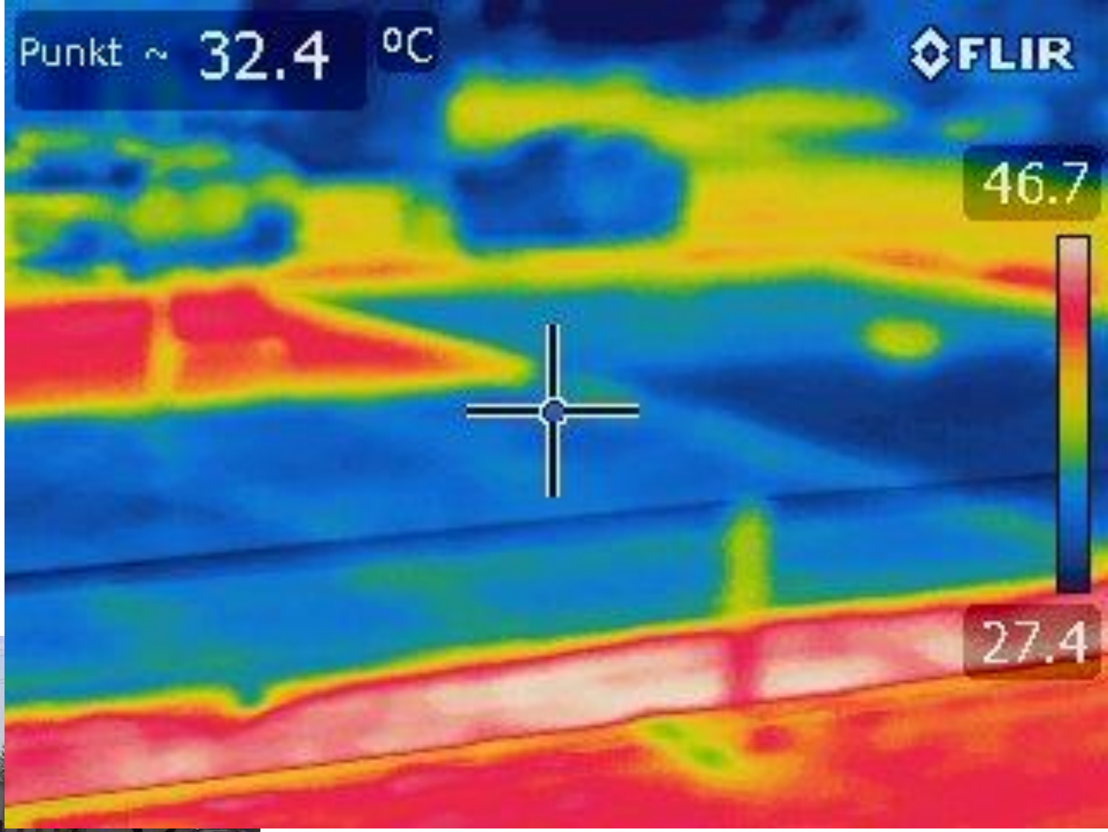




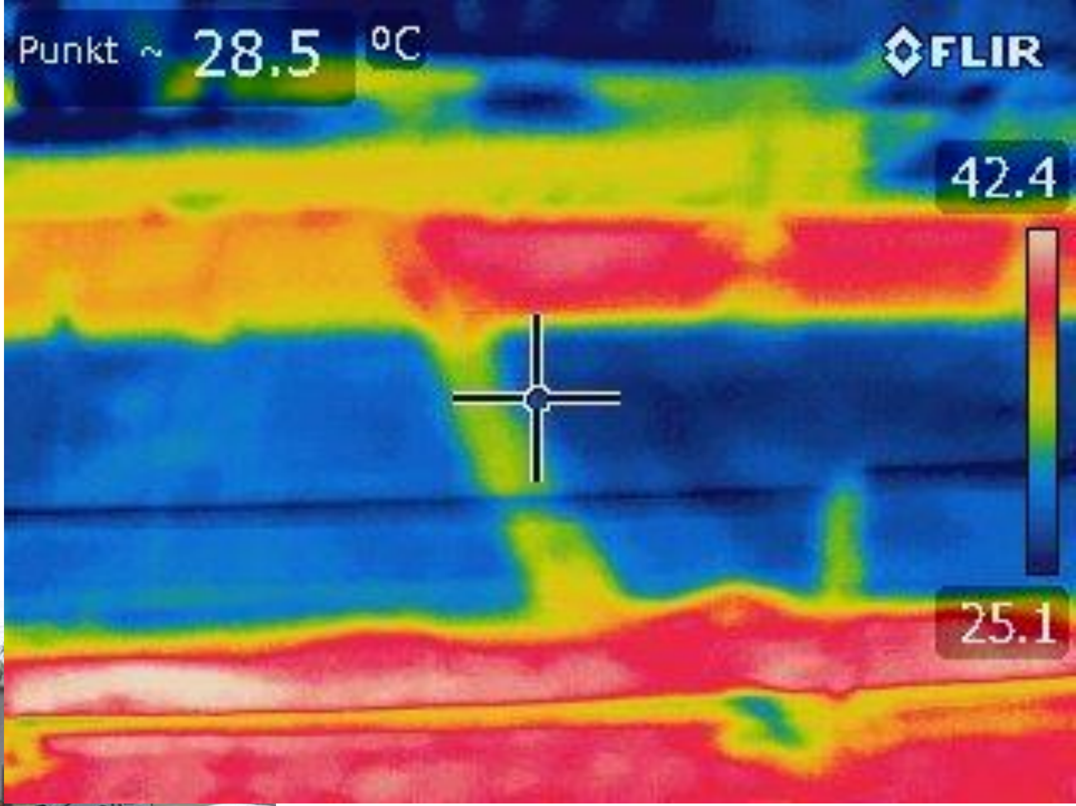
ALBEDO of the 6 surfaces
ALBEDO
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Concrete 1
Concrete conventionel
Concrete 2
Concrete 3
Asphalt 1
Asphalt 2
08:42:00
08:46:00
08:50:00
08:54:00
08:58:00
09:02:00
09:06:00
09:10:00
09:14:00
09:18:00
09:22:00
09:26:00
09:30:00
09:34:00
09:38:00
09:42:00
09:46:00
09:50:00
09:54:00
09:58:00
10:02:00
10:06:00
10:10:00
10:14:00
10:18:00
10:22:00
10:26:00
10:30:00
10:34:00
10:38:00
10:42:00
10:46:00
10:50:00
10:54:00
10:58:00
11:02:00
11:06:00
11:10:00
11:14:00
11:18:00
11:22:00
11:26:00

Surface	Albedo	Measurement uncertainty
Concrete 1	0.5668	0.0123
Conv. concrete	0.4298	0.0073
Asphalt 1	0.1186	0.0032
Asphalt 2	0.1257	0.0018
Concrete 2	0.4655	0.0018
Concrete 3	0.4841	0.0013

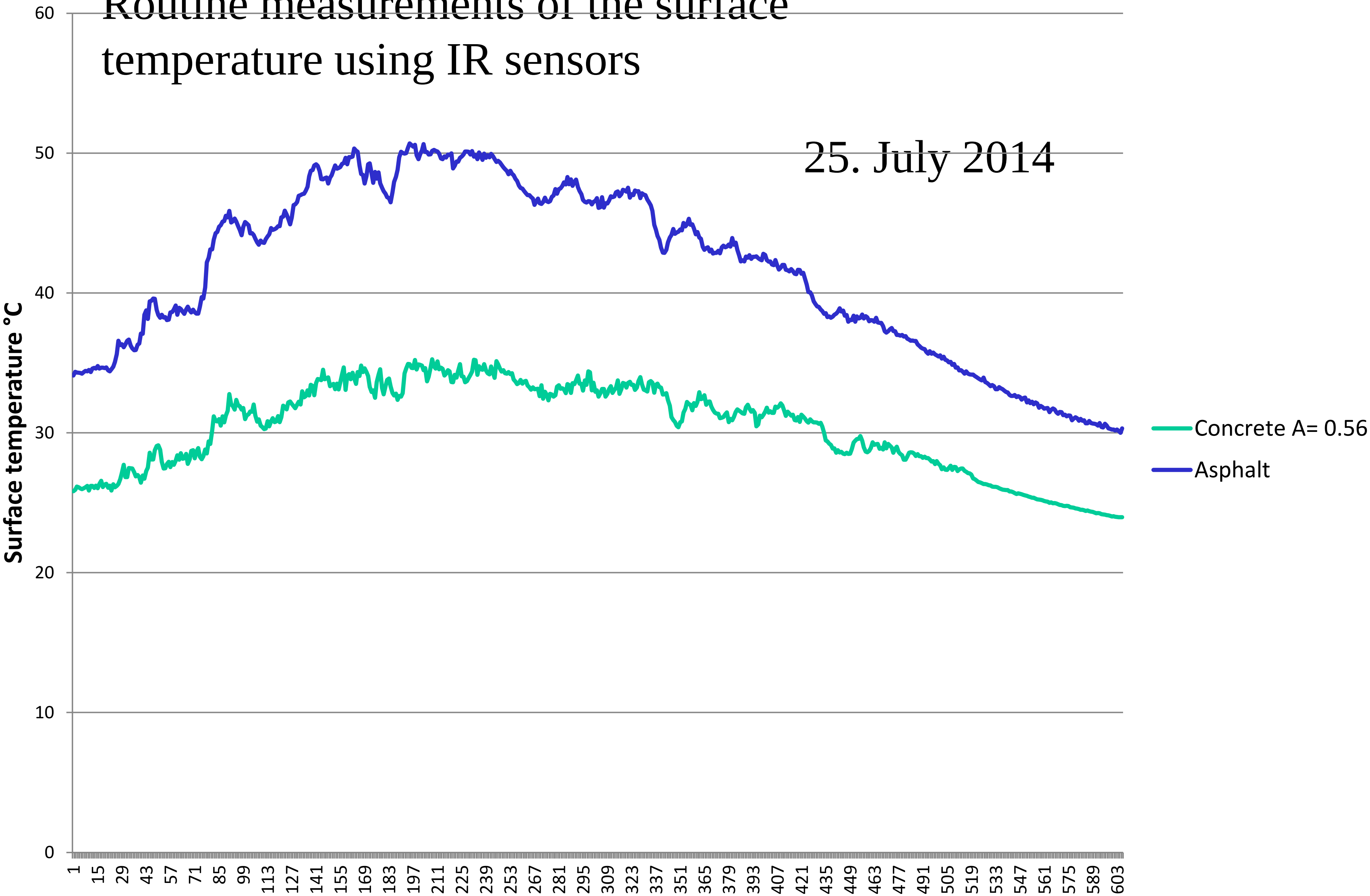
Thermal IR Measurement
17. July 2014 11:46 MET



Thermal IR Measurement
17. July 2014 11:46 MET



Routine measurements of the surface temperature using IR sensors



Measurements on 17.7.2014:

sunny, 2/8 cloud fraction.

Surface	Albedo	Surface Temp.
Concrete 1	0.5668	27° ± 1°C
Conv. Beton	0.4298	34° ± 1°C
Asphalt 1	0.1186	42° ± 1°C
Asphalt 2	0.1257	40° ± 1°C
Concrete 2	0.4655	30° ± 1°C
Concrete 3	0.4841	29° ± 1°C

Comparison longwave measured and calculated

Surface	Longwave measured (mean over 15 minutes)	Longwave calculated with Stefan Boltzman law ε = 1 Using mean of measured surface temperature	ε required to get a fit
Concrete 1 with high reflection	462 W/m^2	471 W/m^2	0.98 (± 0.007)
Concrete 2 with high reflection	503 W/m^2	508 W/m^2	0.99 (± 0.008)
Asphalt 1	518 W/m^2	545 W/m^2	0.95 (± 0.018)
Asphalt 2	528 W/m^2	539 W/m^2	0.98 (± 0.02)

Surface	*Albedo*	*Surface temperature [°C]*	*Emissivity*	*Specific heat capacity [J/(kg.K])*
Asphalt 1	*0.12*	*40 ± 1°C*	*0.95 ± 0.02*	*901*
Asphalt 2	*0.13*	*42± 1°C*	*0.98 ± 0.02*	*901*
Conventional concrete	*0.43*	*34 ± 1°C*	*0.99 ± 0.02*	*721*
High reflecting concrete 1	*0.57*	*27 ± 1°C*	*0.99 ± 0.02*	*891*
High reflecting concrete 2	*0.47*	*30 ± 1°C*	*0.99 ± 0.02*	*891*
High reflecting concrete 3	*0.48*	*29 ± 1°C*	*0.99 ± 0.02*	*891*

Introduction

Methods

Location of measurements and instrumentation

Results (preliminary)

Measurements

→ Model simulations

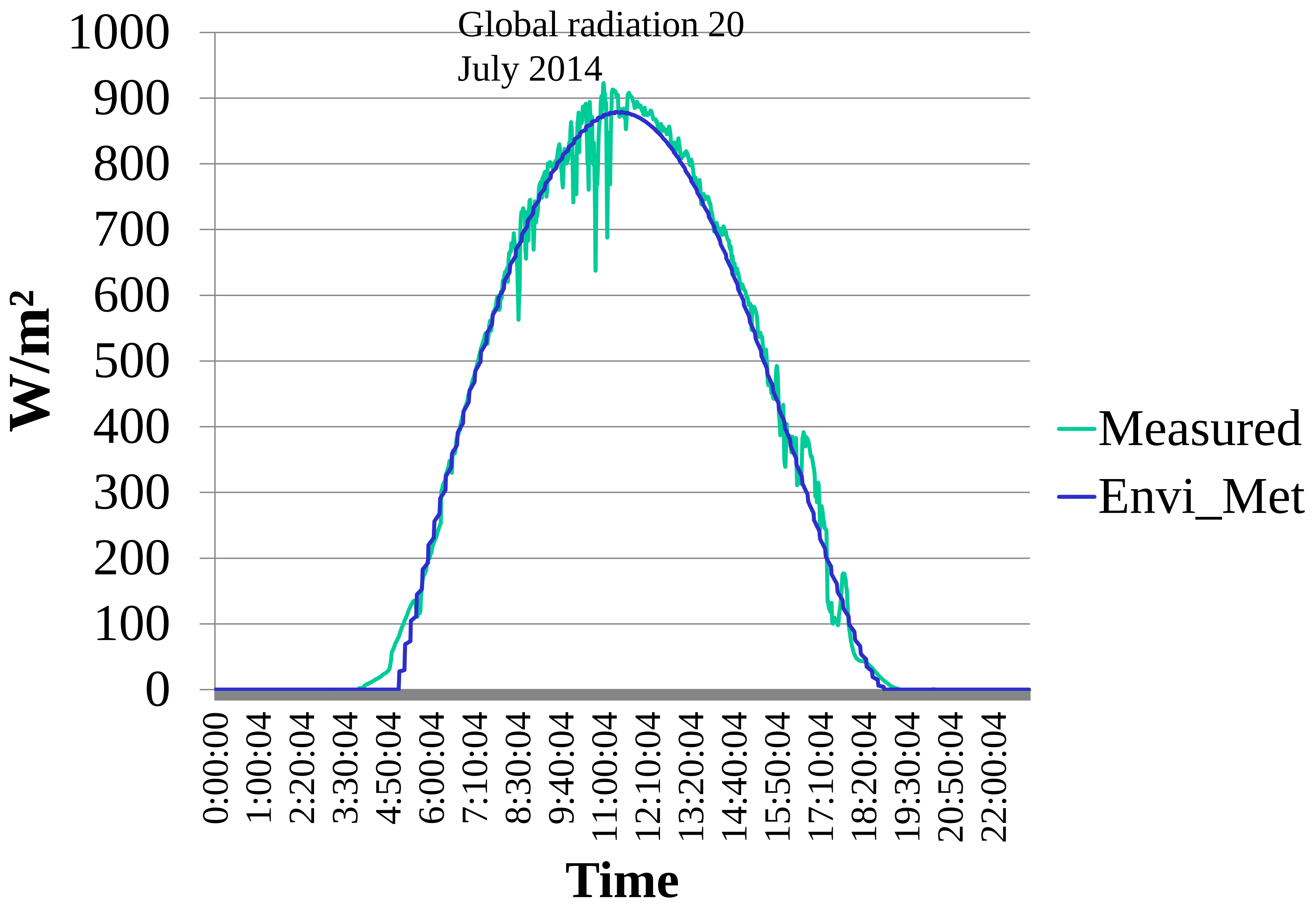
Conclusion

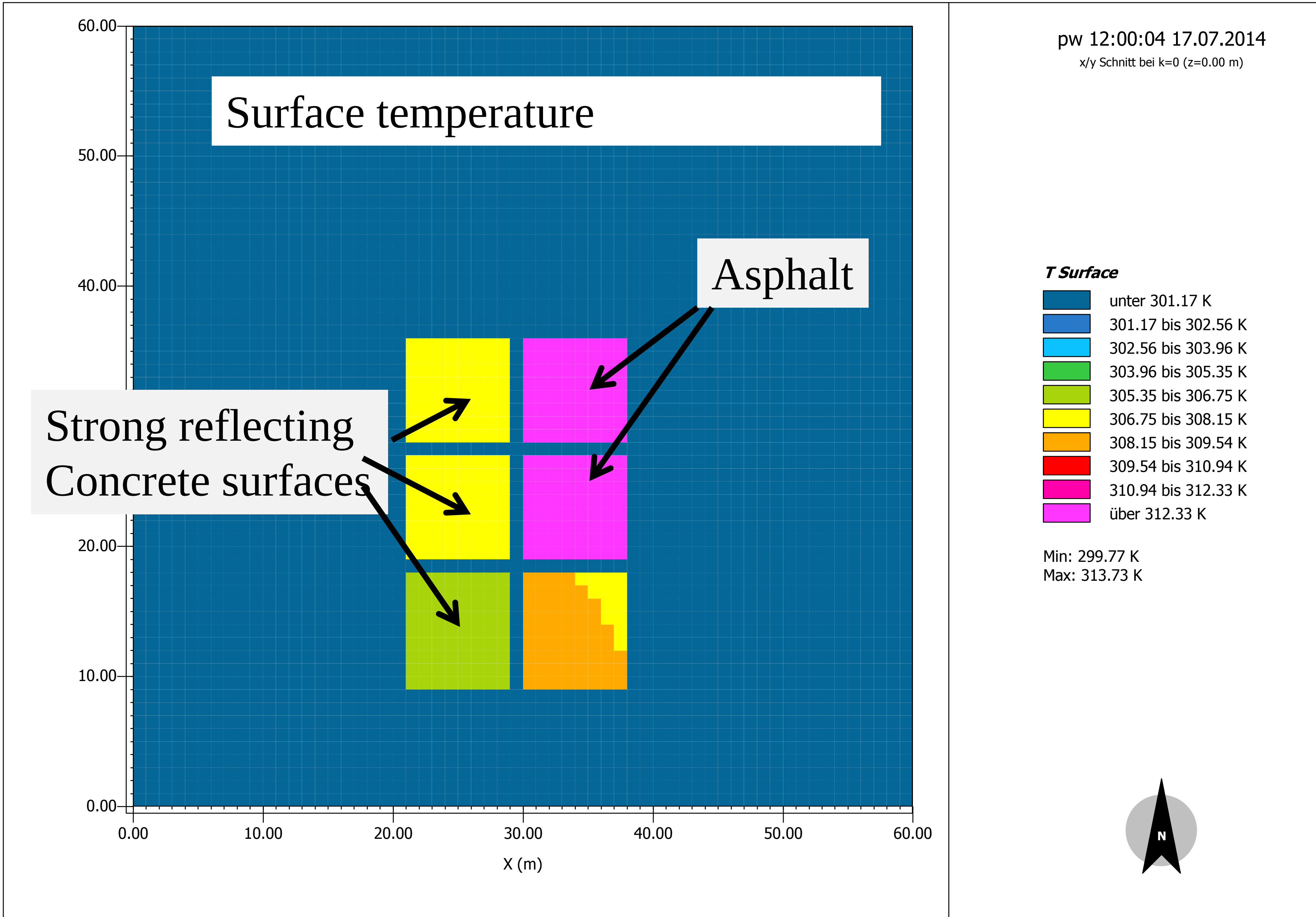
Simulations with the urban Energy balance model Envi-Met (3.99 Beta version) (Bruse et al)

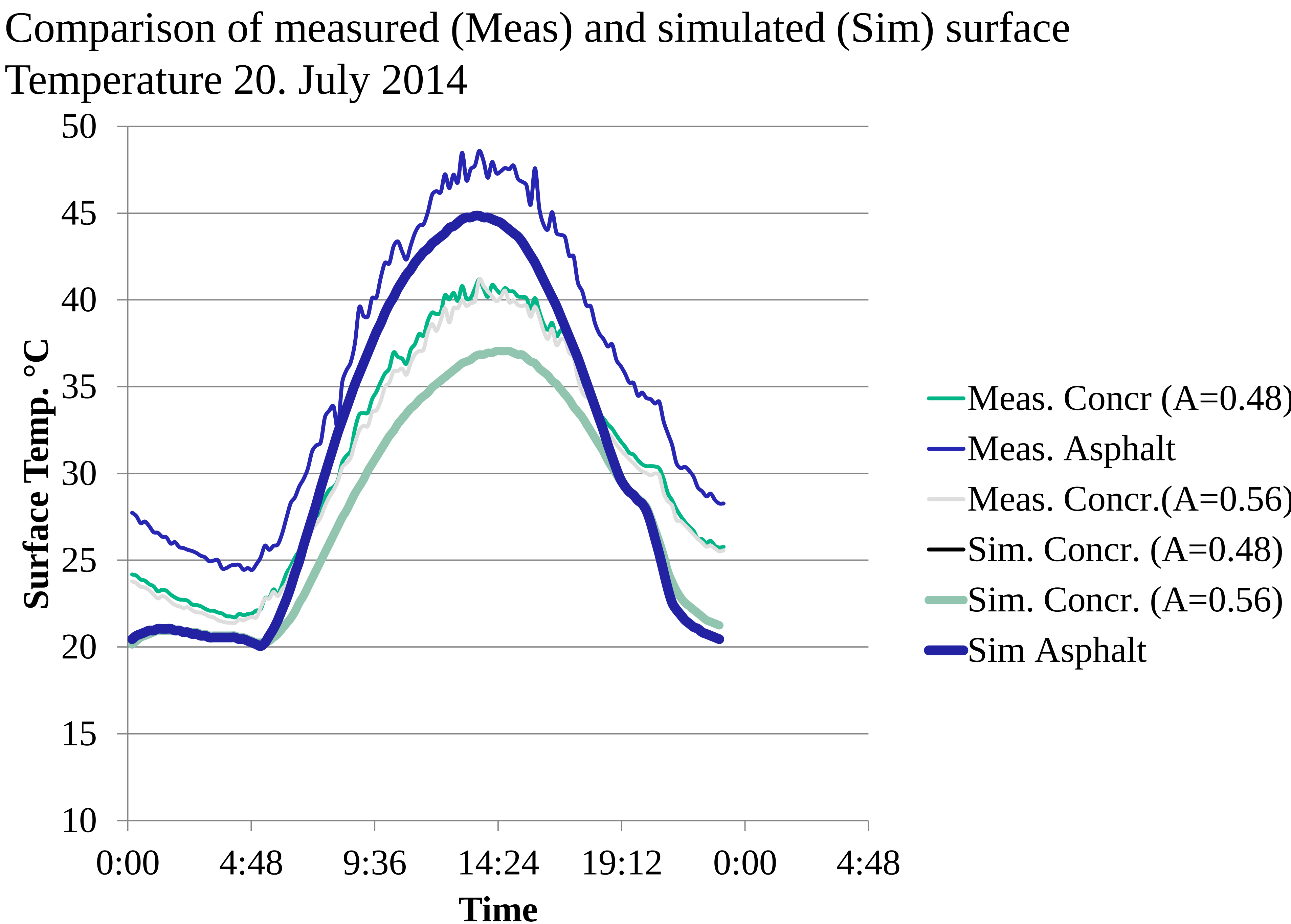
A) Simulations for the test area

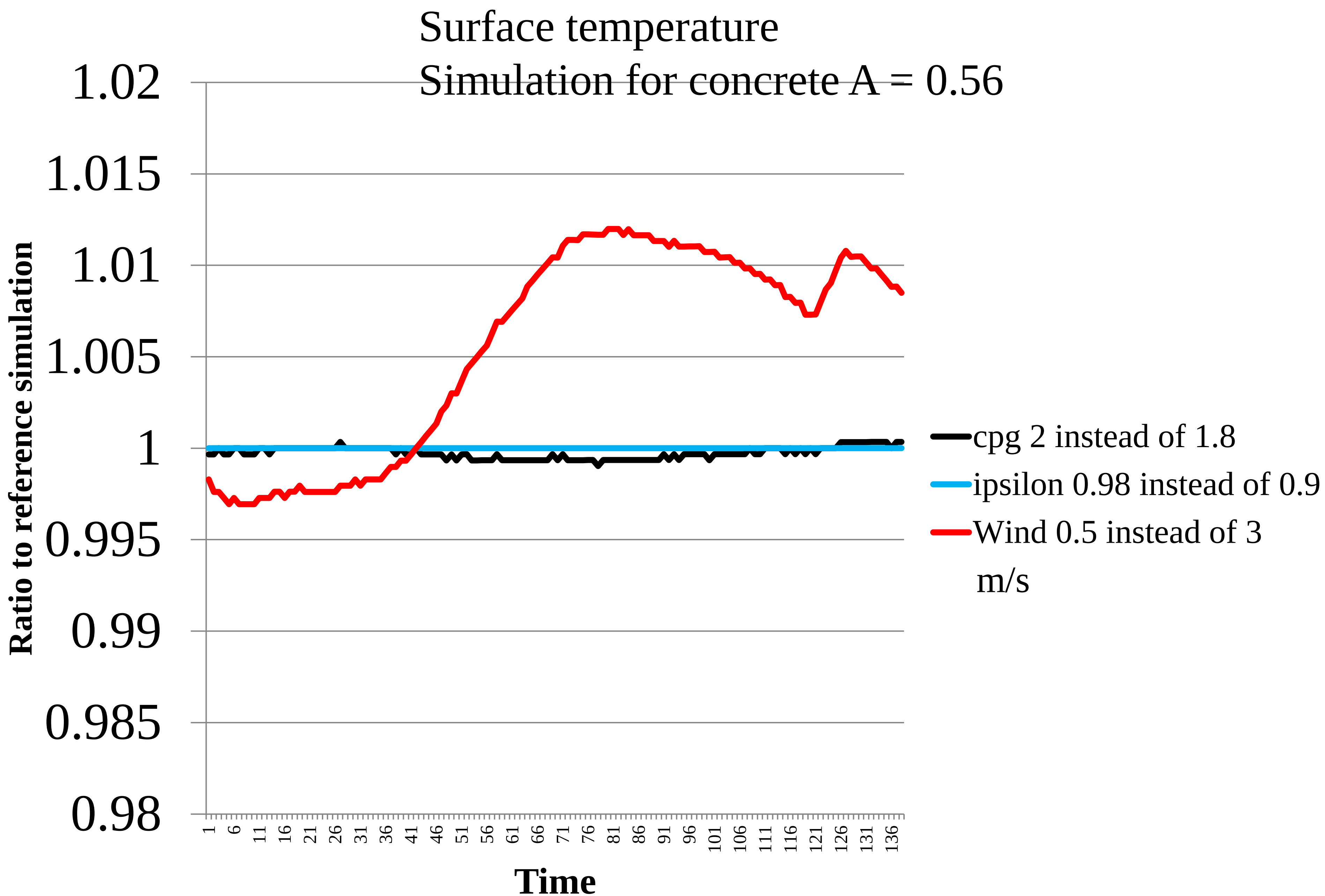
Input parameters of EnviMet

Global radiation	measured (fit obtained with EnviMet)
Longwave radiation	EnviMet Algorithm
Albedo	Measured (input of EnviMet)
Specific heat capacity of surfaces	(Input of EnviMet) assumption according to lit. is going to be measured
Emission constant of surfaces	measured (Input EnviMet)
Wind	measured in 2 m (Input of EnviMet)
air temperature and humidity	measured (forcing of model possible)


Global radiation 20 July 2014
W/m2
1000
900
800
700
600
500
400
300
200
100
0
0:00:00
1:00:04
2:20:04
3:30:04
4:50:04
6:00:04
7:10:04
8:30:04
9:40:04
11:00:04
12:10:04
13:20:04
14:40:04
15:50:04
17:10:04
18:20:04
19:30:04
20:50:04
22:00:04
Time
Measured
Envi_Met

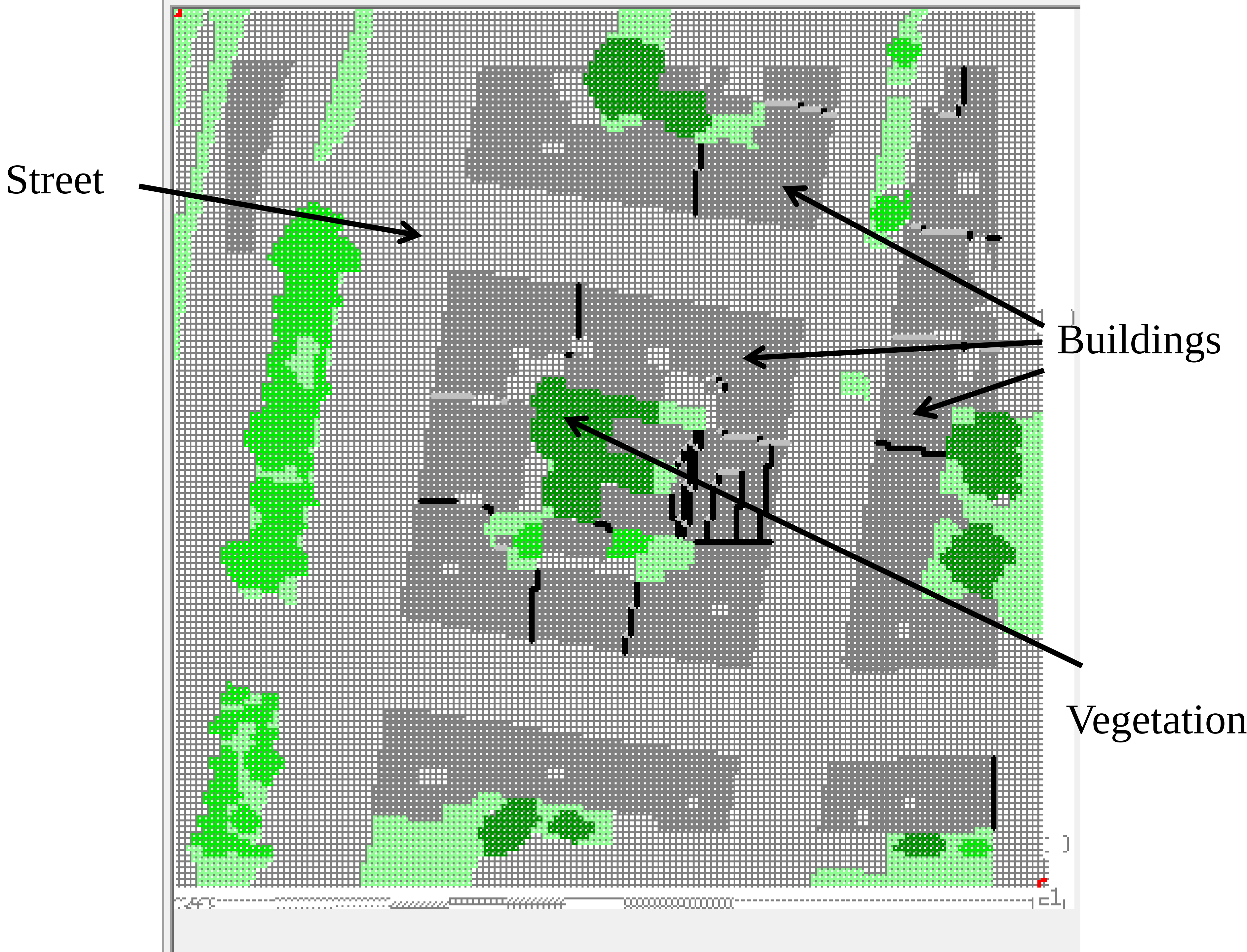

pw 12:00:04 17.07.2014
x/y Schnitt bei k=0 (z=0.00 m)
Surface temperature
Asphalt
Strong reflecting
Concrete surfaces
60.00
50.00
40.00
20.00
10.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
X (m)
T Surface
unter 301.17 K
301.17 bis 302.56 K
302.56 bis 303.96 K
303.96 bis 305.35 K
305.35 bis 306.75 K
306.75 bis 308.15 K
308.15 bis 309.54 K
309.54 bis 310.94 K
310.94 bis 312.33 K
über 312.33 K
Min: 299.77 K
Max: 313.73 K
N


Comparison of measured (Meas) and simulated (Sim) surface Temperature 20. July 2014
50
45
40
35
30
25
20
15
10
Surface Temp. °C
0:00
4:48
9:36
14:24
19:12
0:00
4:48
Time
Meas. Concr (A=0.48)
Meas. Asphalt
Meas. Concr.(A=0.56
Sim. Concr. (A=0.48)
Sim. Concr. (A=0.56)
Sim Asphalt



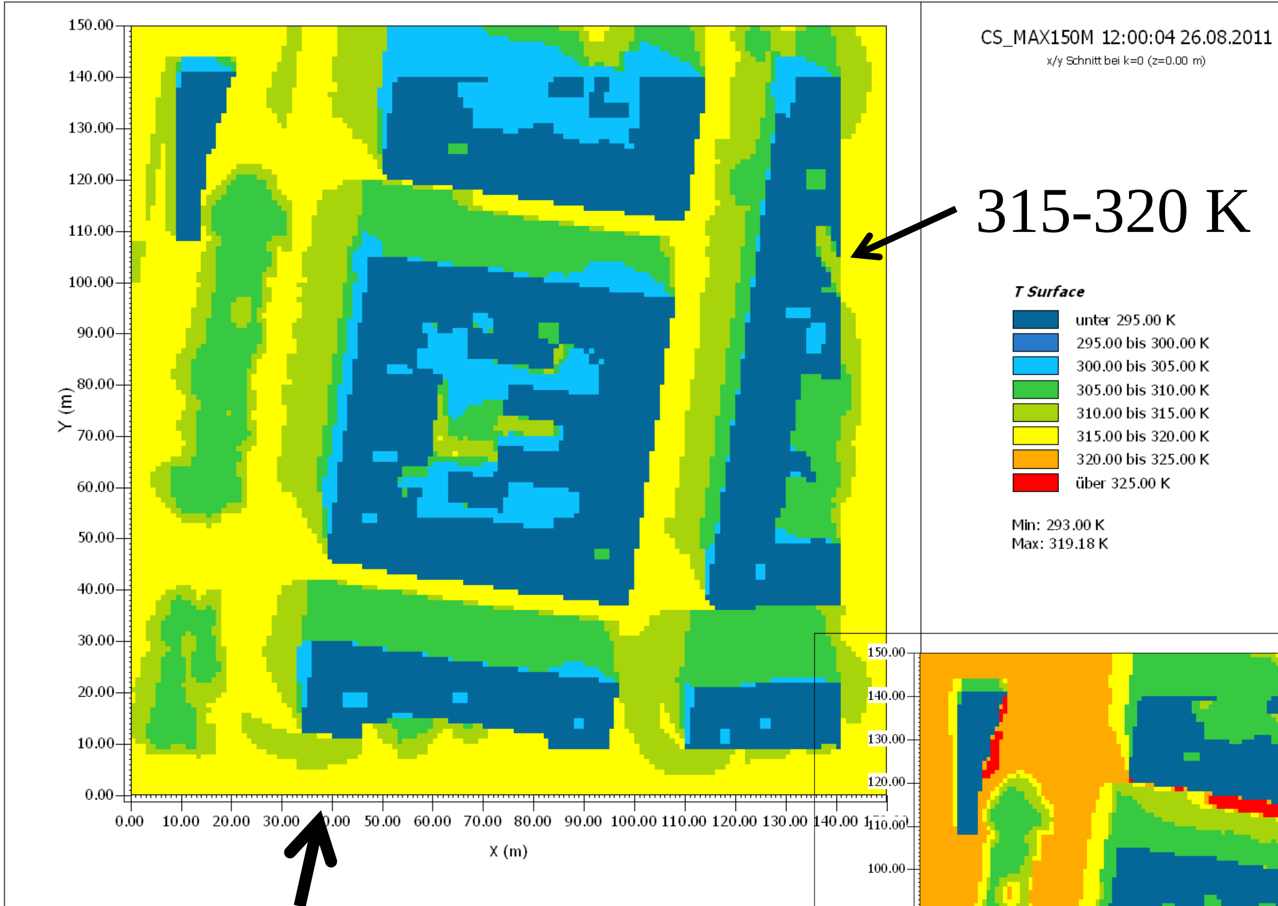
cpg = specific heat capacity in K/(J.kg); epsilon = emission constant

B) Simulations for chosen city districts:
Simulation of the effects of changing albedo


Street
Buildings
Vegetation

Surface temperature at noon

T Ground surface

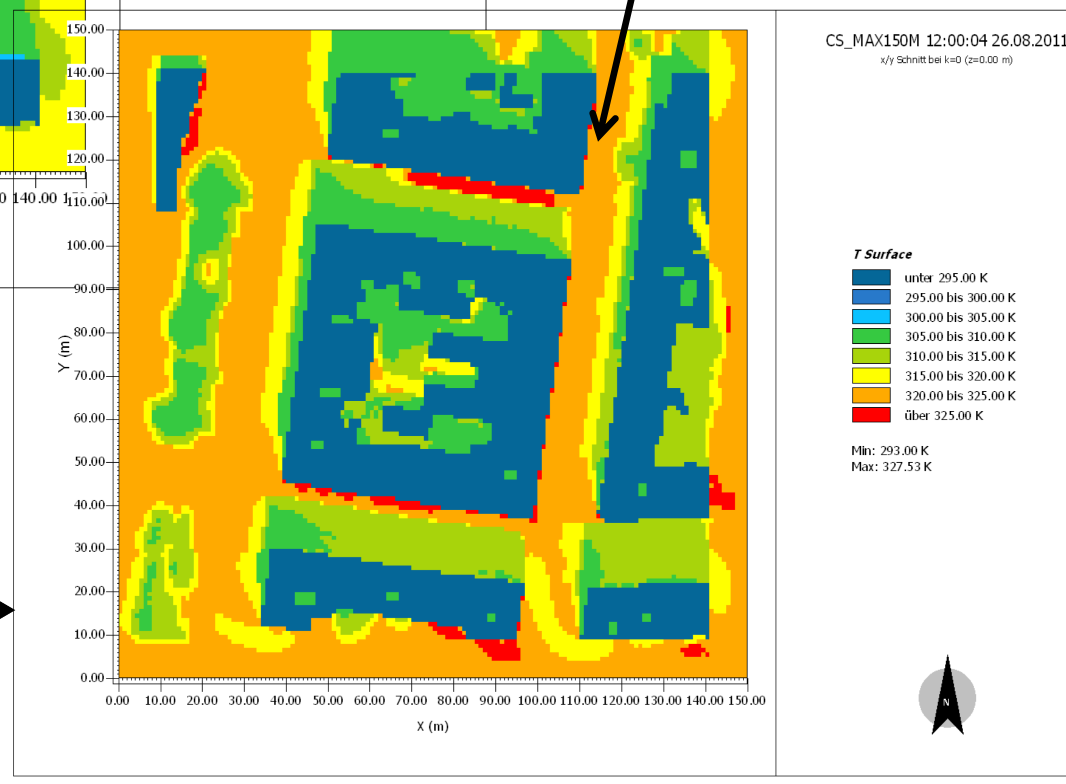


315-320 K

Concrete A=0.56

320 -325 K

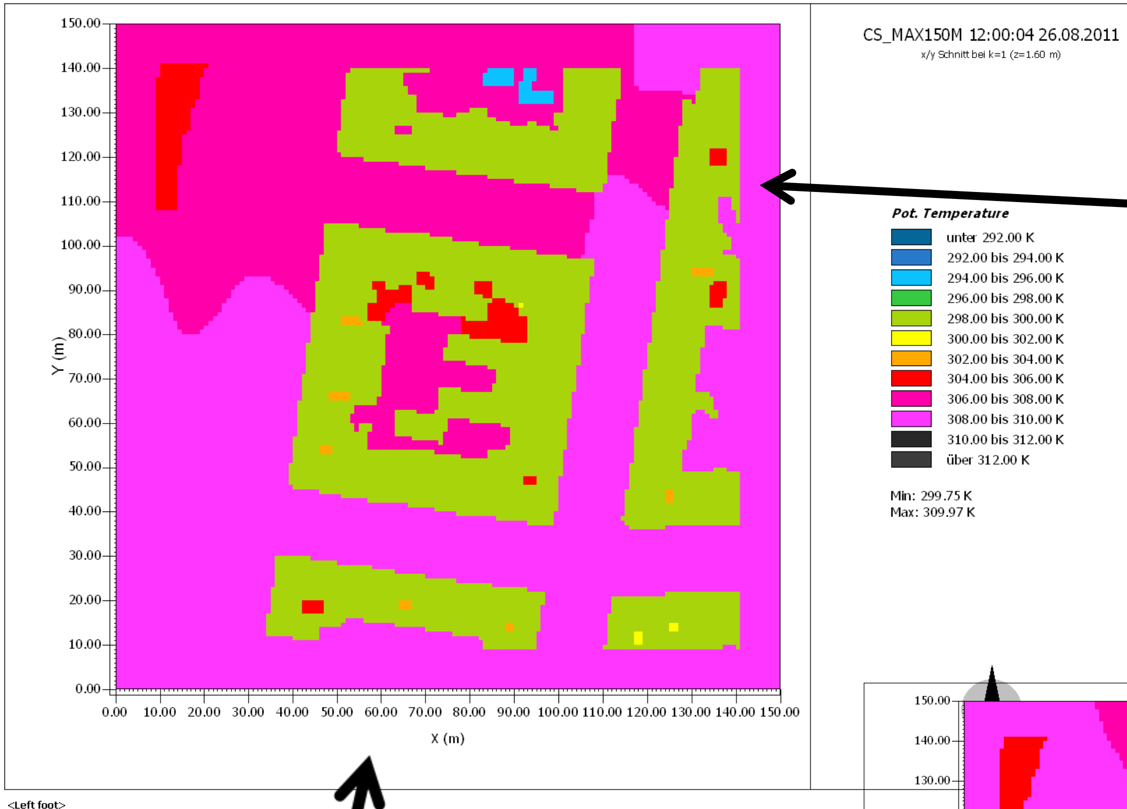
Asphalt A= 0.12



Potential temperature in 1.6 m height at noon

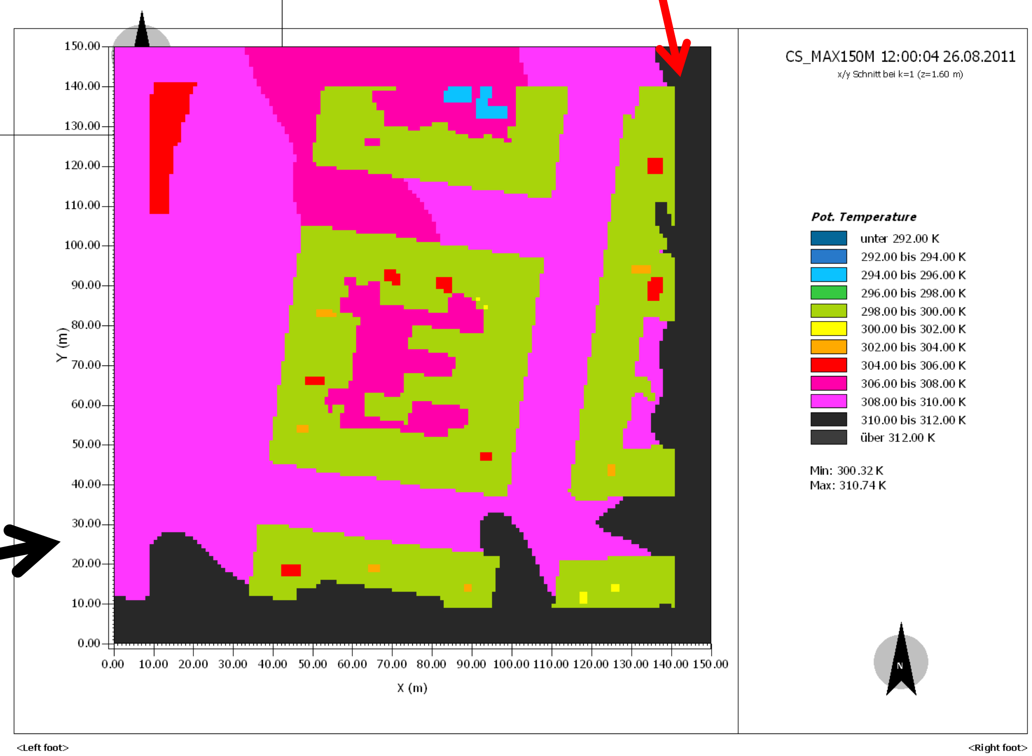
Potential Temperature

308 – 310 K



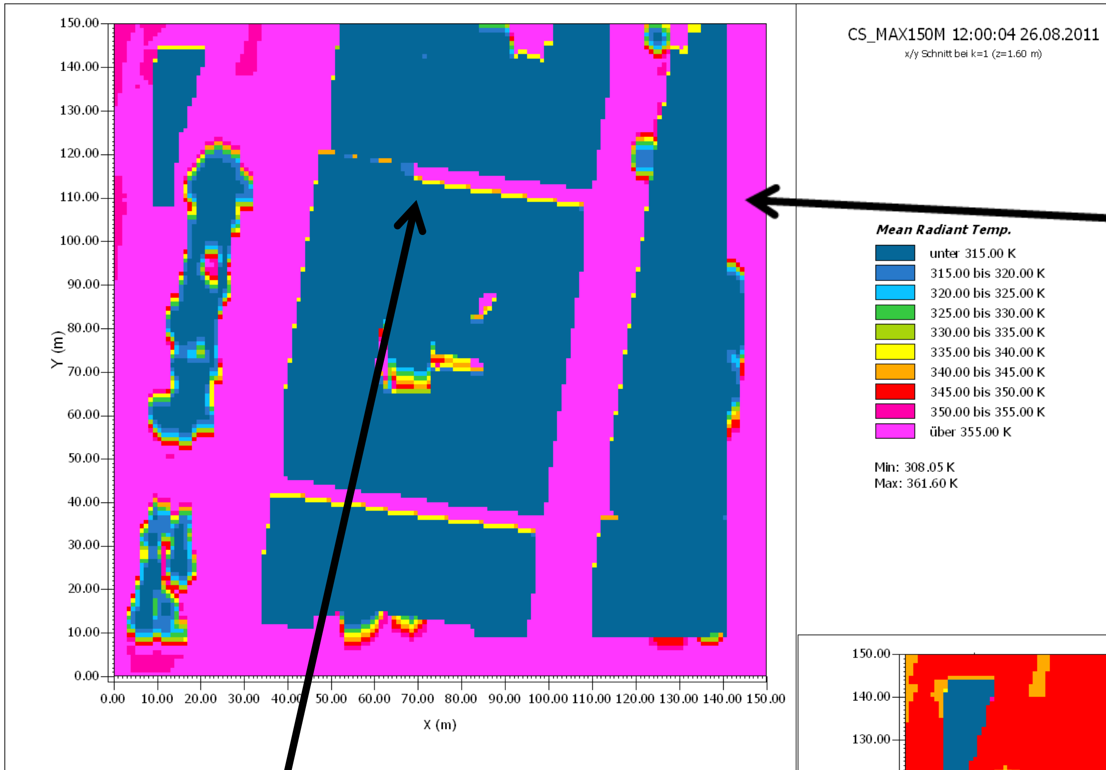
Concrete A=0.56

310 – 312 K



Asphalt A= 0.12

Mean radiant temperature in 1.6 m height at noon



<Left foot>

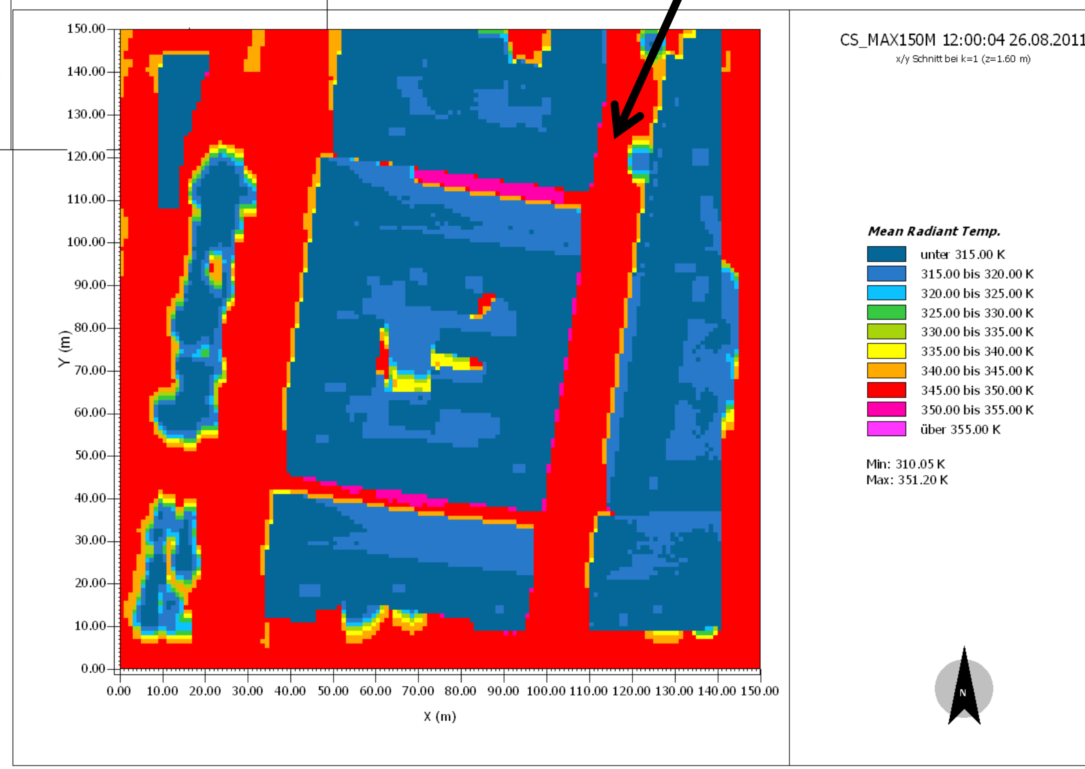
Mean radiant temperature

air temp =33°C

355 – 360 K
UTCI = 43.9°C

very strong heat stress!!

345 – 350 K
UTCI = 41.3°C



<Left foot> <Right foot>

UTCI in shade = 32°C
=> moderate heat stress

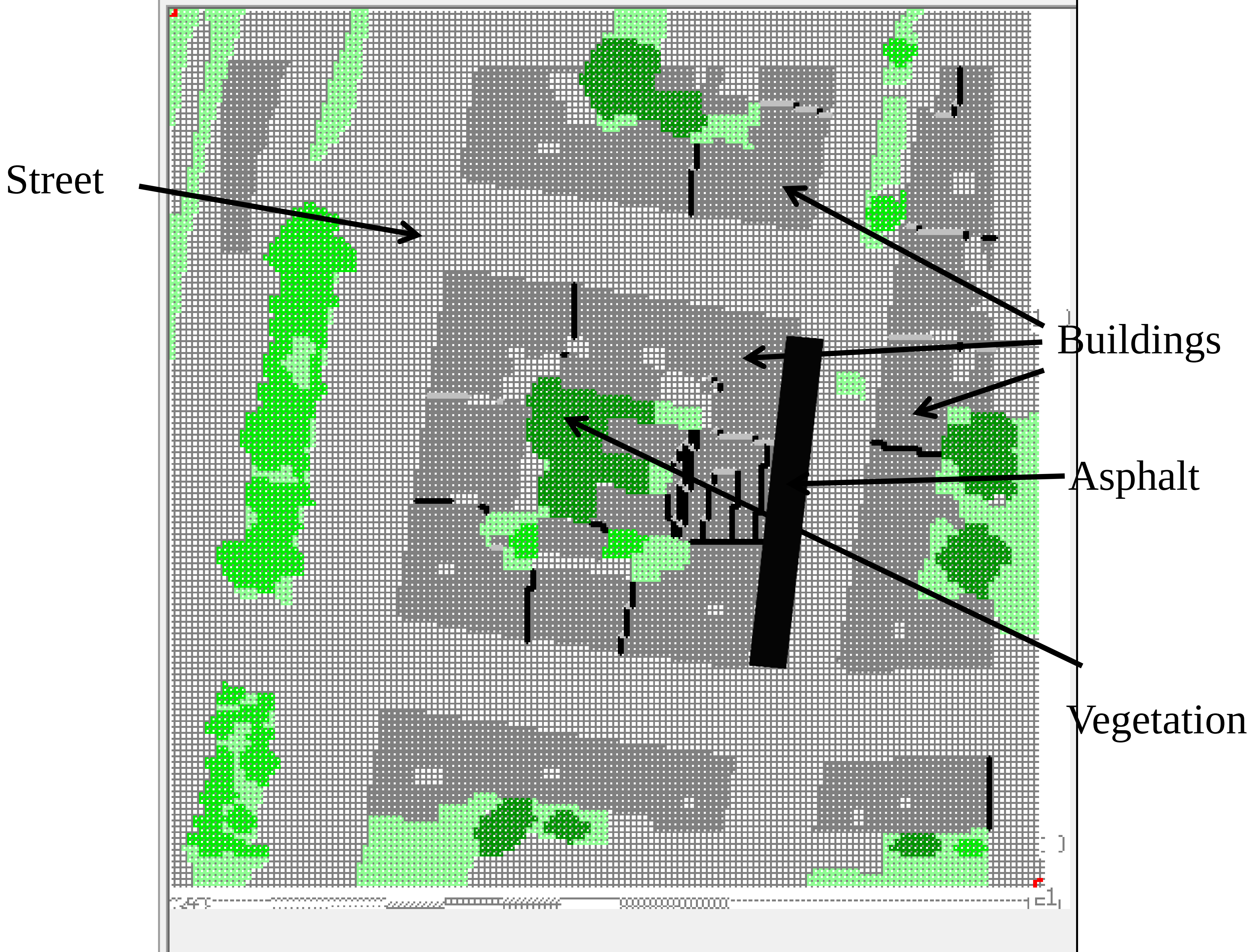
Concrete A=0.56

Asphalt A= 0.12

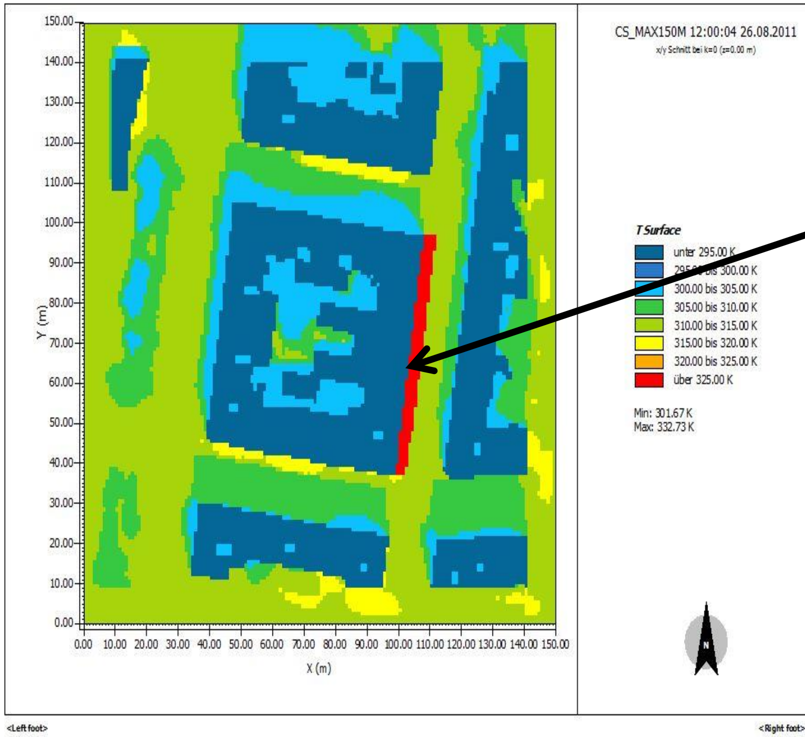
UTCI = universal thermal climate index

Simulations to find solutions for reducing thermal stress on humans

(very first results)


Street
Buildings
Asphalt
Vegetation

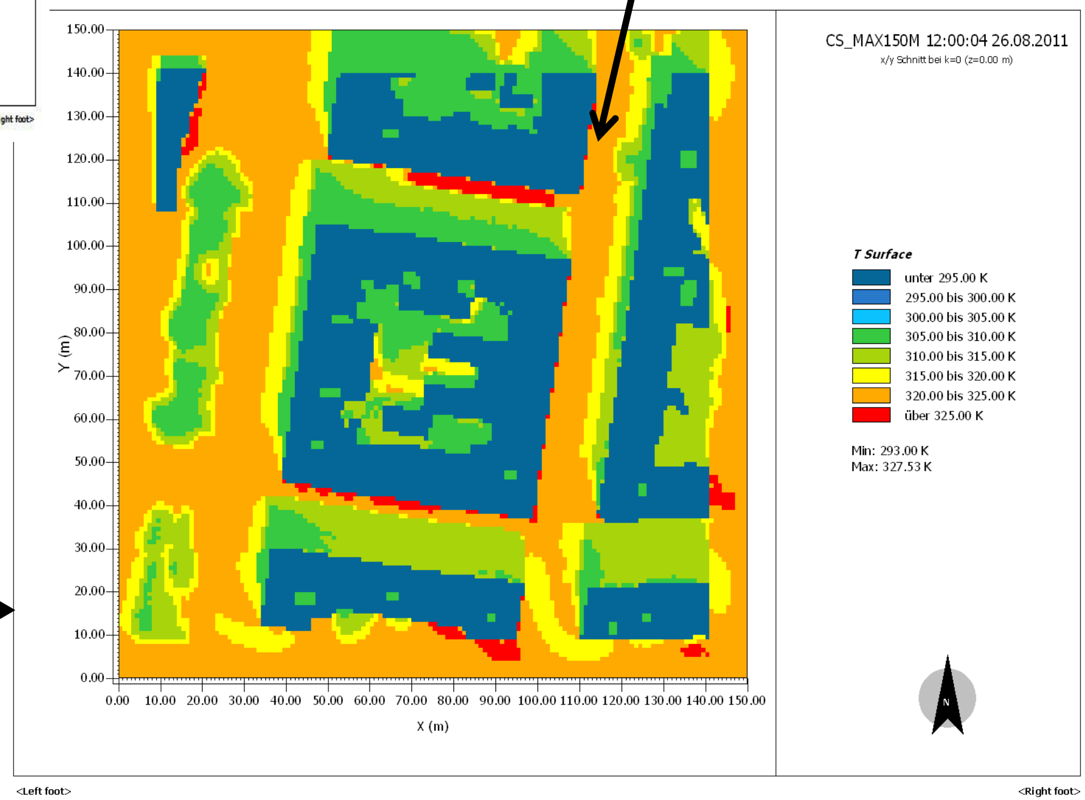
T Ground surface



>325 K

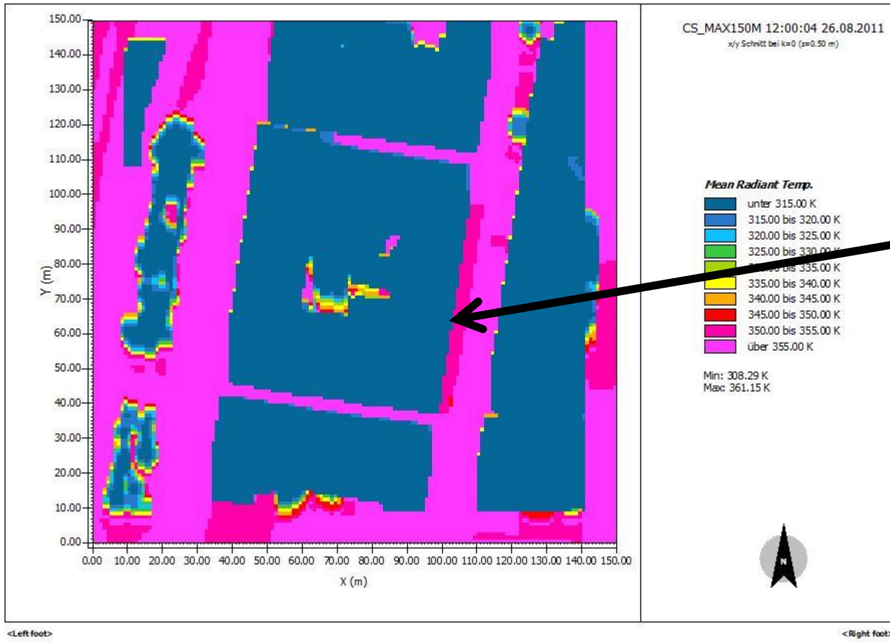
320 -325 K

Concrete + asphalt
A=0.56



Asphalt A= 0.12

Mean radiant temperature



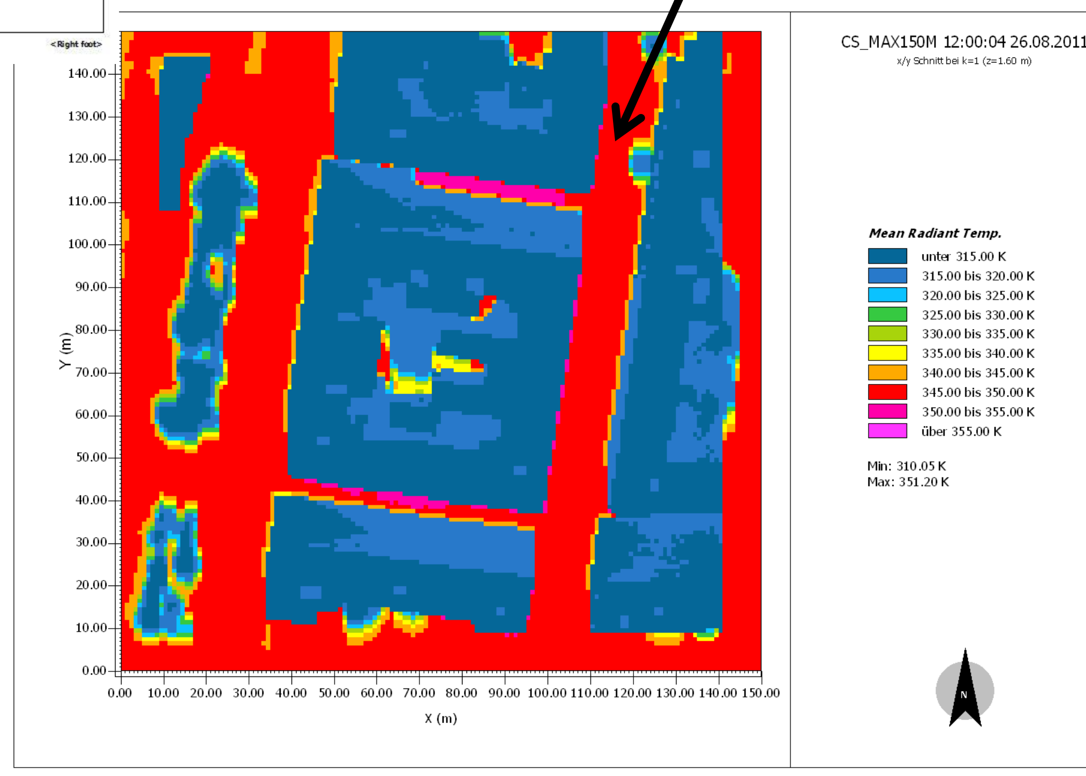
350 – 355 K UTCI = 41.9

345 – 350 K

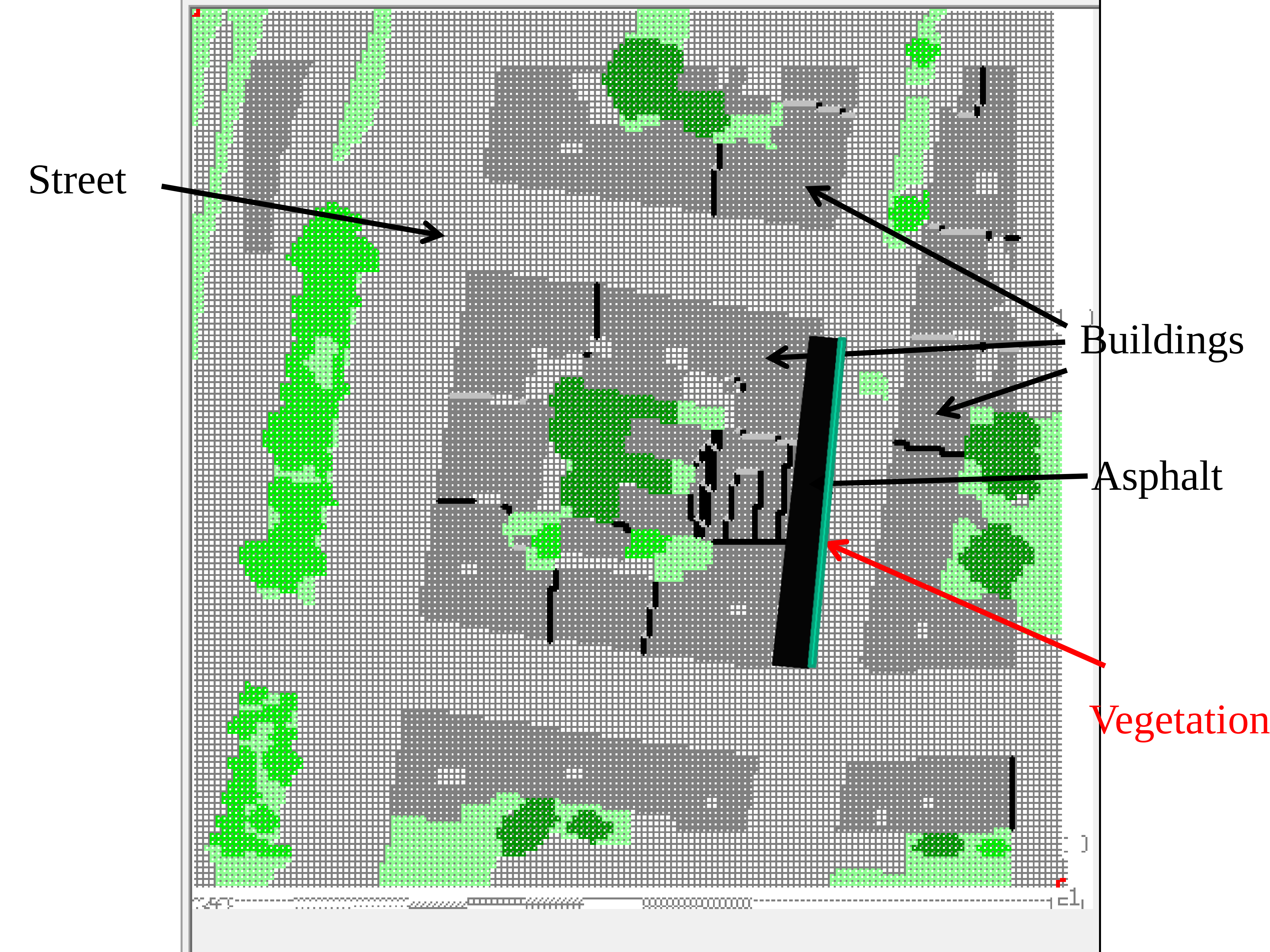
UTCI = 41.3

Concrete A=0.56 + asphalt

Asphalt A= 0.12

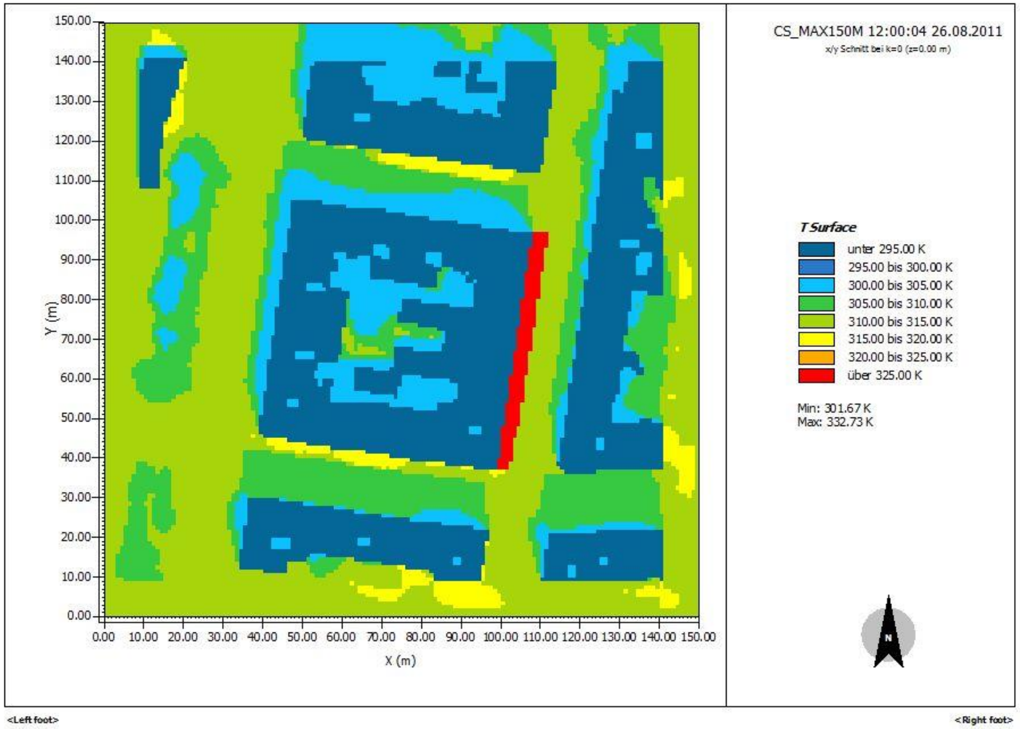


UTCI = universal thermal climate index



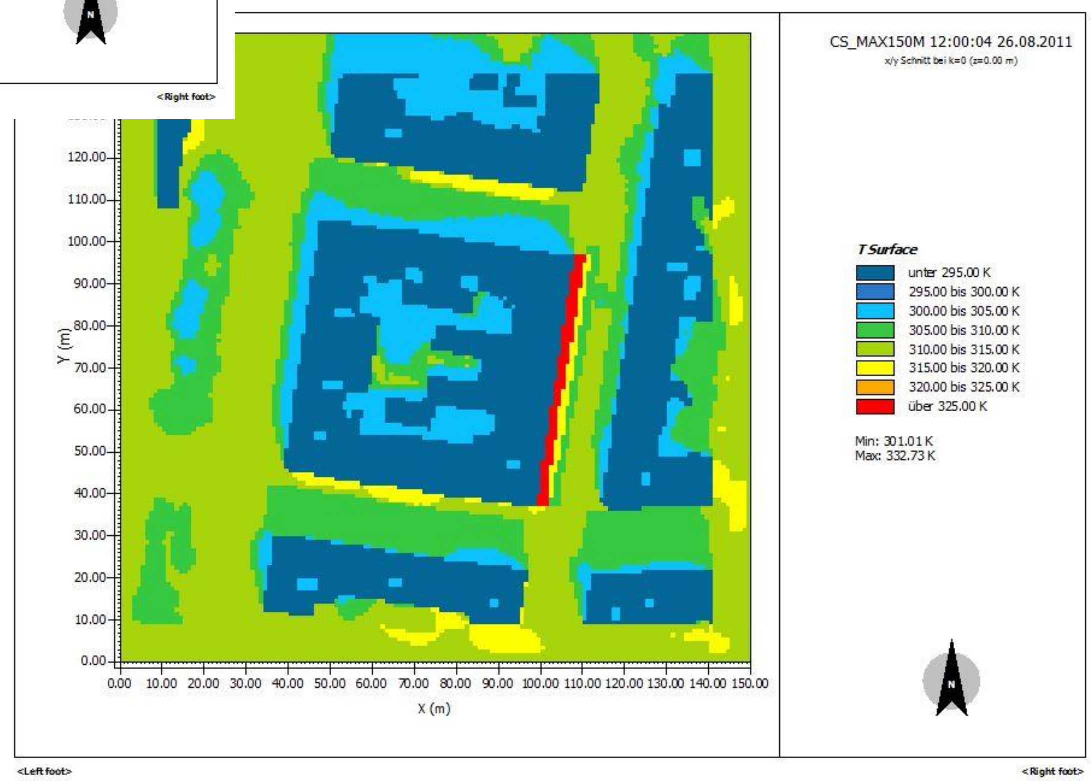
Street
Buildings
Asphalt
Vegetation

Temperature of surface

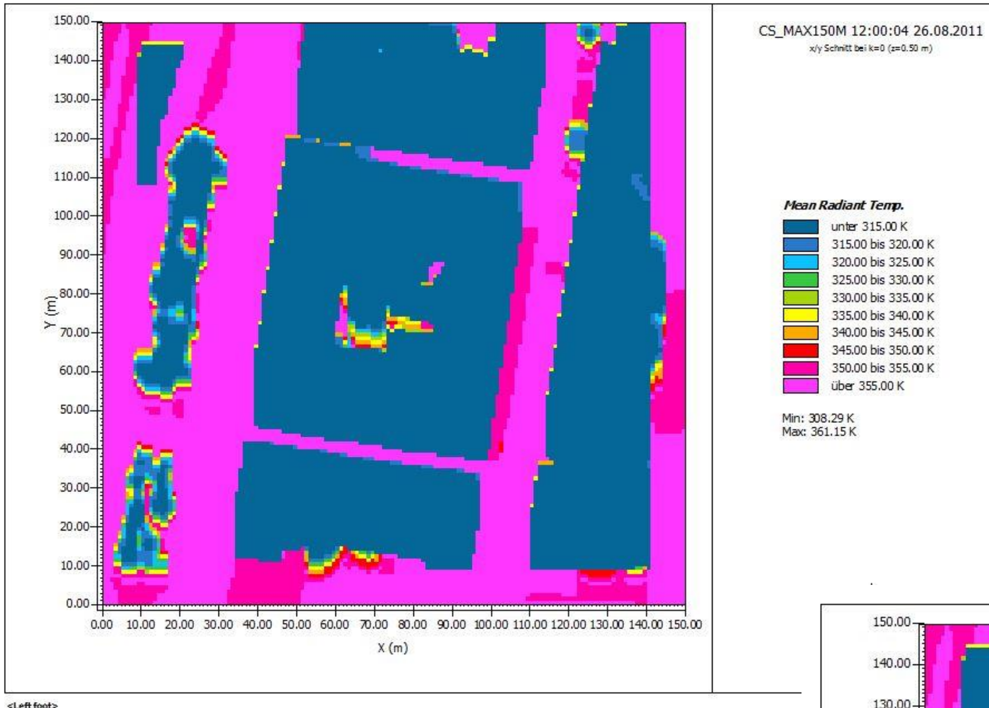


with pavement

with pavement and hedge

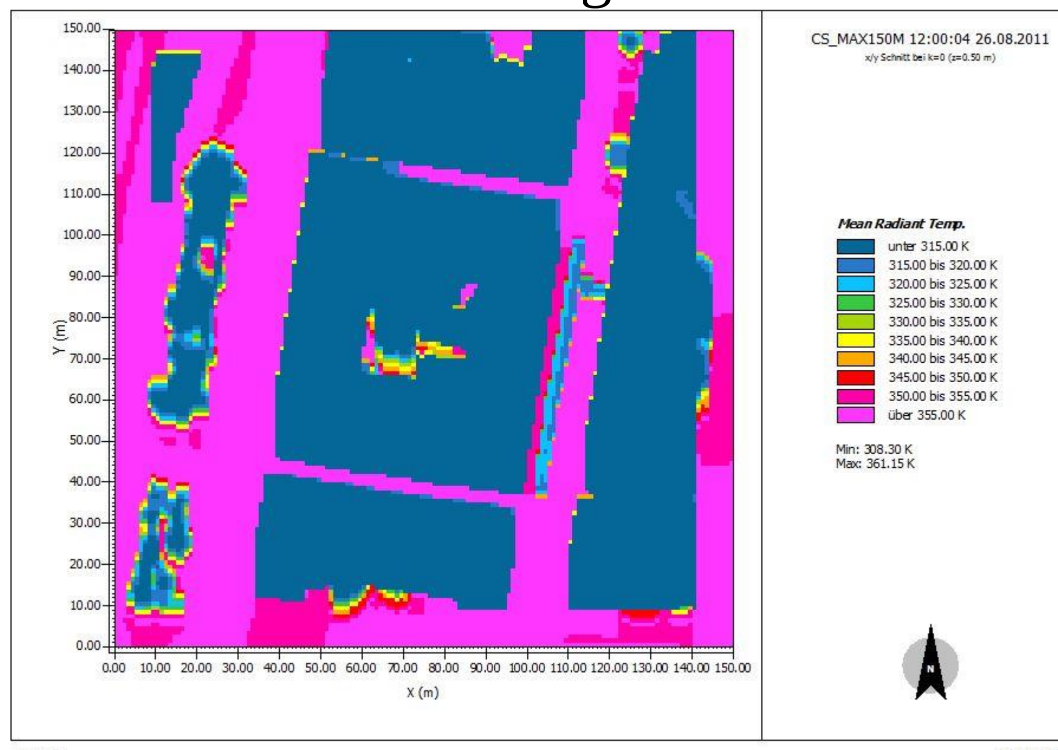


Mean radiant temperature

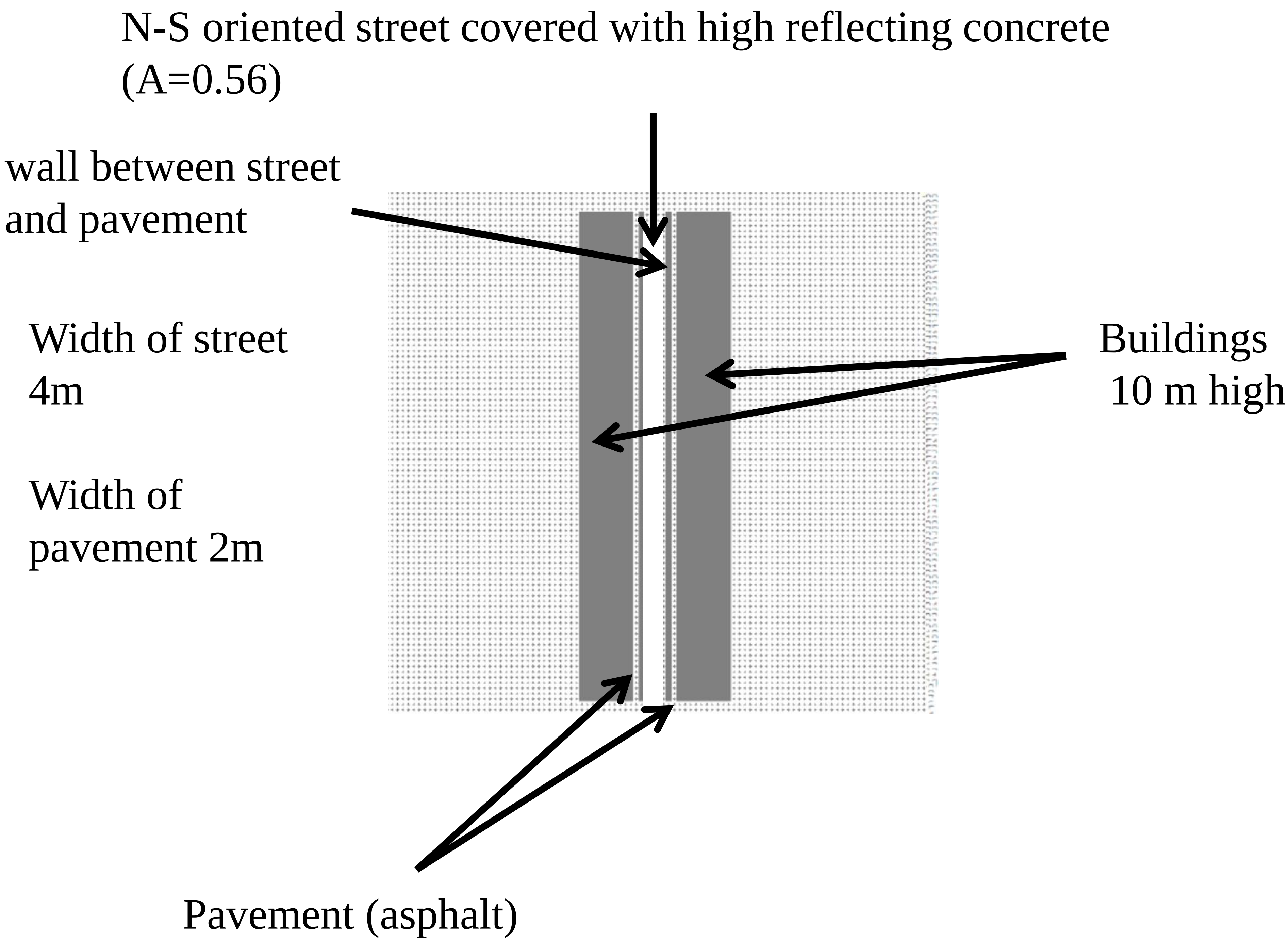


with pavement

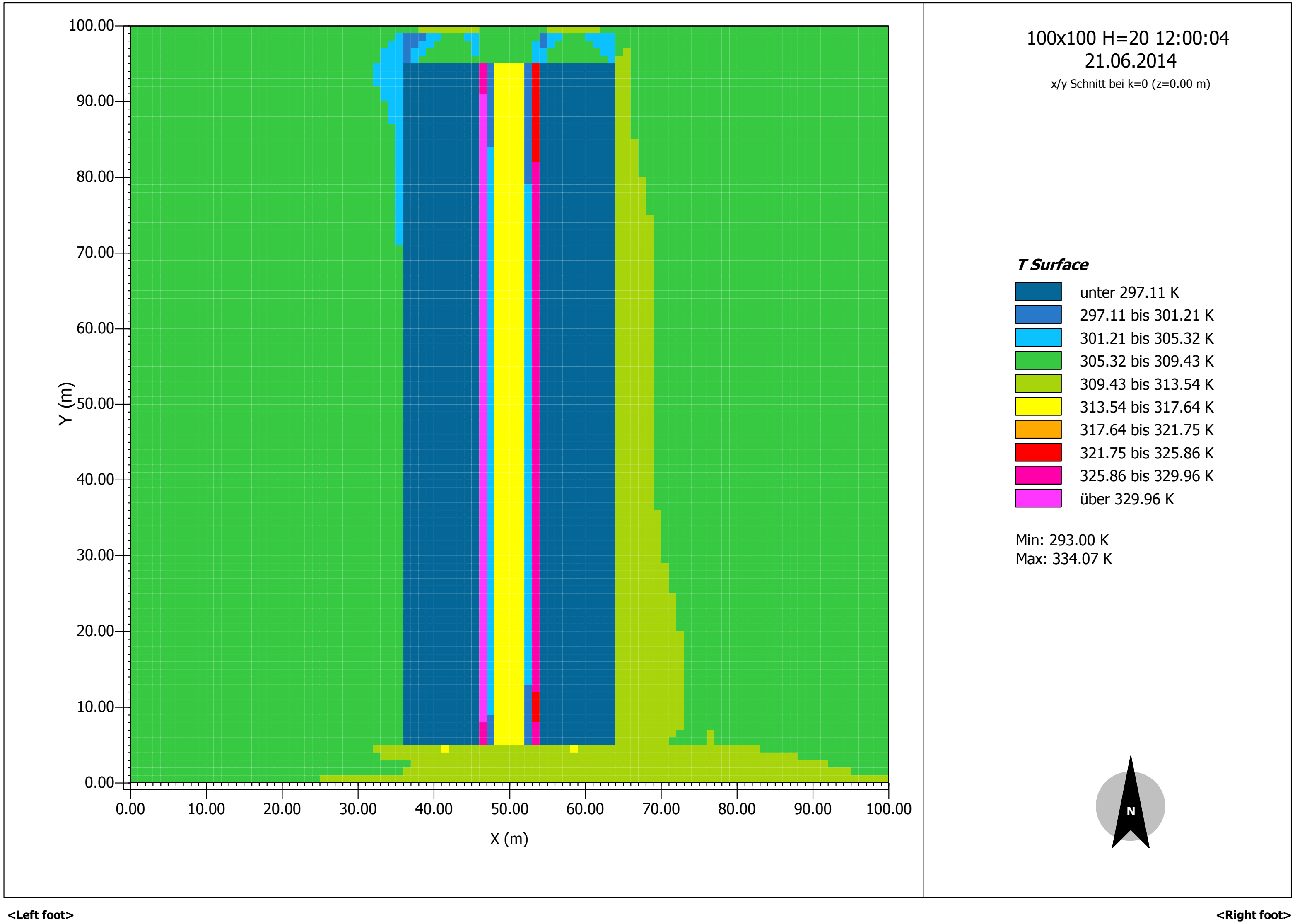
with pavement and hedge



Simulations for street canyons

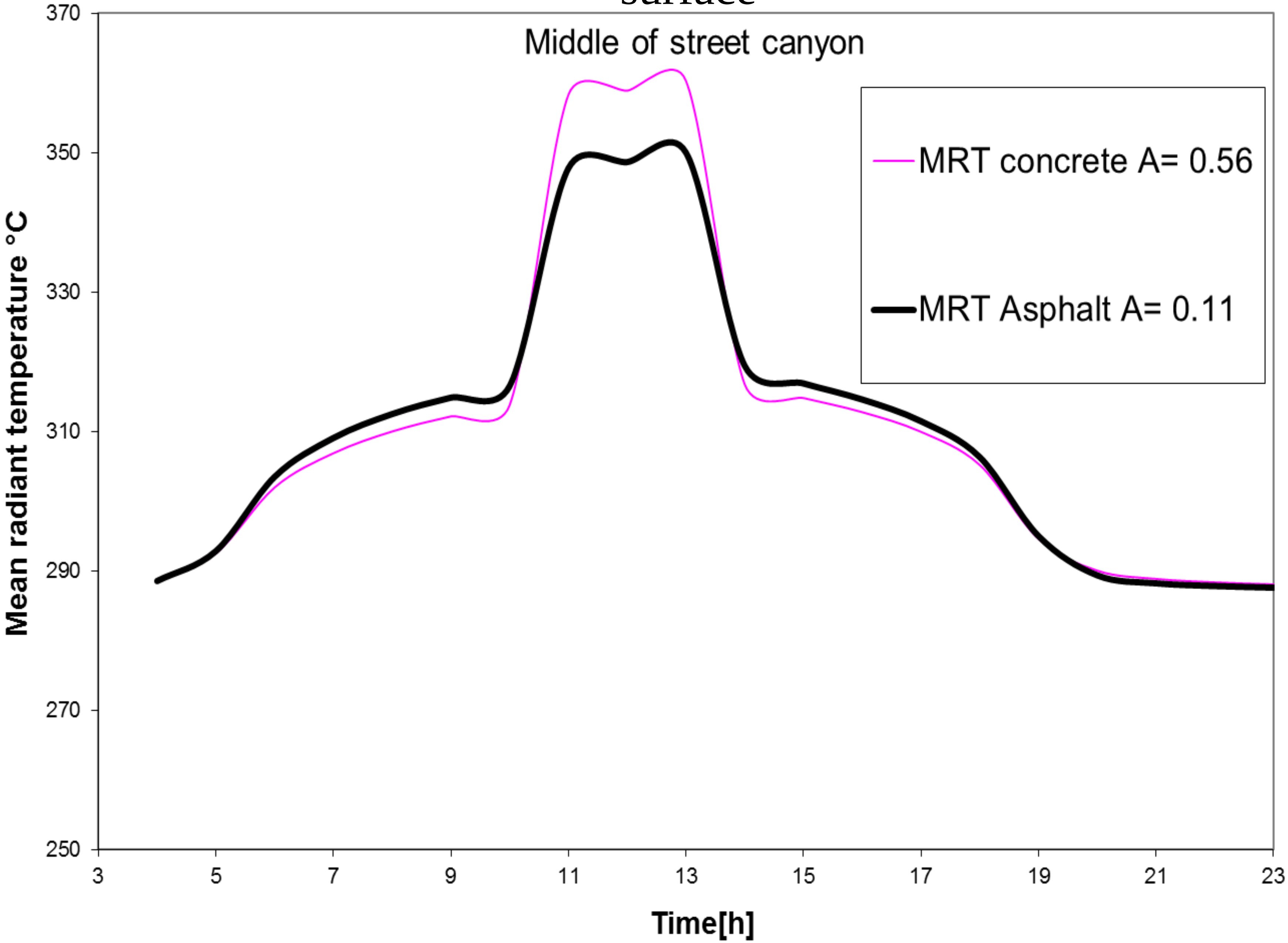

N-S oriented street covered with high reflecting concrete (A=0.56)
wall between street and pavement
Width of street 4m
Width of pavement 2m
Buildings 10 m high
Pavement (asphalt)

Simulations for street canyons

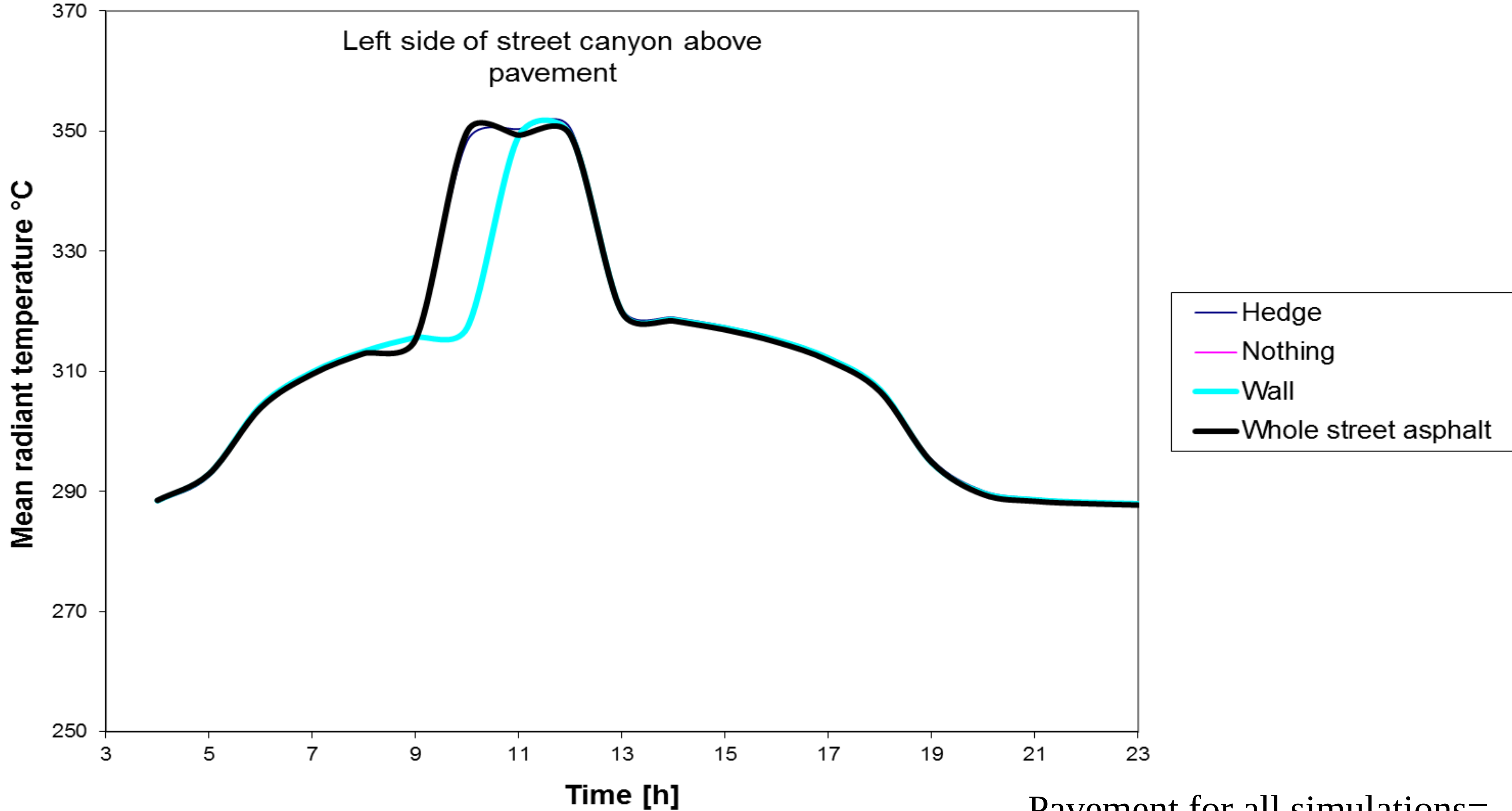


Simulation of surface temperature with hedge and high reflecting street, pavement = asphalt

Mean radiant temperature(MRT) in1m height as a function of street surface



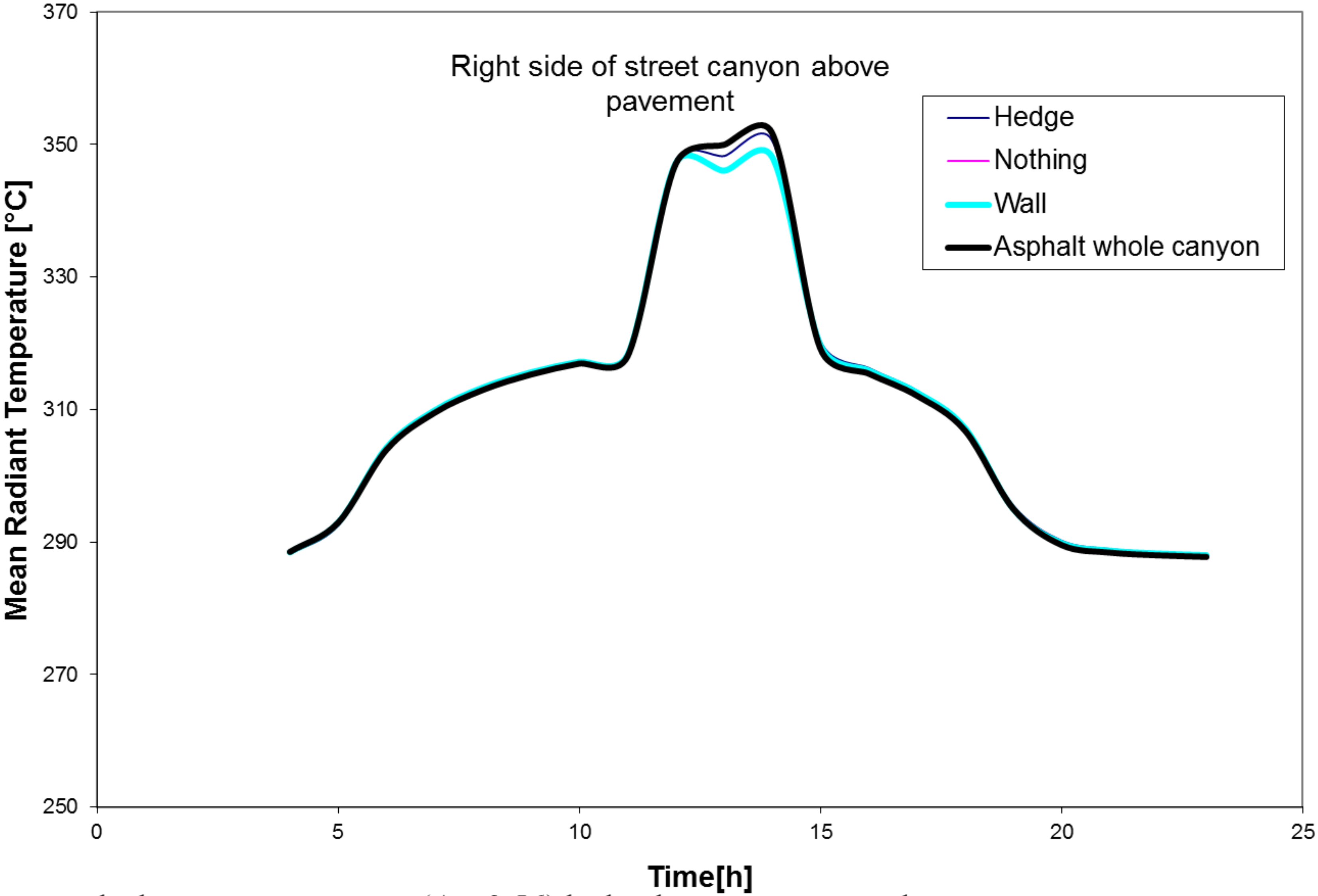
Mean radiant temperature above pavement on the left side of the street.



Pavement for all simulations= asphalt
Albedo (A) asphalt = 0.11

hedge: street = concrete(A =0.56) hedge between street and pavement,
wall: street = concrete(A =0.56) wall between street and pavement,
nothing: street = concrete(A =0.56) nothing between street and pavement
whole street asphalt : pavement + street = asphalt

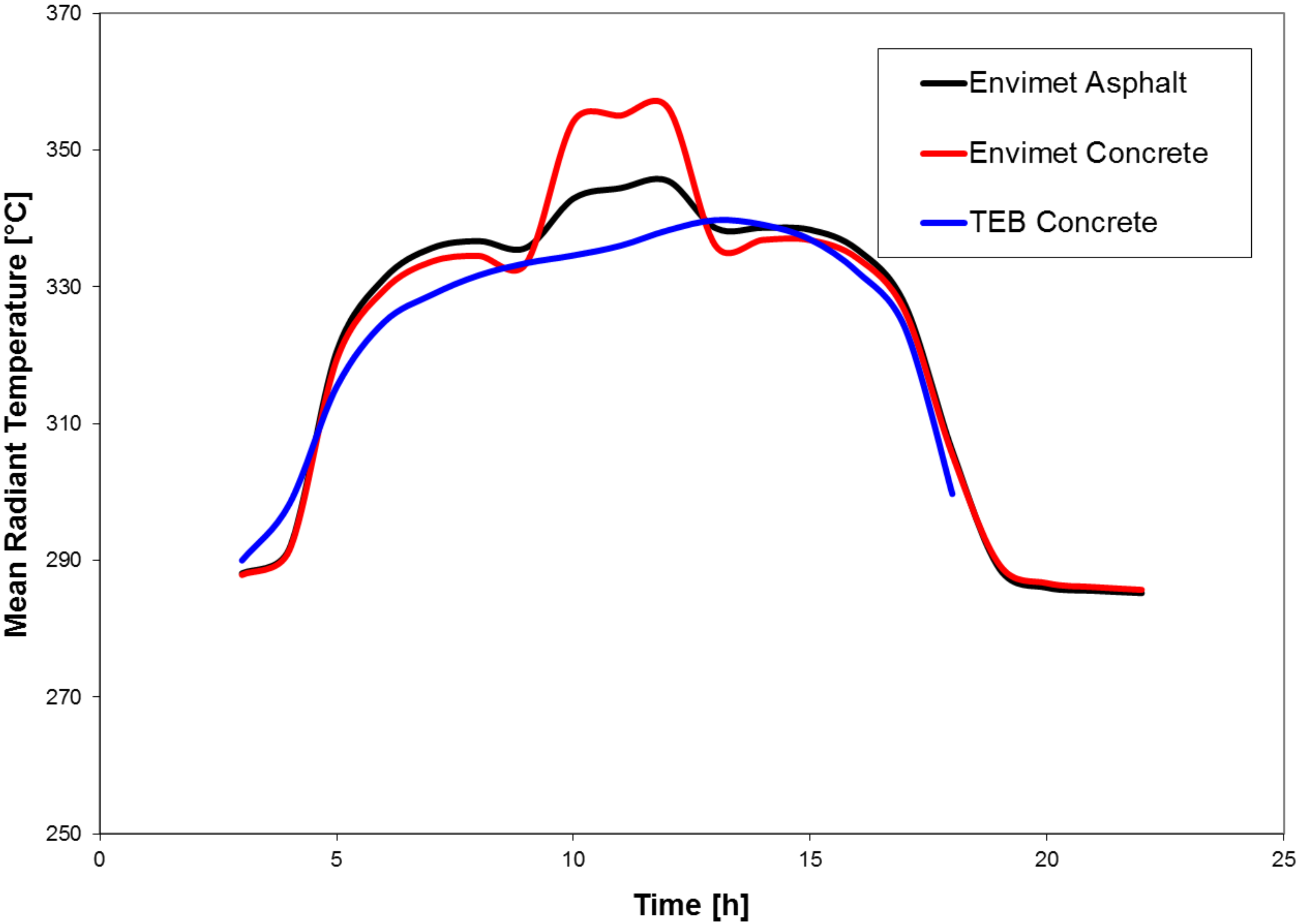
Mean radiant temperature above pavement on the right side of the street.



hedge: street = concrete(A =0.56) hedge between street and pavement,
wall: street = concrete(A =0.56) wall between street and pavement,
nothing: street = concrete(A =0.56) nothing between street and pavement
whole street asphalt : pavement + street = asphalt

Comparison Envi-Met with TEB
Preliminary results

Comparison of mean radiant temperature calculated using TEB and surface with albedo (A) = 0.56 with Envimet simulations at center of street for asphalt (A=0.11) and concrete (A=0.56) surface



Conclusions (1)

- Agreement between measurements of surface temp. and EnviMet simulations within 3°C
  Difference of surface temperature between surfaces is well reproduced (more analysis is going to be done!!)

- Higher albedo leads to a reduction of the surface temperature at noon of up to 15 °C and probably to a reduction of air temperature

- Increased reflected shortwave radiation leads to higher mean radiant temperature (by up to 5°C) and to increased thermal stress

Conclusion (2)

- First results seem to indicate that as soon as surface of pavement is asphalt pedestrians may be protected from the thermal stress due to the higher reflection from the street. More simulations for height of 1.5 -2 m need however to be made

- First comparison between Envi Met and TEB show a reasonable agreement. More analysis will be made.

Conclusion (3) Remarks

Our study confirms previous results

- The reduction of surface temperature (micro scale) caused by an increase in albedo e.g. Synnefa et al.(2011)

- The influence of albedo which leads to an increase in mean radiant temperature and heat stress (e.g.Lee et al., 2014; Hui Li, 2012)

Conclusion (4)

Further remarks

European and US cities have albedo around 0.15 to 0.2 (Taha, 1997)

Sealed surfaces cover around 29 to 44% of the area of cities. (Akbari and Rose, 2008)

On the assumption that 20% of the urban areas are street (not including the pedestrian footpath) and
assuming and average albedo of streets of 0.3,
introducing high reflectance street surface with albedo of 0.5 => average albedo of city would increase from 0.2 to 0.25

Thank you for your attention!!