Urban heat islands in the future Hanoi City:
Impacts on indoor thermal comfort and cooling load in residential buildings

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Outline

1. Introduction

2. Results of urban climate simulation

- Impacts of land use change on the future climate of Hanoi City

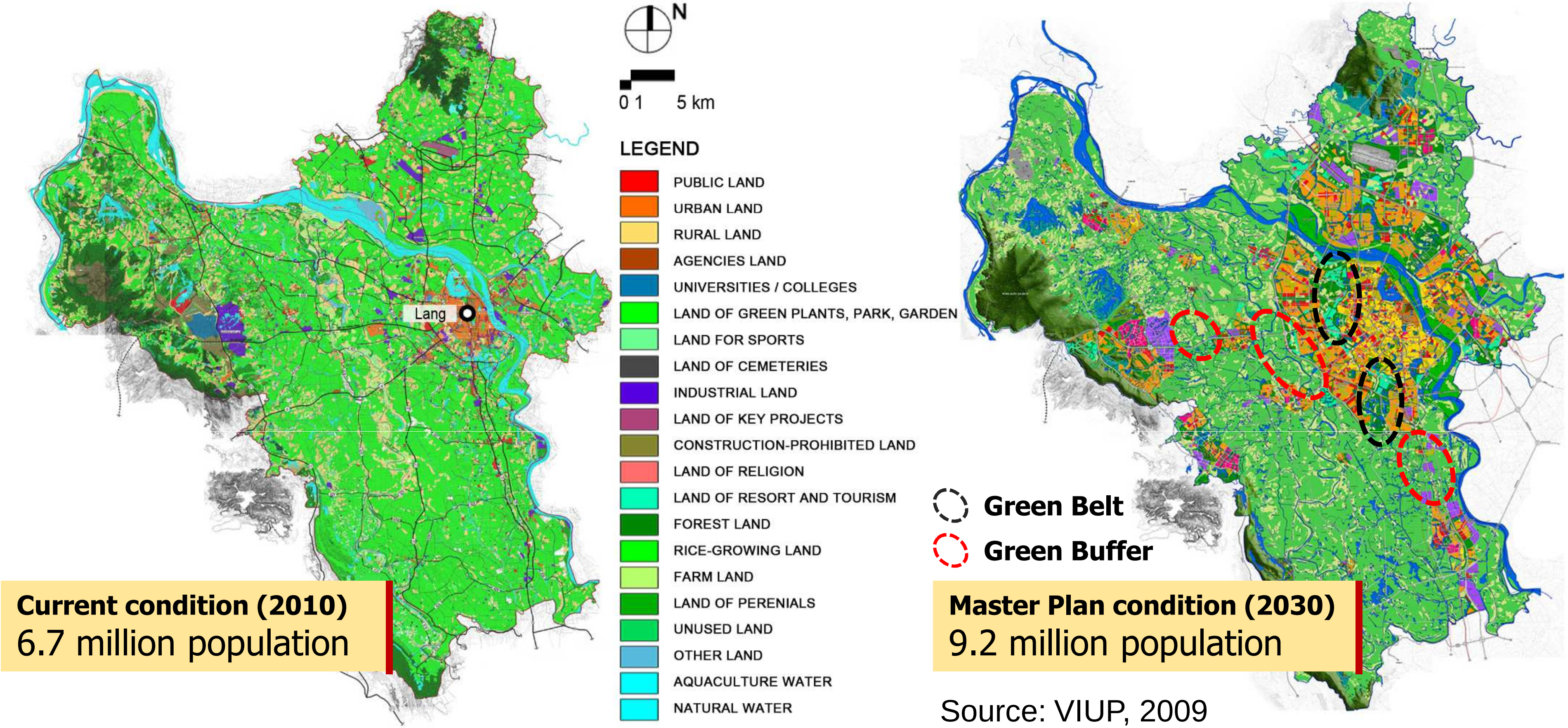
3. Results of building simulation

- Thermal comfort evaluation for typical urban row house
- Cooling load evaluation in typical urban row house

4. Conclusions

Introduction: The Hanoi Master Plan 2030

proposed by Vietnam Institute of Urban and rural Planning



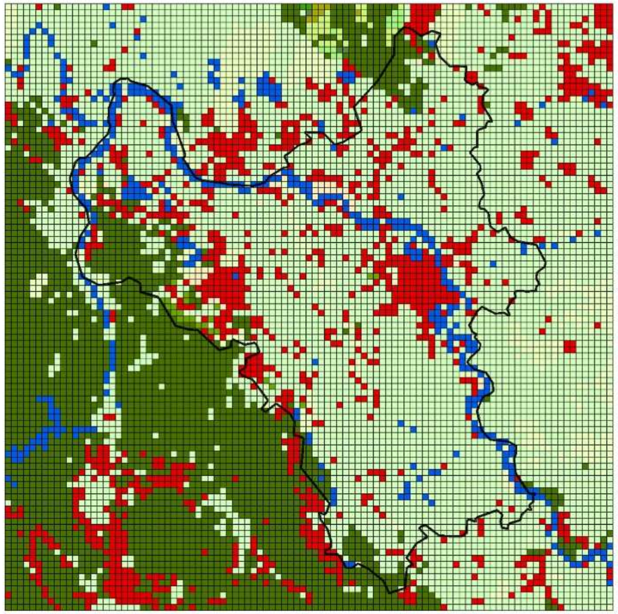
Source: VIUP, 2009

- This massive urban development is predicted to alter the urban climate and accelerate the urban heat islands (UHIs) in the future.
- The effects of the proposed green network for mitigating urban heat island (UHI) have not been evaluated.

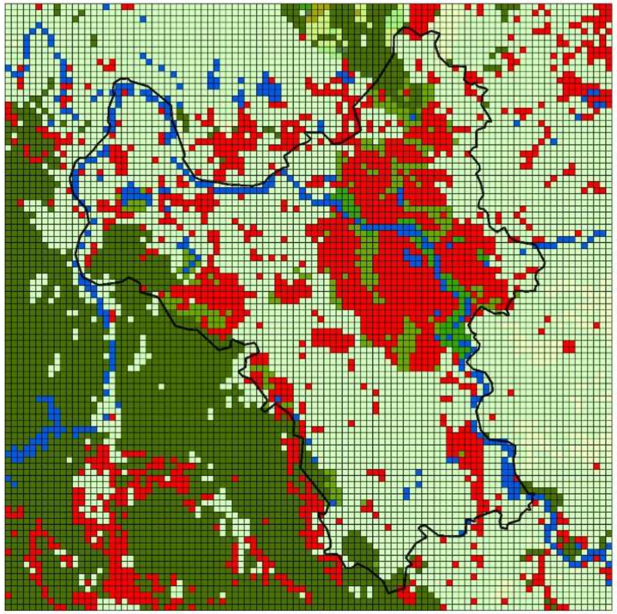
Introduction: Residential buildings in Hanoi

- About **69%** of the building in Vietnam is dominated by the row houses (Parkes, 2013).
- The achievement of **thermal comfort by natural ventilation** is predicted to be more difficult in those buildings due to the occurrence of UHI.
- UHI in the future will force occupants to use the air conditioning (AC) so the **energy consumption for cooling** will also increase.

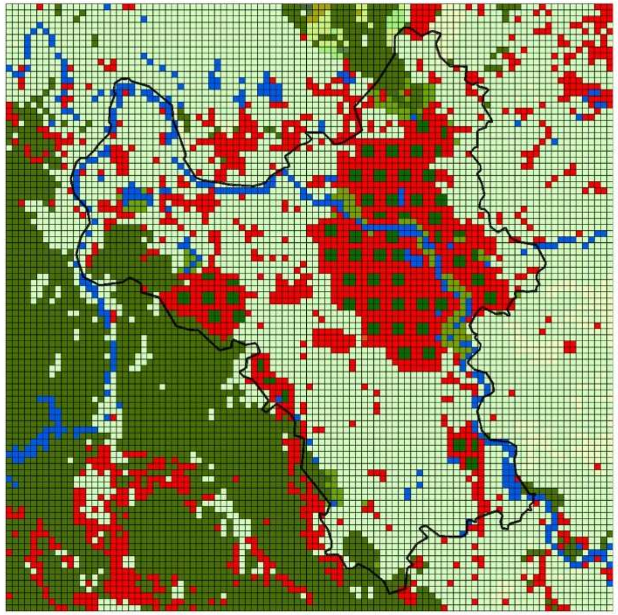
Simulation scenarios



Case 1
(current condition)



Case 2
(master plan condition)



Case 3
(UHI mitigation scenario)

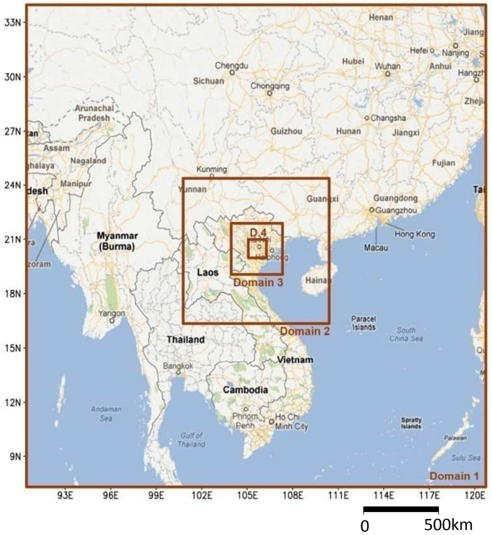
Aims of the study:

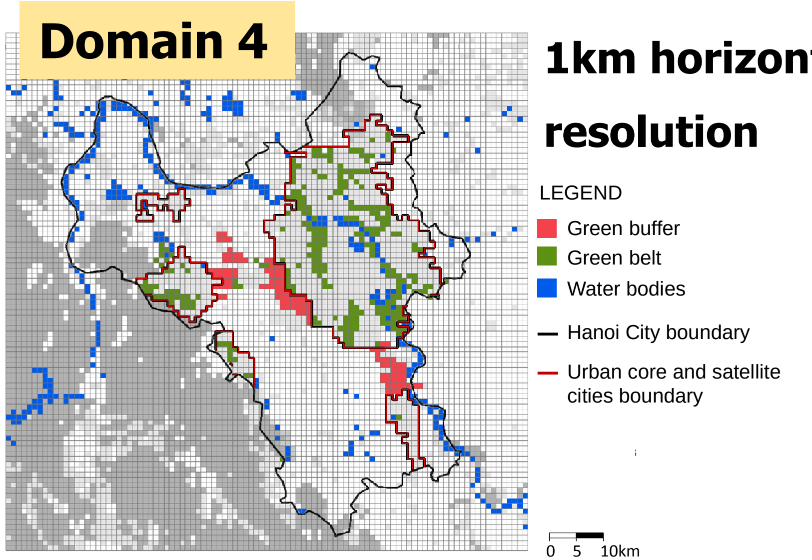
1. To investigate the UHI under the present land use condition, the master plan, as well as under the UHI mitigation scenario.
2. To evaluate the thermal comfort and cooling load of the urban row house in Hanoi under each case.

Urban climate simulation

Meteorological modelling is performed using the Weather Research and Forecasting (WRF) version 3.5. (Skamarock et al., 2008)

Domain configuration





1km horizontal resolution

WRF model set-up and parameterization

Items	Conditions
Simulation period	00:00 UTC 1 to 00:00 UTC 30 June in 2010
Vertical grid	30 layers
Horizontal grid	100x100 grids
Meteorological data	NCEP FNL
Microphysics	WSM 3-class
Long-wave radiation	RRTM long-wave scheme
Short-wave radiation	Dudhia short-wave scheme
PBL scheme	YSU Scheme
Cumulus scheme	Kain-Fritsch scheme
Surface scheme	NOAH-LSM
Surface layer	Monin-Obukhov scheme

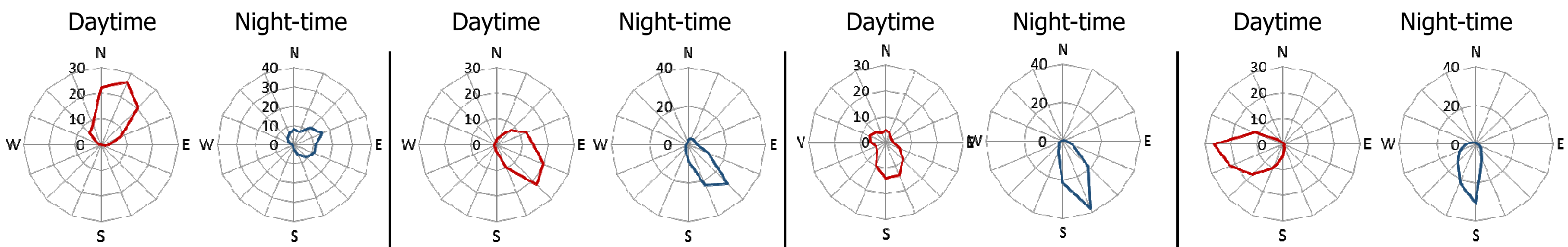
Climatic classification

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

The month of June 2010 was classified into the following four periods based on the climatic conditions.

- **Cool period**: Relatively **cool** temperature with northeast winds.
- **Warm period**: **Warm** temperature with southeast winds.
- **Hot period: Hot** temperature with southeast winds
- **Hottest period:** The **hottest** temperature with westerly Foehn winds.

Wind direction and air temperature of each period



(a) Period 1
Ave. : 29.3°C
Max: 33.2°C
Min: 25.3°C

(b) Period 2
Ave. : 29.9°C
Max: 34.6°C
Min: 26.6°C

(c) Period 3
Ave. : 33.8°C
Max: 39.6°C
Min: 28.7°C

(d) Period 4
Ave. : 35.2°C
Max: 40°C
Min: 29.9°C

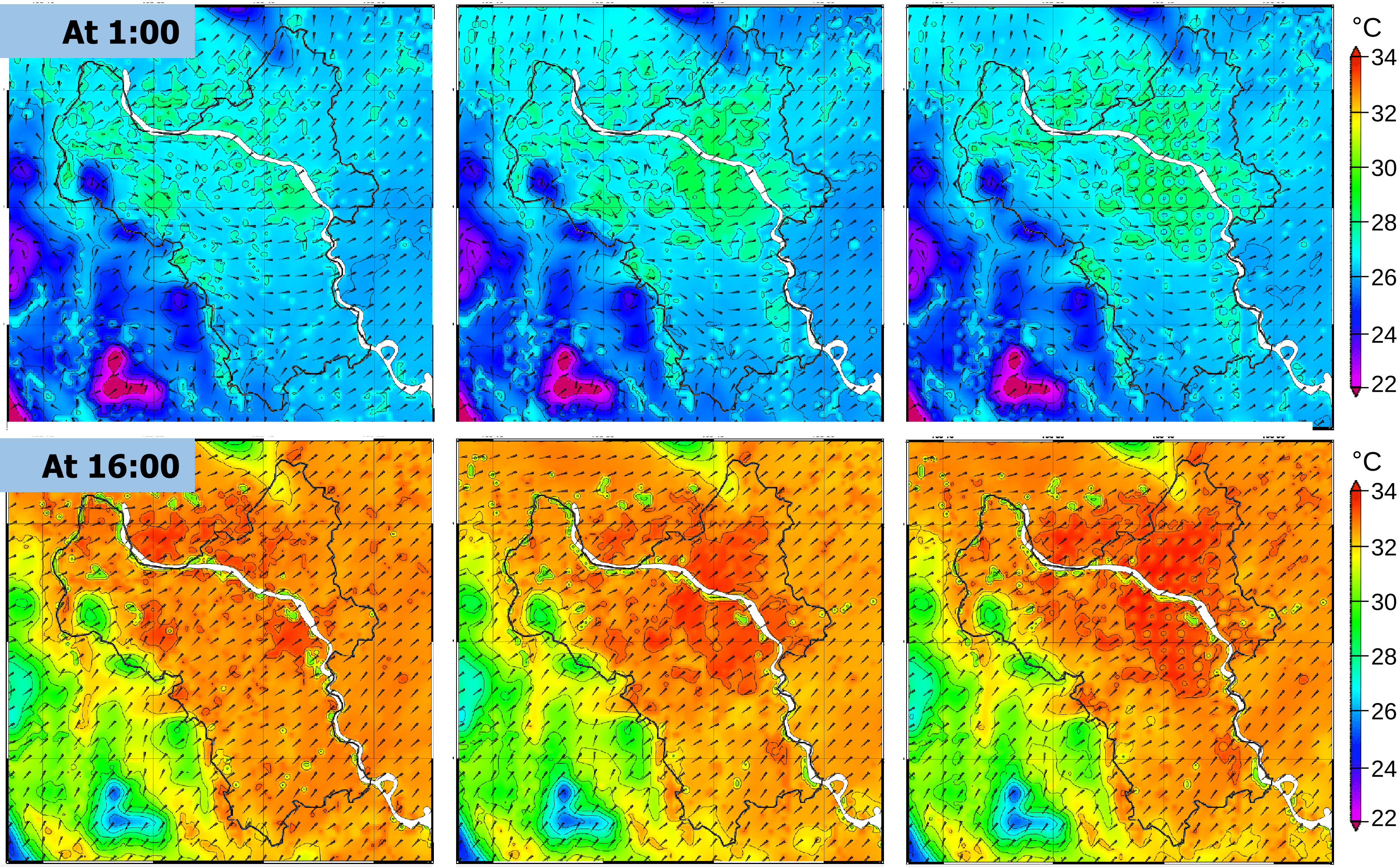
Results: Urban climate simulation

Spatial distribution of air temperature (2m) and wind conditions (10m)
averaged from the results in cool period

Cool period

At 1:00

At 16:00

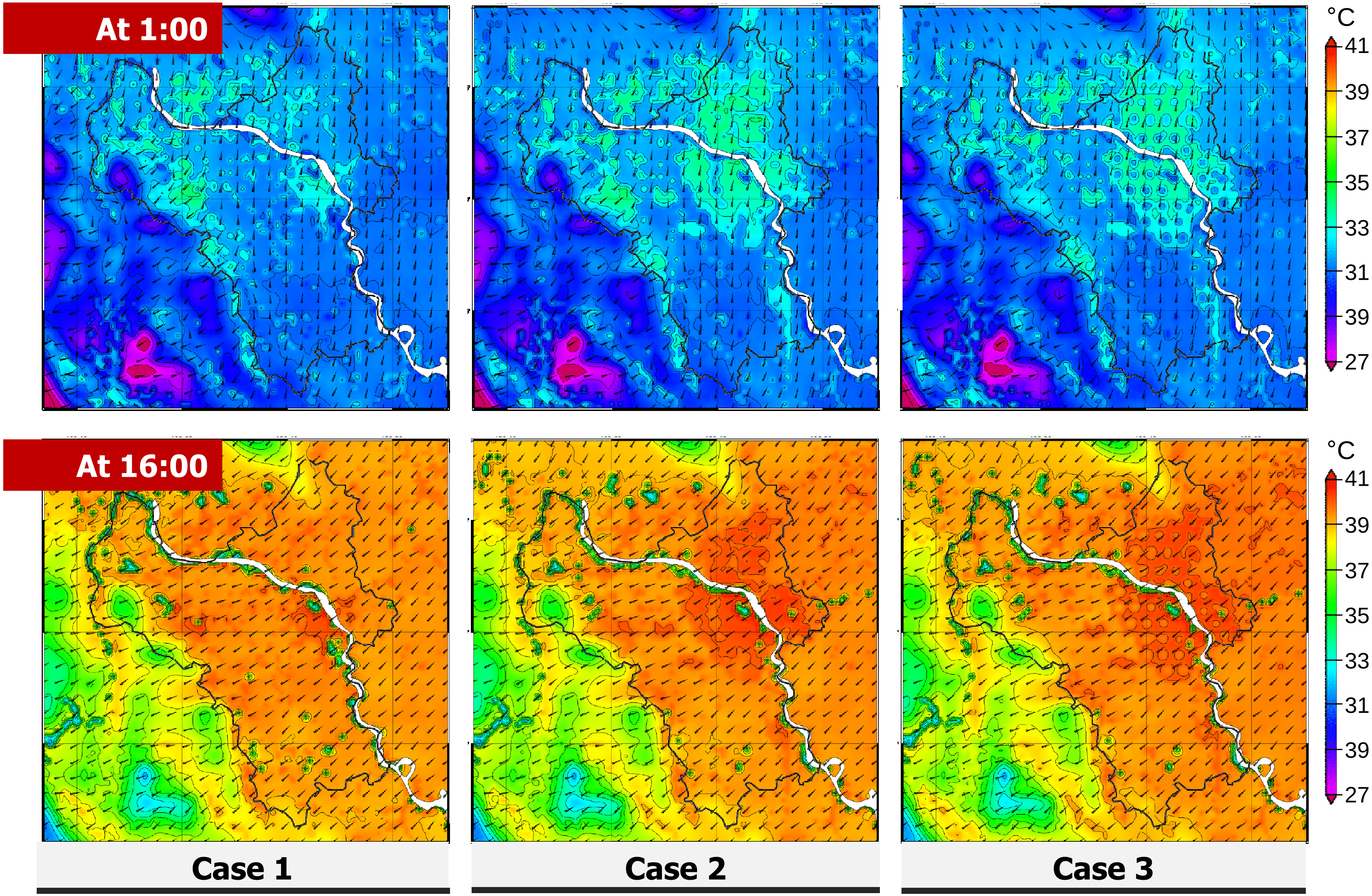


Case 1 | **Case 2** | **Case 3**

Results: Urban climate simulation

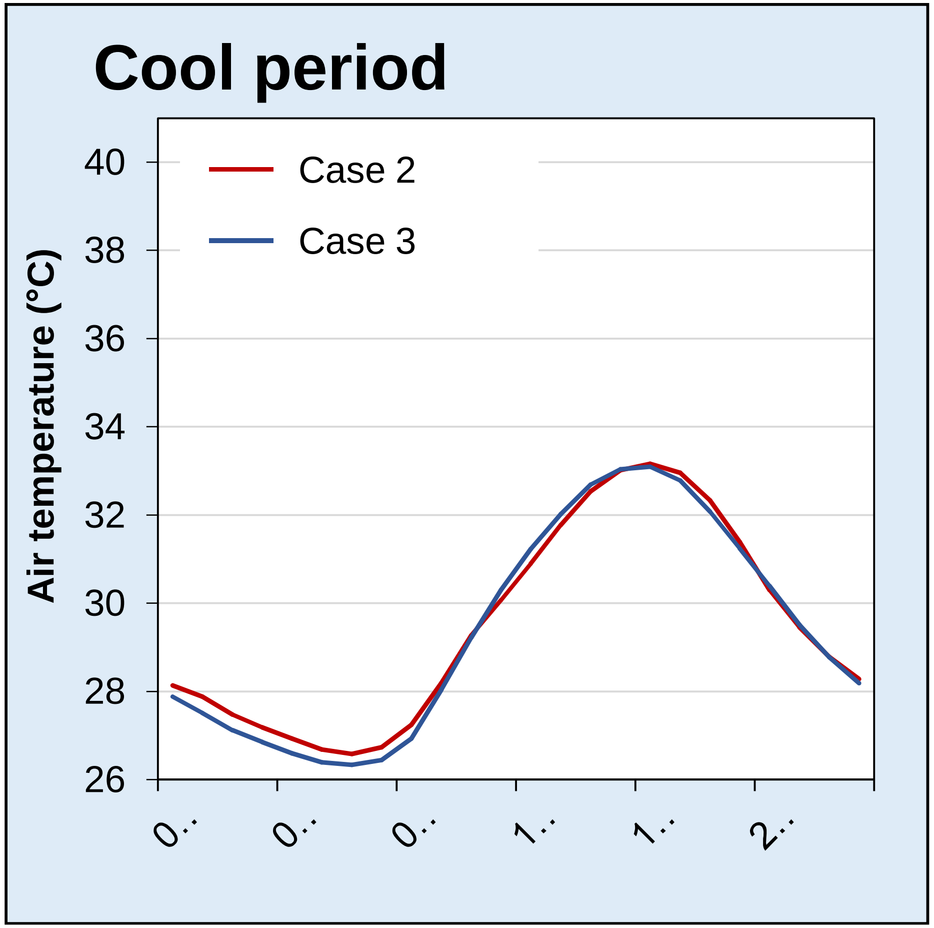
Hottest period

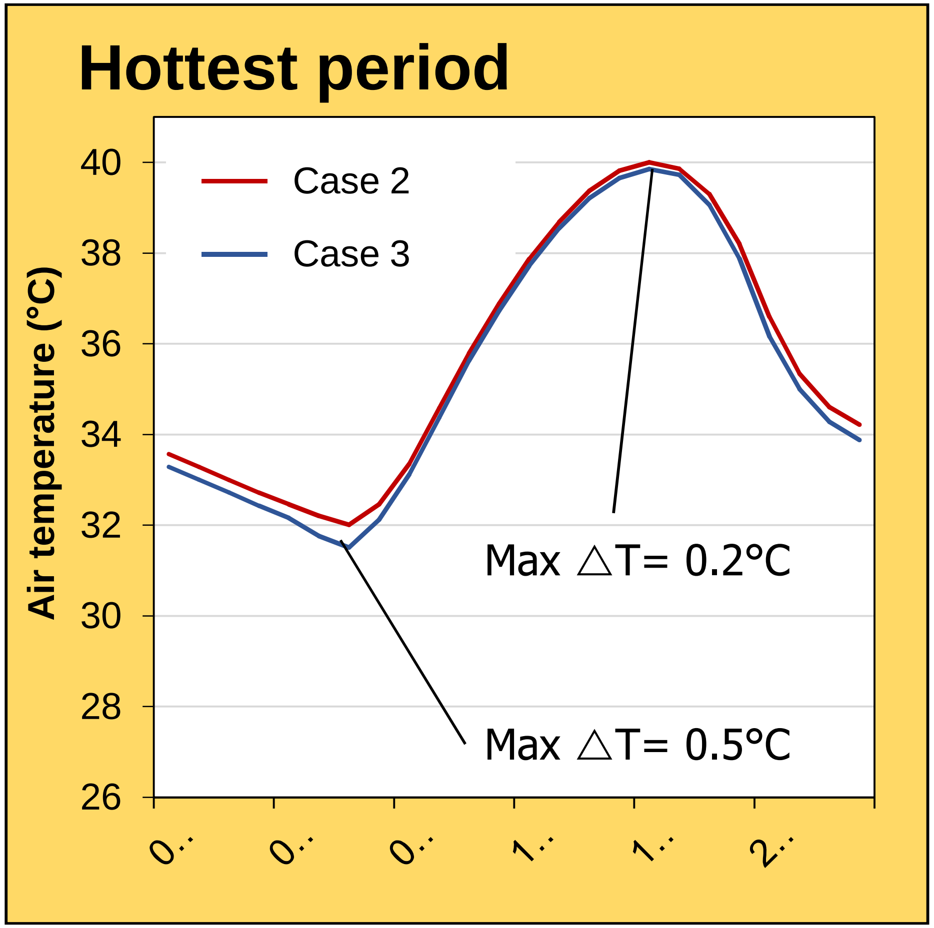
Spatial distribution of air temperature (2m) and wind conditions (10m) averaged from the results in hottest period



Results: Urban climate simulation

Daily average air temperature in built-up areas

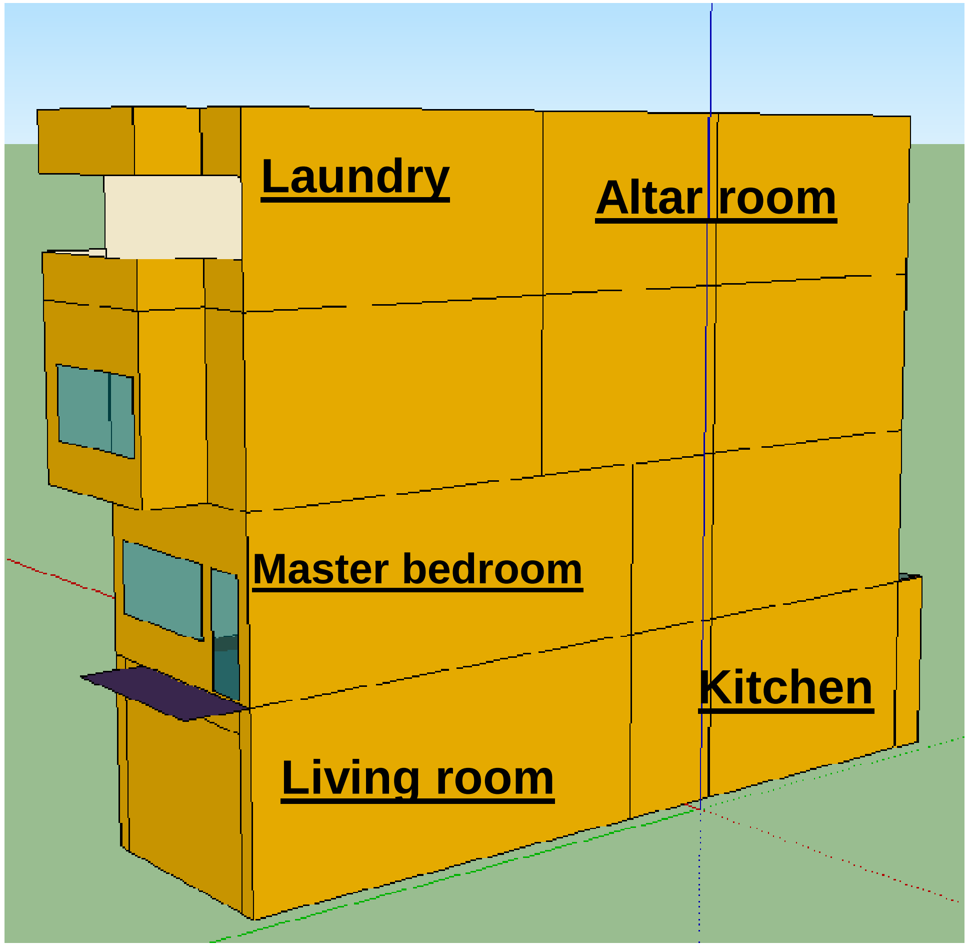




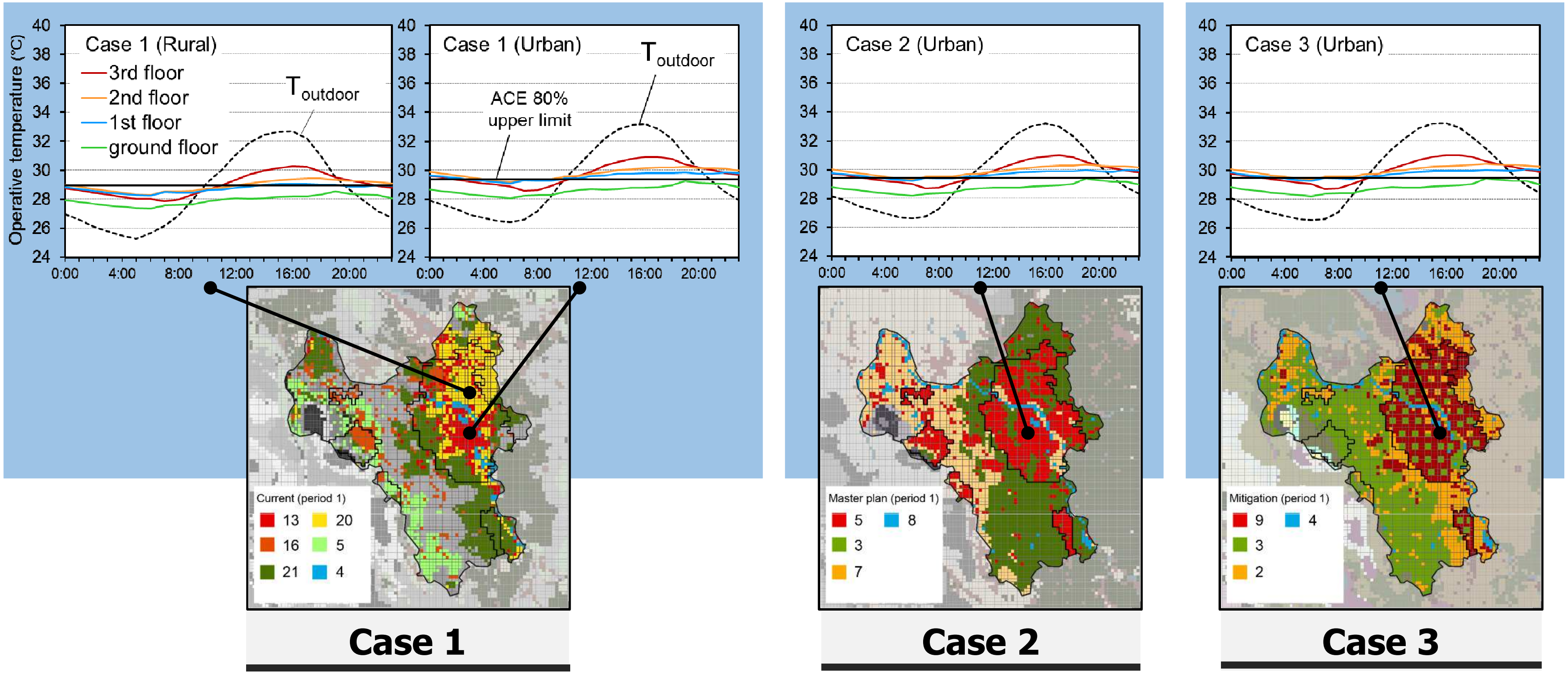
The equally distributed green network shows better performance at cooling the nocturnal air temperature in the built-up areas

Building simulation: Thermal comfort evaluation

- The building simulations were conducted using TRNSYS17 in the typical urban row house.
- The indoor thermal comfort was evaluated by using adaptive comfort equation developed by Toe and Kubota (2013) which suitable to use in hot and humid climate.



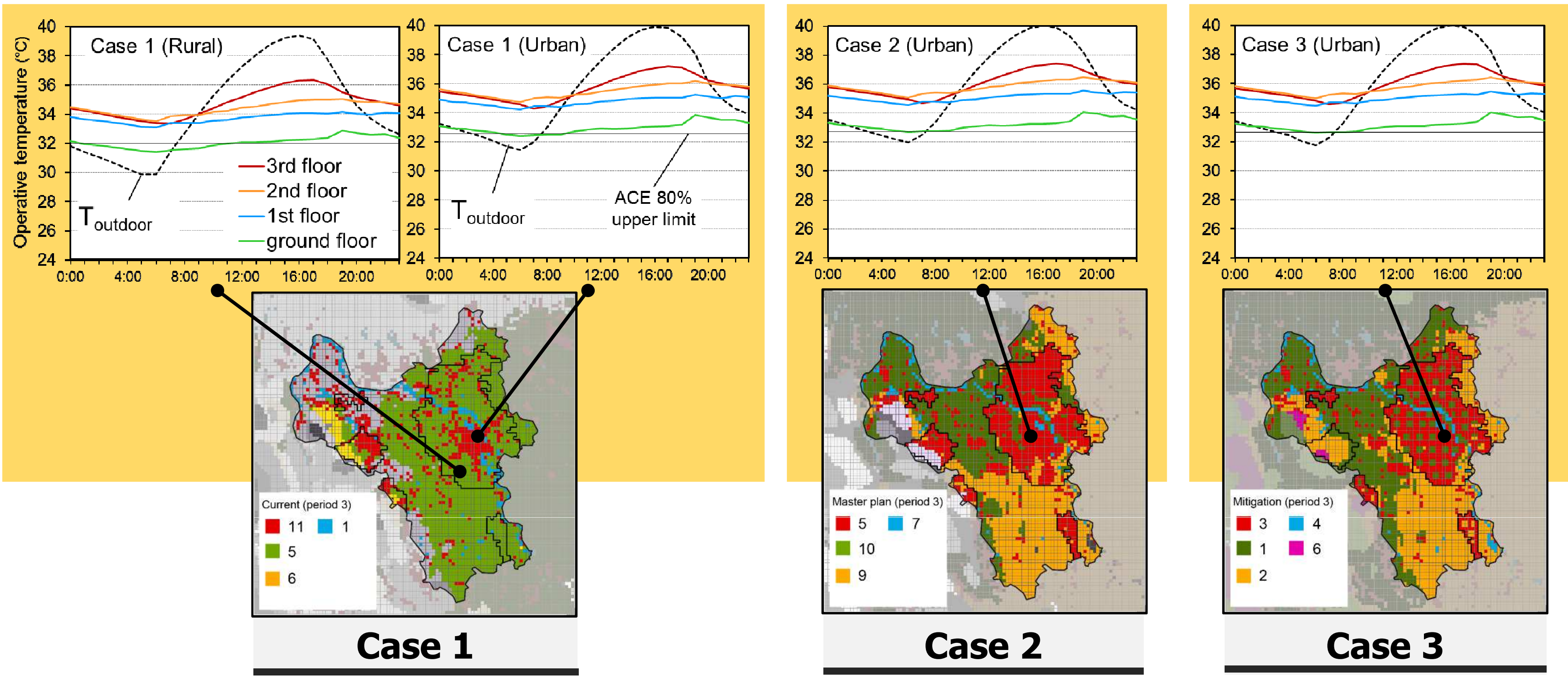
Cool period



Summary of thermal comfort evaluation

Floor level	Cool period			
	Case 1		**Case 2**	**Case 3**
	Rural	Urban	Urban	Urban
	Exceeding period (%)			
GF	**0**	**0**	**0**	**0**
1F	**29**	**71**	**75**	**75**
2F	**54**	**88**	**92**	**92**
3F	**46**	**63**	**67**	**67**

Hottest period



Summary of thermal comfort evaluation

Floor level	Hottest period			
	Case 1		Case 2	Case 3
	Rural	Urban	Urban	Urban
	Exceeding period (%)			
GF	**54**	**79**	**96**	**88**
1F	**100**	**100**	**100**	**100**
2F	**100**	**100**	**100**	**100**
3F	**100**	**100**	**100**	**100**

Building simulation: Cooling load calculation

- Cooling load was calculated in master bedroom of the row house.
- AC will be used if the night ventilation cannot achieve the thermal comfort during the duration of 22:00 to 3:00.

Period of AC usage

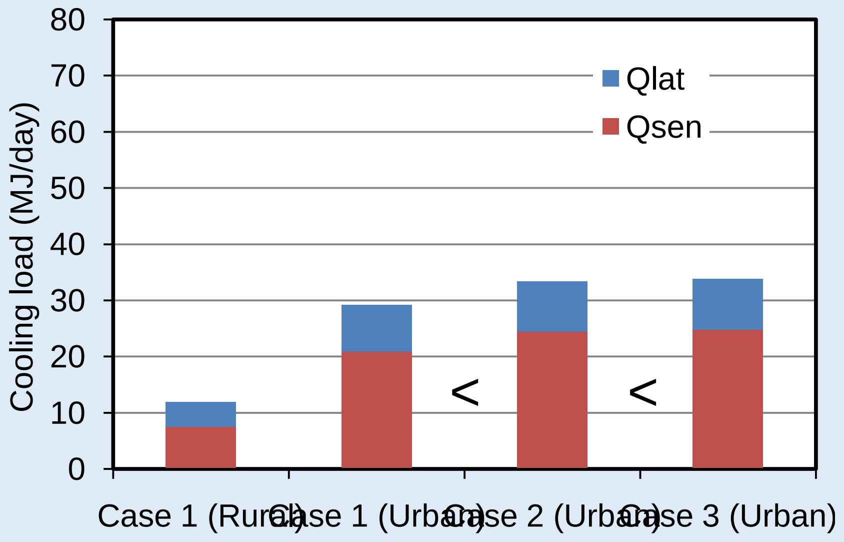
Time	Cool period				Hottest period			
	Case 1		Case 2	Case 3	Case 1		Case 2	Case 3
	Rural	Urban	Urban	Urban	Rural	Urban	Urban	Urban
7:00	0	0	0	0	1	1	1	1
8:00	0	0	0	0	1	1	1	1
9:00	0	0	0	0	1	1	1	1
10:00	0	1	1	1	1	1	1	1
11:00	0	1	1	1	1	1	1	1
12:00	0	1	1	1	1	1	1	1
13:00	0	1	1	1	1	1	1	1
14:00	1	1	1	1	1	1	1	1
15:00	1	1	1	1	1	1	1	1
16:00	1	1	1	1	1	1	1	1
17:00	1	1	1	1	1	1	1	1
18:00	1	1	1	1	1	1	1	1
19:00	1	1	1	1	1	1	1	1
20:00	0	1	1	1	1	1	1	1
21:00	0	1	1	1	1	1	1	1
22:00	1	1	1	1	1	1	1	1
23:00	0	1	1	1	1	1	1	1
0:00	0	1	1	1	1	1	1	1
1:00	0	1	1	1	1	1	1	1
2:00	0	1	1	1	1	1	1	1
3:00	0	0	1	1	1	1	1	1
4:00	0	0	0	0	1	1	1	1
5:00	0	0	0	0	1	1	1	1
6:00	0	0	0	0	1	1	1	1

‘0’ indicates comfort period, ‘1’ indicates discomfort period and highlighted period indicates AC usage.

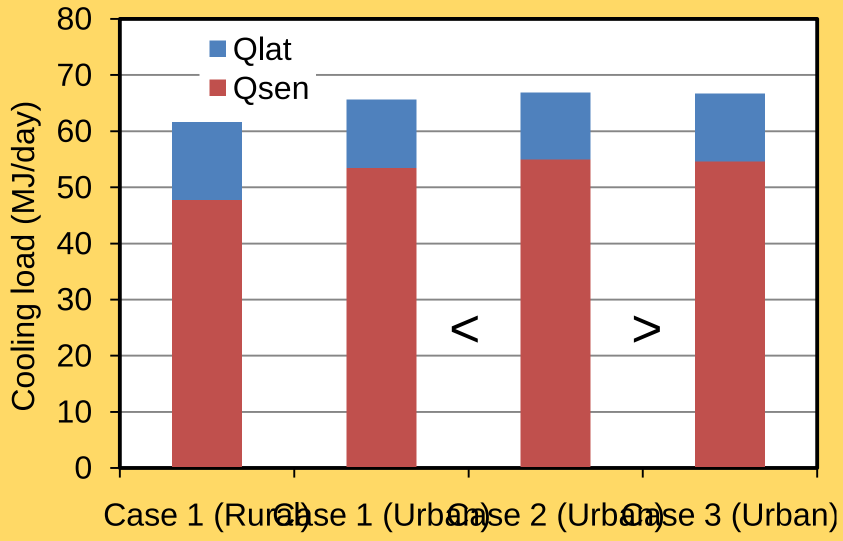
Results: Cooling load simulation

Sensible and latent cooling load

Cool period



Hottest period



Conclusions

1. The peak air temperature in summer is already very high (40-41℃) and remain at almost the same level even after the implementation of the master plan.

2. The hot spots would expand widely over the planned built-up areas under the master plan scenario.

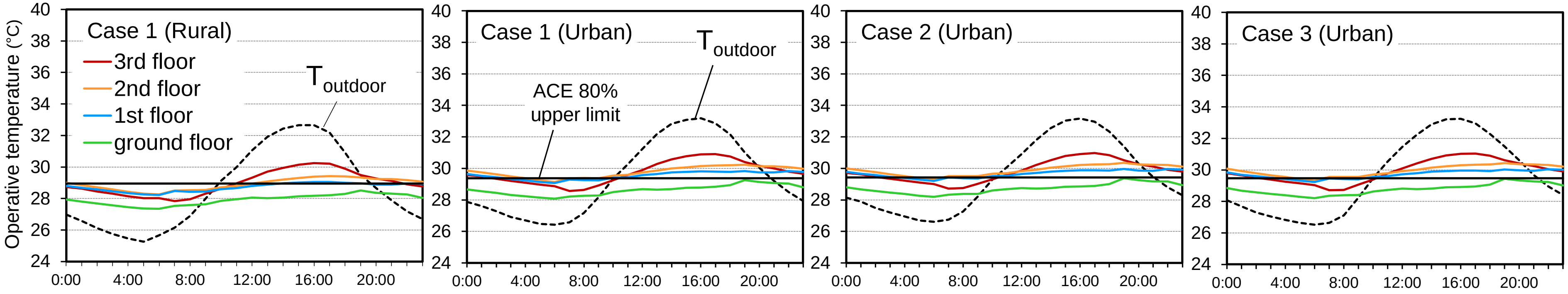
3. The small and equally distributed green network is slightly more effective at cooling nocturnal air temperatures.

4. If a row house in the rural area is situated in the urban area in the future, then the indoor operative temperatures are predicted to increase by 0.5-1.1℃ in the cool period and 1-1.6℃ in the hottest period.

5. The implementation of the master plan increases the average cooling load in the row house by up to 33.3 MJ/day in the cool period and 66.9 MJ/day during the hottest period.

Appendices

Cool period



Hottest period

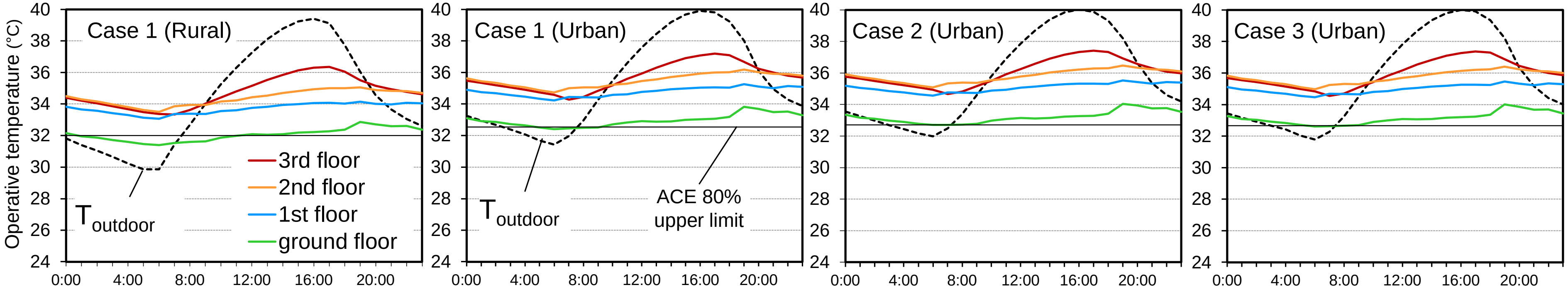
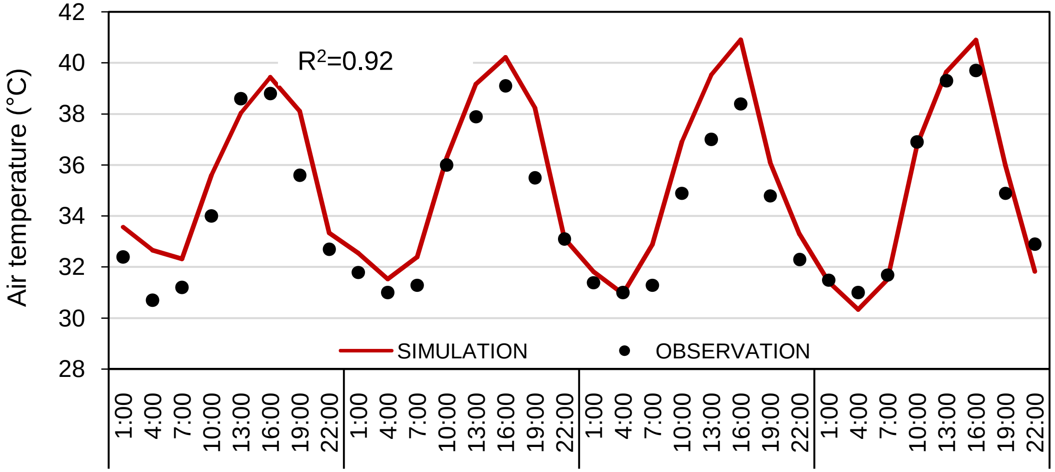


Table 2. Summary of thermal comfort evaluation

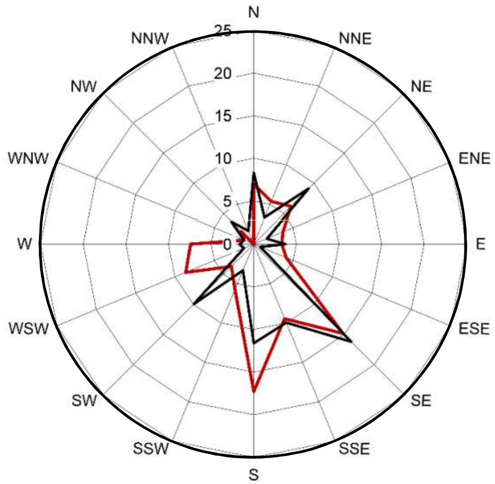
Floor level	Cool period				Hottest period			
	Case 1		**Case 2**	**Case 3**	**Case 1**		**Case 2**	**Case 3**
	Rural	Urban	Urban	Urban	Rural	Urban	Urban	Urban
	Exceeding period (%)				Exceeding period (%)			
GF	0	0	0	0	54	79	96	88
1F	29	71	75	75	100	100	100	100
2F	54	88	92	92	100	100	100	100
3F	46	63	67	67	100	100	100	100

Validation results of WRF model

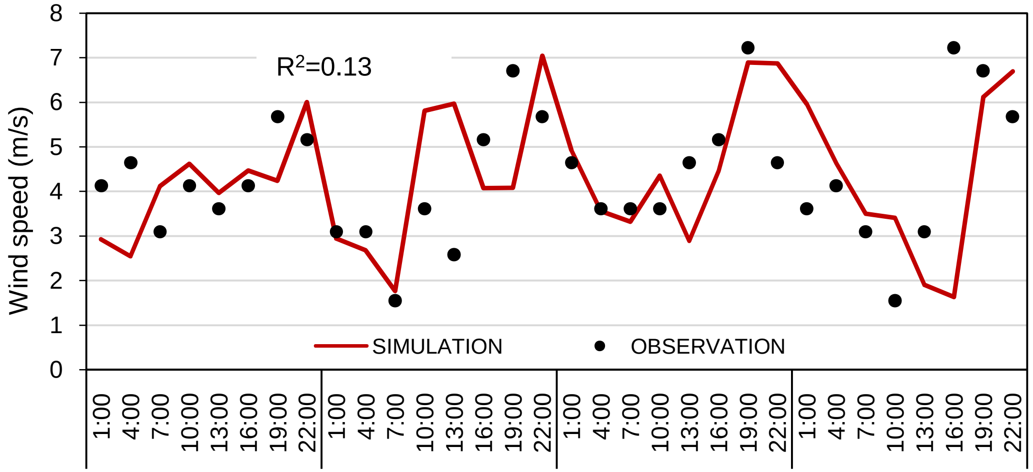
Air temperature at 2m (°C)



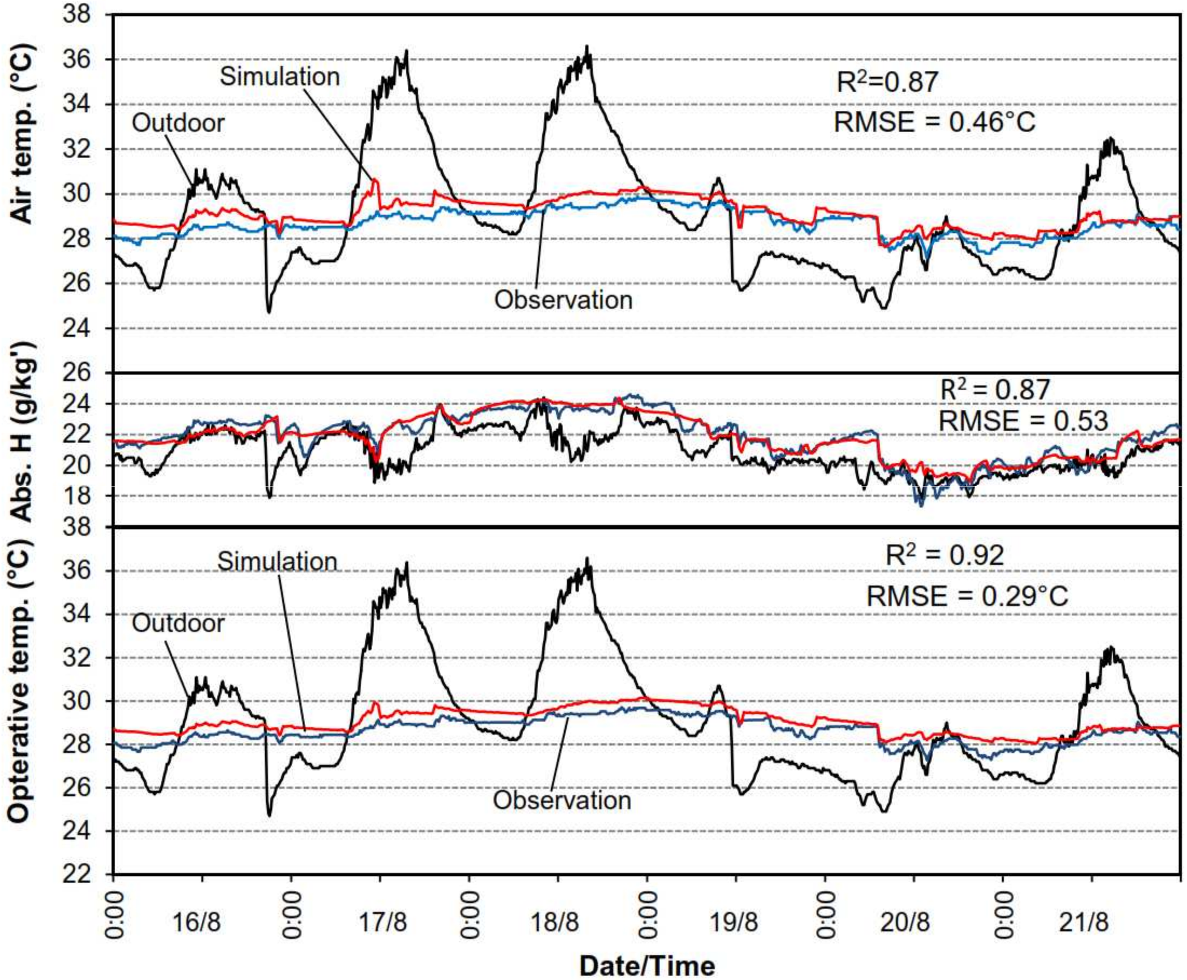
Wind direction at 10m



Wind speed at 10m (m/s)



Validation results for TRNSYS



Relationships between measured and simulated temperatures and humidity in the master bedroom

Items	Description
Total floor area of typical urban row house	240 m^2
Thermal Properties of building materials	National Technical regulation on energy efficiency buildings by the Vietnam Government. (Ministry of Construction, 2013)
Structure	Concrete frame and plastered bricks