Determining the Optimal Grid Size of Local Climate Zones for Spatial Mapping in High-density Cities

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Background

- Urbanization results in distinctive features of urban climate.
- Consequences such as urban heat island effect and associated outdoor thermal comfort issues
- Spatial mapping of urban climate
  - Understand the climatic conditions of urban environment
  - How urban morphology affects urban climate conditions
  - Assist urban planners and designers in their practices
- Qualitative guidelines and quantitative standards can be developed
  - Take urban climate into consideration
  - Incorporate into urban planning and design framework

Local Climate Zones

- Characterize surface environment with regard to their effect on local climate
- "Regions of uniform surface cover, structure, material, and human activity that span hundreds of meters to several kilometers in horizontal scale" (Stewart and Oke, 2012, p.1884)
- Distinguishable physical properties which help to determine the UHI intensity between two LCZs in terms of temperature difference
- Therefore, it offers an objective comparison of the climatic characteristics between different areas (Lelovics et al., 2014).

Local Climate Zones

Nancy, France (Leconte et al., 2015)

Olomouc, Czech Republic (Lehnert et al., 2014)

Dublin, Ireland (Alexander and Mills, 2014)

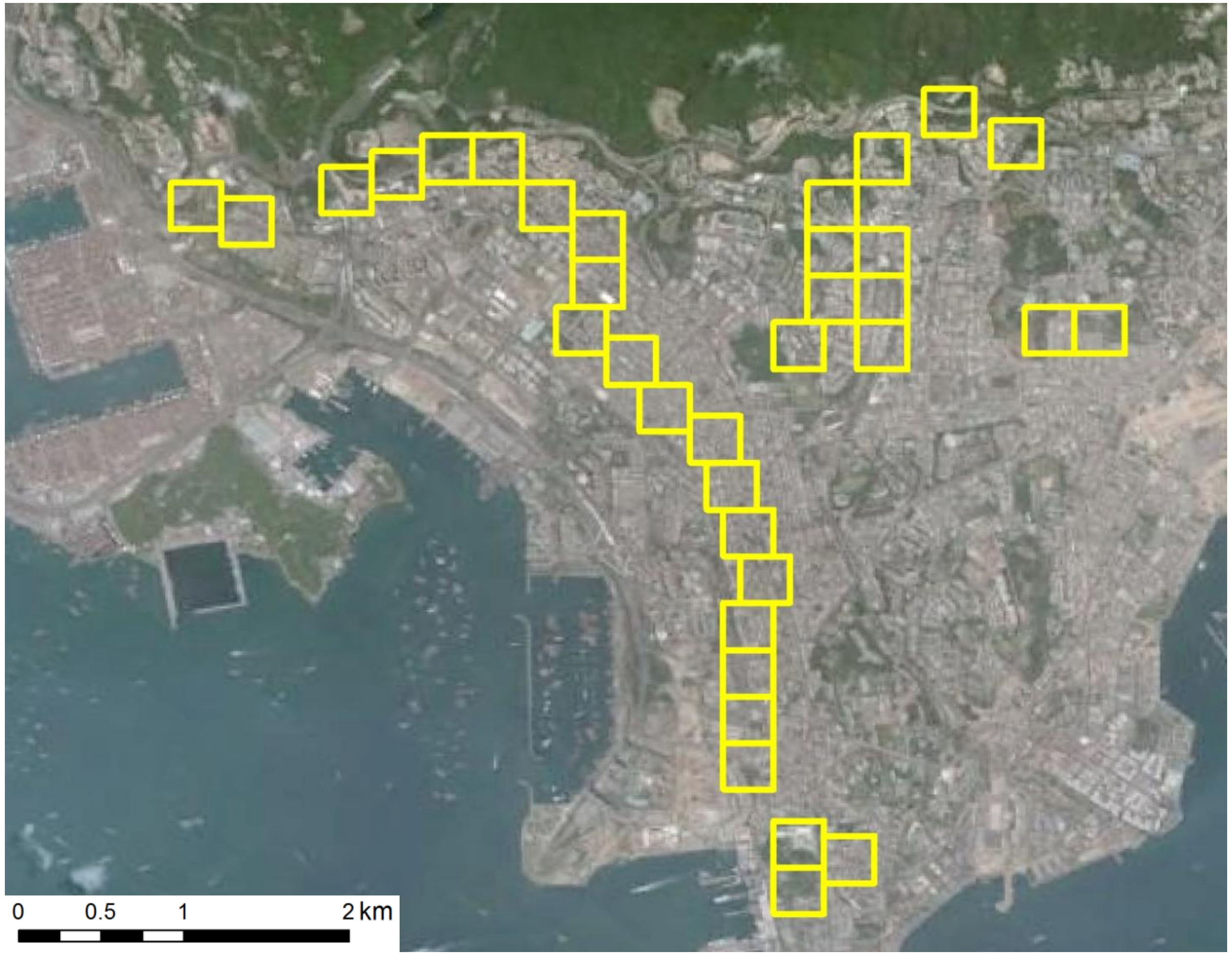
Szeged, Hungary (Lelovics et al., 2014)

High-density Cities

Objectives

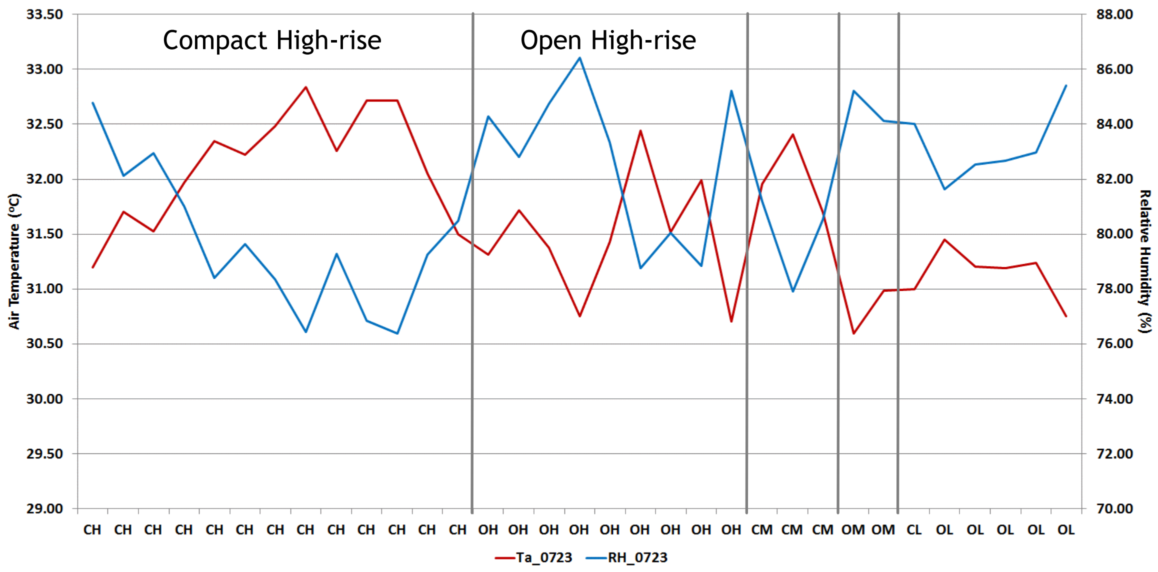
- LCZ classes are not adequate to characterize high-density cities
- Potential LCZ classes are required for extremely high-density areas
- How should it be categorized?
- What is the optimal spatial resolution for characterizing LCZ classes?
  - What is best for describing the homogeneity of surface environment within grids?
  - What is the minimum spatial resolution for presenting the intra-urban heterogeneity of urban morphology?

Mobile Traverse Measurements



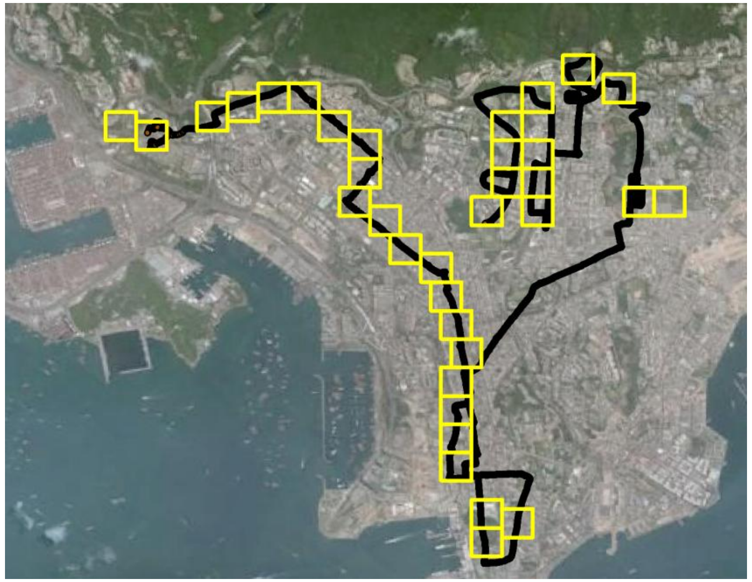
- Kowloon Peninsula
- Duration: 2 hours
- Covers six LCZ classes: Compact High-rise to Open Low-rise (LCZ 1-6)

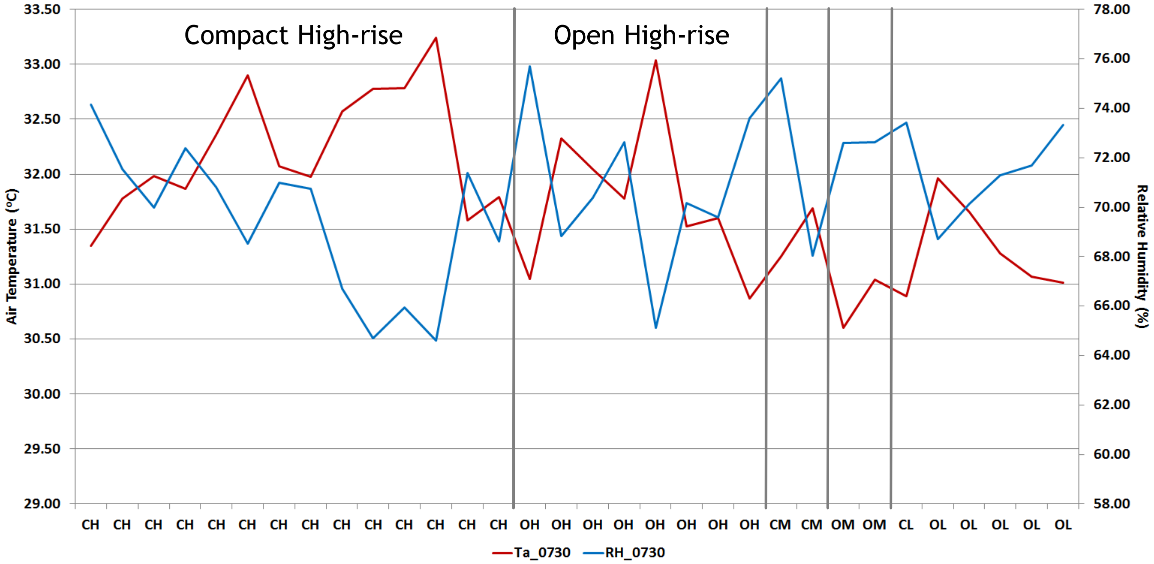
Intra-urban Differences



- Kowloon Peninsula
- 23 July 2014, 20:00-22:00
- T_a: 30.6°C, Wind Speed: 0.53m/s, Cloud: 60%
- Max difference in T_a: 1.64°C for Compact High-rise, 1.75°C for Open High-rise
- Max difference in RH: 12.37% for Compact High-rise, 6.16% for Open High-rise

Intra-urban Differences





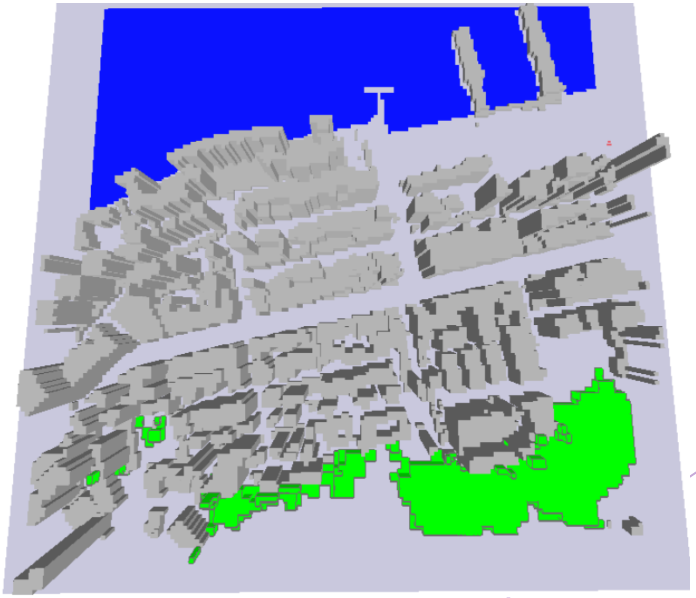
- Kowloon Peninsula
- 30 July 2014, 20:00-22:00
- T_a: 30.3°C, Wind Speed: 1.20m/s, Cloud: 34%
- Max difference in T_a: 2.19°C for Compact High-rise, 1.46°C for Open High-rise
- Max difference in RH: 9.55% for Compact High-rise, 10.56% for Open High-rise

ENVI-met Simulation

- To examine the effect of grid size on nocturnal T_a and RH
- Modelled period: 20:00 – 22:00
- Areal averages and standard deviation are calculated for modelled Ta and RH of ground pixels

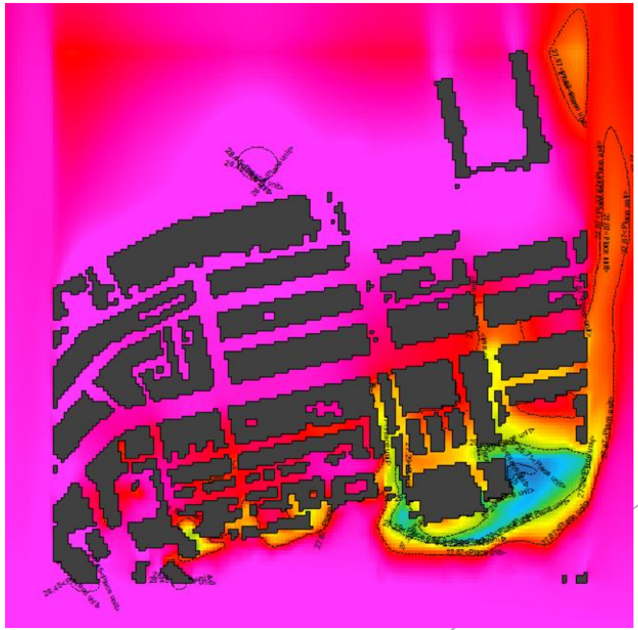
Input parameters:

- Starting time for simulation = 14:00
- Wind speed at 10m above ground = 2.1 m/s
- Roughness length at reference point = 0.1
- Initial air temperature = 30.3^{o}C
- Relative humidity at 2m = 79%



ANOVA and Tukey's Test

- Areal average and standard deviation (SD) of Ta and RH were calculated for each study area
  - At the four grid sizes (200m, 300m, 400m, 500m)
- Analysis of Variance
  - Examine whether there are any significant differences between grid sizes
- Post-hoc Tukey's Test
  - Identify significantly different pairs
  - Potential optimal grid size



Effect of Grid Size (ANOVA)

- No significant differences in average Ta and RH
  - Grid size does not have any significant effects on areal average
- Significant differences in SD of Ta and RH
  - There are significant differences in the homogeneity of surface characteristics

		SS	*df*	*MS*	*F*	*Sig.*
Ta_Mean	Between Groups	0.01	3	0.00	0.11	0.95
	Within Groups	1.53	52	0.03		
	Total	1.54	55			
Ta_StdDev	Between Groups	0.04	3	0.01	6.77	**0.00**
	Within Groups	0.11	52	0.00		
	Total	0.16	55			
RH_Mean	Between Groups	0.18	3	0.06	0.08	0.97
	Within Groups	39.85	52	0.77		
	Total	40.03	55			
RH_StdDev	Between Groups	0.89	3	0.30	7.27	**0.00**
	Within Groups	2.12	52	0.04		
	Total	3.01	55			

Post-hoc Tukey's Test

- No significantly different pairs for average Ta and RH
- For SD of Ta and RH, 200m and 300m are significantly different from 400m and 500m
  - 200m and 300m are not significantly different from each other
- Homogeneity within study areas is different across grid sizes

Ta_Mean	500m	400m	300m	200m
500m				
400m	1.00			
300m	0.97	0.99		
200m	0.96	0.99	1.00	

Ta_StdDev	500m	400m	300m	200m
500m				
400m	0.71			
300m	**0.04**	0.36		
200m	**0.00**	**0.02**	0.46	

RH_Mean	500m	400m	300m	200m
500m				
400m	1.00			
300m	0.98	1.00		
200m	0.97	0.99	1.00	

RH_StdDev	500m	400m	300m	200m
500m				
400m	0.74			
300m	**0.04**	0.34		
200m	**0.00**	**0.01**	0.37	

Homogeneity within Grids

- Decreasing standard deviation with grid size for both Ta and RH
- Standard deviation of Ta is reduced by 12.6% (400m), 31.9% (300m), and 50.2% (200m)
- Standard deviation of RH is reduced by 11.7% (400m), 30.0% (300m), and 48.1% (200m)

Increasing homogeneity within grids

Ta_StdDev	1102	1106	1108	1111	1112	1114	1301	1401	2101	2103	2111	2113	2120	3210
500m	0.181	0.082	0.127	0.138	0.134	0.122	0.106	0.174	0.292	0.073	0.116	0.119	0.236	0.114
400m	0.164	0.075	0.107	0.129	0.121	0.127	0.086	0.150	0.248	0.058	0.081	0.109	0.179	0.113
300m	0.157	0.079	0.076	0.101	0.074	0.115	0.043	0.134	0.143	0.042	0.056	0.104	0.131	0.083
200m	0.145	0.086	0.042	0.102	0.028	0.111	0.023	0.067	0.108	0.024	0.030	0.049	0.092	0.066

RH_StdDev	1102	1106	1108	1111	1112	1114	1301	1401	2101	2103	2111	2113	2120	3210
500m	0.914	0.411	0.642	0.656	0.680	0.618	0.536	0.851	1.181	0.364	0.499	0.614	0.984	0.589
400m	0.823	0.377	0.543	0.607	0.612	0.647	0.438	0.741	1.035	0.289	0.368	0.563	0.837	0.570
300m	0.786	0.397	0.381	0.520	0.373	0.587	0.217	0.667	0.622	0.211	0.259	0.534	0.664	0.427
200m	0.726	0.432	0.211	0.526	0.142	0.561	0.117	0.341	0.500	0.119	0.143	0.250	0.466	0.373

Sky View Factor

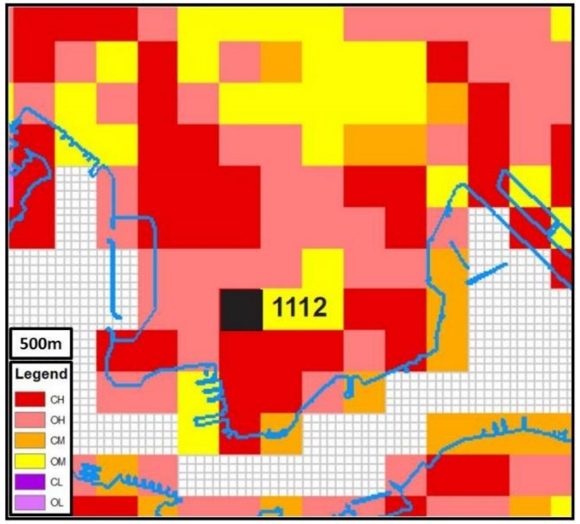
- Pearson correlation is calculated between average Ta, RH and mean SVF
  - Negative correlation between Ta and SVF
  - Positive correlation between RH and SVF
- For SD of Ta and RH, the highest correlation is observed at 300m grid size

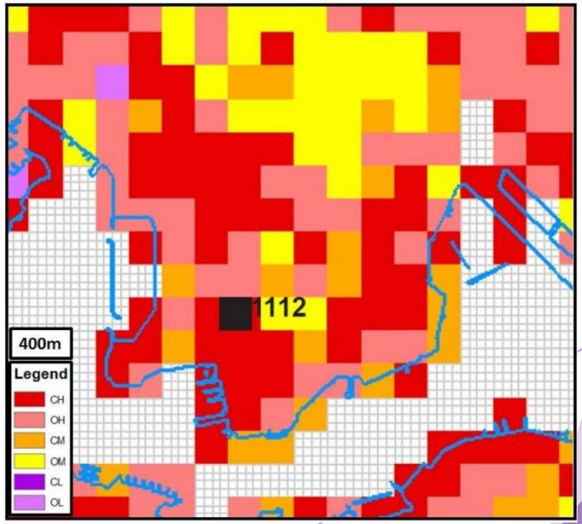
	Mean SVF		SD SVF
Average Ta, 500m	-0.43	*SD Ta, 500m*	0.62
Average Ta, 400m	-0.39	*SD Ta, 400m*	0.60
Average Ta, 300m	-0.51	*SD Ta, 300m*	0.69
Average Ta, 200m	-0.29	*SD Ta, 200m*	0.27

	Mean SVF		SD SVF
Average RH, 500m	0.44	*SD RH, 500m*	0.58
Average RH, 400m	0.42	*SD RH, 400m*	0.59
Average RH, 300m	0.50	*SD RH, 300m*	0.63
Average RH, 200m	0.33	*SD RH, 200m*	0.27

Spatial Variation of LCZ Classes

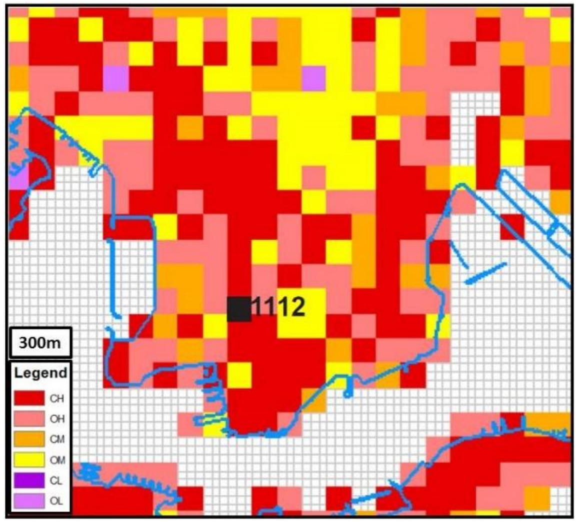
- Mostly CH and OH for the central part of the Kowloon Peninsula at 400m and 500m grid sizes
- Medium-density residential area dominates the northern part of the Peninsula
- The extent of medium-density areas are not sufficiently shown

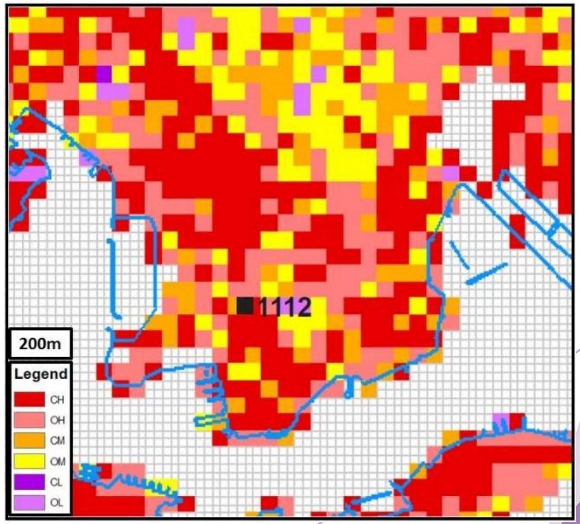




Spatial Variation of LCZ Classes

- Clearer picture of variations in urban morphology at 300m grid size
- "Density" associates with land use better
- Spatial pattern is similar at 200m although it would be more accurate to identify ventilation corridor in the area





Conclusions

- An appropriate grid size is very important to the spatial mapping of urban climatic conditions and urban morphology
- Traverse measurements show that there are substantial variations within the Compact High-rise (CH) LCZ class in Hong Kong
- There are significant differences in the standard deviation of Ta and RH
  - Decreasing grid sizes show increasing homogeneity within grids
- 200m and 300m grid sizes are significantly different from 400m and 500m
- Using 300m grid size sufficiently describes the spatial variability across urban areas

Further Work

- Spatial resolution determined will be used in the classification of LCZs in Hong Kong
- Also for further development of new LCZ classes for high-density cities
- Grid size of 200m may also be considered for identifying ventilation paths at district level.
- The validity of the grid size will be enhanced by defining the relationship between urban heat island intensity and various urban design parameters.
- Further field measurements will also be required in order to validate the development of LCZs in such a high-density urban environment.