

1 Original research paper

2 Explore the accuracy of the pedestrian level temperature esti- 3 mated by the combination of LCZ with WRF urban canopy 4 model through the microclimate measurement network

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17 **Abstract:** Due to the urban heat island effect getting more evident in the cities in Taiwan, the urban
18 climate has become an essential factor in urban development. Taiwan is located on the border of
19 tropical and subtropical climate zones, the climate condition is hot and humid, and the city shows
20 high-density development. The dense urban development has increased the heat storage capacity
21 of the ground and buildings. However, if only apply the climate stations set by the Central Meteor-
22 ological Bureau to observe the climate data, the predicted results would differ from the actual urban
23 climate conditions due to the small number of these stations and the too far distance between them.
24 Therefore, this study employs the Local Climate Zone (LCZ), which can classify the land features
25 by considering both land use and land cover and can be freely generated from satellite images. The
26 LCZ classification method can view the type of the city through the height and density of obstacles.
27 This study also combines the urban canopy model (UCM) of the mesoscale climate prediction model
28 Weather Research and Forecasts (WRF). This approach can calculate vertical and horizontal planes
29 of the city, such as building volume, road width, the influence of streets and roofs, roof heat capacity,
30 building wall heat capacity, etc., to predict the climatic conditions in different lands in the study
31 area. Simultaneously, to understand the actual distribution of urban climate more accurately, this
32 study used the microclimate measurement network built in the research area to produce pedestrian-
33 level temperature distribution and compared the estimated results with the actual measured values
34 for urban climate assessment. This study can understand the cause of urban heat islands and assist
35 urban planners in more appropriately formulate heat island mitigation strategies in different re-
36 gions.

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37 **Keywords:** Local Climate Zone; Weather Research and Forecasting model; urban canopy model;
38 Satellite image; Measurement network

1. Introduction

As the population increases, the phenomenon of urbanization becomes more and more evident. The heat emission, the reduction of vegetation coverage, the growth of impervious layer area, and other phenomena accompanying urban expansion will lead to the so-called urban heat island effect, which affects the urban climate (Chen et al., 2018; Lin et al., 2017). Many research has conducted relevant discussions on the topic of urban

1 heat islands. In addition, global environmental changes have also received attention in
 2 recent years, and extreme weather events have emerged one after another.

3 According to previous studies and global warming, the phenomenon of global ur-
 4 banization is also becoming more serious. The urban environment cannot ignore the ur-
 5 ban heat island effect and air pollution caused by dense populations. To better simulate
 6 the atmospheric conditions in urban areas to improve urban heat islands, air quality de-
 7 terioration, and other related urban issues, many studies have used Weather Research and
 8 Forecasts (WRF) coupled urban canopy model (UCM) for associated discussions (Brousse
 9 et al., 2016; Martilli et al., 2002).

10 The UCM model focuses on the original land use. The urban areas are subdivided
 11 into three categories: low-density residential areas, high-density residential areas, and in-
 12 dustrial and commercial areas. The classification process makes the meteorological field
 13 simulation closer to observational data in urban areas (Lin et al., 2016; Chen et al., 2011).

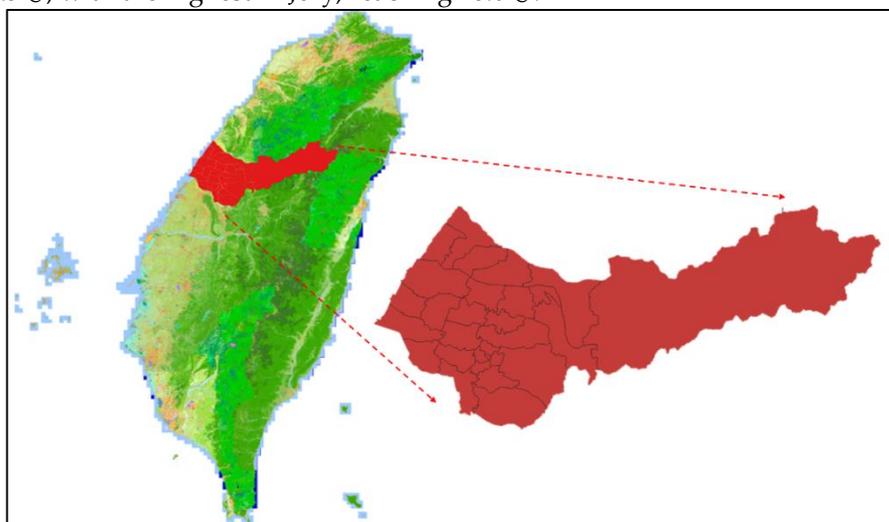
14 This research target is mainly in middle Taiwan; the simulation of the UHI is car-
 15 ried out in Taichung City. Because the original UCM model only provides three types of
 16 urban types and simplifies the diversity of today's buildings. Therefore, this study in-
 17 cludes the local climate zone (LCZ) based land use classification, based on the height and
 18 compactness of buildings, provides ten types of land use in urban areas, and attempts to
 19 construct the corresponding urban parameters under the LCZ classification to simulate
 20 urban canopy patterns.

21 Improve the simulation of meteorological fields in urban areas by providing a more
 22 satisfactory urban type. The simulation results are compared with the measurement data
 23 from the observation stations to test the products of the urban canopy model on simulat-
 24 ing the UHI. And try to develop a set of methods that are more suitable for the classifica-
 25 tion of urban land use in Taiwan, and improve the inexhaustible parts of the original land
 26 use classification, to apply it to Taiwan. Other cities in the region discussed related issues
 27 such as the heat island effect.

28 **2. Method**

29 *2.1. Study area*

30 The base selected for this study is located in the metropolitan area of Taichung City.
 31 It is surrounded by mountains and cut by many rivers. The diversified land use and cover
 32 types make the city's cooling and ventilation have the specific potential for change, as for
 33 the climate and environment. Taichung City is located in a subtropical climate zone, with
 34 high temperatures and more than 200 days in summer. The annual average temperature
 35 is 22.5°C, with the highest in July, reaching 28.0°C.



36 **Figure 1.** The study area Taichung city.
 37

2.2. Urban pattern distribution

2.2.1. Building information

Multiple urban development factors were used in the research process. Among them, building floor area information is important urban vector information, which includes building area and floor height and total floor area information for subsequent calculations of energy and comfort.

Through this layer, you can quickly calculate the urban development characteristics in different terrain areas. The density and location of buildings in the center of Taichung City far exceed that of the suburban areas on the east and west sides. From the total floor area map, compared with the less densely built areas on the east and west sides, you can see the downtown area because of the number of building floors. More and lead to a more prominent area distribution of buildings.

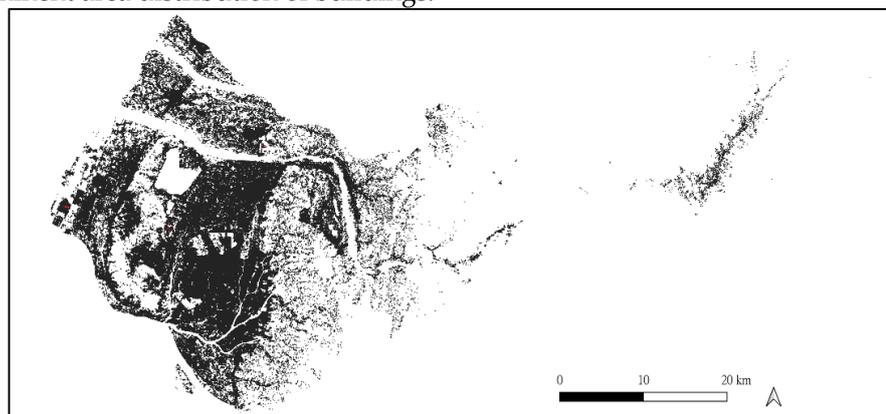


Figure 2. The building distribution in Taichung city.

2.2.2. Green information

This research uses Normalized Difference Vegetation Index (NDVI) to analyze the green cover. NDVI usually uses telemetry data, including satellite images and aerial cameras, and is equipped with instruments to shoot red light and near-infrared light.

The purpose of normalization is to prevent the numerical error of division by zero and to limit the ratio to between -1 and +1 for easy comparison; the value range of NDVI is as described above, between -1 and 1, the index is more When it is large, it means more vegetation, and the index is less than zero. It usually belongs to non-vegetable waters, roads, buildings, and the soil of open land. Past studies in Taiwan have shown that 0.2-0.5 is about grass and shrubs, and more than 0.5 is mostly trees (Liu, 2020). When calculating the green cover rate, if the overall scope of Taichung City is considered, there will be a relatively high degree of green cover rate of about 66%.

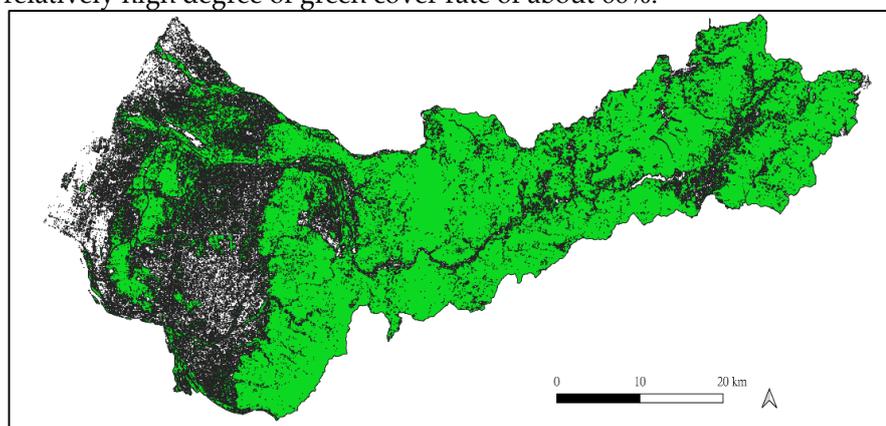


Figure 3. The green area distribution in Taichung city.

2.3. Local climate zone

2.3.1. Classification scheme

Because countries have different descriptions and definitions of various artificial and natural environments on the surface, establishing a set of urban platforms that can adapt to multiple users must go through systematic and standardized climate and environmental factor criteria. LCZ was originally proposed by Stewart & Oke.

The climate zoning system and a series of quantification and verification of relevant data information include sky visibility, building height, street aspect ratio, building projection area, impervious pavement area ratio, average building height, surface roughness, etc. The surface environment factors are used to summarize the LCZ system (Stewart & Oke, 2012) that has most of the characteristics of the urban built-up environment in a broad sense. The classification and naming form is LCZ_x, X is marked by numbers 1 to 10 in built-up areas, and X is A in non-built-up areas. To G mark.

2.3.2. Classification process

The satellite has a resolution of 30m and carries 11 spectral bands, and passes through the same area every 16 days. The calculation result is to exclude the error value caused by the cloud and fog conditions, and use the quality band to confirm the full range of data. The classification procedure of the LCZ system is constituted by WUDAPT.

The entire system uses telemetry images as the basic reference layer, and then uses Google Earth Pro to manually select the demonstration area and provide classification software to identify surface features. According to the final classification process, SagaGIS (2.2.0) software is used for supervised classification. The images taken by the Landsat8 satellite in this study are used as the basic layer for classification.

When classifying, you can set the classification resolution by referring to the size of the research area and the classification accuracy evaluation. In this study, Google map was used for repeated comparison, and the 200m*200m grid size was used as the classification resolution of Taichung City LCZ in this study.

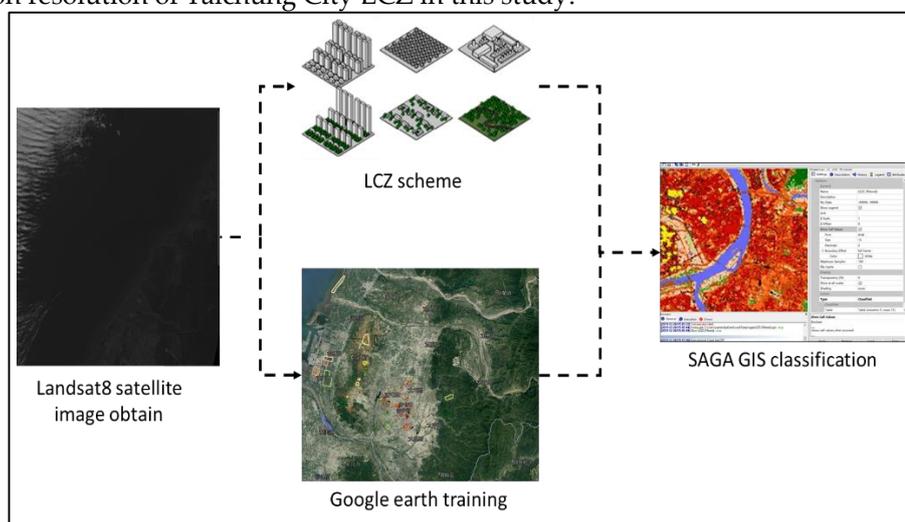


Figure 4. The classification process of local climate zone.

2.4. Weather Research and Forecasts

2.4.1. Urban canopy model

In simulating the phenomenon of urban heat islands, accurate urban development values and patterns, including surface coverage, height, etc., are the keys to the accuracy of the estimation. With the development of the city. Urbanization has led to many land use and land cover changes, and it will also have a significant impact on the local climate (Salamanca et al., 2011).

Natural surfaces are replaced by impervious artificial materials and structures in cities, such as roads and buildings. The increase of artificial materials will change the thermodynamic properties of the surface, such as emissivity, albedo, and energy balance, reduce evaporation from vegetation and soil, and increase surface roughness to reduce urban wind speed. In the past, WRF mostly used the land use data of the United States Geological Survey and the three levels of the firm, medium, and weak for simulation analysis.

Therefore, this study will use LCZ's urban development numerical information combined with WRF's mesoscale climate prediction function. And use urban types and their corresponding urban development values to simulate urban canopy, and use the urban canopy model (UCM) and Taichung City. The urban development parameters of the core area are used to analyze the simulation results of the Taichung area.

2.4.2. Urban canopy parameter by LCZ

UCM includes two models: Single-layer urban canopy model (SLUCM) and Multi-layer urban canopy (BEP). This study will use BEP for more accurate urban climate simulation and Heat island strength evaluation because it also considers the influence of vertical planes.

Factors such as building volume facades and horizontal planes such as streets and roofs, including building height, road width, roof heat capacity, building wall heat capacity, ground heat capacity, and roof thermal conductivity, building wall thermal conductivity, ground thermal conductivity, roof surface albedo, building wall albedo, roof surface divergence, building wall divergence, etc., and can also import and use the variety of LCZ Information (Chen et al., 2019; Shih et al., 2021).

This study will also verify the urban climate results simulated by WRF with the climate measurement network of Taichung City to confirm the accuracy of the LCZ applied to subsequent urban climate simulations. In addition, it will also be conducted with traditional urban development factors. They compared the results of the wind and heat environment forecast, understanding and analyzing the difference between it and the actual situation.

Table 1. The WRF urban canopy model parameters of various LCZ

Parameters	definition	LCZ1	LCZ2	LCZ3	LCZ4	LCZ5	LCZ6	LCZ7	LCZ8	LCZ9	LCZ10
<i>FRC_URB2D</i>	Fraction of the urban landscape which does not have natural vegetation.	0.95	0.85	0.58	0.45	0.4	0.35	0.58	0.75	0.25	0.5
<i>CAPR</i>	Heat capacity of roof	1970000	1970000	1970000	1970000	1970000	1970000	1970000	1970000	1970000	1970000
<i>CAPB</i>	Heat capacity of building wall	1630000	1630000	1620000	1630000	1720000	1620000	1610000	1860000	1610000	1610000
<i>CAPG</i>	Heat capacity of ground (road)	1940000	1950000	1980000	1940000	1950000	1980000	1950000	1940000	1980000	1950000
<i>AKSR</i>	Thermal conductivity of roof	1.1	1.04	1.01	1.2	1.2	1.01	1.01	1.24	1.01	1.01
<i>AKSB</i>	Thermal conductivity of building wall	1.2	1.2	1.01	1.2	1.1	1.02	1.01	1.2	1.01	1.01
<i>AKSG</i>	Thermal conductivity of ground (road)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
<i>ALBR</i>	Surface albedo of roof	0.13	0.18	0.15	0.13	0.13	0.13	0.15	0.18	0.13	0.1
<i>ALBB</i>	Surface albedo of building wall	0.25	0.2	0.2	0.25	0.25	0.25	0.2	0.25	0.25	0.2
<i>ALBG</i>	Surface albedo of ground (road)	0.15	0.15	0.18	0.2	0.2	0.21	0.24	0.17	0.23	0.21
<i>EPFR</i>	Surface emissivity of roof	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
<i>EPFB</i>	Surface emissivity of building wall	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
<i>EPFG</i>	Surface emissivity of ground (road)	0.95	0.95	0.95	0.95	0.95	0.95	0.92	0.95	0.95	0.95
<i>ZRG</i>	Roughness length for momentum, over ground (road)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
<i>ZOR</i>	Roughness length for momentum over roof	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
<i>ZR</i>	Roof level (building height)	45	15	5	40	15	5	3	7	5	8
<i>SIGMA_ZED</i>	Standard Deviation of roof height	1	1	1	1	1	1	1	1	1	1
<i>ROOF_WIDTH</i>	Roof (i.e., building) width	10	5.1	4.3	8	5.3	3.2	3	5.5	2.9	10
<i>ROAD_WIDTH</i>	road width	10	5.1	4.3	8	5.3	3.2	3	5.5	2.9	10
<i>AH</i>	Anthropogenic heat	100	35	30	30	15	10	30	40	5	300
<i>TRLEND</i>	Lower boundary condition for roof temperature [K]	293	293	293	293	293	293	293	293	293	293
<i>WRLEND</i>	Lower boundary temperature for building wall temperature	293	293	293	293	293	293	293	293	293	293
<i>TGLEND</i>	Lower boundary temperature for ground (road) temperature	293	293	293	293	293	293	293	293	293	293
<i>H/W</i>		4.25	3.25	2.75	4	1.25	0.75	2	0.2	0.15	0.35
<i>SVF</i>		0.3	0.4	0.6	0.5	0.6	0.7	0.4	0.7	0.8	0.8
<i>street width</i>		10.6	4.6	1.8	10	12	6.7	1.5	35	33.3	22.9
<i>building height</i>		45	15	5	40	15	5	3	7	5	8

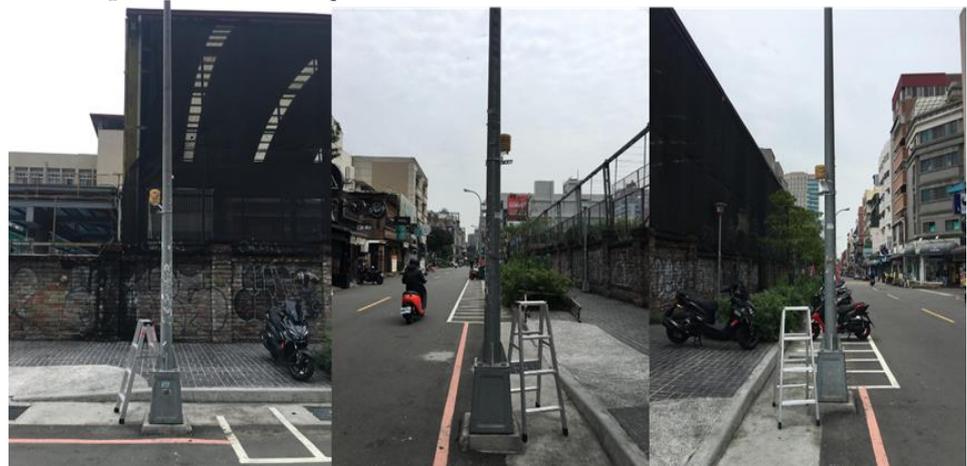
2.5. Meteorological observation network

The measuring instrument used in the Taichung microclimate measurement network to be used in this project is an external temperature and humidity measuring instrument from the Unabiz sensor.

The measurement network is through Sigfox technology, can instantly transmit data collected by temperature and humidity instruments at various points to the online cloud for a long time while saving power and serve as an essential reference for long-term stable map data application.

1 The stability of the system and the reliability of transmission have become more ma-
 2 ture. The location and method of erection are divided into grids at equal intervals within
 3 the research area. There are 25 erection locations. The erection locations will mainly
 4 choose roads with index properties. To ensure the safety of pedestrians and vehicles dur-
 5 ing installation and maintenance; the equipment should be installed at the height of 2.5
 6 meters above the ground, and in consideration of sunlight and waterproofing, a shield
 7 and waterproof cover will be used together to reduce the heat storage and water ingress
 8 of the shield (Chen et al., 2019).

9 Measurement errors and the components and erection methods used in the erection
 10 have been sent to structural technicians for testing in the past, and it has been confirmed
 11 that this structure will not cause traffic and pedestrian dangers due to accidental factors
 12 such as strong winds and earthquakes.



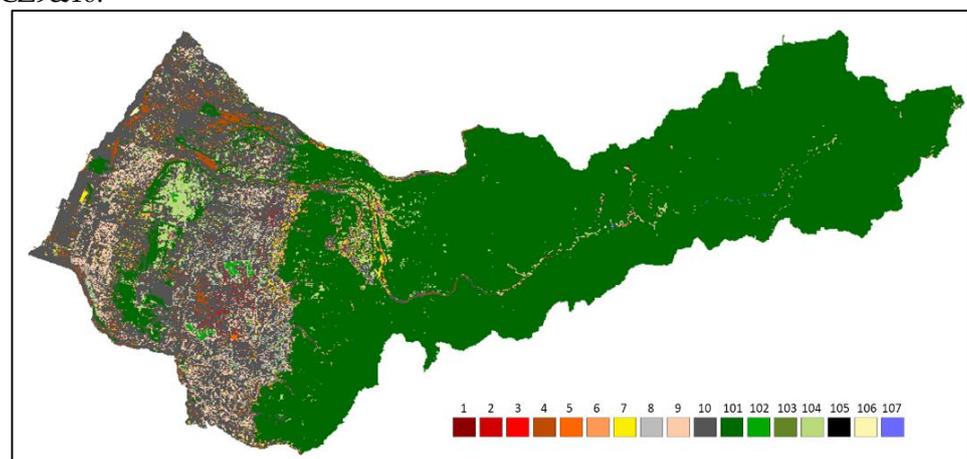
13
 14 **Figure 5.** The Sigfox instrument in wind and water shield and install in 2.5m height.

15 **3. Results**

16 *3.1. LCZ distribution*

17 The layout of the LCZ in Taichung presents Taichung’s high-density development
 18 characteristics of the city center. The built environment in Taichung City is mainly based
 19 on LCZ2, 4, 9 & 10. This indicating that Taichung’s urban development is primarily in the
 20 form of medium and high floors.

21 While the eastern side is a surrounded by mountainous area and a nature reserve,
 22 the forest landscape of LCZ101 is primarily, and the west side is because the coastal areas
 23 are industrial principally areas, which presents another type, mostly densely distributed
 24 in LCZ9&10.



25
 26 **Figure 6.** The LCZ classification result in Taichung city.

3.2. WRF Modeling temperature result

Using WRF combined with LCZ to simulate the surface temperature of 2 meters in average December 2020, it is found that urban hot spots are mostly concentrated in the denser areas of LCZ1-3.

In addition, industrial areas such as LCZ9 and 10 will also produce higher temperatures about 18°C -19°C due to higher heat dissipation and building materials—the phenomenon of low temperature in natural areas, including mountainous and hilly regions.

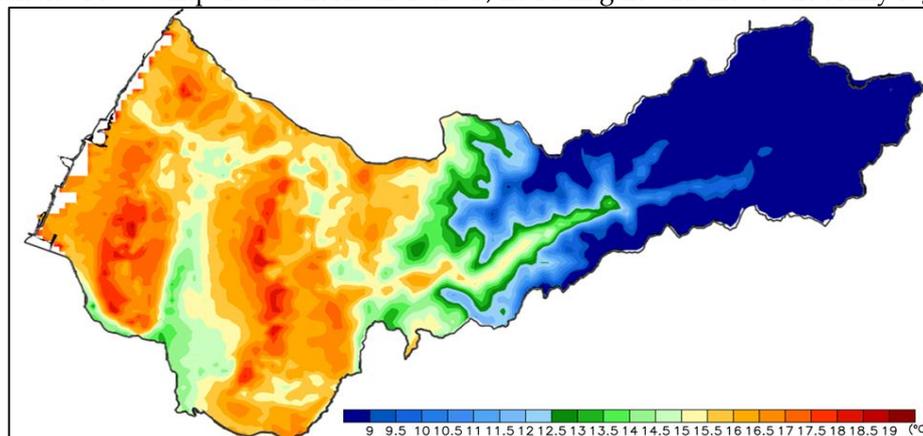


Figure 7. The average air temperature distribution condition estimate by the combination of LCZ and WRF in Taichung city.

3.3. Measurement temperature result

The actual temperature measurement results show that the daily average temperature conditions in December 2020 are similar to the estimated conditions using the combination of WRF and LCZ.

High-temperature hot spots are mostly located in high-density residential areas in the city center, industrial areas on the west side and the commercial regions with intensive activities the high temperature can reach 20 °C, which is about 1 °C higher than the predicted result, and the same in the mountainous area, it is about 8 °C, which is about 1 °C lower than the expected result.

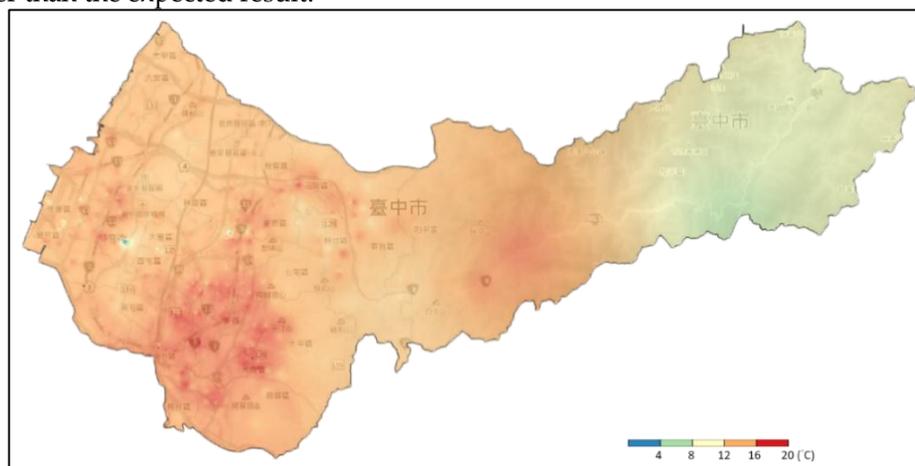


Figure 8. The average air temperature distribution condition measured by the meteorological observation network in Taichung city.

5. Conclusion

LCZ divides urban land use into ten types and non-land use into seven types. In response to the increasing degree of urbanization and diverse land use, compared with the three simple types of urban morphology in the model, including low-density residential

1 areas, high-density residential areas, and industrial and commercial areas, more types of
2 urban morphology classifications are more in line with today's social land Using the ac-
3 tual situation can provide more diverse urban forms. It is helpful to simulate the weather
4 field for manufacturing urban-related issues such as the UHI phenomenon.

5 The three types of urban land use in the original WRF model are increased to ten
6 categories, a new land use index is generated, and the urban parameter values corre-
7 sponding to each type are included in the Urban canopy parameter. The settings in the
8 urban scheme are modified to perform urban model simulation.

9 Future studies will try to incorporate the LCZ-based land use classification, provide
10 ten types of urban land use categories, construct the corresponding urban parameters un-
11 der the LCZ classification to simulate the urban canopy model. Then providing a more
12 refined urban classification simulation of the regional meteorological field and testing the
13 results of the urban canopy model simulation of UHI. Further, try to develop a set of more
14 suitable urban land use classification methods in Taiwan, improve the incomplete part of
15 the original land use classification, and apply it to other cities in Taiwan with related is-
16 sues such as the UHI, energy consumption, and air pollution

17
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20 and Fang-Yi Cheng; Writing, Yu-Cheng Chen. All authors have read and agreed to the published
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27 be construed as influencing the position presented in, or the review of, the manuscript entitled.

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