CLIMATE JUSTICE
氣候正義

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臺灣都市熱島挑戰與應對：即時監測、歷史數據與未來預測的綜合分析

UHI Effect in Taiwan: Real-Time Monitoring, Historical Data, and Future Projections

臺灣都市面臨嚴重的熱島效應。2020 年 6 月 29 日，臺北市氣溫高達 38.9°C，創下當月新高紀錄，並於 7 月 24 日達 39.7 °C，創下自 1896 年以來的歷史新高。都市區域的溫度顯著高於郊區，這主要由於不透水鋪面、大量的混凝土建築、以及人工熱源（如交通排放、空調使用等）所造成。隨著都市化的推進，尤其是在熱島效應較為明顯的季節，都市地區的溫度可能比郊區高出 3° C 至 5° C，這不僅增加了居民在夏季的熱適應負擔，也對公共健康、能源消耗、環境和生態造成了嚴重影響。

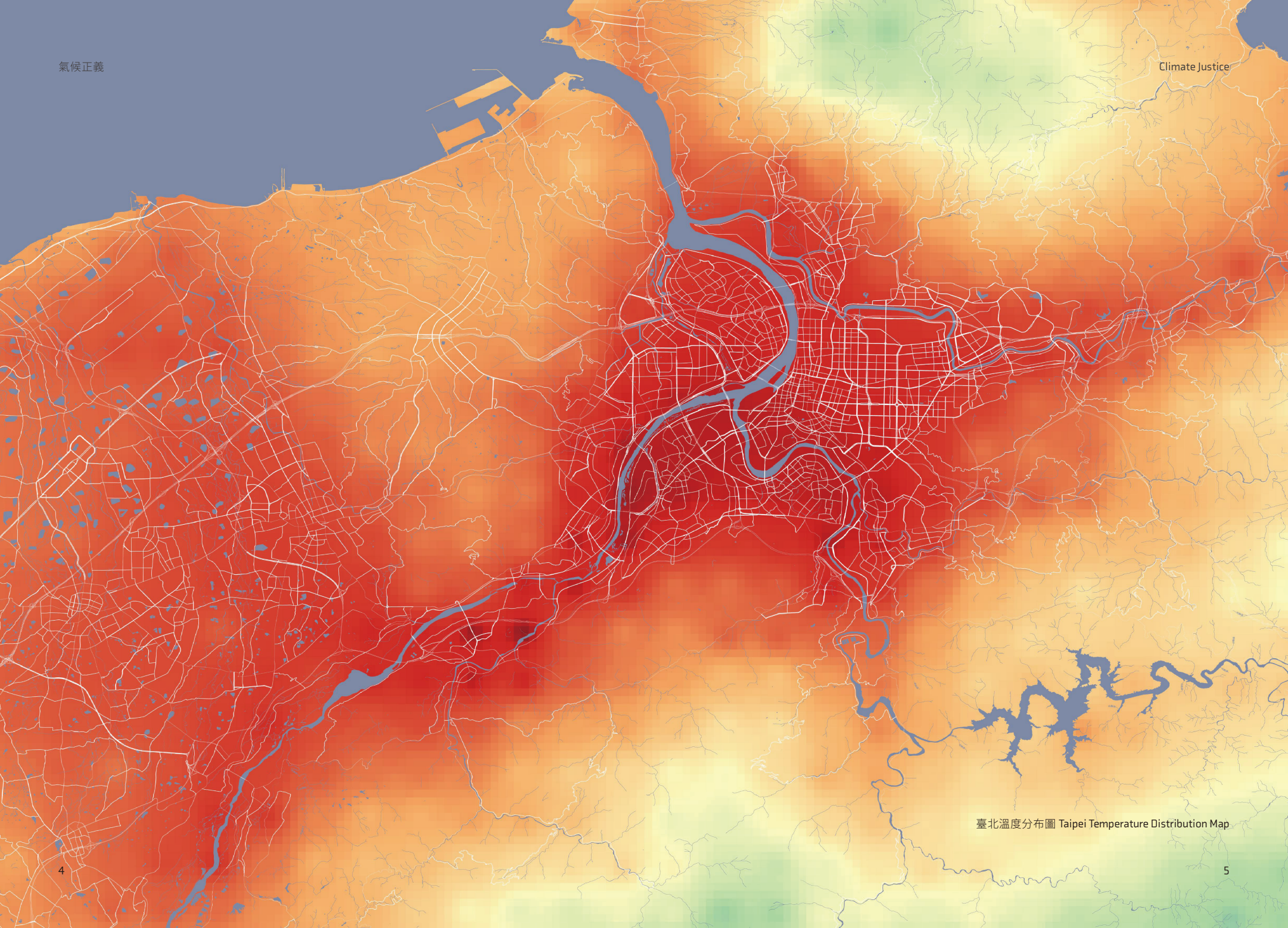
為取得即時的溫度資料以深入理解都市熱島現象，國立成功大學建築學系林子平教授帶領的建築與氣候研究室（BCLab），為臺灣市六個都會區建立了高密度溫濕度即時量測網 HiSAN，專注於提供更細緻的降尺度數據。透過結合土地使用、土地覆蓋、建築高度與國家災害防救科技中心（NCDR）所產製的氣候變遷資料，掌握都市建成環境到街廓與建築物尺度的氣候變化，推估全球暖化下都市將面臨的熱危害風險與衝擊趨勢，利用網格化資料呈現環境資料空間分布，精準分析都市熱環境的影響，強化即時展示與預警的能力。

關於過去歷史氣候資料，BCLab 搭配國科會 TCCIP 計畫所產製之 2 公里解析度 TReAD（臺灣歷史氣候重建資料）長期氣候資料，取 2011 至 2018 年間的數據製作臺灣都市熱環境氣候地圖，呈現行人層氣溫、相對濕度、輻射、風速，以呈現都市長期氣候特徵，為都市熱島效應提供精確的數據支持與分析。另外關於未來的氣候變遷資訊，BCLab 則採用由 TCCIP 計畫產置 RCP8.5 暖化情境下的 HiRAM 資料，模擬期間包括基期 1995–2014 年、升溫 2° C（2034–2053 年）和升溫 4° C（2073–2092 年）的未來情境。結合即時、過去、未來微氣候資料，即可對於都市高溫進行深入分析。然而亦需結合都市的暴露度、脆弱度的資訊，才能充分掌握高溫對於環境、社會、經濟的綜合影響。

Taiwan's urban areas are experiencing severe heat island effects. On June 29, 2020, Taipei reached 38.9°C, the highest for the month, and on July 24, temperatures hit a record 39.7°C. Urban temperatures are much higher than in suburban areas due to impermeable surfaces, dense buildings, and artificial heat sources like vehicular emissions and air conditioning. As urbanization intensifies, temperatures in cities can exceed suburban levels by 3°C to 5°C, increasing thermal stress, and impacting public health, energy consumption, and environmental stability.

To acquire real-time temperature data for a comprehensive understanding of the urban heat island effect, Professor Tzu-Ping Lin of NCKU's Department of Architecture leads BCLab in establishing the High Density Street-level Air-temperature Observations Network (HiSAN) across six metropolitan areas in Taiwan. HiSAN provides refined downscaled data. By integrating land use, land cover, building height, and climate change data produced by the National Science and Technology Center for Disaster Reduction (NCDR), BCLab examines climate variations from the urban built environment to the neighborhood and building scales. This approach enables precise assessment of urban heat hazards under global warming. Gridded data visualization supports spatial analysis, enhancing real-time monitoring and early warning.

Regarding historical climate data, BCLab utilizes the long-term climate dataset TReAD (Taiwan ReAnalysis Downscaling data), produced under the National Science and Technology Council's TCCIP project with a 2 km resolution. These maps provide precise tools for studying the urban heat island effect. For future projections, BCLab uses HiRAM data under the RCP8.5 scenario, covering baseline (1995–2014) and future warming scenarios of 2°C (2034–2053) and 4°C (2073–2092). By integrating real-time, historical, and future data, BCLab enables detailed analysis of urban extreme heat, while incorporating exposure and vulnerability data is crucial for assessing the full impact on the environment, society, and economy.



臺北溫度分布圖 Taipei Temperature Distribution Map

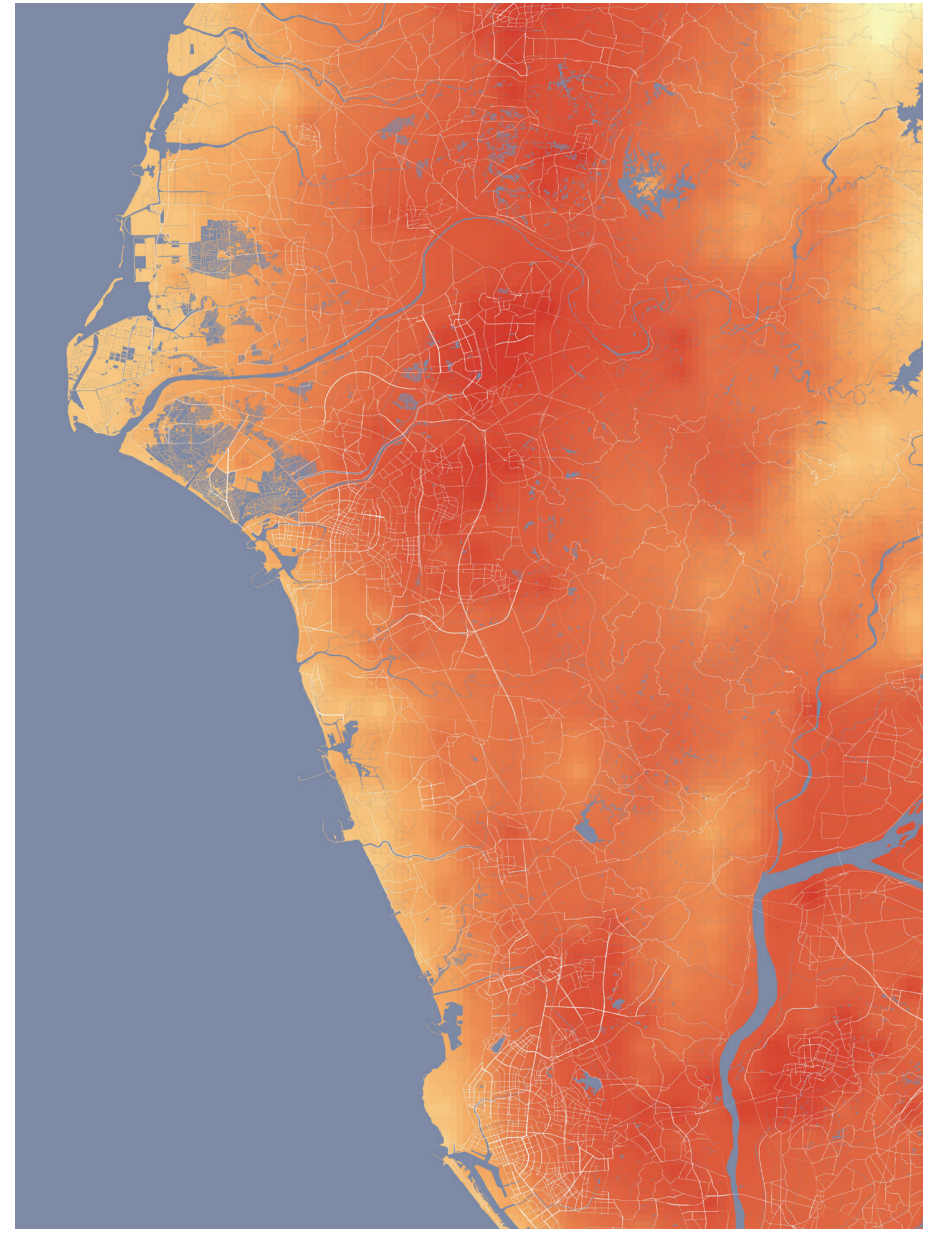
熱島效應加劇社會脆弱度與環境不公正問題

UHI Effect Exacerbates Social Vulnerability and Environmental Injustice

在社會經濟層面，BCLab 針對熱島效應與社會脆弱度的影響，臺灣災害防救科技中心對過去十年夏季氣溫進行空間分析，並透過社會經濟脆弱度的量化指標，評估地區的社會情況，如經濟水平、人口結構與醫療資源分布等。這些指標能有效衡量地區在面對極端高溫等天然災害時，可能遭受的損害程度，以及其應對、抵抗與調適能力。本研究使用「社會經濟資料服務平臺」提供的數據，將「二級發布區」作為空間統計單元，選取六項評估指標，包括「工商家數」、「14 歲以下幼年人口數」、「65 歲以上老年人口數」、「醫療院所家數」、「低教育程度人口數」及「低收入戶戶數」分析臺北市各區的社會經濟脆弱程度及其分布特徵。

由 BCLab 研究結果顯示，臺北市社會經濟脆弱度較高的地區主要集中在中山區和萬華區；而低脆弱度地區則多分布於擁有高收入水平與完善公共設施的市中心行政區。然而，大安區與松山區雖位於高溫區域，卻因其較強的調適能力，脆弱程度相對較低。此外，「109 年第一次臺北市交通民意調查報告」指出，萬華區居民在通勤與通學方式上，步行比例達 8.6%，顯著高於臺北市其他行政區；而使用自用客車的比例僅為 4.9%，明顯低於其他區域。這表明萬華地區對環境的負擔相對較低，但同時也承受著更高的極端高溫風險，突顯了環境不公正的現象。因此，了解社會經濟脆弱度的空間分布，不僅能幫助政府更有效地分配資源，減少極端氣候對弱勢群體的衝擊，亦有助於提升社會整體的抵抗與調適能力。

熱島效應除了影響社會群體之外，隨著高溫加劇、城市快速發展對環境、生態、健康和社會經濟等其他方面也帶來深遠影響。在經濟快速發展與都市化進程中，大量水泥建築、不透水鋪面、各類經濟活動所產生的熱源，以及高密度開發等因素進入都市，同時原有的自然藍綠空間逐漸縮減，導致環境失衡，氣溫調節功能下降。這使得都市地區的氣溫顯著高於周邊郊區，都市熱島效應愈發嚴重。

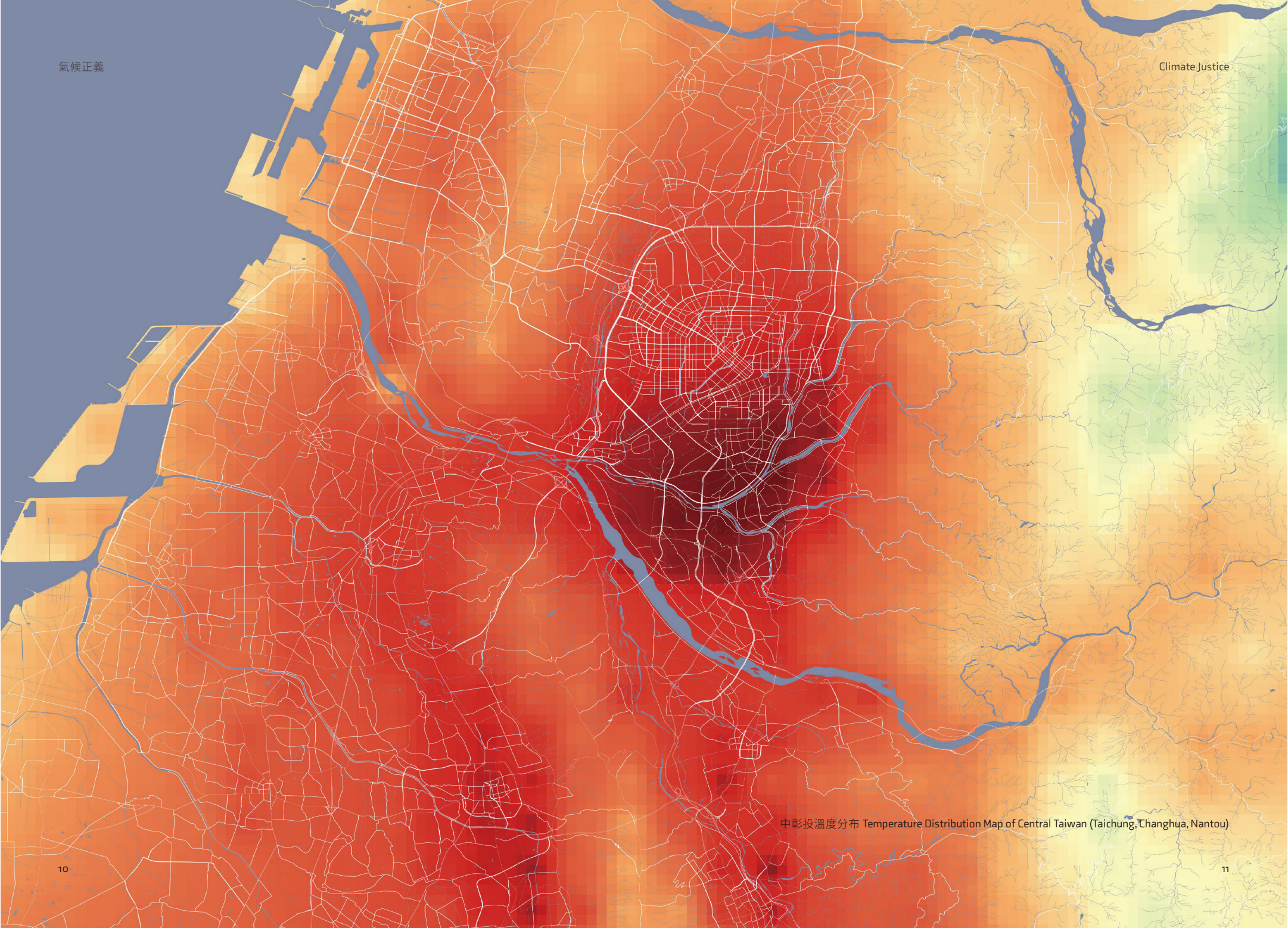


南高屏溫度分布圖 Temperature Distribution Map of Southern Taiwan (Tainan, Kaohsiung, Pingtung)

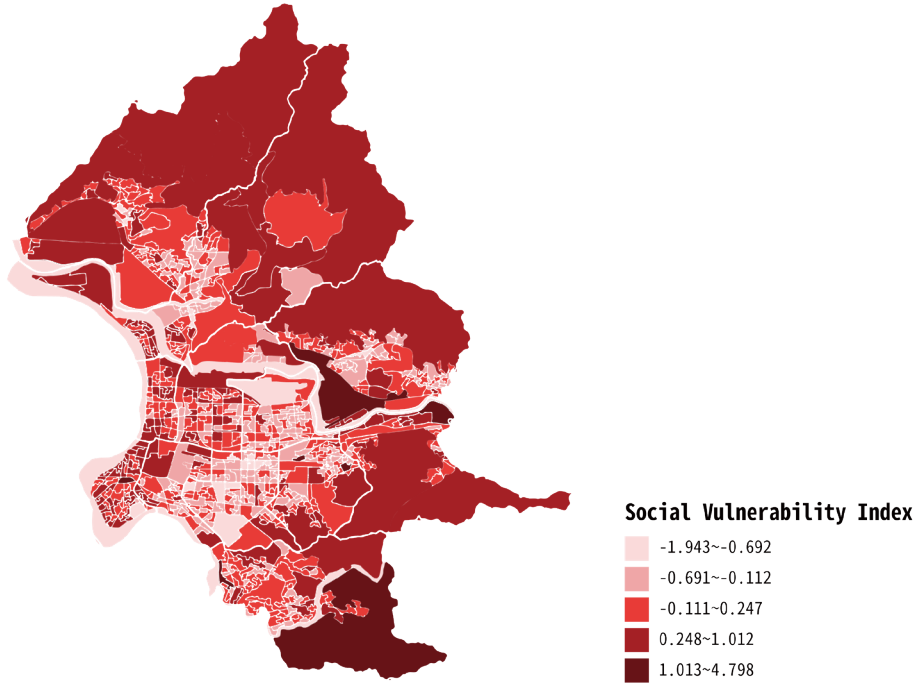
BCLab investigates the socio-economic impact of the urban heat island effect on social vulnerability. Using a decade of summer temperature data analyzed by the National Science and Technology Center for Disaster Reduction, the study assesses regional socio-economic conditions, including economic status, population structure, and medical resource distribution.These indicators effectively measure the potential damage a region may face during extreme heat events and its capacity for response, resistance, and adaptation.Drawing from the "Socio-Economic Data Service Platform" and using the "Secondary Statistical Area" as the spatial unit, six indicators are examined: number of businesses, populations under 14 and over 65, number of medical institutions, population with low education levels, and low-income households. These metrics evaluate regional vulnerability, resilience, and adaptation capacity to extreme heat, with a focus on Taipei's district-level disparities.

BCLabs research findings indicate that socio-economically vulnerable areas in Taipei are primarily concentrated in Zhongshan and Wanhua districts, while lower-vulnerability areas are mostly located in central administrative districts with higher incomes and well-developed infrastructure. Despite being in high-temperature zones, Da'an and Songshan districts exhibit relatively low vulnerability due to their stronger adaptive capacity.Additionally, the 2020 Taipei City Traffic Opinion Survey Report reveals that 8.6% of Wanhua residents commute or travel to school by walking—significantly higher than in other districts—while only 4.9% use private cars, a notably lower proportion. This suggests that while Wanhua has a lower environmental burden, it faces a heightened risk of extreme heat, highlighting issues of environmental injustice.Understanding the spatial distribution of socio-economic vulnerability enables more effective resource allocation, helping mitigate climate impacts on disadvantaged groups and strengthening overall societal resilience and adaptive capacity.

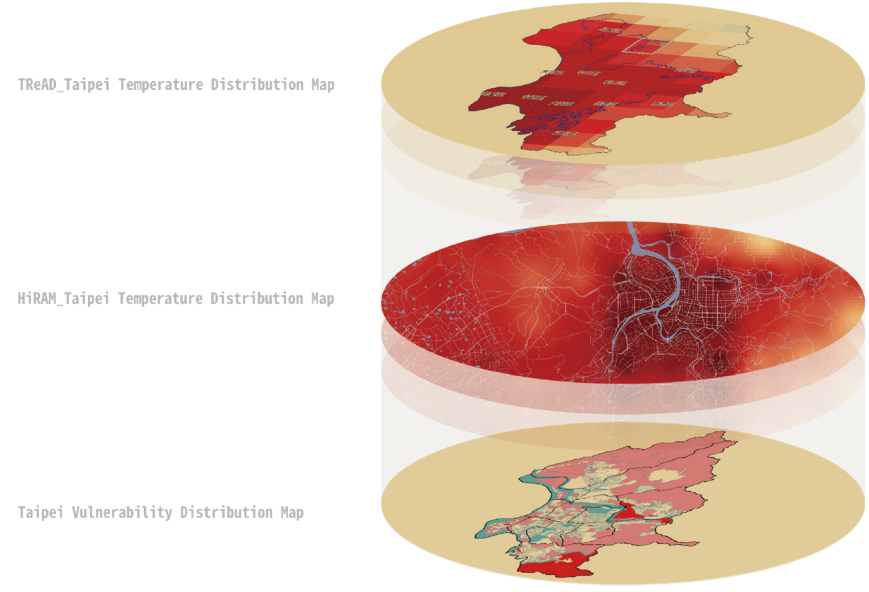
Beyond its impact on social groups, the urban heat island effect—intensified by rising temperatures and rapid urbanization—has significant environmental, ecological, health, and socio-economic consequences. Rapid economic growth and dense urban development, characterized by extensive concrete structures, impervious surfaces, and heat from economic activities, contribute to rising urban temperatures. Meanwhile, the reduction of natural blue and green spaces disrupts environmental balance and weakens temperature regulation, further amplifying the heat island effect.



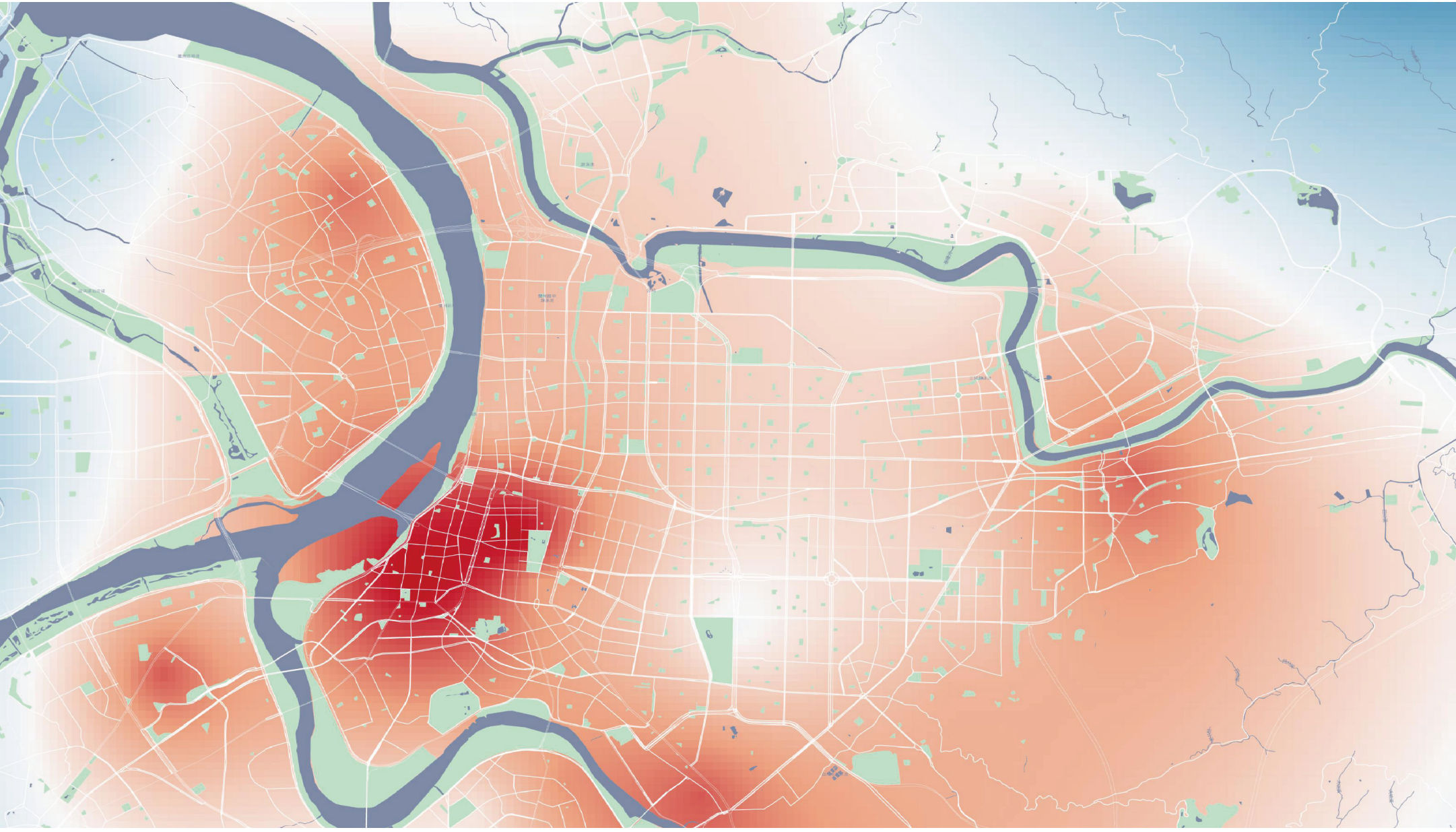
中彰投溫度分布 Temperature Distribution Map of Central Taiwan (Taichung, Changhua, Nantou)



臺北市脆弱度分布 Taipei City Social Vulnerability Index



臺北溫度分布研究疊圖 Overlay Map for Temperature Distribution Study in Taipei



臺北與大安森林公園氣溫溫差分布圖 Temperature Difference Distribution Map with Da'an Forest Park And Taipei

都市用電與溫室氣體排放：熱島效應的間接影響與應對策略

Urban Energy Use & Greenhouse Gas Emissions: UHI Impact & Responses

都市及建築用電導致的溫室氣候排放，亦是都市熱島衍生的間接課題。根據國土測繪中心對臺電住商用電數據及土地利用與開發強度的分析，統計顯示六大都市區的土地單位耗電量是全國最高的。同時，臺灣東部的花蓮、臺東、宜蘭、南投等傳統市中心的耗電量也不低，一些工業區則顯示出較高的用電特徵。都市的用電大多來自空調，而空調所產生的熱量是造成都市高溫的主要原因，高溫又進一步加劇空調使用，形成了惡性循環。

以雙北市為例，盆地地形容易蓄熱，再加上高度的都市發展，市中心的溫度常比郊區高出 3° C 以上，這樣的情況越來越頻繁，顯示都市戶外熱環境正變得愈加嚴峻。因此，如何減緩並調適戶外高溫，成為當前的重要議題。此外，研究顯示位於高溫市中心的住宅，其室內溫度通常高於低溫郊區住宅，導致市中心住宅的耗電量更大。都市熱島效應所帶來的衝擊，不僅影響高溫不適與公共健康，還涉及社會經濟與能源使用行為等層面。臺灣正面臨氣候變遷的挑戰，政府需要從政策和技術層面加強調適措施，以減少環境衝擊並緩解能源壓力。

為了應對都市熱島問題，臺灣已於 2023 年 1 月 10 日訂定《氣候變遷因應法》立，內容更是明確提出臺灣將在 2050 年達成溫室氣體淨零排放的目標，該法也將是未來我國氣候管理等一應相關法規的主要法源，除了規範都市開發以及各種人為活動的碳排放量，亦加強對於高溫危害、空氣品質惡化等項的重視與管控。在地方政府的政策上，臺北市政府已經展開熱環境調查，分析夏季高溫分佈的特徵，並針對一些示範區域提出熱島緩解策略。臺北市都發局則以「體感降溫 2°C」為目標，將自然及人工遮蔭整合評估導入建築設計，並由公有建物帶頭做起。目前已完成修改既有綠化規則，將原先僅以總綠化面積計算的「綠覆率」規定，額外考量個別喬木對遮蔭涼適效果的加權，鼓勵設置系統性的遮簷設施，整合出「綠容率」的創新方案，且依不同基地規模及屬性進行基準值的規範。

臺中市則根據當地的氣候特徵和過往研究，將 PET（生理等效溫度）大於 45.5° C 的區域劃定為熱區，並優先進行改善。市政府提出了四大降溫策略——水綠降溫、通風散熱、遮蔭涼適與節能減排，並將這些策略納入都市規劃中。對於高溫熱區，市政府提出了短期、中期和長期的行動方案，同時參考國際的風廊政策，通過風阻特性將都市風廊劃分為三個層級，根據不同層級進行相應的管制。這些規劃與措施表明，各地政府已高度重視都市熱島效應，並致力於改善居民的生活品質，以應對氣候變遷的挑戰。這些由科學研究導入都市熱島退燒的倡議政策，將有助於促進民眾、政府、設計師、建築商及維護者之間的對話，並共同選擇適合的降溫對策，進一步提升各界的環境意識與參與度，改善都市的高溫問題並增強調適能力。

Greenhouse gas emissions from urban and building electricity consumption are an indirect consequence of the urban heat island effect. According to the National Land Surveying and Mapping Center's analysis of Taipower's residential and commercial electricity data, combined with land use and development intensity, Taiwan's six major metropolitan areas exhibit the highest per-unit land electricity consumption. Traditional city centers in eastern Taiwan, such as Hualien, Taitung, Yilan, and Nantou, also show elevated electricity usage, with some industrial zones consuming even more. A significant portion of urban electricity consumption is attributed to air conditioning, which generates heat and exacerbates urban temperatures, creating a feedback loop that increases energy use.

In Taipei and New Taipei City, the basin topography traps heat, and coupled with intensive urban development, temperatures in the city center are often over 3°C higher than in suburban areas. This increasingly frequent phenomenon highlights the intensifying urban heat island effect, making the mitigation and adaptation to high outdoor temperatures a critical issue. Additionally, studies show that residential buildings in high-temperature urban centers experience higher indoor temperatures than those in cooler suburban areas, leading to greater electricity consumption. The urban heat island effect impacts not only thermal comfort and public health but also social, economic, and energy consumption patterns. To address these challenges, the government must enhance adaptation measures through policy and technological advancements to reduce environmental impacts and ease energy burdens.

To address the urban heat island effect, Taiwan enacted the Climate Change Response Act on January 10, 2023, establishing a goal for net-zero greenhouse gas emissions by 2050. This act provides the legal framework for future climate management and related regulations. In addition to regulating carbon emissions from urban development and human activities, it also strengthens controls on high-temperature hazards and air quality degradation.

In terms of local government policy, the Taipei City Government has initiated a heat environment survey to assess the distribution of high summer temperatures and develop heat island mitigation strategies for select demonstration areas. The Taipei City Department of Urban Development aims for a "2°C perceived cooling" target and has integrated natural and artificial shading evaluations into building design, beginning with public buildings as models. Additionally, the city has revised greening regulations, shifting from a focus on total greening area to incorporating the shading and cooling effects of individual trees. The updated regulations promote systematic shading structures and introduce an innovative "green volume rate" plan, with benchmark standards tailored to various site scales and characteristics.

In Taichung, based on local climate conditions and prior studies, areas with a Physiologically Equivalent Temperature (PET) exceeding 45.5°C are designated as heat zones, prioritized for remediation. The city government has proposed four primary cooling strategies: water-green cooling, ventilation and heat dissipation, shading and cooling comfort, and energy conservation and emission reduction, all integrated into urban planning. For high-temperature zones, the government has developed short-term, mid-term, and long-term action plans. Additionally, adopting international wind corridor policies, the city classifies urban wind corridors into three levels based on wind resistance characteristics and implements corresponding regulations for each level. These measures reflect the local government's commitment to addressing the urban heat island effect and enhancing residents' quality of life in response to climate change. Through science-based cooling initiatives, the city aims to foster collaboration among the public, government, designers, builders, and maintainers, selecting appropriate strategies to improve urban heat conditions, strengthen environmental awareness, and enhance adaptive capacity.