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Data-Driven Monitoring and Evaluation of Effects of Urban Cooling Technologies

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Introduction

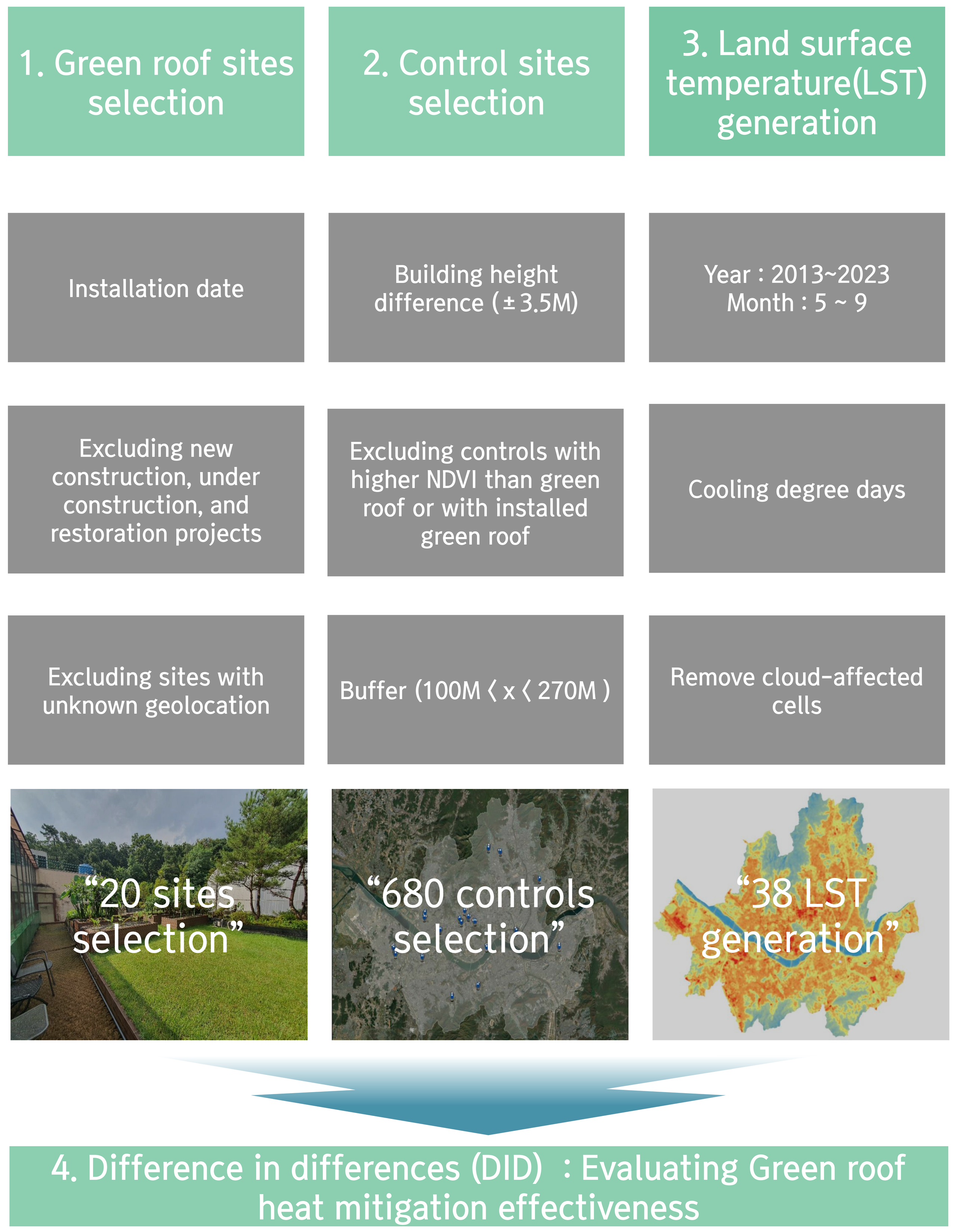
- Climate change is causing global temperatures to rise steeply, and urban populations are increasingly exposed to climate extremes. Decision-makers and urban planners are trying to adapt to climate change by improving the deteriorating urban heat environment through green infrastructure that can effectively reduce urban heat.
- Among them, green roof technology is one of the most prominent technologies in urban structures where available land is scarce. Green roof technology has been widely adopted for urban heat reduction under climate change, but there is a lack of scientific information on whether the effect of green roof technology is sustained and whether the effect of individual projects is valid. Therefore, this study aims to quantify and evaluate the effectiveness of green roofs for multiple projects by adopting a quasi-experimental method through satellite image panel data. 136 green roof sites built from 2014 to 2023 in Seoul, South Korea, were selected as research subjects. Among them, 20 sites suitable for the study were extracted, and their effects were evaluated.

Research Question & Purpose

- Can small-scale green roofs help mitigate long-term microclimates by reducing surface temperatures?
- Provide scientific evidence by evaluating whether small-scale green roofs can help mitigate long-term microclimates.

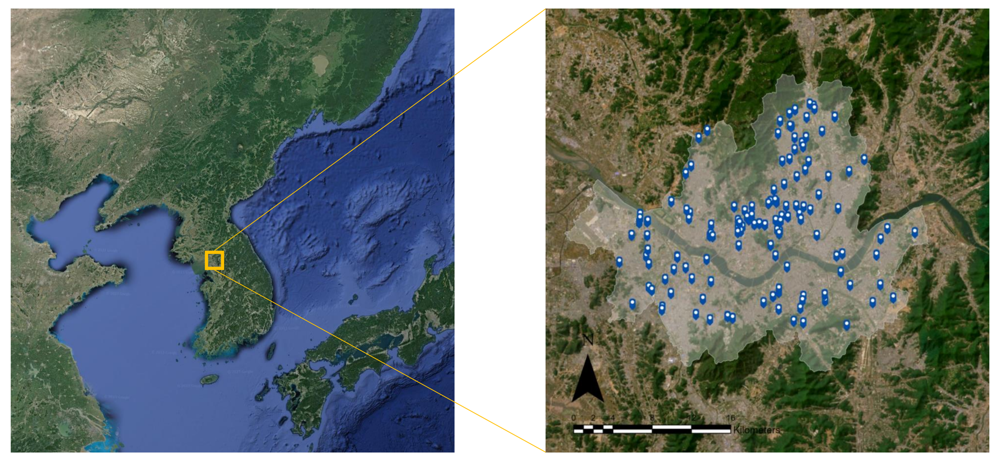
Method

Methodology diagram



1. Green roofs sites selection

- Of the 136 green roof data, 20 projects were extracted by excluding projects that may cause bias, such as the period of building construction, whether the building was new during the evaluation period, and restoration vegetation work



2. Control sites selection

- To minimize spatial and climatic heterogeneity, a control group was selected from a specific range of the green roof area, excluding nearby buildings that could be affected by green roofs and applying buffers of 270 meters and 100 meters.
- Buildings with a height difference of ±3.5m were selected as the building height significantly affects temperature.
- The control group selection also considered the presence of other green space projects and the influence of surrounding green spaces. Control buildings with higher NDVI values than the green roof treatment site were removed, as well as those controls group with green roof, identified qualitatively

3. Land surface temperature generation

- In order to determine how much the land surface temperature (LST) of the green roof sites was reduced before and after the project period compared to the control group, we generated LST data for May and September from 2013 to 2023. May and September are the months when the demand for cooling energy occurs in Korea.
- We further checked the weather conditions through historical weather observation data on the day of the LST, and selected a day that satisfied the cooling degree day (average temperature above 18℃).
- To remove cloud-affected cells, QA bands were utilized to remove values that fall under the influence of clouds. As a result, a total of 38 LSTs were constructed

4. Differences in differences : Evaluating Green roof heat mitigation effectiveness

- The DID (Difference-in-Differences) method is a quasi-experimental method that is introduced as a useful way to obtain robust inferences from observational data. It controls for unobservable bias by defining the policy effect as the difference in the average change in the pre- and post-treatment means between the treatment and control groups.
- Spatial and temporal characteristics are unobserved heterogeneity in the data, which cannot be controlled for through simple comparisons, but can be controlled for through DID methods. Since this study is a DID method using panel data, we applied a regression model with fixed effects, which was estimated using the panel DID regression function in the Stata 17 version of the statistical program. The regression equation for the DID model is as follows :

$$y_{ist} = \gamma_S + \gamma_t + z_{ist}\beta + D_{st}\delta + \varepsilon_{ist}$$

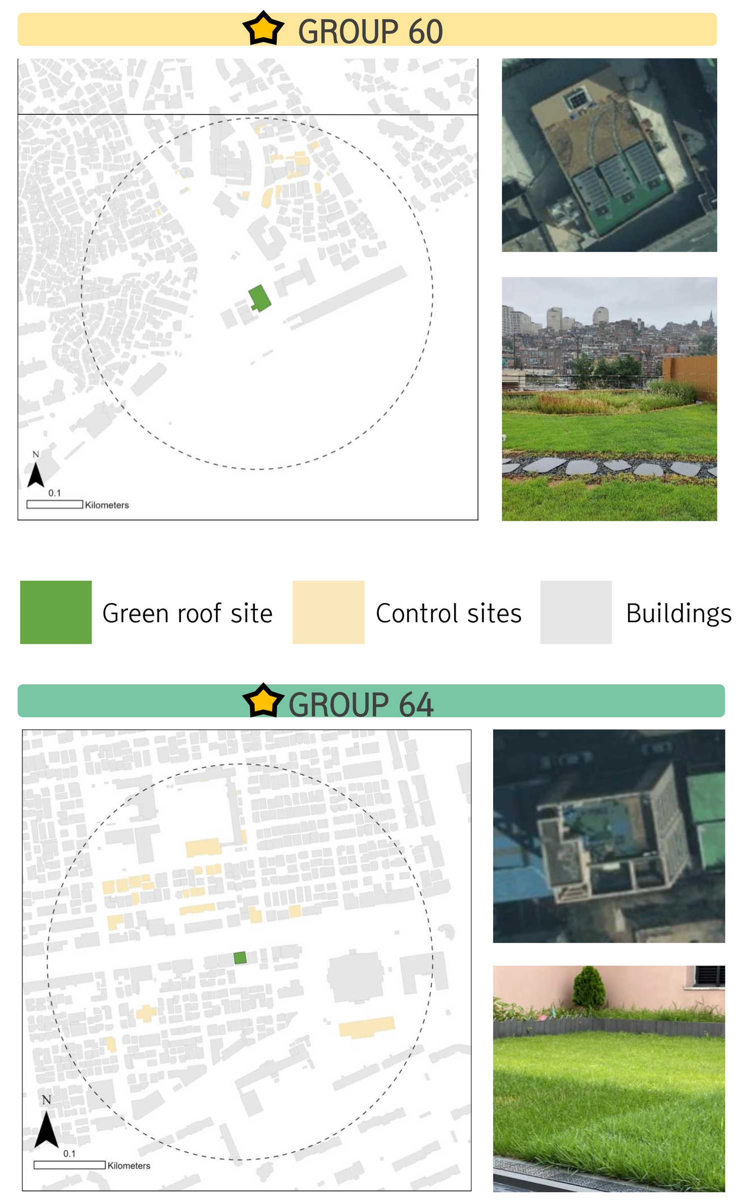
Results

- The DID regression analysis showed that the ability of green roofs to adjust the microclimate can be divided into two types: the first is when the NDVI index increases and the LST temperature decreases simultaneously, and the second is when the NDVI index increases but no decrease in LST is detected. To interpret these results, we summarize the regression coefficients of the DID analysis with the rooftop recording type of the two results as follows
- The yellow color classification of green roofs increased NDVI after the project, but no ability to regulate the microclimate was detected when the type of green roofs was Extensive or Complex. These types of vegetation were found to be dominated by herbaceous and grassy species. The green roofs of the green color classification showed an increase in NDVI and a decrease in LST after the project, and the types of green roofs were Intensive and Complex. In this case, the vegetation type was found to be a mixture of shrubs and grasses, and sometimes even shrubs were planted.

* p<0.05 ** p<0.01 *** p<0.001

GROUP	LST	NDVI	TYPE
32	0.248***	0.155***	Extensive
36	0.230***	0.00633*	Extensive
43	0.192***	0.0136	Complex
48	0.105***	0.0199	Complex
52	0.159***	0.0385***	Extensive
59	0.141	0.0187***	Extensive
☆ 60	0.441***	0.0421***	Extensive
61	0.0811	0.0203***	Extensive
71	0.190***	0.0108**	Extensive
73	0.493***	0.000916	Extensive
74	0.137***	0.00285	Extensive
134	0.151***	0.00567	Extensive

GROUP	LST	NDVI	TYPE
38	-0.0434*	0.0235***	Intensive
41	-0.273***	0.0116	Intensive
44	-0.320*	0.00525	Intensive
56	-0.0281	0.0160*	Intensive
58	-0.259***	0.0721***	Intensive
☆ 64	-0.197***	0.0270***	Complex
72	-0.0478**	0.0322***	complex
133	-0.169*	0.00786	Intensive



Discussion & Conclusion

- Currently, many green roof projects in Seoul have been expanded due to their contribution to urban heat reduction, but the results of this study show that not all green roof projects can effectively contribute to urban heat reduction. In the Seoul climate zone, the intensive type of small-scale green roofs had an impact on microclimate regulation, but the extensive type of green roofs had no detectable microclimate regulation in the satellite image data. Therefore, when expanding small-scale green roofs for urban heat reduction, the intensive type of green roofs may contribute to creating a better urban thermal environment.
- In future building energy demand modeling studies, it is necessary to investigate the extent to which the impact of the microclimate changed by green roofs can affect building energy demand in conjunction with climate change mitigation and adaptation.

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