Case Study Title:	
	
Project Name	Tokyo Metropolitan Bus Office (Shinagawa) Radiative Cooling Demonstration Project
Location	Shinagawa, Tokyo, Japan
Climate Zone	Humid Subtropical, ASHRAE 4A
Latitude/Longitude	35.6234°N, 139.7408°E
Building Type	office
Floor Area [sqm]	600 sqm
Building Height [m]	10 m
Number of Storeys	2F (Ground + 1 upper floor)
Completion Year	Estimated around 1975 (based on original architectural drawings)
Project Team	• Developer / Client: Tokyo Metropolitan Bureau of Transportation • Technology Provider: SPACECOOL INC. • Waterproofing Partner / Contractor: Lonseal Co., Ltd. • Technical Advisor: SPACECOOL R&D Team (collaboration with Ritsumeikan University) • Evaluation / Monitoring: Tokyo Metropolitan Bureau of Transportation

*mock-up experiments and other research-based experiments could be included as case study, aside from actual building construction projects if similar information could be provided.

1. Project Description

Project Overview
1) The Tokyo Metropolitan Bureau of Transportation conducted this demonstration to improve the air-conditioning efficiency and contribute to decarbonization while continuing to use a building constructed more than 50 years ago. Many older buildings in Japan have little or no insulation, resulting in high cooling loads during summer. As the impacts of global warming and the urban heat island effect intensify, enhancing cooling efficiency in such existing buildings has become an urgent challenge. The project targeted a three-story bus office building that operates from early morning to late at night, maintaining continuous air-conditioning for staff comfort. 2) A passive radiative cooling waterproof sheet, “Innovation Proof RR” developed by SPACECOOL INC. and Lonseal Co., Ltd. was installed on the reinforced-concrete flat roof with existing PVC waterproofing and 30 mm internal insulation (Drizol board). Unlike conventional heat-shielding sheets with 75–80 % solar reflectance, the new material exhibits about 95 % solar reflectance and 95 % infrared emissivity, enabling the surface temperature to fall below ambient under clear-sky conditions. The installation method and maintenance requirements are identical to standard waterproof membranes, making it easily applicable to existing buildings without major structural changes. 3) The installation of the radiative cooling waterproof sheet resulted in an average reduction of **7.8 % in electricity consumption** at the bus office during the summer of 2024, compared with the previous year, while outdoor temperatures remained nearly identical. The roof surface temperature decreased by up to 16 °C (average 7 °C), and solar heat inflow was reduced by an average of 74.6 % and up to 86.2 %. These results demonstrate that cooling loads can be effectively reduced without altering existing building systems. Building upon these findings, the Tokyo Metropolitan Government is now expanding the adoption of this technology to **public facilities such as schools and gymnasiums**, which also serve as emergency shelters. The technology provides an immediate, low-cost solution for enhancing energy efficiency in existing buildings while mitigating heat stress and contributing to climate-change adaptation.

2. Climate & Site Context

Basic Climate Conditions		
Temperature	Annual Average	16.7°C
	Annual Range	5°C (January) - 31°C (August)
Relative Humiditiy	Annual Average	64%
	Annual Range	50% (January) - 78% (July)
Annual Degree-Days (ASHRAE Standard 169-2020)		N/A

Climate Analysis
Tokyo has a humid subtropical climate characterized by hot, humid summers and mild winters. During the cooling season (May to September), the average daily maximum temperature frequently exceeds 30 °C, and in recent years, **extreme heat events with temperatures above 35 °C have become common, with some days approaching 40 °C.** High humidity levels (60–80 %) limit the effectiveness of natural ventilation,and the dense urban fabric with asphalt surfaces intensifies the heat island effect, keeping nighttime temperatures elevated. Strong solar radiation and high humidity also suppress longwave heat emission to the sky, resulting in a substantial increase in building cooling loads. Under these conditions, **Passive Daytime Radiative Cooling (PDRC)** technologies are highly effective, as they can dissipate heat both during the day and at night without energy consumption. During the summer of 2024, several consecutive heatwave days occurred, providing realistic conditions to evaluate the performance of the PDRC waterproof membrane in Tokyo's urban climate.

Site Analysis
The demonstration site is the Tokyo Metropolitan Bureau of Transportation's Shinagawa Bus Office, located in a highly urbanized district near Shinagawa Station, one of Tokyo's major Shinkansen hubs. The surrounding area is densely built with low- to mid-rise offices, houses, and apartment buildings, with limited green coverage and extensive paved surfaces that trap heat during summer. Situated on the Kanto Plain about one kilometer from Tokyo Bay, the site is flat with no surrounding mountains. Although close to the sea, the bayfront is lined with reclaimed islands, resulting in a distinctly urban microclimate. The area is separated from the high-rise business districts, so strong downdrafts are minimal, but nearby buildings limit the penetration of sea breezes. As a bus depot, the site is surrounded by asphalt parking areas with no shading elements, providing realistic conditions for evaluating the performance of Passive Daytime Radiative Cooling (PDRC) materials under intense solar radiation and typical urban heat-island conditions.

3. Passive Cooling Design Details

Passive Cooling Strategies (please tick implemented passive cooling strategies)
☐ Building Orientation & Form (site orientation, building shape, etc.) ☐ Envelope Design (insulation, air-tightness, shading, window system, thermal mass, etc.) ☐ Natural Ventilation (cross ventilation, stack ventilation, night ventilation, etc.) ☐ Evaporative Cooling (direct/indirect evaporative cooling, etc.) ☐ Ground Cooling (geothermal, ground-coupled systems, basement/underground space,etc.) ☑ Radiative Cooling (cool roof, night sky radiation, radiant barriers, reflective surfaces, etc.) ☐ Nature-based Solutions (green roof/wall, tree shading, etc.) ☐ Others (human behavior, clothing, semi-passive (fans, etc.))
Description (please describe one strategy per box – you can add more boxes below if needed)
This project adopted a passive cooling strategy using a radiative cooling waterproof membrane, *Innovation Proof RR*, co-developed by SPACECOOL INC. and Lonseal Co., Ltd. The membrane integrates a **Passive Daytime Radiative Cooling (PDRC) material** (*SPACECOOL*) with a waterproof sheet. The PDRC material combines a high solar reflectance of approximately 95% with a high infrared emissivity of about 95%, reflecting most incident sunlight while radiating heat efficiently toward the sky. Under clear-sky conditions, the roof surface can cool below the ambient air temperature. By integrating the PDRC material into the waterproof sheet, the system can be installed without any structural modification, using the same construction method as conventional PVC waterproofing. For low-rise office buildings with few windows—where most heat gain occurs through the roof—reducing roof surface temperature is particularly effective in improving energy efficiency. The PDRC membrane requires no power, control, or water, and its maintenance is equivalent to standard waterproof systems, enabling immediate and large-scale application to existing buildings.
N/A
N/A

4. Active Components

Active (Hybrid) Cooling Strategies (please describe one strategy per box – you can add more boxes below if needed)
No additional active or hybrid cooling systems were introduced in this project. The existing air-conditioning system of the office building remained unchanged throughout the demonstration, in order to accurately assess the performance of the passive radiative cooling membrane. The objective was to verify the reduction in heat load and electricity consumption achieved solely through the application of the PDRC waterproof sheet on the roof. This approach ensured that the measured effects represented the genuine contribution of the passive system without interference from mechanical or control-based cooling strategies.
N/A

5. Performance Data

Cooling Energy Use
Electricity consumption during the summer period (May–September 2024) was monitored to evaluate the effect of the Passive Daytime Radiative Cooling (PDRC) membrane installed on the roof. The measurement was conducted under comparable weather conditions to the previous year, with no change to the building's existing air-conditioning system. The results showed an **average reduction of approximately 7.8% in electricity consumption** compared with the previous year, demonstrating that the passive radiative cooling intervention effectively reduced the cooling energy demand. The reduction was achieved solely through the roof application of the PDRC waterproof sheet, without the use of any additional mechanical or control-based systems. Although absolute energy data are not disclosed due to confidentiality requirements by the Tokyo Metropolitan Bureau of Transportation, the verified energy-saving ratio provides clear evidence of the potential for significant cooling load reduction in existing low-rise office buildings in hot and humid climates.
Indoor Thermal Comfort
The indoor thermal comfort of the office building remained stable throughout the demonstration period, as the entire facility is air-conditioned during working hours. No noticeable change in occupants' perceived comfort was reported. However, the application of the Passive Daytime Radiative Cooling (PDRC) waterproof sheet contributed to maintaining the same comfort level with a lower cooling energy requirement. By reducing the roof surface temperature and suppressing solar heat inflow, the cooling load on the existing air-conditioning system was decreased, resulting in improved operational efficiency without compromising comfort. The findings indicate that PDRC materials can enhance energy efficiency in continuously cooled buildings while preserving indoor comfort conditions.

6. Financial Data

Cost Benefits
Detailed financial figures are not disclosed at the request of the Tokyo Metropolitan Bureau of Transportation. However, the project demonstrated clear cost benefits through the integration of the Passive Daytime Radiative Cooling (PDRC) material into a standard waterproofing system. The *Innovation Proof RR* membrane can be installed using the same construction process as conventional PVC waterproofing, without additional structural work or specialized labor. In typical heat-mitigation projects, installation costs account for the majority of total expenses. By embedding the radiative cooling function directly into the waterproof sheet, this approach eliminates separate installation costs for heat-shielding materials, resulting in a highly cost-effective solution. The combined product thus enables simultaneous waterproofing renewal and thermal performance enhancement, offering a practical and economically viable pathway for retrofitting existing buildings under decarbonization programs.

*Please try to extract passive cooling cost and savings; however, if it is difficult, please annotate the premise. (e.g., the calculation includes the cost for both passive heating and cooling, etc.)

7. Passive Cooling Operation

Maintenance Requirement
The Passive Daytime Radiative Cooling (PDRC) waterproof sheet requires no special maintenance beyond that of conventional waterproof membranes. Routine inspection and cleaning schedules are the same as those for standard PVC roofing systems. Because the PDRC function is integrated within the waterproof sheet itself, there are no mechanical, electrical, or control components that require operational management or replacement. The material's durability and weather resistance are equivalent to those of ordinary waterproofing products, ensuring long-term stability of both waterproofing and radiative cooling performance. This allows building owners to benefit from continuous energy savings without any increase in maintenance cost or effort compared to conventional systems.

8. Lesson Learnt / Recommendations

Technical Challenges, Solutions and Achievement
A key technical challenge was to evaluate the radiative cooling performance without modifying the existing building structure or air-conditioning system. This was solved by integrating the Passive Daytime Radiative Cooling (PDRC) material into a waterproof membrane, allowing direct roof application with conventional construction methods. The experiment confirmed that the PDRC system can be implemented on aged buildings without disrupting daily operations. The project demonstrated that radiative cooling technology can be combined with essential building functions such as waterproofing, making it an effective and practical solution for retrofitting existing public facilities.
Financial Challenges, Solutions and Achievement
As the project was conducted under a public institution, detailed financial information could not be disclosed. However, by integrating the Passive Daytime Radiative Cooling (PDRC) material into the waterproofing system, the project established a cost-efficient implementation model in which the installation cost of the radiative cooling layer can be included within the normal waterproofing renewal process. In typical heat-mitigation retrofits, labor and

installation costs represent the largest financial burden rather than material costs. By combining the PDRC material with the waterproofing membrane, this barrier can be avoided. The model offers a replicable and cost-effective approach for municipalities seeking to advance building decarbonization during routine waterproofing renovations.
Other Challenges, Solutions and Achievement
Initially, there was some hesitation among stakeholders to introduce a new material into public facilities. However, confidence grew as clear measurement data demonstrated significant temperature reduction and energy-saving effects, and as Lonseal Co., Ltd. began providing installation warranties for the system. This combination of verified performance and guaranteed quality encouraged greater willingness for adoption. The project also revealed that simple, maintenance-free passive technologies tend to be more readily accepted by facility managers. Following the success of this demonstration, the Tokyo Metropolitan Government has already started expanding the application of the technology to schools and gymnasiums, where heat mitigation is critical for ensuring safe environments in case of disasters. This model has high potential for replication and global dissemination as a practical climate adaptation measure.

9. Free Description

Free Description
This project demonstrated a replicable model for introducing Passive Daytime Radiative Cooling (PDRC) technology into existing buildings through standard waterproofing renovation. By integrating the PDRC material into the waterproof sheet, the system can be applied without structural modification or specialized labor, allowing simultaneous renewal of waterproofing and enhancement of thermal performance at no additional installation cost. This approach is particularly suitable for low-rise public buildings, such as offices, schools, and gymnasiums, where roof heat gain represents a major portion of cooling load. From a policy perspective, the project provides a practical example of how local governments can incorporate passive cooling technologies into routine maintenance programs to advance decarbonization. The demonstration in Tokyo also highlighted that public acceptance increases when the technology is simple, maintenance-free, and supported by reliable performance data and installation warranties. The model is expected to be widely replicable in other cities with hot and humid climates, especially in Asia and other urban regions facing severe heat stress. The use of PDRC-integrated waterproof membranes offers not only energy savings but also contributes to resilience in emergency shelters during power outages or disasters. The findings suggest that combining passive radiative cooling with essential building envelope functions could become a key strategy for sustainable and climate-adaptive architecture worldwide.

10. Annex

Supporting documentations

A comparison of electricity consumption at the bus depot between 2023 and 2024 is shown in Table 1. As a result, the installation of the SC sheet led to a reduction in electricity use during the summer season, with a **maximum decrease of 8.7 % and an average reduction of 7.8 %**. These findings confirm the effectiveness of the SC sheet in reducing the facility's energy consumption. Since the average outdoor temperatures in Tokyo were nearly identical for both years, it is assumed that the impact of air temperature on the electricity consumption was minimal.

Table 1. Reduction in Electricity Consumption at the Depot in 2024 Due to SC Sheet Installation

Month	July	August	September	Average
Year-on-year comparison	– 6.7%	– 8.7%	– 8.4%	**– 7.8%**
(Ref.) Avg. Temperature in Tokyo, (FY2023)	28.7°C	29.2°C	26.7°C	—
(Ref.) Avg. Temperature in Tokyo, (FY2024)	28.7°C	29.0°C	26.6°C	—

To verify the energy-saving and temperature-reduction effects of the SC sheet, the following two types of data were examined. Table 2 is calculated based on the thermal properties of each roof-layer material, including thermal conductivity, heat transmission coefficient, solar reflectance, and infrared emissivity. The analysis estimated that, compared with the conventional waterproof sheet, the introduction of the SC sheet reduced solar heat inflow by up to **86.2 %** and on average by **74.6 %**. When compared with a conventional heat-shielding waterproof sheet, the reduction was estimated at a maximum of **27.0 %** and an average of **26.7 %**.

Table 2. Estimated Reduction in Solar Heat Gain with SC Sheet

Month	July	August	September	Average
vs. Waterproof sheet	– 74.6%	– 68.5%	– 86.2%	**– 74.6%**
vs. Heat-shielding sheet	– 27.0%	– 26.5%	– 26.5%	**– 26.7%**

Figure 1 compares the roof surface and attic temperatures under two conditions: installation of the SC sheet and installation of a conventional heat-shielding waterproof sheet.
In August 2024, when the average outdoor temperature was highest, the roof surface covered with the SC sheet showed a **maximum temperature reduction of about 16 °C** and an **average reduction of about 7 °C** compared with the heat-shielding waterproof sheet.
For the attic temperature, a **maximum reduction of about 5 °C** was observed during the monitoring period.While typical heat-shielding waterproof sheets generally achieve only about a 1 °C decrease in attic temperature, the SC sheet demonstrated a significantly greater cooling effect.
In addition, due to the suppression of solar heat accumulation, the cooling benefit of the SC sheet continued **throughout the day and night**, providing 24-hour temperature moderation even after sunset.Although the material did not cool below the ambient air temperature, this was attributed to **Japan's extremely humid summer climate**, where high atmospheric

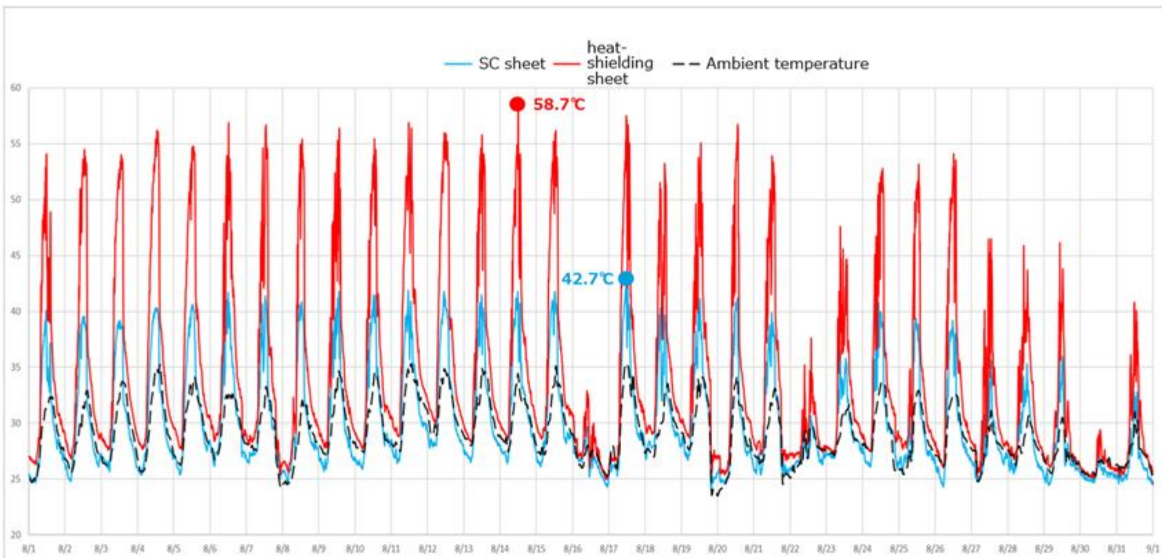
humidity in August inhibits long-wave radiation from the roof surface, limiting radiative heat loss.

Under drier conditions — such as in autumn or in arid regions like California — the same Passive Daytime Radiative Cooling (PDRC) material has been shown to achieve sub-ambient cooling.

Nevertheless, even under such humid conditions, the SC sheet consistently maintained lower surface temperatures than the conventional heat-shielding waterproof sheet.

This demonstrates that radiative cooling materials can achieve the **lowest possible surface temperature in any climatic environment**, making them highly effective for reducing building air-conditioning energy demand.

Therefore, PDRC technology offers a versatile and reliable passive cooling solution that enhances energy efficiency and resilience across a wide range of climatic regions.



Max Surface Temp. SC sheet : 42.7℃ / heat-shielding sheet : 58.7℃

Avg. Surface Temp. (8:00–18:00) SC sheet : 33.7℃ / heat-shielding sheet : 40.8℃

Figure 1: Comparison of Roof Surface Temperature in August 2024 (SPACECOOL Sheet vs. Conventional Heat-Shielding Waterproof Sheet)

11. Citation

Citation
1. *SPACECOOL Technology Overview – Passive Daytime Radiative Cooling (PDRC) for Buildings and Infrastructure.* Retrieved from https://spacecool.jp/en/technology/ 2. *Demonstration Trial with Tokyo Metropolitan Bureau of Transportation Confirms SPACECOOL's Effect in Reducing Air Conditioning Load Lower Energy Consumption at Bus Depot Contributes to a Carbon-Neutral Society.* Retrieved from https://spacecool.jp/en/news/20250521/ 3. *Demonstration Results of the Radiative Cooling Material "SPACECOOL"* Retrieved from https://www.kotsu.metro.tokyo.jp/pickup_information/news/others/2025/otr_p_2025052112045_h.html 4. *SPACECOOL and Ritsumeikan University to Announce Joint Research Results on Building Energy Efficiency – Visualizing the Practical Application of Radiative Cooling Materials in Buildings –* Retrieved from https://spacecool.jp/en/news/20250530/

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