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Cooling Architecture: Prototyping an Optimised PDEC-integrated Façade Panel to Enhance Urban Thermal Comfort

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Abstract: Integrating passive downdraft evaporative cooling (PDEC) into facades offers an innovative method of decreasing surface temperatures and creating downdraft currents that help cool buildings and their surroundings. Analysis of available literature revealed a significant lack of understanding in the effects PDEC-generated downdraft on internal and external environments. This paper is a summary of a dissertation aiming to design an effective PDEC-façade panel and evaluating its cooling potential and effect on surrounding microclimates. Prototype testing in the evaporative cooling (wet) experiment resulted in surface temperature 11 ºC lower than the control (dry) experiment. The prototype produced an equivalent cooling energy of 2800Wh. These results show a clear cooling benefit of the panel, demonstrating its potential use in new builds or retrofit construction projects, helping reduce cooling loads and improve comfort conditions around the building.

Keywords: Passive-evaporative-downdraft-cooling, terracotta, clay, façades, passive cooling

1. Introduction

Rising global temperatures and rapidly expanding high-density cities cause the exacerbation of the urban heat-island effect (UHI) (Gregory and Azarijafari, 2021). Simultaneously, increasingly stringent building energy regulations push built-environment designers to seek innovative passive strategies to replace or enhance air-conditioning systems. Facades have become essential in regulating energy consumption and user comfort in modern buildings (Technal, 2023). Passive downdraft evaporative cooling (PDEC), when integrated into facades, helps decrease UHI, lower cooling loads and increasing user comfort by creating a cool downdraft current. In high-rise facades, the integration of PDEC would transform these generally under-utilised vertical planes into integral components of climate-resilient cities.

2. Background

Passive evaporative cooling in the built environment describes the evaporation of water from hard surfaces (Pokorny, 2019). It is most effective in hot, dry climates, such as those found in the Middle East (Ford et al., 1998), explaining its presence in the region’s vernacular architecture. However, climate predictions indicate a general global trend towards drier and hotter weather (Caretta et al., 2022), increasing PDEC’s suitability to more areas.

PDEC works based on latent cooling, consisting in an adiabatic drop in temperature with increase in relative humidity (Abdullah et al., 2023). Its chilling effect is driven by water phase change from liquid to gas, which causes a temperature drop in the directly adjacent air (Pokorny, 2019). As water evaporates, air density rises, resulting in the now water-saturated air sinking, and creating a downwards moving current. Increased air movements and temperature differentials created by PDEC directly enhance user comfort (Palacios, 2021), with significant potential to decrease the effects of UHI (Ford, 2001).

Modern examples of PDEC elements studied for this paper include the Bioskin by Nikken Sekkei Architects (Figure 1a), the Hydroskin by the University of Stuttgart Institute of Lightweight Structures (Figure 1b) and the Torrent Research Centre by Abhikram Architects (Figure 1c). Table 1 presents a comparison of their PDEC features.

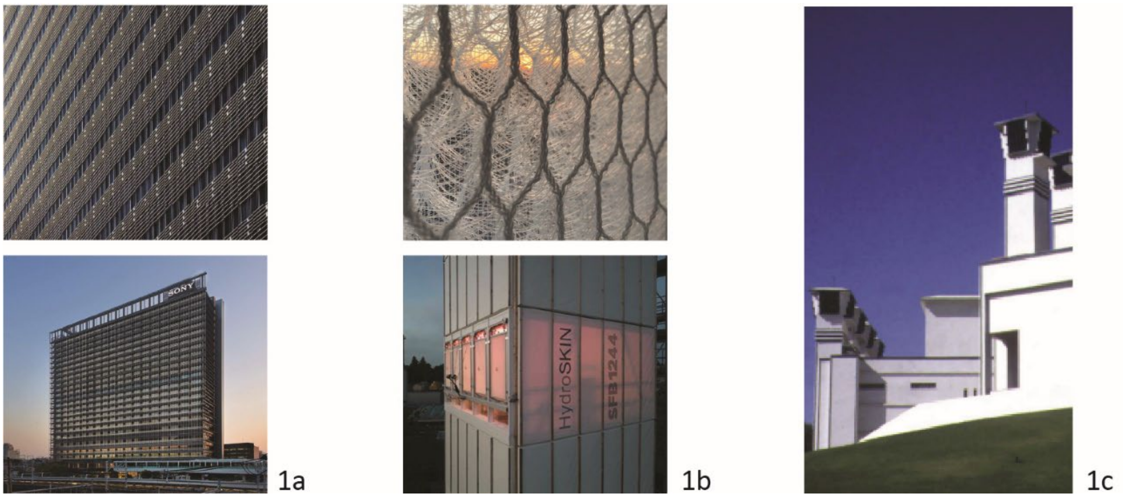


Figure 1. Visuals of the modern PDEC built systems.

Table 1. Evaporative cooling feature comparison of modern PDEC built systems.

	Bioskin	**Hydroskin**	**Torrent Research Center**
Evaporation mechanism	Water travels through the hollow ceramic handrail and evaporates on its outer surface.	Water droplets wet then evaporative off a 3D synthetic sheet placed over glazing.	Water is sprayed in a wind tower. The small droplet size allows fast evaporation in the air.
Main evaporative surface material	Ceramics	Synthetic fabric	Air
Evaporative surface location	Balcony railings	Over glazing	Building wind tower
Evaporative surface size	110mmxlength of handrail (around 2000mm)	1800mmx500mm	---

3. Methodology

The research was carried out in 3 main parts: pre-design research, prototype design/fabrication and experimental testing. The pre-design phase consisted in a literature review and case study analysis to understand PDEC governing factors and current challenges with its implementation within facades. Prototype design incorporated the research learnings and explored appropriate materials considering cost, accessibility and fabrication feasibility. Finally, the experimental phase quantified the cooling potential and effect of the prototype panel.

It was hypothesised that a flat PDEC façade panel would bring cooling benefits to microclimates within a one-meter radius by decreasing air temperatures, quantifiable by measuring the water evaporation through the panel surface and microclimate temperatures and RH values.

3.1 Design Process

From the literature review, it was understood that a higher internal porosity would increase the rate of water migration and absorption, hence increasing evaporation. London clay was selected as the prototype material for its ease of manufacturing, accessibility, high porosity and its existing large usage within the façade industry.

Afterwards, various design iterations were carried out to establish the best design following a balance of high evaporation rate to weight ratio and manufacturing ease. The final prototype is shown in Figure 2, inspired by traditional Syrian tile geometries. The panel functions by water being poured into an interior channel. Thanks to the unglazed clay, the water travels through the panel wall to the exterior face where it can evaporate.

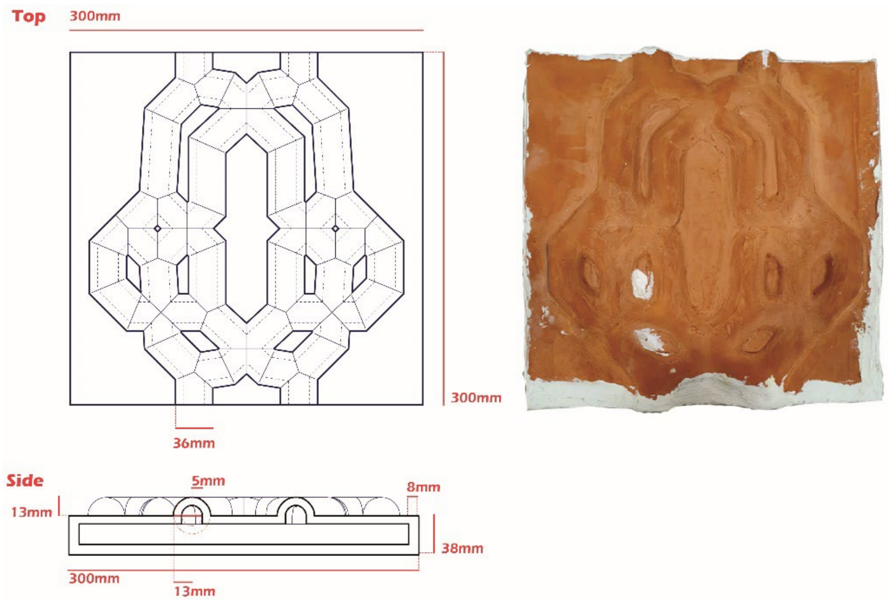


Figure 2. Final prototype dimensions and picture. By Author.

3.2 Experimental Set-up

The experiment set-up (Figure 3) re-creates similar conditions to those generated in a real-life operation of the system when used as external cladding for a facade. The insulation box emulates an interior space within a building. The experiment was held in semi-controlled conditions of a non-sealed laboratory room.

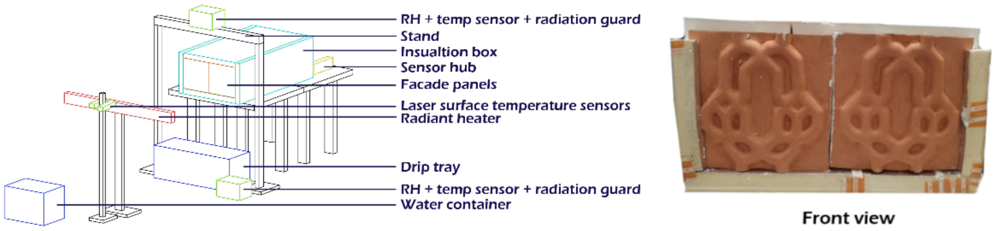
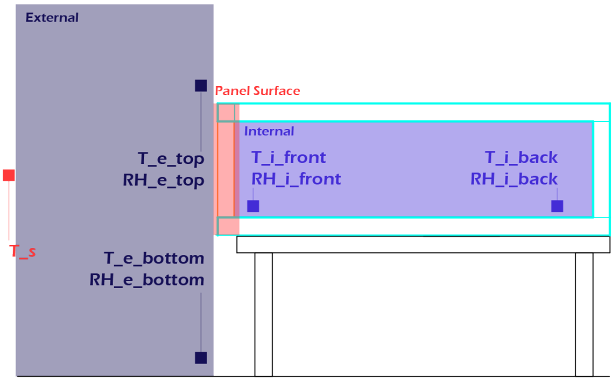


Figure 3. Experimental set-up diagram. By Author.

The panels were placed as the front face in a 1.2mx0.6mx0.5m box made of 100mm thick rigid insulation board sealed with airtight tape. A radiant heater was placed 1m in front of the box, generating circa 2.6kW/m^2 on the panel surface.

Sensors, placed as shown in Figure 4, were used to measure the effects on the three surrounding microclimates: external (air within 100mm of the external panel face), internal (isolated air volume enclosed by the insulation box), and panel surface (panel surface temperature). A drip tray was placed under the panel to ensure any leakage could be recorded.



Acronym	Sensor
T_s	Laser surface temperature
T_e_top	Air dry bulb temperature
RH_e_bottom	Air relative humidity
T_e_top	Air dry bulb temperature
RH_e_ bottom	Air relative humidity
T_i_front	Air dry bulb temperature
RH_i_front	Air relative humidity
T_i_back	Air dry bulb temperature
RH_i_back	Air relative humidity

Figure 4. Cross-section of experiment set-up showing sensor placement with the box. By Author.

3.3 Experimental Procedure

Each tile was weighed and positioned, and sensors attached to the back-face. A first round of measurements to determine the initial conditions. The panel was filled with 5l of water and radiant heater immediately turned on. Data was automatically collected from the sensors at programmed intervals. Manually collected data was measured at pre-established times. The experiment run-time was two hours. Every 30 minutes, the height of the water in the drip tray was recorded and 1l of water was added inside the panel. At end of the experiment, the water was emptied from the panel into the drip tray and the height of water in the drip tray measured. The panels were weighed to determine the amount of water remaining in their walls.

A 'dry' experiment was conducted to determine the control conditions of the panel, to understand the microclimates around the panel with no water in the panel. Subsequently, two trials of the 'wet' experiment were conducted.

4. Results

4.1 Panel surface temperature

In the wet experiment, T_s consistently dropped after the addition of water, while in the dry experiment, T_s continually increased (Figure 5a). The drop was caused both by the energy absorbed during the evaporation of water and the low water temperature.

The dry experiment increased by +20.2 degrees from the experiment start, while the wet only by +11.8 degrees. Hence, adding water to the panel and allowing PDEC to happen produced 8.4 degrees lower surface temperature than that of the dry panel alone.

4.2 Internal Microclimate

During both experiments, T_i_front increased, though the wet T_i_front was less than the dry T_i_front, reaching a temperature at 110mins of 25.6 ºC and 22.3 ºC respectively (Figure 5b). RH_i_front decreases in both experiments, where at 110min it was 51% for the dry and 57% for the wet. The differences between the starting and 110min values in the dry experiment of RH_i_front and T_i_front were +5% and -2.8 ºC respectively, while for the wet experiment these were 5.9% and +0.8 ºC.

T_i_front increases in both experiments due to the thermal conductivity of the clay. This showed that the box should have been better isolated from the external environment to understand the full cooling potential of the panel.

The drop in RH_i_front and RH_e_top was associated to the increased ability of the air to hold water vapor. Peaks in RH_i_front can be attributed to large cracks opening in the panel.

4.3 External Microclimate

Similarly to internal microclimate, T_e_top and T_e_bottom increased over the duration of both experiments. The dry experiment consistently registered higher temperatures than the wet (Figure 5c). The inverse is true for the RH.

The dry experiment increased 2.6 ºC in T_e_top and decreased 4.6% in RH_e_top from the experiment start, while the wet produced increased 2.9 ºC at T_e_top and decreased 5.1% at RH_e_top.

The higher difference T_e_top produced in the wet experiment disprove the hypothesis, however due to uncontrolled conditions of the laboratory space, this would need further investigation.

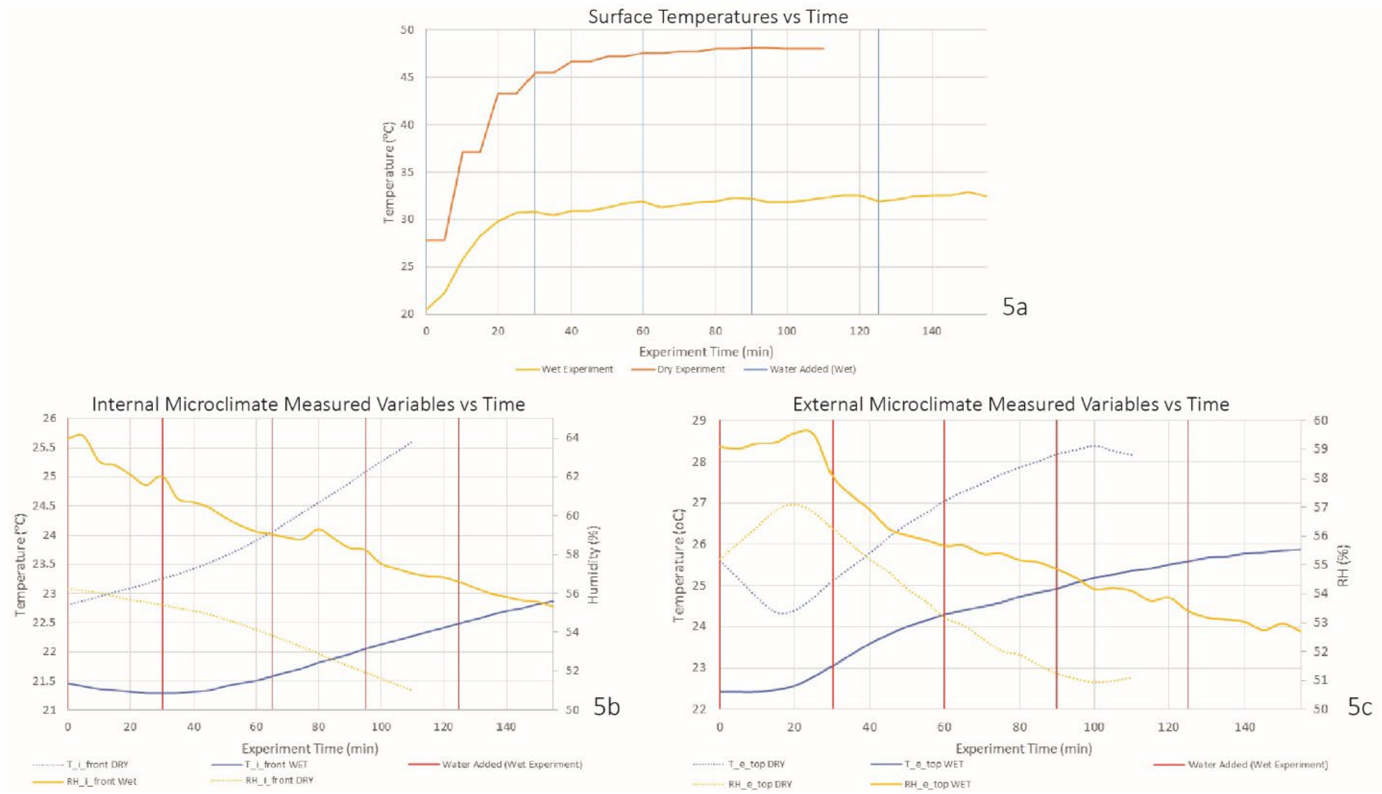


Figure 5. Graphs of measured variables in each microclimate. By Author.

4.4 Generated Cooling Energy

A rudimentary calculation was made for the cooling energy generated from the water evaporation through the wet experiment, using E1:

$$E = H_{vap} \times n_{evap}$$

Where: E (kJ) is the cooling energy generated; H_{vap} (kJ/mol) is the latent heat of vaporisation of water at 20 ºC and atmospheric pressure; n_{evap} (mol) is the quantity of moles of water evaporated during the experiment

This calculation assumes that water evaporates only through the exterior face of the panel. Overall, 10008kJ of cooling energy was produced over the course of the wet experiment, translating to 2800Wh. This equivalates to 15560Wh/m2 for this façade panel system.

5. Discussion

The experiments show that the prototype has a cooling effect on the microclimates around it. These findings align with experiments of the Hydroskin, where recorded temperatures from the wet panel produced a façade surface temperature reduction of 8-12 ºC (Eisenbarth et al., 2022).

The calculated cooling energy of 10008kJ should be regarded as a high-level estimate due to the assumptions made, such as evaporation occurring only at the panel surface. Leakage in the drip-tray introduce further uncertainties.

Additionally, the small-scale of this experiment prevented the measurement of downdraft currents, which are a key component of PDEC strategies. The nature of fluid dynamics is such that gas behaviours change with scale, meaning that the downdraft generated by a PDEC façade would vary at building scale compared to laboratory conditions. Moreover, laboratory settings do not allow for large scale testing of PDEC systems in complex urban environment settings. Hence, the future experimentation should focus on external, large-scale set-ups on longer time-scales.

Using thermal mass of water to aide minimising thermal loses from the building fabric, should be considered in future iterations. Lower surface temperatures could allow this system to be used as an alternative to insulation or reducing material and building’s available floor area. Overall, this experiment and fabrication process shows that clay façade panels with PDEC are likely to be effective solutions for lowering building cooling loads.

6. References

Abdullah, S., Zubir, M.N.B.M., Muhamad, M.R.B., Newaz, K.M.S., Öztop, H.F., Alam, M.S. and Shaikh, K. (2023). *Technological development of evaporative cooling systems and its integration with air dehumidification processes: A review.* Energy and Buildings, 283, p.112805. doi:https://doi.org/10.1016/j.enbuild.2023.112805.

Caretta, M.A., A. Mukherji, M. Arfanuzzaman, R.A. Betts, A. Gelfan, Y. Hirabayashi, T.K. Lissner, J. Liu, E. Lopez Gunn, R. Morgan, S. Mwanga, and S. Supratid, 2022: Water. In: *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 551–712, doi:10.1017/9781009325844.006.

Eisenbarth, C., Haase, W., Blandini, L. and Sobek, W. (2022). *Potentials of Hydroactive Lightweight Façades for Urban Climate Resilience*. Civil Engineering Design, [online] 4(1-3). doi:https://doi.org/10.1002/cend.202200003.

Fillet, R., Nicolas, V., Celzard, A. and Fierro, V. (2022). *Better understanding of solar water evaporation systems using a biosourced foam and its modelling*. Applied Thermal Engineering, 214, pp.118802–118802. doi:https://doi.org/10.1016/j.applthermaleng.2022.118802.

Ford, B., Patel, N., Zaveri, P. and Hewitt, M. (1998). *Cooling without Air Conditioning: The Torrent Research Center*. Renewable Energy, 15(1-4), pp.177–182. doi:https://doi.org/10.1016/s0960-1481(98)00150-5.

Ford, B. (2001). *Passive downdraught evaporative cooling: principles and practice*. Architectural Research Quarterly, 5(3), pp.271–280. doi:https://doi.org/10.1017/s1359135501001312.

Gregory, J. and Azarijafari, H. (2021). *Urban Heat Islands*. [online] MIT Climate Portal. Available at: https://climate.mit.edu/explainers/urban-heat-islands.

Palacios, D. (2021). *Case Study II : The Torrent Research Centre in Ahmedabad, by Abhikram*. [online] Architecture et Développement. Available at: https://www.archidev.org/spip.php?article1115&lang=fr [Accessed 27 Nov. 2023].

Pokorny, J. (2019). *Evapotranspiration*. Encyclopedia of Ecology, 2(2), pp.292–303. doi:https://doi.org/10.1016/b978-0-12-409548-9.11182-0.

Technal (2023). *Sustainable facades: Pioneering the path to net-zero architecture*. [online] www.technal.com. Available at: https://www.technal.com/en/tme/informations/blogs/facades-and-different-design-applications/ [Accessed 7 Apr. 2024].