BREATHING SKINS DESIGNED FOR WIND MODULATION THROUGH MORPHOLOGY

Toward integrating turbulence studies within architectural frameworks for facade applications

Abstract. This study aims to investigate the power to manipulate the behaviour and characteristics of air through changing the morphology of building skins. The simple cubic cells in the global system of a porous screen are manipulated to understand how the basic elements or the cells' morphologies change the patterns of air movement in such a system. Experimental and numerical studies were undertaken in parallel: the experimental studies in a wind tunnel with very smooth flow using precision wind sensors, and the numerical studies using Computational Fluid Dynamics (CFD) simulations. The results we discovered from the evaluation of multiple screen systems revealed trends in response to the careful manipulation of effective shape parameters (e.g. modular extrusion depth, the size of apertures, the porosity and the shape of the inlet and outlet openings of screens' components) within a designed matrix of variations (Matrices of possible typologies). The main principles for shaping such typologies were based on: a) Creating pressure differences across the screens as a result of surface intrusion and extrusion compositions. b) Changing the velocity and turbulence within the façade and around it through manipulating the design of the inlet and outlet shapes of the screens' components. The series of results, presented in this paper, point toward the possibility of empowering designers to make informed design decisions based on predictable wind patterns extracted from a geometrically parameterised test matrix (e.g. to magnify convective cooling effects on surfaces, the surrounding air and the human inhabitants beyond the screen).

Keywords. Porous skins; Facade components; CFD ANSYS, Parametric Design and aerodynamic studies; Matrix of study.

1. Introduction

Our surrounding microclimate is formed through the complex synergy of invisible meteorological elements: wind, heat, and humidity. These elements strongly influence our thermal sensations and perceptions, as found in studies by Chatonnet & Cabanac, (1965); Rohles, Woods and Nevins, (1974); Fanger, Melikov, Hanzawa, & Ring,(1988) and de Dear, (2011). In such complex contexts, designers are shaping space through composing and repeating elements of geometry, colour and material; the patterns that are

changing the invisible environmental elements and can be used to form pleasant microclimates around us. In other words, this invisible part of the design context poses challenges for designers while it also provokes them to inform their decision making through the understanding of potential change of the surrounding microclimate with the aid of the pattern as an artistic-scientific tool. As geometry can metamorphose the invisible, designers need to be supported toward integrating buildings with their local climatic contexts through a better understanding of the relation between the morphology of a building's skin and the possible modification of hidden meteorological elements by highlighting the role of geometry in this metamorphosis. Herein we are presenting part of an ongoing research trajectory demonstrating the power of the pattern, in this case, repeated geometries, in changing air pattern as one of the main meteorological elements of environments that directly modifies other factors such as heat and humidity.

1.1. WIND MODULATION THROUGH GEOMETRIES: FROM URBAN TO POROUS SCREENS STUDIES

Engagement with the complex dynamic system of our surrounding atmosphere poses challenges for the designer due to invisible phenomena that are both influenced by and influencing architectural designs. This challenge becomes critical in extreme environmental conditions such as hot and arid climates, where the thermal performance becomes an essential aspect of design. In such conditions air movement and turbulence intensity are important factors for removing high-temperature air and providing greater perceived air quality. Additionally, air movement improves heat transfer from the body (Zhao, Sun, & Ding, 2004). This raises the question of how geometry can affect wind characteristics such as wind velocity, turbulence intensity and pressure. Different studies at diverse scales point to the role of geometry in changing the air movement and the resultant thermal improvement such as: large-scale studies of a city and the impact of street geometry (Golany, 1996) to the shape of domed roofs (Yaghoubi, 1991), to smaller scales of facades and balconies. Research conducted by Montazeri and Blacken (2013) showed how the geometries of buildings with different balconies strongly affect the wind pressure distribution across facade surfaces and create separation and recirculation zones on them.

Studies by Hrynuk, Van Luipen, and Bohl (2012) show how the density of porosity affects the micro-scale flow patterns near porous screens. Nonetheless, few investigations consider comparable studies of porous screens for architectural applications.

1.2. POROUS SCREENS

Traditionally, porous screens were used for passively modifying and encourage breezes into private or semi-enclosed places while protecting the interior from thermal radiation (Figure 1). Mashrabiyas are examples of such systems, used for multiple functions such as controlling light, reducing temperature and increasing humidity (Fathy, 1986) while adding aesthetic characteristics to buildings located in hot and arid regions. These lattice-

opening systems within the facades are formed by repeating two-dimensional timber components. They display a variety of designs with differing patterns and opening sizes. While most of the existing literature

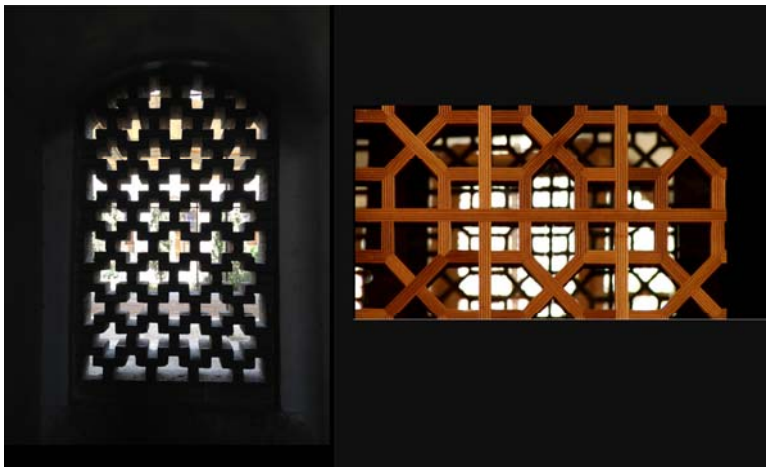

Figure 1. Traditional Porous screens

and studies are focusing on the light analysis of such opening systems, the versatility of their function raises the question of how the variation of the screen morphology could affect airflow patterns within and around the screens for different applications. This ongoing research answers this question by illustrating different wind patterns occurring in such a system in response to the geometrical manipulation of cells and their global composition through parametric design of the sub-components (Figure 2). Although, most of the existing tools are for supporting outdoor analysis of the wind and general form of buildings in the urban contexts, our empirical investigation aims to demonstrate the power of geometry in shaping the air patterns and altering its pressure and velocity through geometrical modification of porous surfaces for future architectural applications.

2. Form exploration and Matrix of phenotype as a start point

Environmental analysis is complex – especially when exploring the effect of multiple parameters. To reduce this complexity, a matrix of phenotypes is an essential guideline and start point since it gives higher control and identification of correlated parameters and possible generations out of them. The effective primary parameters for generating the elements of this matrix could be identified from pieces of literature and primitive investigations. In this case, multiple configurations were defined by varying parameters such as surface undulation, the depth of apertures (changing across the rows of the matrix (Figure 2)), the porosity (increasing along the columns), and the shape of the inlet and outlet openings of screen's components (Figure 2). Two main principles, extracted from literature, informed the typologies for the mentioned alterations: a) Creating pressure differences across the screens as a result of surface configurations, and b) changing the velocity and turbulence intensity within the façade and around it through manipulating

the design of inlet and outlet shapes of the screen's components. The shape study in this cluster began with exploring the Venturi effect to accelerate and decelerate the wind flows: the funnel shape of the cells' ingress channels the airflow through the funnel causing a decrease in static pressure and an increase in dynamic pressure; hence an increase in local velocity (Bernoulli's principle).

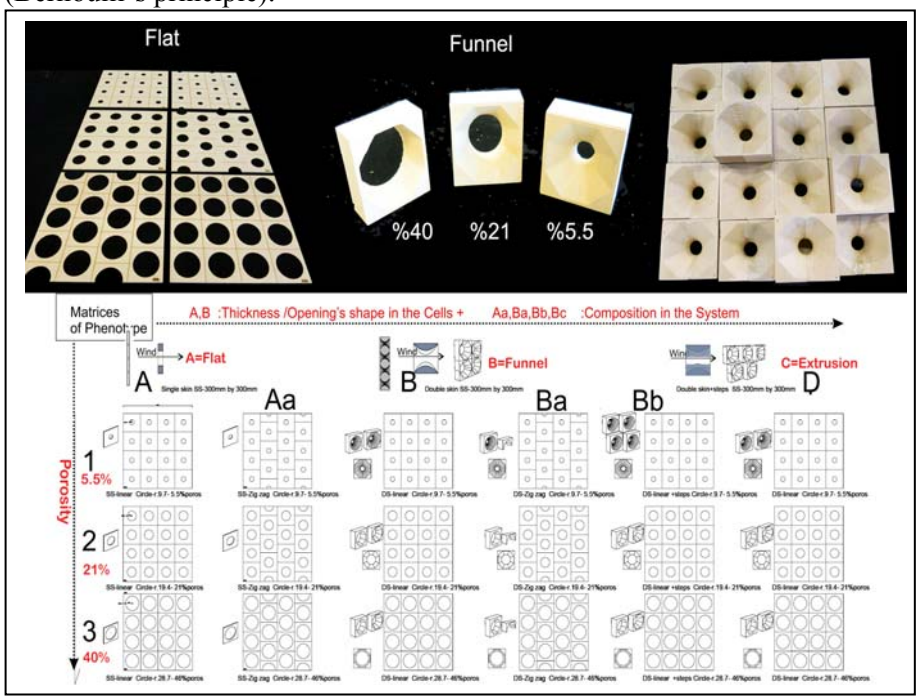

Figure 2. Matrices of Variation based on two principles: Wind pressure on the screens and composition of cells/Wind velocity changes based on opening shapes and sizes. e.g. A=flat section with different porosity ratio across the column of the matrix , B= Iterations have funnel shape of profiles and D= iterations have extrusion profile shape with same porosity along same raw of A and B iterations

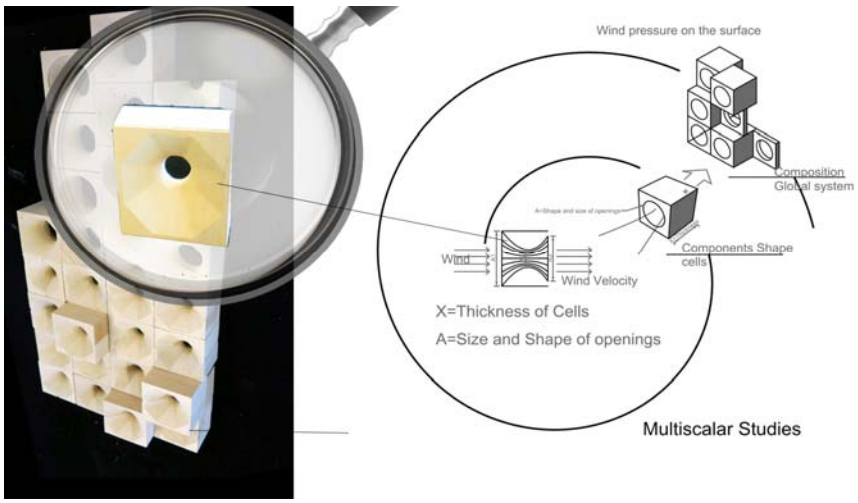

*Figure 3.*We proposed a porous skin as a system of varied cubic cells as subsystems

This matrix has been designed to vary across logical parameters e.g. the iterations A and Aa have different configurations and opening positions with the same porosity increasing across the columns of the matrix. A cubic system of cells enables the designer to form several configurations during experiments (Figure4). This predefined matrix of variation using modular components or blocks was a practical approach for the rapid design and construction of porous screen prototypes for physical wind simulations as well as CFD simulations (Figure 3).

3. Experimental method and theoretical considerations

An Aeronautical Wind Tunnel (AWT) and numerical simulations with ANSYS CFX were used for this study. The AWT, used for the physical investigations was a closed-circuit wind tunnel with an octagonal tunnel test section measuring 2,100 mm long, 1,370 mm wide and 1,070 mm high. Numerical simulations were conducted with ANSYS-CFX using a K-Epsilon turbulence model, 5m/s inlet velocity with a turbulence level set to <1% (Figure 4). The test domain was a 30cm by 30cm by 60cm box for representation of a room with a totally open outlet. The qualitative CFD outcome matched what was expected after the analysis of the physical wind tunnel results.

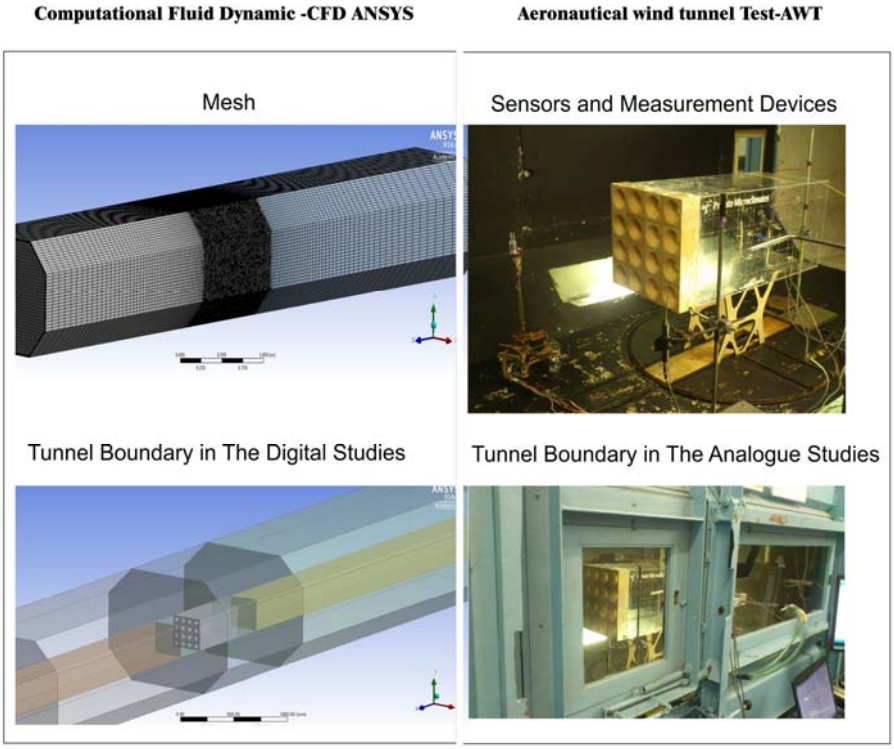

Figure 4. Experimental Platforms-The accuracy of results in the wind tunnel tests depend on the devices and in the CFD depend on mesh

3.1. PHYSICAL EXPLORATION AND TEST SETUP FOR WIND TUNNEL

The graphs in Figure 8 are the measurements from the Cobra Probes (CP) across the 3x3 grid (9 locations) for screens A3 and B3 (40% opening with different profile shape) within the AWT. CPs are precision tools for detecting the pressure of air to resolve velocity and local static pressure in real time at a point in the flow field (Prohasky and Watkins, 2014). The top graph in Figure 7 is the non-dimensional average wind speed (for each position in the grid). The reference value for the non-dimensional wind speeds was the freestream velocity generated with the wind tunnel. The measurement was done for both ~5m/s and ~14m/s wind speed. The results show that variation across the grid is independent of wind speed (within this range of average wind speeds). The results indicate that, on average, the turbulence intensity of iteration A3-40%-Flat is higher than B3-40%-Funnel in the opening section (Figure 7). Additionally, the represented colour map of the AWT results show a higher local average velocity behind the funnel shapes compared to the other with the same porosity (40%) and different aperture profile (Figure 7), which matched the CFD measurements for the same iteration (Figure 6). This demonstrates how the iteration B3-40%-Funnel is extending the boundary effects of wind with significant changes of the flow in the openings' throat section with respect to the equivalent flat screen (Figure 7).

3.2. DIGITAL SIMULATION USING CFD ANSYS

The full-scale wind tunnel domain size and shape was simulated in ANSYS-CFX to replicate the wind tunnel tests in a virtual environment. The physical tests involved grid point measurements at 300mm from the leeward face of the porous screen. These measurements could not provide information of the flow field around and behind the screens (physical flow visualisation techniques will be used in the near future). Hence, we used CFD to reveal what could be happening around and within these iterations.

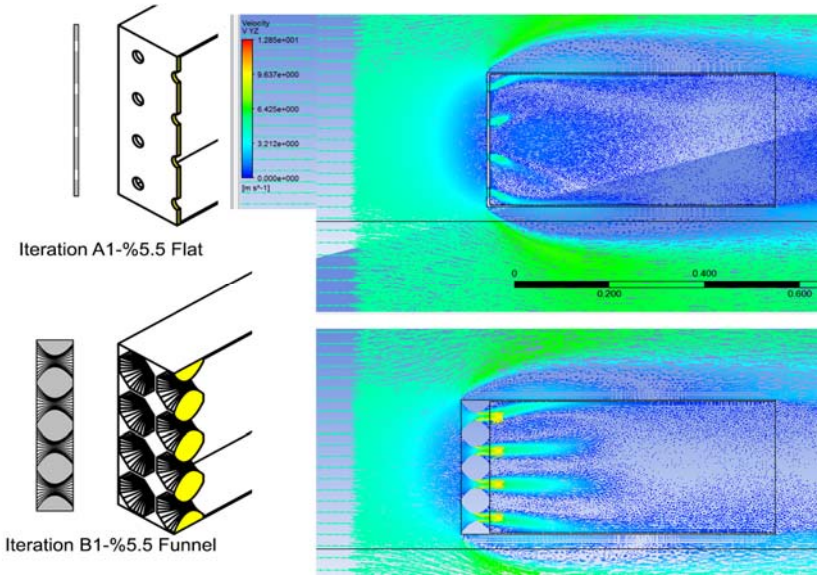

Figure 5. Results for the CFD simulation for iterations A1-5.5% flat and B1 -5.5% funnel shape

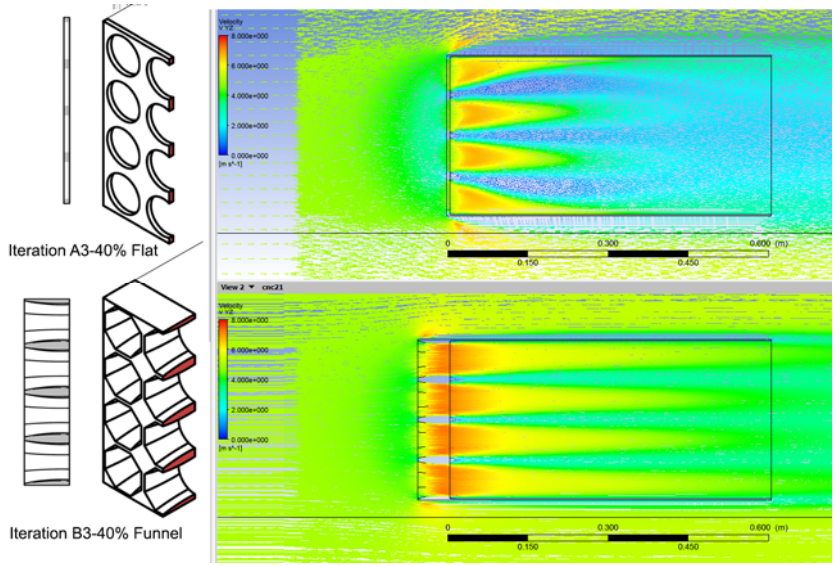

*Figure 6.*Results for the CFD simulation for iterationsA3-40% -Flat and B3 -40% -Funnel

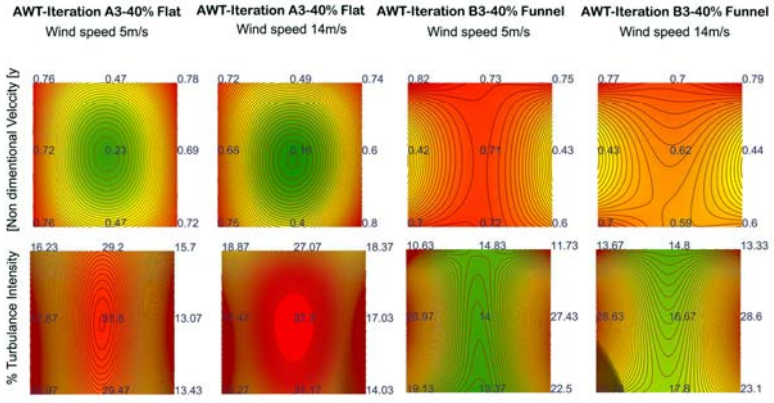

Figure 7. Turbulence intensity and velocity from AWT experiment for iterations A3 -40% Flat and B3-40% Funnel –with 5m/s and 14m/s wind speed for inlet-Grasshopper were used for post visualisation of the extracted data from the CPs

The results demonstrate significant differences in the flow pattern behind the screens with the same porosity but various opening shapes. The gradation of geometric profile towards a funnel (from left to right in Figure 8) (i.e. in general – sharp edges towards continuous topology) creates more ordered flow (Figure 8), hence less mixing and extended jets. In other words, the shapes of the openings form different wind patterns behind and within the porous system. The edges of the test chamber tend to separate the airflow

away from the exterior walls - the effect of this flow dispersion directly influences the interior when the screen is flatter. By extending the depth of the screen and creating more of a funnel shaped profile – the flow can be projected further into the space (e.g. this information is especially useful for the design of apertures near the corners of a building). This does not accelerate the airflow globally, there was still a global deceleration caused by the screen. However, the flow was more ordered which caused the airflow pattern to penetrate further into the room - hypothetically mitigating wind gusts, but allowing greater air changes within the space. Though, it is important to consider the incident wind characteristics within the building's context when applying this in situ.

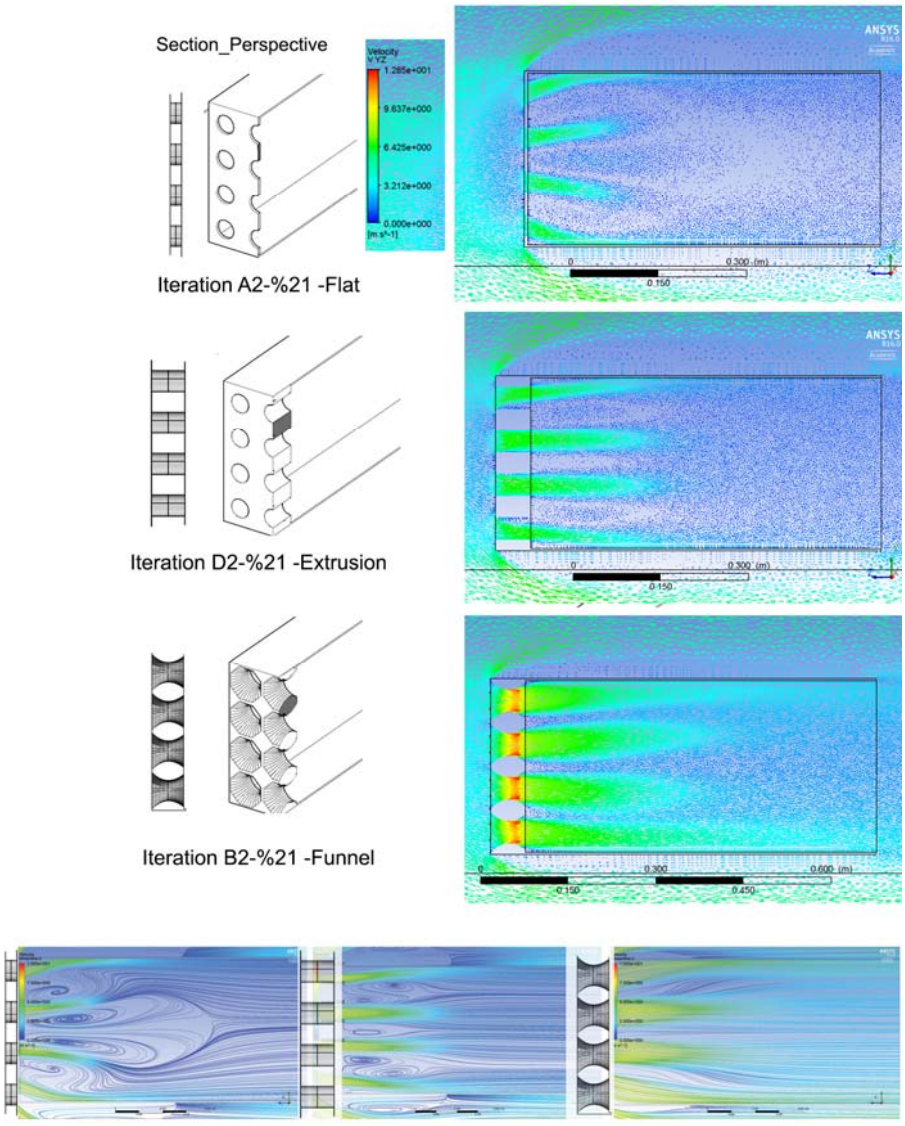

Figure 8. Results for the CFD simulation for iterationsA2-Bb2 and B2. Bottom image :CFD stream lines demonstrates wind pattern for vasriations: A2/B2 Flat and Funnel.

If one looks closely at the effect of the walls within the screen: A3-40%-Flat separates the flow from the interior face of the screen; the D2-21%-Extruded

iteration separates the flow at the inlet and reattaches it along the thickness of the screen (Figure 8); the B3-40%-Funnel does not separate the airflow from its funnelled walls (Figure 6). This effect may be advantageous for trying to magnify the effectiveness of evaporative cooling when the screen is damp.

4. Discussion of possible architectural applications and scenarios

This study demonstrates the value and possibility of considering the versatility of opening shapes across facades based on air movement, local acceleration of the wind, desired turbulence intensity and fluctuations. The scenarios and implications of such studies are diverse. From the viewpoint of energy saving - this study has several applications in architecture: façade components for second skins; ventilated facades and porous screens; for cross-ventilation to the larger scale of façades and balcony forms. For instance, it is predictable that for double skin facades the profile shape of holes could enhance air circulation and turbulence intensity within the two layers of skins for cooling purposes. For cross ventilation scenarios, the results shed light on the power of geometry for magnifying the wind velocity by the aid of profile shaped openings and proper allocations of the opening position across the facades e.g. using funnelled and extruded profiles within a porous screen to extend the penetration of wind patterns within the interior while self shading and protecting the interior from solar radiation.

5. Conclusion

The series of results presented in this paper, point toward the possibility of empowering designers in make informed design decisions based on predicted wind phenomena to passively cool surfaces and their surroundings and thus mitigate the effect of heat. This study shows how we could project natural air fluctuations within indoor space, to offset high air temperature, promote better-perceived air quality as suggested by (Zhao, Sun, & Ding, 2004) and introduce opportunities to create moments of positive alliesthesia experienced through the dynamics in the wind (de Dear, 2011). Based on these studies it was possible to train fluctuations of air through porous screens using the versatility of shape e.g. both wind-tunnel and CFD results indicated the effects of funnel shapes in extending jets of air - delaying the dissipation of the turbulent pattern within the interior apartment space (Figure 6, 7 and 8). The CFD results demonstrated that the extruded or flat porous screens produce greater flow resistance and higher turbulent fluctuations which are similar to the wind tunnel results. However, further work is needed to verify the quantitative analysis of the CFD simulations which will be documented in the near future. This study has made a significant contribution to scholarship by showing how geometry in building skins can morph the wind and thus the microclimate within buildings. In other words the results shed light on the role of detailed studies of façade

components and their possible impact on shaping the wind and consequently sculpting our surrounding microclimate. It also demonstrates design simulation strategies to support designers to understand the relational dynamics between airflow and porous screens for building facades. Additionally, it highlighted the need for user-friendly platforms for wind behaviour to enable the parametric analysis of porous screens within the architectural framework. Most of the existing tools are for outdoor analysis of the wind and general form of buildings in the urban contexts.

6. Future research

In these studies the test box (test domain) had a completely open outlet to simplify the experiments. It would be interesting to consider other scenarios, such as closed and semi-closed spaces to simulate effects of such variations in cross ventilation. Also integrating other strategies such as self-shading and evaporative cooling will be valuable based on design specifications and scenarios which were studied and will be published soon.

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