Holistic approach to Human Comfort

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ABSTRACT

The consideration for human comfort in the urban plane has largely been focused on the wind speed that a pedestrian might experience due to the surrounding built form design, prevailing winds and site exposure. As such, wind criteria have been developed by councils for precincts around the world which are focused on the wind speed for safety as well as being aimed at providing comfortable conditions for the intended uses. However, human comfort is not only affected by the experienced wind force, but also temperature, relative humidity, solar radiation, clothing and other parameters. A comprehensive model has been developed by RWDI for the assessment of holistic human comfort, including accounting for seasonal climate variance. This can also be further refined to consider other key parameters such as noise and air quality.

This paper will demonstrate the application of a developed human comfort model which has been carried out for projects in different climate zones. It will detail the importance of considering all aspects, holistically, when determining the true comfort level for an outdoor microclimate. Subsequently, discussion will be provided on how the design community and planning authorities could utilise this assessment to greatly improve the usability and enjoyment of public spaces.

INTRODUCTION

The assessment of pedestrian comfort in public domain spaces has become of increased importance in society, with growing concerns for the environment and the quality of life provided in urban contexts. The interaction of the local wind conditions with the built environment has the potential to generate adverse wind conditions (comfort for use and safety) which have come under increased scrutiny in recent times in capital cities within Australia as well as around the world. This has led to changes in wind comfort criteria and assessment requirements in local Development Control Plans (DCP) to address these experienced issues and concerns. Traditionally, pedestrian level comfort criteria of acceptability dealt only with the mechanical impact of wind on pedestrians. (Lawson 1975).

It has become apparent; however, from experience, field studies and literature on the topic, that pedestrian comfort is not solely dependent on wind force alone. An outdoor thermal comfort model was initially developed by (Soligo et al, 1993 and 1995) which presented a comprehensive model for the assessment of pedestrian comfort; considering wind force, thermal comfort and wind chill. The comfort level pedestrians experience is a combination of a few environmental effects including wind, temperature, humidity, terrestrial radiation, metabolic rates, solar radiation, noise levels, air quality, persons clothing as well as other factors. While some of these elements relate to an individual's choice, these elements are largely governed by the urban environment. With the increasing urbanisation of cities around the world, greater focus is placed on the health-related urban well-being of residents to undertake outdoor activities. Accounting for and improving the comfort levels as part of the urban design process not only benefits the individual, but also benefits the city due to increased outdoor interactions (Chen 2012).

In recent years, greater focus has been placed on the greening of urban precincts throughout the streetscape, but also on the built form as noted with Central Park in Sydney and Bosco Verticale in Milan. (Wong, 2005) undertook a comparative study of the maximum temperature difference between the central business district and densely planted areas in Singapore. He found a maximum temperature difference between these two environments of 4°C. This has serious consequences on the vitality and urban livability of these spaces, with the creation of urban heat islands (UHI). Case studies were discussed by (Soligo et al 1999) which consider three different types of projects (Hotel, Sport Stadium and a Medical Facility) located in three different environments; hot, cloudy and cold. The case studies highlighted the importance of the pedestrian thermal comfort model developed by (Soligo et al 1993) on the overall comfort conditions experienced by the patrons.

Further to this, historically, city developments have been largely focused on individual developments and their potential impact to the nearby environment. City-wide masterplan studies have largely focused on the overall aesthetics and built form, with most high-level consideration given to the comfort levels for the entire precinct. The aim of this paper is therefore to discuss the importance of the consideration for human comfort as part of the planning process and present how precinct wide masterplanning can contribute to better overall outcomes for current and future urban precincts.

COMPONENTS OF A HUMAN COMFORT STUDY

To evaluate and understand the importance of providing better and/or suitable human comfort conditions in urban precincts, it is important to first understand the individual components which contribute to human comfort levels. This section will provide some context as to the drivers for each individual component on pedestrian comfort levels.

Wind Force Component

Consideration for the wind force effect on pedestrian in urban environment is considered by many, but not all planning bodies, to enable suitable wind conditions for safe and comfortable conditions, based on an intended use or duration of stay at given places.

Wind is also a fluctuating quantity, with variance in speed, directionality and probability of occurrence. It is therefore necessary to consider the frequency of the occurrence of varying wind speeds, experienced by a pedestrian in the public domain, that would be deemed acceptable. The wind direction is of notable importance when considering the local wind climate; however, from a pedestrian's comfort level, they are largely focused on the resulting wind force including both the wind velocity and its mechanical effects on them. These effects can include minor impacts such as blowing hair or flapping clothes, to more severe effects such as restricting movement or balance during strong wind events as noted in the Modified Beaufort Scale.

Pedestrian wind comfort levels have developed over the years with varying approaches; however, all generally categorise wind velocity ranges being suitable to conduct a certain type of activity (or duration of stay). It has generally been found that an evaluation of wind comfort criteria should consider both the mean and gust values by applying a Gust Equivalent Mean (GEM) process (Soligo et al 1998). The benefit of this approach is that, in more turbulent environments, the gust value becomes more critical, while, in less turbulent environments, the mean component is more important. Conditions experienced by pedestrians are governed by both the macro and micro scale levels with the surrounding built form and topography being significant contributors to both scales.

Thermal Component

The assessment of thermal comfort considers the heat balance of the human body. (ASHRAE, 2013) notes that thermal comfort is defined as “condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”.

The exchange of heat between the human body and its surrounds depends on six basic parameters (Parson, 2014). These include four key environmental components: air temperature, humidity, wind speed and solar radiation (long and short wave) as well as human related factors including clothing and the activity level of the person. Further to this, the exposure time determines how long the person may withstand these experienced conditions for. There are numerous models that these variables can be incorporated into to determine thermal comfort, two of which are the Fanger model and the Pierce two-node model (Chowdhury, 2007). There are similarities between these models as they both utilise energy exchange mechanisms with physiological derived parameters to predict the thermal comfort feeling relative to a person’s environment (Doherty and Arens, 1988). The Fanger model is based on a steady state energy balance model and as such assumes that equilibrium has been reached. For pedestrians outdoors, this assumption is not applicable given the expected movement of a person as well as their dynamic and temporal thermal adaption (Chen, 2011). Although originally made for indoor environments, RWDI found that the Pierce two-node model evaluates the inner body temperature and skin temperature and has better validity over a wider range of activity levels and outdoor environments, although is not suitable for higher intensity activities. Spaces to be used for higher activity levels are not the target for public urban realm areas.

Wind Chill Component

The combination of wind speed and air temperature can result in a chilling effect to exposed skin, particularly for cooler environmental areas. While the thermal component discussed above is focused on a balance of body heat which accounts for clothing worn by the person, the wind chill component is, to some degree, generally not affected by the clothing level worn by a person. Even with warm clothing a person’s extremeties (hands, face, ears etc) are still exposed. This effect becomes of greater concern for pedestrian comfort in regions that experience seasonal temperatures which generally fall below 10°C. The Wind Chill Index (WCI) developed by the Joint Action Group for Temperature Indices provides an empirical estimate of how cold air feels on the human skin, including the rate to which frostbite can occur (NWS, 2001). The equivalent wind chill (watts per meter square, W/m^2) can be determined from:

$$Wind\ Chill = \left(12.1452 + 11.6222\ x\ \sqrt{Wind_{sfc}} - 1.16222\ x\ Wind_{sfc}\right) x\ (33 - T)$$

Other Comfort Factors

Human comfort for both indoor and outdoor environments has largely been focused on the acceptable wind conditions and thermal comfort levels that a pedestrian may experience. However, this is only part of a person’s perception and acceptance of a space. Two other critical considerations are the acoustics or noise levels within these outdoor areas and the quality of the air which they breath. These two components are discussed in further detail below.

Air Quality

Development Control Plans for new developments which have wind comfort requirements are largely focused on making sure that conditions are not too windy; however, some, such as in Hong Kong, also consider the importance of a lower-bound limit to ensure suitable “flushing” of the city can be achieved. City environments include numerous odours and/or pollution emitting sources which need to be considered and accounted for. This can include industrial pollution sources, car exhaust, smells from retail areas, mechanical ventilation sources as well as environmental contributors such as smoke and dust. Without sufficient air movement within a city, stagnation regions can develop which reduces the air quality levels for the outdoor environment. While some environmental contributors may be sporadic, and people can adapt their use of a space to suit, constant pollution levels will make outdoor public areas unusable despite how thermally comfortable the design may make them.

Designing and accounting for suitable air quality levels can come in numerous forms, including, but not limited to, the location of outdoor areas in locations which are shielded from predominant pollution sources, locating exhaust sources on a development away from sensitive areas or such that they operate to disperse the nuisance exhaust into the free-stream to enable suitable dilution to not impact a receptor. The design of a precinct to ensure that suitable airflow is maintained, especially for the prevailing wind events is generally an overall suitable design outcome. (Steeneveld et al, 2018) also noted there is somewhat of a correlation between heatwave episodes and poor air quality levels in an environment.

An Air Quality Index is a suitable means to measure the pollution levels in the ambient environment, which has a direct link to human health. Most Environmental Protection Agencies (EPA) around the world measure 5 key pollutants; ground-level ozone, particle pollution (include effects of dust storms, fires etc.), carbon monoxide, sulphur dioxide and nitrogen dioxide (Steeneveld et al, 2018). The (NSW EPA, 2017) has been undertaking a Clean Air of NSW Study, with initial findings to be presented in 2019, to monitor the trends in pollution levels throughout NSW. Further study is scheduled to then be carried out to obtain a better understanding of its impact on human health and a more intricate monitoring network. As noted in Figure 1, measures from 2014, show the high levels of particulates in the atmosphere for some of the capital cities around the world, which affects the urban experience.

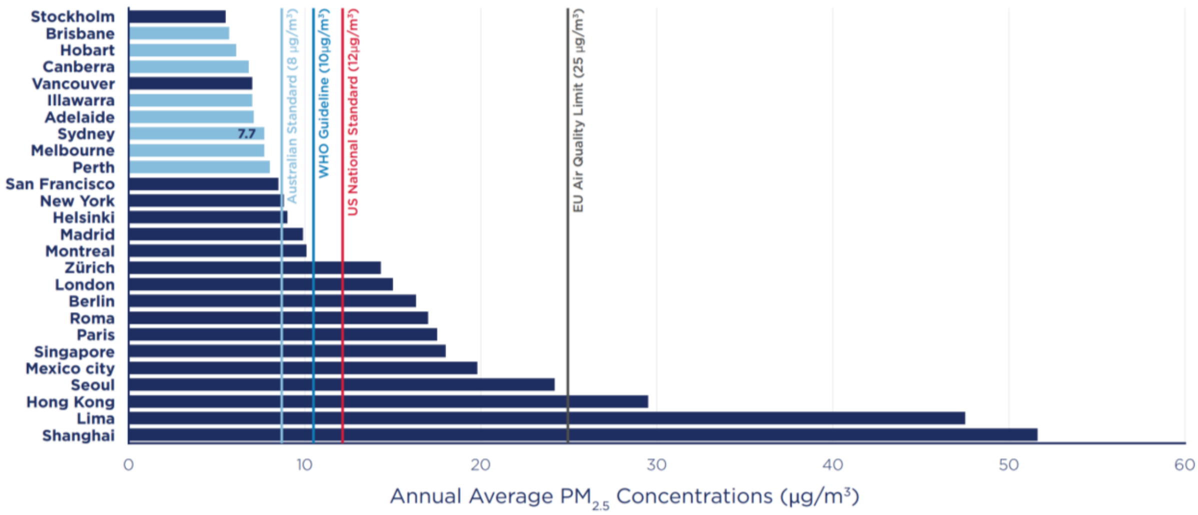

Figure 1. Annual average $PM_{2.5}$ levels measured in Sydney compared to levels in other National and International Cities – 2014 Measurements (NSW EPA, 2017)

Noise Levels

The design of outdoor spaces, especially in an urban context needs to consider, and account for, the intended uses. While a design might be able to consider the thermal comfort levels, wind conditions and air quality aspects for a given outdoor space, the potential impact of noise pollution can significantly impact the "quality" for the people using the area and nearby community. The World Health Organisation undertook a study to investigate the impact of noise pollution on a person's health. It found that environmental noise was one of the most frequent sources of environmental complaint in Europe, especially in dense urban areas and residential spaces located near highways, railways and airports (WHO, 2011). The "Night Noise Guideline for Europe" (WHO, 2009) detailed the damage to one's health from nighttime exposure and recommended that nighttime exposure should not exceed 40dB outdoors. The 2011 study found that the impacts on human health due to noise pollution included "annoyance, sleep disturbance, cardiovascular disease, cognitive impairment, hearing impairment and tinnitus" (WHO, 2011).

An impact report of traffic noise pollution on human comfort was undertaken for public parks in London. The report (CPRE, 2018) found that one-third of London parks are severely impacted by traffic noise (corresponding to 50-100% of the parks experiencing traffic noise of 55dB or above). These noise levels reduce the usability and benefit of these parks to both humans and wildlife. An example is shown in Figure 2 of the traffic noise levels in Wanstead Flats, located in the London Borough of Redbridge.

Figure 2. Traffic noise levels on Wanstead Flats, Redbridge, East London (CPRE, 2018)

It is also important to consider the type of noise and not just the volume of noise which is generated. For instance, when someone goes to the park, they would expect to hear noise sources such as people playing sport, wildlife, trees rustling and either wind or water sounds. The tolerance to these sounds would also be somewhat dependant on these expectations. (Schafer, 1977) introduced the concept of "soundscape" as a way of moving beyond just thinking of noise levels, but also considering the human experience in the given environment and its cultural relationship. This involves looking at the sound in its given context. An urban park may exceed desired noise levels but these noises are from contextual sources (nature, birds and expected park sounds). Although exceeding desired noise levels the occupants would preceive these sounds as contextually acceptable. Comparatively, if the same desired noise levels are exceeded due to adverse, non contextualised, sounds (road traffic, aircraft etc.) the occupants would have a less positive perception and level of acceptance (de Paiva Vianna et al, 2015).

Outdoor Human Comfort Model

The overall human comfort model considered by RWDI, to provide guidance on suitable conditions for ideal use, involves an overlay of these abovementioned components. By considering each environmental aspect noted above, a clearer picture can be developed as to the usability of a space throughout the day and over the course of the year. As we have noted by looking at the individual components discussed above, a location could very easily achieve the required wind comfort and thermal comfort conditions; however, given its adjacency to a busy road, would not be considered suitable due to noise and pollution levels. Conversely, an area which may be suitable during the summer months, due to the pleasant breeze which cools the area and flushes exhaust concerns, may become problematic during the winter period, as it would be perceived as too cold. To add an additional layer of complexity, colder conditions may be considered acceptable in exchange for better air quality levels given it will impact less people using the space and enable better overall comfort. The combinations and considerations are quite endless. As such it is important to develop an overlay that considers all of these issues in one assessment, instead of incoherently trying to overlay multiple studies independently.

RWDI's approach initially considers the three weather components (the mechanical force of wind, the thermal comfort of the human body and wind chill effect on exposed skin) which are combined to generate a single comfort evaluation for comparison against expected uses. For a given space to be considered acceptable, during a given hour period, all three components would need to satisfy the considered comfort criteria for the given meteorological hour period. Should any one of these components not satisfy, then pedestrians would not consider that space to be acceptable during that period. This approach and associated analysis is discussed in greater detail by (Soligo et al 1998).

The effects of noise pollution and air quality is a further overlay for each area of consideration as part of the holistic assessment of human comfort. Noise pollution has some degree of consistency, depending on the nearby sources; however, there is also notable variances for considerations. This includes traffic noise variance during periods of the day and days of the week, nearby venue locations (bars and clubs) and other periodic noise sources, such as schools and construction sites. Air quality levels within a city can also be governed by large scale environmental effects, such as dust storms or bush fires, which are difficult to account for as part of a design scheme, except to ensure sufficient "flushing" of the area can be achieved if the wind conditions increase. Air quality conditions, which are governed by more localised effects, can be enhanced by suitable design strategies of public realm planning. As such, it is an important consideration as part of the overall human comfort level for outdoor spaces. Should an area be not too windy, enable thermal suitable conditions and be relatively quiet, but be exposed or capture polluted air, its suitability and hence use of the space by pedestrians will be very limited.

CASE STUDY AND DISCUSSION

To be able to have a better understanding of the importance of developing and understanding a holistic picture for human comfort, two examples will be discussed in further detail on how the environmental effects have been considered for larger scale precincts for current and future planning. The first example is focused on MASDAR City, which is located in Abu Dhabi, United Arab Emirates. RWDI was heavily involved in a city-wide environmental study during the early conceptual planning process. This work helped to ensure the city, as a whole, could consider and benefit from key design approaches, especially given the harsh climatic environment.

The second example is focused on work being undertaken for the City of London. As such, it is essentially a review of the current conditions within the developed city environment with a view to then develop a better understanding for masterplanning going forward.

Masdar City, Abu Dhabi, UAE

Masdar City was a proposed master planned city located to the east of the Abu Dhabi CBD precinct, adjacent to the Abu Dhabi International Airport. During the initial masterplanning, it was proposed as the first net-zero carbon city in the world, in an environment generally not considered suitable throughout the entire year. Given the significant objective of this goal, RWDI was heavily involved from the conceptual stage of the project to provide guidance on how this could be achieved. Work involved the development of an Energy Design Guideline for the city, capturing all aspects such as energy usage, building performance and the environment. This included the impact of the expected climate change on weather conditions as well as the effect of future urbanisation on the surrounding landscape and weather patterns.

A significant array of studies were undertaken for this project by RWDI; however, only the areas directly linked to human comfort will be discussed in this case study.

Noise Levels

The site's location was in close proximity to several different transportation networks, with the objective of not having cars operate within the city itself. As such, it was important to understand the noise pollution impacts of these surrounding areas to the city when providing guidance on the masterplan design. A number of critical aspects, as noted in Figure 3 below, were considered as part of the noise study; air traffic noise from the nearby Abu Dhabi International Airport, road and traffic noise surrounding the site, the Light Rail Transit (LRT) system to service the area, as well as the proposed high-speed rail corridor to the east of the site. As can be noted in Figure 3, this enabled the generation of a combined noise map for the precinct. Guidance from this was able to then be provided on suitable areas for outdoor uses, how built form could be developed to provide sanctuary areas within the city as well as guidance on building façade and opening location which would feed into the ventilation approach.

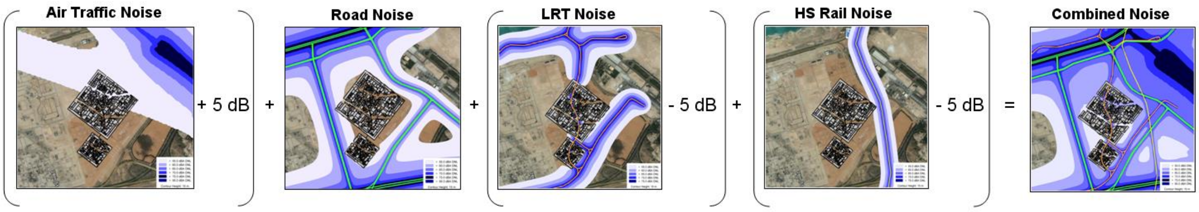

Figure 3. Masdar City External Noise Source Masterplan Overlay

Thermal Comfort

Abu Dhabi is quite a warm environment despite its location adjacent to the Arabian Sea. As a result, consideration was made with regards to the masterplan and if there were ways to improve the planning of the city, as a whole, to enable the prevailing north-westerly sea breezes to penetrate the city and enhance the overall cooling effect. On top of this, solar studies were carried out for the precinct to understand the solar implications in terms of both daylight (potential energy usage for lighting) and radiance (additional heat loading to the building façade and urban realm). As can be seen in Figure 4 below, by modifying the open corridors between the building forms (and height changes) the prevailing north-westerly sea breezes were able to better penetrate the precinct, which in turn provided greater cooling performance.

The impact of thermal heat loading was also considered with the location of solar panels atop the various building structures. This questioned how solar arrays could be positioned above the building forms to reduce the heat load to the buildings themselves, while also minimising losses of solar panel performance associated with higher heat loads. The information then feeds into the discussion below regarding air quality levels and how exhaust stacks need to account for these solar panel elements.

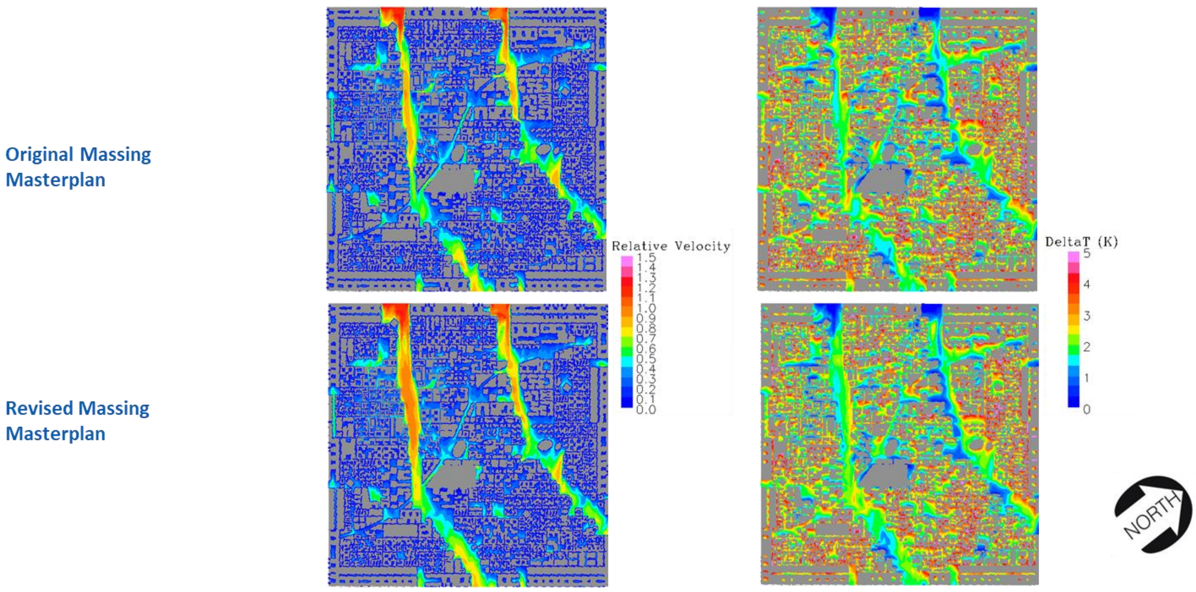

Figure 4. Wind and Temperature Variance for North-Westerly Winds

The impacts of the above-mentioned design changes and considerations for a holistic human comfort level can be better understood in Figure 5. In this figure, an overlay has been provided for the external noise impacts, in conjunction with the thermal comfort levels (accounting for wind, temperature, humidity and solar radiance). For this case it was during a summer period. By developing a precinct approach to human comfort levels, we can firstly see the improved comfort levels throughout the entire city, including the two east-west public realm corridors. However, more importantly, by considering the design holistically, we can appreciate the benefit provided to the southern corridor. Such benefit enhanced thermal conditions and enabled a more acoustically pleasing environment. This can then enable focus to be placed on the urban design for this region as a placemaking location.

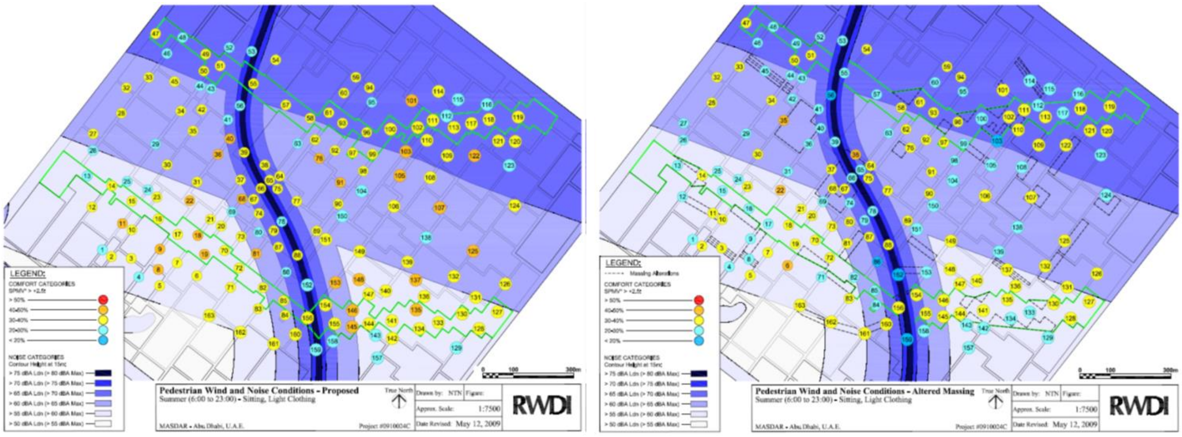

Figure 5. Thermal Comfort and Noise Level Overlay (Proposed and Revised Design)

Finally, consideration was also made with regards to the air quality performance due to the regional impacts and design of the city itself. Initially, given the proximity to industrial facilities and to help establish a baseline air quality level, assessment of the pollutant and particulate concentrations at Baniyas and Mussafah were considered, with variance, throughout the course of the year. There was a noted trend in higher concentrations of PM_{10} particulates during the summer months of the year compared to the cooler months. This needed to be accounted for. This information provides guidance for when outdoor uses may be otherwise limited, due simply, to the regional air quality, irrespective of the masterplan design.

Further to this, as with any city, there are exhaust sources and smells which need to be accounted for so nearby outdoor areas aren't negatively impacted. This would include kitchen smells, washroom odours and mechanical plant exhaust. Firstly, initial design advice was provided, followed by wind tunnel modelling to better understand the flow patterns from exhaust sources to the overall precinct. This provided information on where exhaust stacks should be located, including their height, exhaust velocity and potential impact to sensitive outdoor areas and intakes. For some areas, the exhaust location was somewhat limited to ground level regions. This therefore required guidance on cencentration levels and the need for filters etc. for some given areas.

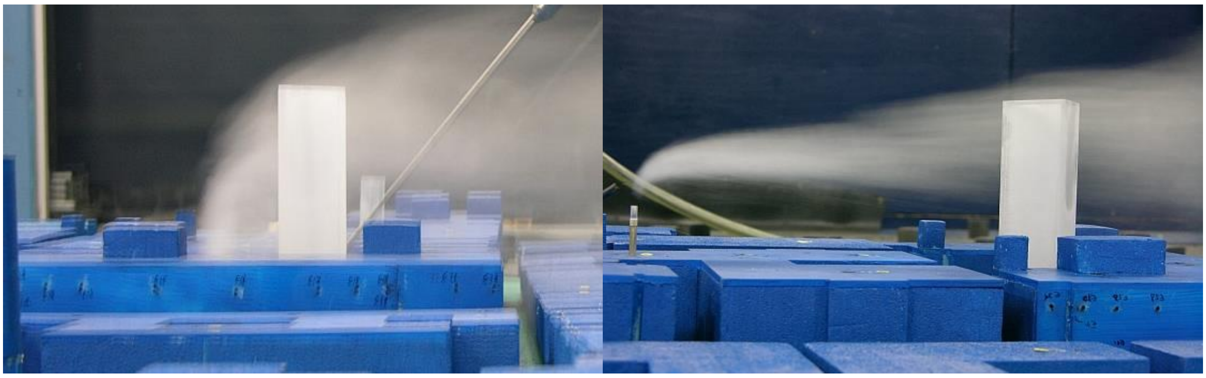

Figure 6. Exhaust Location Performance (Ground Source and Rooftop Source)

City of London

RWDI was initially commissioned by the City of London Corporation to develop the Wind Assessment Guidelines. This was on the back of an increase in high-rise development in the City of London, reported windy conditions by BBC News and the proposed future planned construction of high-rise towers in the city. As such, the city undertook steps with RWDI to ensure the comfort levels of the city into the future (Shilston et al, 2018). While this study was initially focused on the comparative difference between utilising wind tunnel testing and computational fluid dynamics (CFD) and comfort criteria for wind assessments, it has led into further studies to obtain a better and more complete understanding of the city's environment. As can be seem in Figure 7 below, a City of London model was created, which was focused on the Eastern Cluster precinct. The two models were aimed initially at providing the city with a better understanding of the benefits and limitations of each tool, as part of the overall planning process (Jayyaratnam, 2017). This noted the benefit of CFD modelling to allow for a holistic view of large-scale wind interactions, while wind tunnel modelling enabled a far higher quality of data at chosen measurement locations. However, both have limitations which need to be balanced and accounted for.

Another interesting point, as part of this study, was noted by (Hackett and Krishnan, 2017) with regards to the wind climate model used as part of these studies. While wind climate is noted as a critical link in the Davenport Wind Loading Chain, its application to wind environment expectations was noted for London. This research showed the variance in exceedance of probability of wind speeds and directionality for selected meteorological weather stations located around the perimeter of the City of London. Given that planning assessments are largely based on a pass or exceedance of a given probability of wind speed exceedance, this was noted to be quite critical in the outcome of results. The development of a suitable wind climate model for the city was subsequently developed in conjunction with RWDI to help ensure a more consistent and holistic approach to wind comfort for the city going forward. Consideration for similar potential impacts should be made in Australia with regards to the Western Sydney region given its distance away from the coast and proximity to the Blue Mountains, or in Melbourne with variance in wind speeds, probability and directions from sites located around Port Phillip Bay to the south of the city.

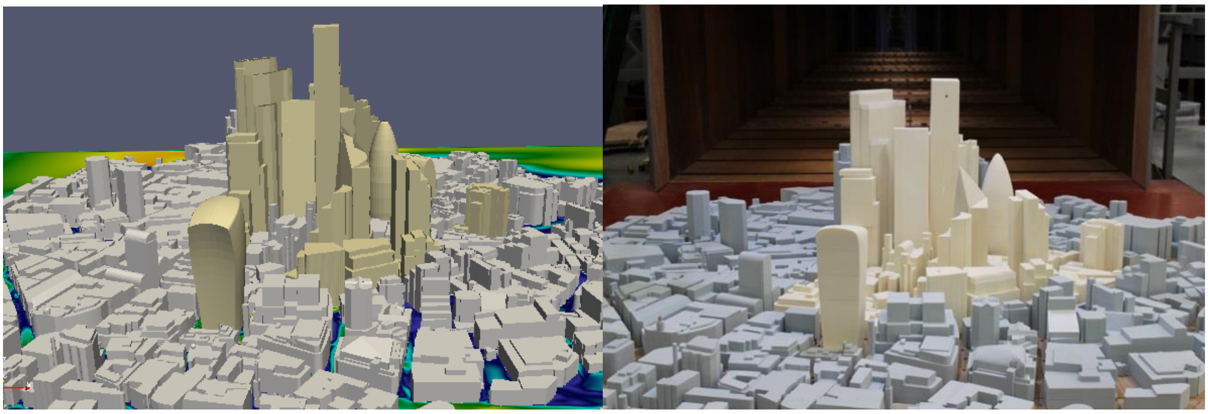

Figure 7. RWDI's City of London Wind Models (CFD, left, and wind tunnel, right)

Modelling was also undertaken on the solar performance for selected key buildings located throughout the city area. Access to sunlight in outdoor spaces and daylight to interior spaces is recognised as an important aspect for human health and well-being. As such, the Annual Probable Sunlight Hours (APSH) is a measure of the amount of sunlight that a given window of a building may expect to experience over a period of one year, as noted in the Greater London Authority (Greater London Authority, 2013) which is based on the BRE Guidelines. Figure 8 shows the percentage value for APSH for select building facades nearby to the Eastern Cluster in London. This helps to understand the impacts of overshadowing from taller buildings to nearby areas, but also the impacts of street-widths. Alignments in the design of city precincts are also a key driver.

Additional modelling is currently underway as an extension to this work to enable a better understanding of the thermal comfort level throughout the city. This will provide better guidance on comfort levels associated with the future built form of the city and how high-rise tower design can be better integrated into the city as a whole. The importance of how thermal comfort will vary throughout the year, the impact of wind chill as well as solar radiance to different areas and urban parks throughout the city will help to ensure more favourable outcomes for future urban realms.

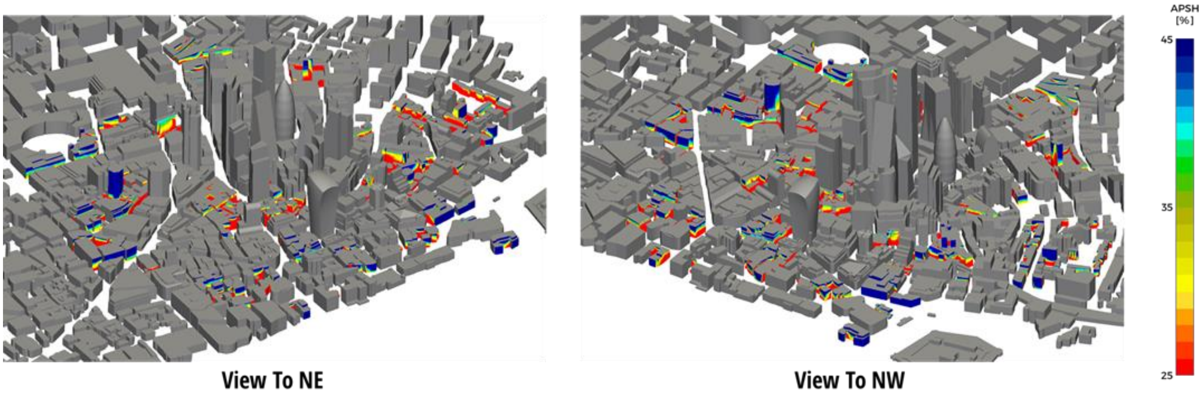

Figure 8. Probability of Access to Sunlight Hours for Selected Building Facades.

Furthermore, an air quality study of the city model is being undertaken to complete this holistic comfort model for the city. Whilst, from a wind comfort aspect, conditions are typically aimed at reducing the wind speeds, it is equally important to understand how areas of calmer conditions can result in pollution build up or recirculation regions of exhaust which impact air quality. Information on the outcomes of this analysis is currently not available for discussion but will be in the near future.

CONCLUSION

Consideration for comfort in outdoor environments has largely been viewed as individual elements with little consideration for the holistic conditions that a person feels when they are utilising a space. While the wind conditions may inform how windy or safe an environment may feel, due to the mechanical force of the wind, how a person experiences that space would be notably different between the warmer summer months and cooler winter months of the year. We as humans do not feel and experience each part of the environment individually; however, the more prevelent means by which comfort levels are assessed is on an individual basis, with some elements not even addressed.

While the earlier work developed at RWDI was ground breaking in creating an understanding outdoor thermal comfort for pedestrians, advancements were necessary to consider this politically as well as to include other key impact elements, such as air quality and noise pollution. This paper has presented this advancement for a holistic approach to human comfort which should be considered for future masterplan and city developments. This would help to provide a true overlay of how a person will actually experience an outdoor space and provide better guidance for suitable design approaches and outcomes into the future.

Furthermore, planning authorities should consider how the current and future conditions of a city or precinct will perform, as a whole, from an environment comfort perspective, instead of purely considering large scale precincts from an architectural perspective. It is equally important to consider both components to understand the complete picture of how a masterplan (existing or future) will be experienced by its residents and users.

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BIOGRAPHY

Kevin is a respected engineer and is the Regional Manager for RWDI's work throughout Australia and New Zealand. His project experience includes more than 1,000 buildings, neighbourhoods and campuses across Australasia and the Middle East. As a wind engineer and microclimate specialist, clients benefit from the depth of Kevin's expertise in the modelling of pedestrian wind and of natural ventilation in tall buildings. His work and passion are focused on improving the performance levels and overall end outcomes for both the client and the environment. Kevin and his team work closely with clients from the conceptual stage through to project completion.

As President and CEO, Michael works with RWDI's senior leadership team to set strategy, define key priorities and guide all levels of the organization in pursuing our vision. A wind engineer and microclimate specialist who has completed scores of notable projects around the world, he brings a wealth of experience to his efforts to drive growth, extend the firm's international reach and deepen our technical capabilities in emerging areas such as sustainable building consulting and numerical weather modeling. Committed to strengthening our culture of collaborative problem solving and continuous learning, Michael and his team maintain an unwavering focus on service, helping clients in more sectors and more locations solve tough engineering problems and execute ambitious building projects.