Analytical Methods to Enhance Passive Urban Design

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ABSTRACT: The purpose of this paper is to present a selection of case studies that illustrate how passive design aims, a low carbon development and a comfortable environment, can be addressed by the use of analytical tools. These tools can be used as part of a holistic design and provide the designer/architect with valuable feedback at early stages. Three case studies, each in a different climate zone, Northern Europe, the Arabian Gulf and Central California, have been chosen to discuss how analytical methods were used on specific microclimatic variables and their impact on the design.
Keywords: microclimate, passive design, urban heat island, analytical tools, wind, comfort, cfd

INTRODUCTION

Low carbon building design starts with appropriate passive design features such as orientation, form and envelope. For optimum benefit, such features should be considered at the inception of the building design project and thus influence architectural response. However, in an urban setting, at this early stage, many opportunities have already been missed. The true, and often overlooked, first line of defence for reduction of building cooling loads is at the masterplanning stage of developments. Poorly designed cities can exacerbate the urban heat island effect, which results in higher temperatures, higher heat gain to buildings and increased cooling loads. The performance of heat rejection equipment is reduced by higher external temperatures, which will tend to increase the carbon intensity of the cooling process. Figure 1 illustrates the importance of passive design measures.

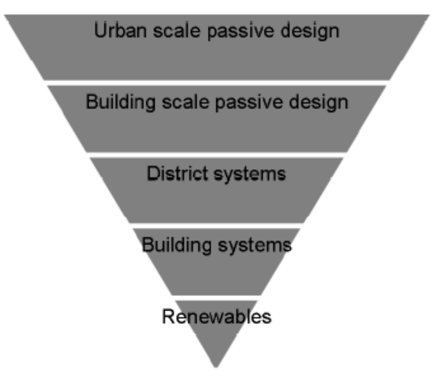

Figure 1: Illustration of sustainable design approach and impact

In addition to low carbon building design, passive design measures can also serve to make the external urban spaces more habitable, usable and appealing. This, in turn, can encourage changes in people's behaviour and reduce energy consumption. On a more psychological level, this can further generate a greater feeling of interaction between people and communities by creating a pedestrian environment.

Recently, urban and building design teams have been considering microclimatic issues in early development more frequently. This work includes projects from the very large masterplan to individual external spaces such as courtyards. Regardless of the size, the aim remains the same - to use the local environment to our advantage to create a comfortable, low carbon development. The difficultly, however, is to identify the most beneficial design strategy and then quantify its advantages.

There are many analytical tools available that allow us to undertake microclimate analyses, e.g. tools that estimate the solar radiation, tools that plot wind roses and wind distributions. However, each tool analyses only a fixed set of parameters. For complete microclimate analysis, it is the combination of all the environmental parameters, such as humidity, temperatures, solar gains etc., as well as building geometries, materials, vegetation, etc., that will dictate the local microclimate and thus have a direct impact on the urban heat island effect, building cooling and heating loads and thermal comfort. By combining the outcome of the relevant analytical tools, such as thermo-dynamic software, computational fluid dynamics (CFD) packages, radiation simulations, etc, general physical indices representing the environment as a whole can be identified. Based on the outcome of the analyses, effective design guidance can be given to enhance the sustainability of the development.

This paper addresses a variety of approaches on how early stage analyses can provide beneficial feedback to architects and designers. This is achieved using three case studies, each in a different climate zone and of a different scale.

BACKGROUND

The theory and methodology behind the analyses for each of the case studies is derived from various accepted industry practices.

Wind analyses were done in a similar manner as in wind tunnel studies. Wind was simulated from the major wind directions. The results were then combined by their respective wind characteristics (shape of the assumed Weibull distribution) and frequency of occurrence. To assess risk or comfort based upon these, the TV Lawson criteria was used [1]. The major difference between wind tunnel studies and the numerical studies is that the simulations were run in steady-state mode. All transient effects, such as gustiness are thus ignored. However, based on comparative in-house studies between numerical and empirical wind simulations, the error associated with this is very small and for early design stages, this approach is valid to indicate windiness.

Solar studies have been simulated using ray-tracing software. Some simplifications to the sky have been made to analyse the effect of seasonal or yearly solar irradiation. The sky was split into different equal angle segments [2]. In each segment the irradiation of each sun hour for the analysis period was summed to provide the total irradiation. Instead of simulating every solar position for a season, the simulation time was limited to a single sky including many suns. There are other ways of segmenting the sky [3], but the proposed method is preferred as it is easier to change accuracy, to sum sun irradiations and is believed to be more representative of the actual sun movements.

Thermal comfort is based on several environmental variables and the person within that environment. Early work from Fanger [4] attempts to index comfort and showed that the difference in people's metabolic rate, dress code and general physic, meant that it is impossible to satisfy everyone. Furthermore, most comfort models are based upon a standard person [6]. However, even with these two drawbacks, comfort models were used [5, 6] to compare the comfort between different areas to gauge environmental effects and to provide an educated understanding within what comfort zone the development was operating.

CASE STUDY 1 – The Arabian Gulf Region

A district of a coastal town in the Gulf region was to be rebuilt. The size of the masterplan stretched over several building blocks, exceeding an area greater than two million square meters. The client's aim was to create a sustainable and pleasant microclimate environment to reduce energy and water consumption, and to enhance social interaction via communal spaces. The challenge in the Gulf is the extreme climate condition that the region is subjected to, especially during the summer season (i.e. hot and very sunny). Our scope was to define general design rules to achieve a passive urban design and to comment on architectural proposals.

The general approach was to reduce solar gains wherever possible. This can be done by building orientation and massing, through the use of good materials (i.e. high albedo, high thermal mass), external shading devices, etc. The absorbed heat was to be removed as quickly as possible. This can be done by guaranteeing minimum air ventilation throughout the development, and especially within external dwell areas. Those two measures would reduce the urban heat island effect on a macro scale and thus reduce the total cooling requirements for this development. On a micro scale, building overhangs and vegetation were suggested to complement the macro scale design.

For this particular case study, the discussion was limited to the assessment of windiness and whether the proposed layout would allow for enough air circulation. To assess windiness, two factors and their correlation were taken into account:

- Wind speed
- Wind direction

The correlation was the frequency at which certain wind speeds occur for a given wind direction, as is illustrated by wind roses. To analyse the windiness on the proposed development site, the frequency, wind speed (or strength) for the major wind directions were considered. Computational fluid dynamics (CFD) was used to predict the typical windiness within the development for each major wind direction. The results were then combined into a frequency plot indicating the frequency of occurrence to exceed a given wind speed, i.e. for what percentage of the year is a certain wind speed exceeded.

Initial climate assessments, based upon the Physiological Equivalent Temperature PET [5], showed that a minimum of 0.5m/s (100fpm) of average wind speed would be the most advantageous to enhance pedestrian comfort, as well as to reduce the urban heat island effect. Figures 2 & 3 are contour maps illustrating the frequency of occurrence to exceed 0.5m/s (100fpm) and 2m/s (400fpm) respectively within the proposed development. Most areas exceed for 80% of the year wind speeds of 0.5m/s (100fpm). However, some of the more sheltered courtyards needed more attention to decrease the local heat island effect and increase pedestrian comfort. Wind speeds of 2m/s are exceeded for over 70% in rural areas. However, they do not exceed 30% in most places of the development.

Figure 2: Percentage of exceedence for a wind speed greater than 0.5m/s (100fpm)

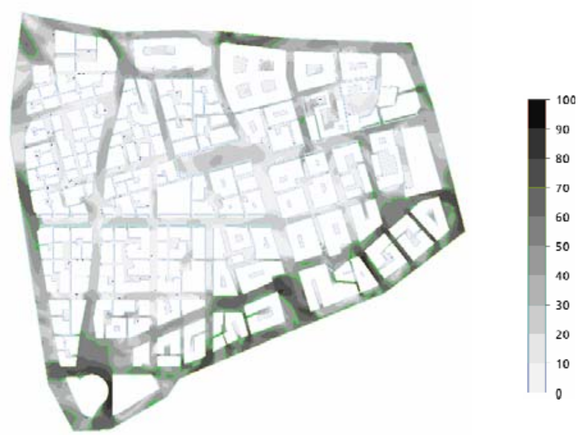

Figure 3: Percentage of exceedence for a wind speed greater than 2m/s (400fpm)

Conclusion – After the initial weather file assessment and the indication of benefit for minimum wind requirements, design guidelines promoting windiness within the development were established. The designs were then tested using analytical methods to check whether the objectives had been achieved, but also to provide visual feedback at early design stages, which would guide architects to optimise their initial draft. The analysis indicated that sufficient ventilation could be provided for 80% of the year in most places and consequently highlighted areas that required further attention. This triggered the architects to consider wind catchers and/or altering the building block height to improve the average windiness in those areas. The same analysis method showed that the general environment was sheltered from strong winds and gustiness, as wind speeds greater than 2m/s (400fpm) on open terrain occur for more than 70% of the year, did not exceed the 30% mark within the development. One of the passive design measures had been achieved.

CASE STUDY 2 – Northern Europe

A building complex was to be redeveloped in one of the major northern European cities. The size of the development was limited to three high rise towers and a communal piazza to access the buildings. The aim was to estimate the microclimate impact that this proposed development would have on pedestrian access and comfort in the areas surrounding the development. The difficulty in predicting comfort is that it is an objective state comprised of several physiological (e.g. air temperature, humidity, windiness, radiation, clothing level, activity, etc.), as well as psychological variables (e.g. whether a person wants to be there). The focus can only be placed on the physiological environment. Several ways of presenting the external environment were proposed:

- Windiness contour map indicating the associated accessibility risk due to wind exposure
- Solar and windiness map indicating areas that will benefit from shade, sun, windiness and wind shelter

CFD and a solar radiation tool were used. Based on the analyses' results, the microclimate created within this development was not ideal as the towers acted as wind catchers. Although the solar gains were good in most areas, the open areas could not be used for extended periods of time as dwell areas. Figures 4 & 5 show how the piazza area to the south of the building complex benefited from solar gains throughout most of the year during the afternoon (i.e. the time people would want to dwell outside the office spaces), but was subject to windiness (windiness is defined as uncomfortable to dwell in for an extended period of time based on the TV Lawson criteria [1].)

Based on the results of this study, a constructive dialogue between engineers and architects was created at the conceptual design stage. Several alternatives were suggested to enhance the local external comfort. Those included the following:

- Re-orientation of the buildings to limit downdraughts and funnelling of wind, as well as to enhance solar exposure to the areas between the high rise towers.
- Local mitigation measures such as tree barriers to divert the wind and translucent canopies between the buildings to shelter the access points from downdraughts.

Some of the above measures were considered for the next design iteration and a hybrid approach was taken. The architect wanted to use the windiness for on-site wind turbines between two of the buildings as a renewable energy source. To mitigate against the consequent downdraughts, the building podiums were enlarged and a canopy over the main access points was considered and was to be tested at later design stages.

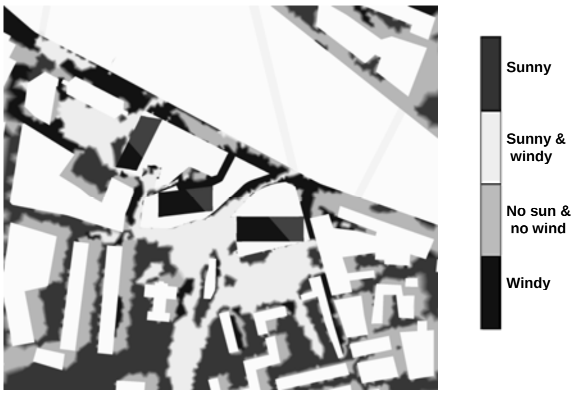

Figure 4: Illustration of sunny/windiness around the proposed development in June at 3pm.

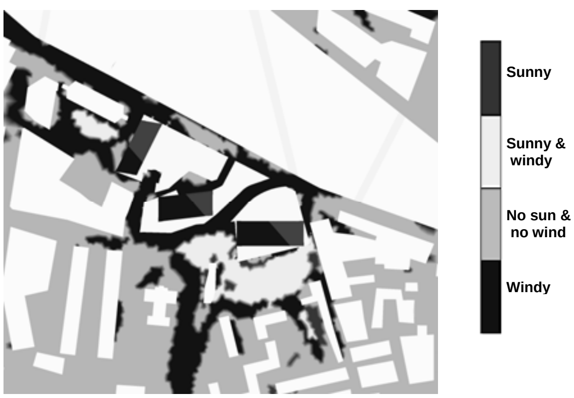

Figure 5: Illustration of sunny/windiness around the proposed development in December at 3pm.

CASE STUDY 3 – Bay Area California

The mechanical systems of a low-rise office development, located in a business park in the Bay Area, were to be designed. The architect and client's aim was to be able to make the building as sustainable as possible. Various passive systems were considered and their feasibility tested. One objective was to naturally ventilate the building and, under favourable climate conditions, allow for free cooling.

The proposed building had deep floor plates and closed perimeter offices along 80% of the façade. The perimeter offices accounted for approximately 40% of the floor space. The remaining floor space consisted of two types of core spaces: deep inner core and the core space within a bar-section (an illustration is shown in Figure 6). These core spaces were removed from façade ventilation opening and at the same time produced significant internal gains (i.e. through lighting, equipment, people, etc.) that needed to be removed.

The proposed façade system consisted of an upper and lower mechanically-controlled opening and a manually operable window. A second upper façade opening would allow air to circulate beyond the perimeter (over the false ceiling) into the core spaces. To enhance natural ventilation within the deep floor plates, inner atria acting as thermal chimneys were proposed by the architect.

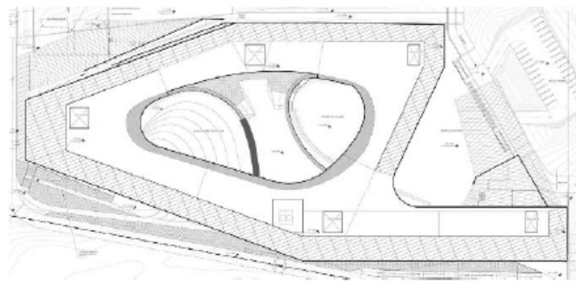

Figure 6: Building layout illustrating the inner core zones, atria locations, bar-sections and perimeter zones

To investigate the feasibility for naturally ventilating the three different spaces (i.e. the possibility and the implications that natural ventilation would have), several analytical tools were used. For the perimeter offices, and deep floor plates, thermo-dynamic simulation packages were used to assess the air flow through each zone. CFD was used on the bar sections between the perimeter offices to determine whether or not the minimum fresh air requirement would be achievable. Figure 7 shows a model of the bar section for a specific climate scenario.

Perimeter offices – single-sided natural ventilation was achievable with the proposed lower and upper façade openings only. Additional operable windows were added for more user control and would result in non-tangible free cooling.

Bar-sections – cross ventilation due to average wind speeds provided sufficient amounts of fresh air to the spaces. Even on still days, and an external temperature of 2°F below the internal set point, the minimum fresh air requirement could just be achieved.

Inner core areas – the thermo-dynamic model and a reverse buoyancy flow calculation of the atria show that natural ventilation was possible. However, the difficulties here were not the façade openings, but rather the atria openings. To allow for the minimum fresh air requirement, the atria roof had to be wide open, which could have noise implications (from roof equipment) and general leakage (e.g. infiltration, leaves, rain, etc.).

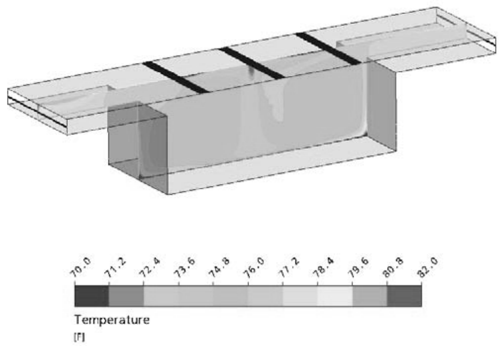

Figure 7: Contour plot showing the average temperature in a bar-section for a still day and an external air temperature 2°F below the internal set point.

The analysis showed that natural ventilation could be achieved for most of the hours of the year. Several analytical tools were used to inform the architect and façade designer of the minimum requirements that needed to be considered, such as the approximate size of mechanically controlled façade openings, the size of atria openings and the need to allow for air passages between the different floor spaces. The advantage in optimizing the façade requirements early in the design allowed for a more precise cost estimate of the integrated façade system. This supplied the client and architect with knowledge not often available at early design stage.

CONCLUSION

Three case studies were chosen as examples to discuss how analytical methods have been used to provide additional feedback on the sustainability of the developments and how this information was implemented thereafter.

The first case study illustrated that windiness, on a large-scale urban development, can be modelled to verify the desired passive design measures. Using comfort models and convection coefficients based upon wind speeds, a desirable minimum ventilation requirement to reduce the urban heat island effect and to increase comfort was derived. The study highlighted at early design stages areas in need of further attention to create a more comfortable and sustainable environment. A constructive dialogue between engineers, planners and architects resulted from this study to amend the design. Large scale and localised mitigation measures were suggested and taken into consideration in the next design phase.

The second case study showed that the combination of physiological variables was used to guide the design and inform the architect of the usability of external dwell areas and accessibility to the building entrances. This resulted in a modification of the architect's building massing. More emphasis was placed on the microclimate in the following design iterations. An ongoing consultation between design engineers and architects, by which more design variables were quantified at early design stages in order to prevent complex mitigation strategies later in the design, lead to a more holistic design process.

The third case study elaborated on the feasibility of using natural ventilation as part of the passive design to reduce the energy consumption within the building. The analyses allowed us to identify: (i) The number of hours a mechanical system would be required; (ii) The minimum façade openings required for the perimeter offices and bar sections; and (iii) The core atria opening sizes for sufficient minimum air circulation.

With this specific knowledge, the façade engineer could design a façade that would allow for natural ventilation and night flushing. Furthermore, an accurate cost associated with the proposed façade option could be derived at schematic design, providing investors with the required information to decide whether that option was to be pursued. This had a positive benefit to both architects and design engineers, as the chances of a major façade change at the value engineering stage is less likely.

Throughout the three case studies, each elaborating on a specific environmental variable and at a different design stage, it was shown that the use of appropriate analytical methods at early design stages provided time and cost savings to all parties involved. Furthermore it was shown that critical design decisions were made upfront, rather than having to redesign major parts of the development, whether building blocks, a specific building shape or a building façade.

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