Inclusive and sustainable housing in Cape Town
Low impact strategies for high comfort and affordable housing

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Abstract:

Cities are major contributors to climate change, and the city of Cape Town is no exception, but this is only one of the many challenges it faces. As a consequence of apartheid planning the city layout of Cape Town remains highly segregated. Approximately 25% of the population remain in informal housing situations, far from the economic hub and opportunities of the city. Innovative development in these areas is a good starting point, but does not address the issues of segregation, or provide equal opportunities for city's residents. A solution is needed that tries to mitigate both climate change and the reverse past effects of spatial planning.

Providing affordable housing in the central city is one solution that creates a sustainable approach through urban regeneration. The objective of the project, aims to establish an inclusive and sustainable housing strategy for the city of Cape Town. More specifically, it seeks to achieve a methodology to convert underutilized office spaces in the city centre for a residential purpose while simultaneously providing high comfort with no active conditioning systems that is affordable and requires low maintenance.

The findings have justified that an indoor comfort criteria is achievable in Cape Town through passive design strategies. The implications of the proposed passive design strategies on a transformed residential unit, can result in a comfortable indoor environment with an overall reduction of the buildings energy consumption, intended to alleviate the ongoing energy crises in South Africa, while simultaneously making use of existing building stock in the city. As a consequence of this solution, improved access to job opportunities around main economic nodes are more viable and increased densities within close proximities can result in more sustainable public transport system, as well as improved inner city safety. It can also assist in mitigating issues of urban sprawl, reducing infrastructure and service costs, and reversing the effects of current spatial planning within the Cape Town metropolitan area. The project offers a viable solution to the constraints facing the city and is one that can assist in providing an inclusive and sustainable housing alternative that can provide high comfort with no active conditioning systems that is affordable and requires low maintenance.

Introduction

At the southernmost tip of the African continent (See figure 1), lies the city of Cape Town within the country of South Africa. The city hosts a population of approximately 3.8 million people within a land area of 2, 4 km² (Frith). Roughly 25% of the city's population live in informal housing situations located far from the city's central business district.

Figure 1 : Cape Town location

Climate context

According to the Köppen classification system[1] Cape Town's climate is classified as Csa- Warm Mediterranean. Geographical conditions such as the; two ocean currents[2] around the peninsula and high mountain ranges (See figure 2), provide a unique micro-climate for the city.

[1] Global climate classification system.

[2] The cold waters of the Atlantic Ocean on the west and the warmer Indian Ocean waters on the east, surround the peninsula of Cape Town.

Figure 2: Cape Town city bowl, encapsulated by mountain range. (Nair)

Average outdoor temperatures range from 7°-26 °C annually. Adequate day and night temperature shifts, occur in summer months which is useful for passively acting thermal mass (See figure 3).

The average summer temperatures range between 16°-26°C, and is characterized by hot, sunny days with cool nights. The average winter temperatures range from 7°-18°C and is characterized by dry, sunny days and cold nights. Cape Town also experiences high, rainfall and wind velocities during its winter season.

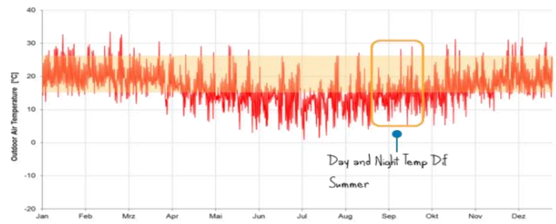

Figure 3: Annual outdoor air temperature in Cape Town (Transsolar)

Since the city is located in the southern hemisphere, majority of the solar radiation occurs on the northern façade.

Socio-Economic context

The biggest challenge in Africa is the inequality that characterizes the 'urban divide' (UNHABITAT). In 1994, South Africa was a nation divided along the lines of race and class (See figure 4). Today, the country still suffers from these inequitable and inefficient city structures inherited from former apartheid regimes.

Figure 4: Cape Town formal and informal housing Source: Unequal Scenes: Unequal Scenes - by Johnny Miller, http://www.unequalscenes.com/kya-sandsboubosrand

Furthermore, South Africa is the largest producer of CO_2 emissions on the continent and is ranked within the top 15, CO_2 emitting countries in the world (Emissions | Global Carbon Atlas) (See figure 5). With a national economy powered by coal, South Africa continues to experience a significant increases, in fossil-fuel CO_2 emissions each year.

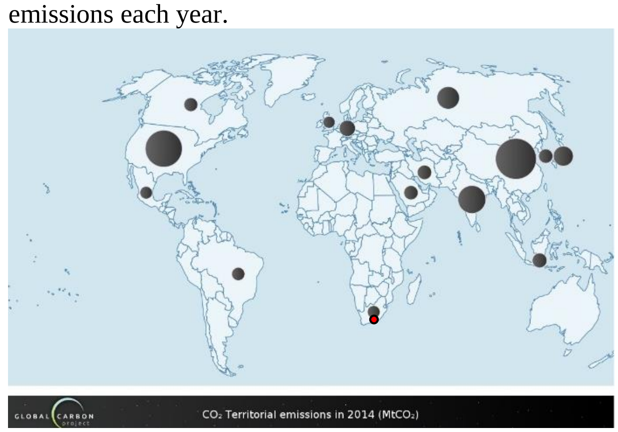

Figure 5: Top 15, CO_2 emitting countries in the world Source : (Emissions | Global Carbon Atlas*)*

Constraints

Previous development grew with disregard to the socio-economic factors and new quick-fix developments occurred to merely address the issue of 'informal housing', rather than the issues of segregation and energy efficiency. Construction that occurs within informal areas or in faraway urban development's further perpetuates the 'urban divide', increases urban sprawl, and requires higher investment in services and infrastructure.

The location of informal settlements far from employment areas, results in long daily commute, transport emissions, poor accessibility and limited access to economic and social opportunities. Densities in and around the city centre itself, are still too low to contribute to efficient public transport and safety throughout the day.

In addition to these constraints, the energy crisis is also a noticeable factor in South Africa. The country has experienced severe load shedding cycles over the decade, as electricity suppliers are unable to keep up with the energy demands of cities. Although the country is making great strides towards energy efficient solutions, a lot of work remains to be done.

Opportunities

There are two main opportunities as highlighted by the authors of the Cape Town Partnership[3] that can alleviate some of the issues faced by Cape Town: The first indicates a potential through tax incentives like the Cape Town Urban Development Zone (UDZ) (Fleming) (See

[3]The Cape Town Partnership is a non-profit organisation founded in 1999 and works towards making the city of Cape Town work.

figure 6), which rewards property owners and developers if they upgrade or build properties within proposed urban areas. The incentive will take place in Cape Town till the year 2020.

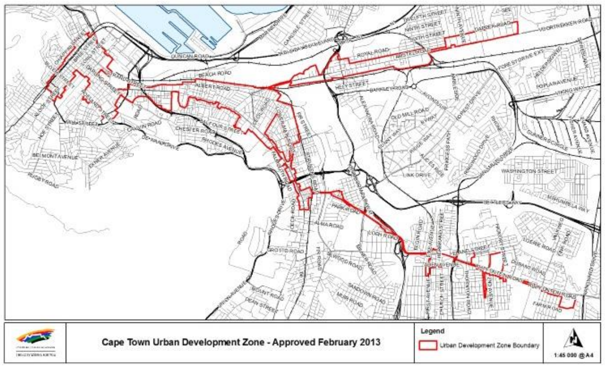

Figure 6: Cape Town Urban Development Zone Source: (CoCT, 2016)

The second opportunity lies within the ever-increasing stock of underutilized existing office buildings within Cape Town (Fleming). These structures provide potential to analyse new strategies for densification and integration within the urban development zone. According to SAPOA's[4], 2015 Office Vacancy Report, Cape Town's CBD, (Central business district) has 1,006,500m² of rentable office space (See figure 7). This is split across different property grades; premium, a, b, and c. Premium refers to newer more modern property and c-grade refers to older property types. Re-use of these underutilized office spaces reduces additional costs required for new infrastructure.

	Total Rentable Area (m2)	Available for leasing (m2)	Vacancy Rate (%)	Previous Months			Gross Asking Rentals (R/m2)		
				3%	6%	9%	MIN	MAX	MED
CBD CAPE TOWN									
P	52,000	16,000	30.8%	30.8%	34.6%	36.5%	185	185	185
A	339,883	32,050	9.4%	8.7%	9.9%	10.6%	95	175	125
B	472,535	44,064	9.3%	9.1%	11.0%	10.4%	76	120	90
C	142,082	25,958	18.3%	20.5%	21.9%	21.8%	50	95	75
Total	1,006,500	118,072	11.7%	11.7%	13.4%	13.4%			

Figure 7: Extract from SAPOA office vacancy report Source: (SAPOA, 17)

Objective

The aim of the project tries to encompass two spheres: Firstly, as an architect and city planner; to provide a meaningful solution for an *inclusive* housing solution that addresses the issues presented previously (see constraints & opportunities chapter). Secondly, as a climate engineer; to prove that it can be done in a *sustainable* manner, by investigating climate responsive strategies for the presented solution. Therefore, the objective aims to establish an **Inclusive and sustainable housing solution for the city of Cape Town.**

By achieving this goal we can begin to facilitate urban regeneration by improving the quality of life for low to middle income residents and provide an indoor environment in which they feel comfortable to occupy.

Approach and methodology

The approach of this project will target, indoor comfort and energy performance relative to a base-case model within a South African context. More specifically it seeks to achieve a methodology of *converting underutilized office spaces for a residential purpose while simultaneously providing high comfort with no active conditioning systems that is affordable and requires low maintenance (See figure 8)*.

Figure 8: Graphic approach and methodology

The approach follows three steps:

1.) Identify the thermal comfort of a '*worst case scenario*'[5] residential unit within an existing office tower, for all possible orientations.
2.) Target the worst performing spaces, based on overheating and overcooling to establish base cases.
3.) Based on the base-case results, identify the main causes of discomfort and provide affordable and low maintenance solutions.

Hypothesis: If comfort can be achieved on the worst cases, then comfort could potentially be achieved for all orientated space types (See figure 9).

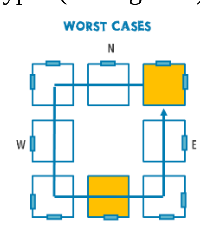

Figure 9: Hypothesis; if comfort can be achieved on the warmest and coldest space _comfort can be achieved for all orientations/space types.

[4] 'SAPOA was founded in 1966 by South African's property investment organizations, to connect all role players in the commercial property field and create a platform for property investors.'

[5] The minimum requirements for a residential unit needed to maintain a typical family.

Model geometry& Internal loads

The base case model evaluated, assumes the worst case inputs for a typical residential unit. The unit is modelled as a 7m by 7m box (smallest size for 4 people) and with a 75% window to wall ratio (WWR) towards the building orientation being tested i.e. N, S, W, E, NW, NE, SE, SW. The construction compromises of lightweight materials found in typical older generation office buildings. Internal loads include: two laptops, standard lighting loads, a family of four people and other additional equipment. Natural ventilation is assumed at 0.6 ACH when windows are open and with a constant infiltration rate of 0.1 ACH throughout the day.

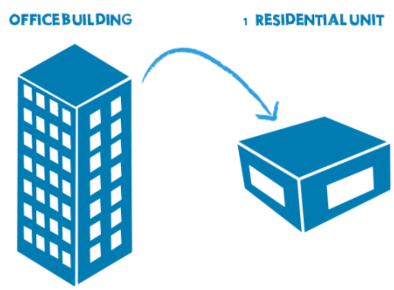

Figure 10: Testing one residential unit within a typical office tower

The glazing also follows typical South African window construction, which compromises of a single pane glass with a visible light transmission of 67%. Where shading will be evaluated, an overhang with an equivalent length of 2 meters is placed above the window. Where daylight is evaluated; surrounding adjacent buildings are also included as worst case scenario.

Comfort criteria and Indicators

The sensation of comfort may differ from person to person depending on one's comfort threshold. For a Capetonian[6] the indoor comfort temperature range, is assumed between 18°-28° C.

Three indictors are used to assess the results:

1. Comfort graph (See figure 11): range between 18°-28° C, a point above or below this range is deemed too hot or too cold.

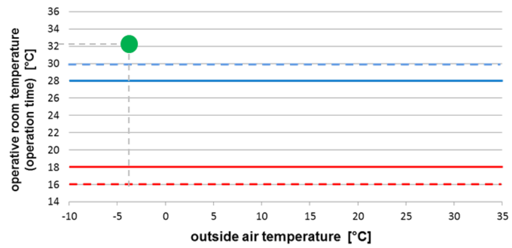

Figure 11: Comfort Chart

2. PMV[7] chart: for a summer and spring comfort criteria, where anything above the range of 1 is deemed uncomfortable (See figure 12), i.e. red dots.

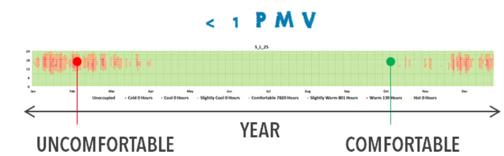

Figure 12: PMV chart

3. Daylight Autonomy[8] (DA) (See figure 13): targeted at 300 lux for 60% of the year. Where colour ranges, below 60%, more artificial illumination will be necessary.

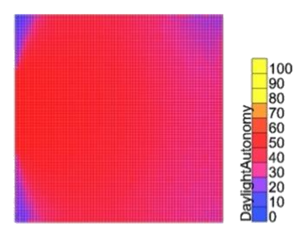

Figure 13: Daylight Autonomy example

PMV[9] range

According to the CBE thermal comfort tool,[10] with 28° C (Peak comfort temperature), a minimum airflow of 0.1 m/s, peak humidity of 80% and a clothing factor of 0.5, equates to a PMV range of 1.1. This may not comply with ASHRAE standards, but with expected higher comfort thresholds of Capetonian's, this range can be deemed satisfactory. Similarly with higher temperatures of 30° C, higher airflow 0.4 m/s (assuming fans are used) and constant humidity and clothing factor results in a similar PMV range of 1.1. This helps us justify a PMV range of 1 for the assessment of our comfort results for a summer comfort criteria (See figures 14 & 15).

[6] Term used for a resident of Cape Town
[7] See chapter on PMV for detailed description.
[8] "Daylight autonomy (DA) is the percentage of the time-in-use that a certain user-defined lux threshold is reached through the use of just daylight. DA is usually given as an annual value but seasonal, monthly and daily presentations can be made. For more historic details, see the Daylighting Pattern Guide site." Source: [1] Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. Leukos, 3(1), 7-31
[9] "PMV = Predicted Mean Vote Index. M = metabolic rate. L = thermal load - defined as the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level." ("Predicted Mean Vote Index (PMV)")
[10] A web-based graphical user interface for thermal comfort prediction according to ASHRAE Standard-55.

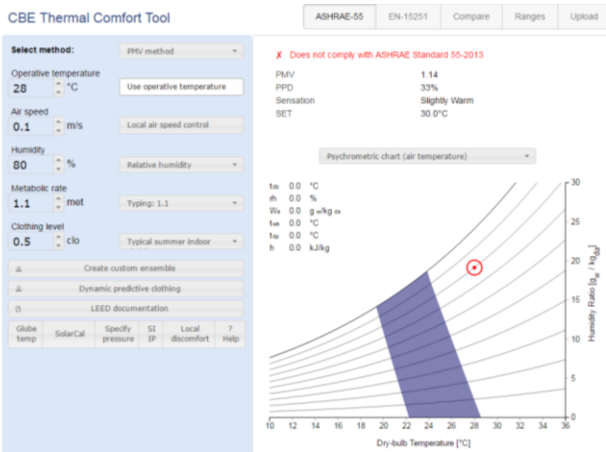

Figure 14 & 15: PMV range based on Cape Town climate conditions not complicate with ASHRAE-55, justifiable for South African context. (CBE Thermal Comfort Tool for ASHRAE-55)

Base case results

The warmest identified spaces based on the results are the; North-East facing space (figure 16) and the coldest the South facing space (figure 17)

NE *S*

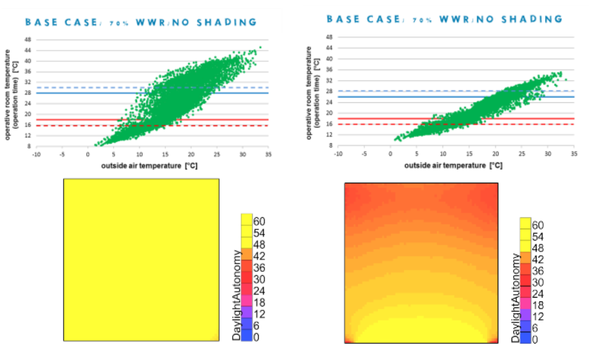

Figure 16 & 17: Warmest and coldest space & corresponding daylight autonomy

Within the ‘warmest space’/North-East Corner, we can visualize majority of the points falling above 28°C line. The daylight autonomy even with the consideration of adjacent buildings achieves the 60% target proposed.

In the ‘coldest space’/South facing space, comfort is at an acceptable level with a few points of overheating and overcooling. The daylight autonomy ranges from 60% to 40% towards the end of the space, as is expected of a space with a single window.

Strategies

Since natural ventilation alone in not sufficient to mitigate issues of overheating, and construction of building cannot combat issues of overcooling. The following passive design strategies are proposed based on most likely to have an impact on indoor air temperature.

All strategies were tested individually to determine which strategy had the greatest impact. Reducing the WWR made the biggest impact, followed by thermal mass and shading. Since thermal mass is a less affordable strategy than shading the following sequence of strategies was proposed:

Proposed solutions (See figure 18):

1. Reduce window to wall ratio
2. Provide fixed shading element
3. Increase thermal mass were thermal mass is lacking
4. Increase air speed : by providing fans

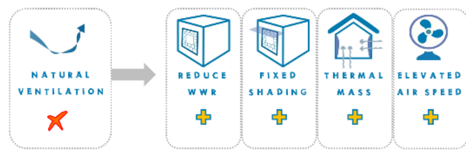

Figure 18: Proposed affordable strategies for cooling

Final Results

Although all orientations are evaluated, only the warmest space/North East space is presented in detail: Each proposed passive design strategy, for the NE corner is clarified:

Strategy 1: Reducing the window to wall ratio indicates a significant improvement in comfort. The PMV summer comfort range is achieved for 87% of the year and daylight autonomy is reduced mostly on the corner spaces and daylight rooms should be designed were 60% DA is achieved (See combined figure 19).

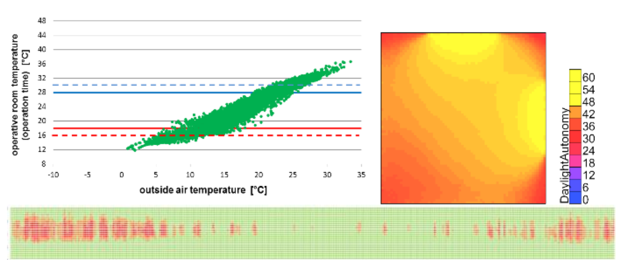

Figure 19: Results for North-East space with reduced window to wall ratio

Strategy 2: Adding a fixed shading elements makes a beneficial impact on operative temperatures but reduces daylight availability significantly. Where shading will be evaluated, an overhang with an equivalent length of 2 meters is placed above the window. Although a fixed shading element requires low maintenance alternative affordable, moveable shading systems should be considered (See combined figure 20).

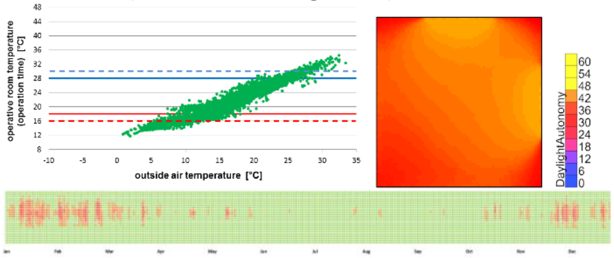

Figure 20: Results North-East space with reduced window to wall ratio and additional shading

Strategy 3 : Increase thermal mass were thermal mass is lacking (no impact on daylight). Thermal mass has a significant impact on mitgating both issues of overheating and overcooling (See combined figure 21). Proposed affordable solutions for increasing thermal mass include : exposing concrete floor by removing surface materials, exposing concrete ceiling and increasing wall thickness of interior walls, potentially through recyclable materials.

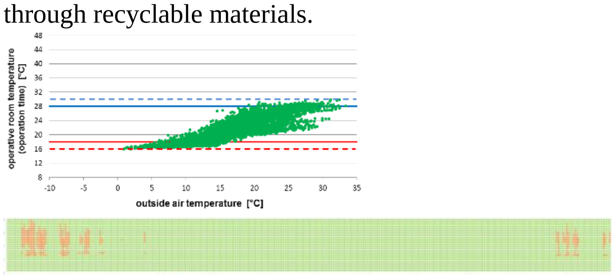

Figure 21: Results North-East space with reduced window to wall ratio, shading and heavier thermal mass.

Stratergy 4 : Increase airflow by providing low energy usage, active systems such as fans (no impact on daylight) (See combined figure 22).

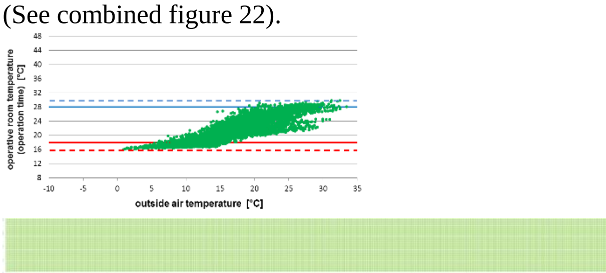

Figure 22: Results North-East space with reduced window to wall ratio, shading and heavier thermal mass.

Summary of results

The following images indicates a summary of the reductions after the implementation of each strategy for the worst performing spaces (See figure 23 & 24).

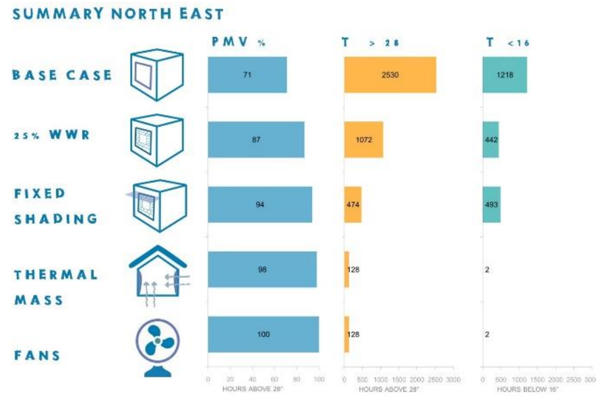

Figure 23: North-East summary of results

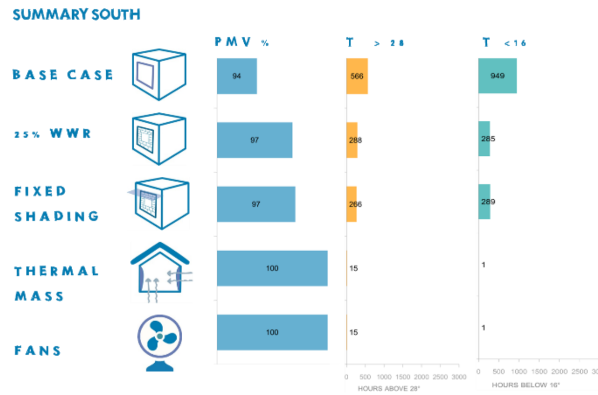

Figure 24: South summary of results

Furthermore all orientation results, were evaluated to identify which strategies were necessary to achieve comfort in terms of operative temperatures and which spaces could be maintained with the minimum amount of retrofit or alteration (See figure 25).

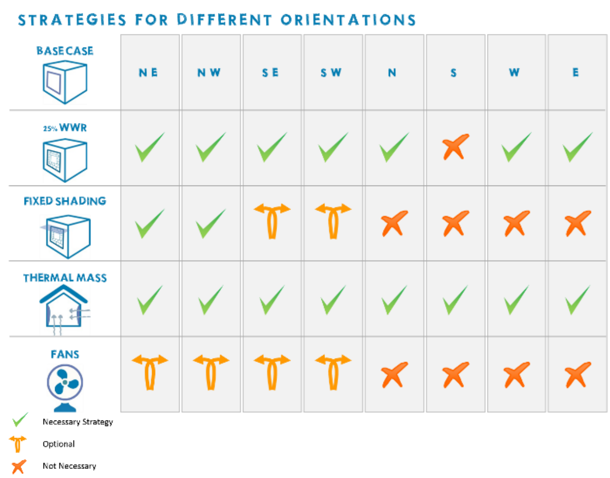

Figure 25: Evaluation of applicable stratergies for each orientation.

Adaptation

Since the model is assumed within the city centre the additional effect of urban heat island (UHI), was included to determine whether an increase in temperatures would affect comfort. The warmest space (NE), with all proposed strategies was evaluated with a progressive temperature range of 1-3° C peaking at night. The results indicated a slight increase in operative temperatures but had no significant impact on PMV comfort:

For this and for future resiliency of the built environment, an additional incentive is proposed; improvement of outdoor conditions. Simple strategies such as providing more green areas and opening up certain spaces as semi-outdoor and surface alterations can help reduce the effect of UHI.

Affordability

The presented solutions provide passive design solution that is low maintenance and affordable as opposed to current conventional systems (See figure 26).

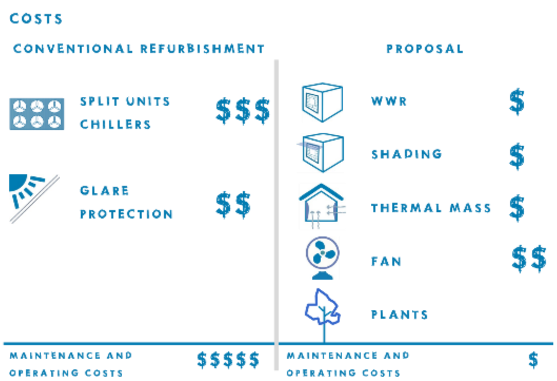

Figure 26: Cost comparison of active systems opposed to passive strategys

Conclusion

The findings have justified that an indoor comfort criteria is achievable in Cape Town through passive design strategies. The implications of the proposed passive design strategies on a transformed residential unit, can result in a comfortable indoor environment with an overall reduction of the buildings energy consumption, intended to alleviate the ongoing energy crises in South Africa, while simultaneously making use of existing building stock in the city.

As a consequence of this solution, improved access to job opportunities around main economic nodes are more viable and increased densities within close proximities can result in more sustainable public transport system, as well as improved inner city safety. It can also assist in mitigating issues of urban sprawl, reducing infrastructure and service costs, and reversing the effects of current spatial planning within the Cape Town metropolitan area.

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