NEOM نيوم

TRANS SOLAR
KlimaEngineering

NEOM Regional Climate Study
Urban Microclimate Design Guidelines

JULY 2020

The land of the **future,**
where the **greatest minds**
and best talents
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pioneering ideas and
exceed boundaries in
a world inspired by
imagination.

Mohammed bin Salman bin Abdulaziz Al Saud

Executive Summary

The regional climate responsive design guidelines address the entire NEOM region and build a framework for regional planning, programmatic decision making and urban design at various scales.

They are informed by climate data measured over 15 years and can be applied to 18 specific example locations. The locations are distributed over three distinct climate zones, the coastal hot and humid climate to the East, the Western arid climate, characterized by larger diurnal swings but generally dry air, and in between the mountain ranges with colder temperatures and the potential for snowfall in winter.

The guidelines also consider thermodynamic computer models, simulating the interaction between the environmental forces, such as sun, wind, temperatures and humidity and different design interventions within the built environment. These include shading, exposure to breezes, the right amount of vegetation, dense walkable city design, mitigation for urban heat island effects and programmatic frameworks for outdoor activities, sports and tourism.

The results of the thermodynamic simulations are interpreted with respect to urban microclimates and the relevance for citizens within the public realm using “outdoor comfort” metrics. As such, UTCI (Universal Thermal Climatic Index) describes the sum of the climatic effects (solar radiation, wind, temperature, humidity, materials) influencing the human experience of the outdoors using temperature equivalences, similar to “feels-like-temperature”.

Modifying the built environment through design and providing protected spaces has the potential to reduce the subjectively felt temperature by up to 12°C and to shift activities into times of the day, or seasons of the year, where they can be comfortably performed. The design interventions hence create valuable outdoor spaces that can be used longer under more comfortable conditions, depending on the location within NEOM.

The guidelines form a framework for prescribed design aspects and planning processes that can be implemented in future NEOM legislation.

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INTRODUCTION

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Evidence Based Planning & Best Practice Guidelines for Urban Microclimate Design

The urban environment is a mosaic of multiple forms and surfaces with unique spatial morphologies and thermodynamic properties that gives rise to distinct meteorological conditions. The urban climate and its study are becoming increasingly important as these regions show significantly higher rates of population growth and development which will exacerbate the environmental challenges that are already present. In order to mitigate the impacts of climate change and population growth, it is important that we no longer operate using trial and error, but instead be more critical of site performance i.e. to adopt evidence-based planning.

Numerical simulations help to elucidate the impact of urban planning and architecture on the environment in a fashion that goes beyond intuition and assumption. Such a holistic approach can resolve the dynamic interaction between buildings, plants and the environment to quantify site-specific environmental performance metrics.

In that spirit, this document summarizes a set of urban microclimate design guidelines derived from climate data measured over 15 years, evidence-based planning principles & international best practices.

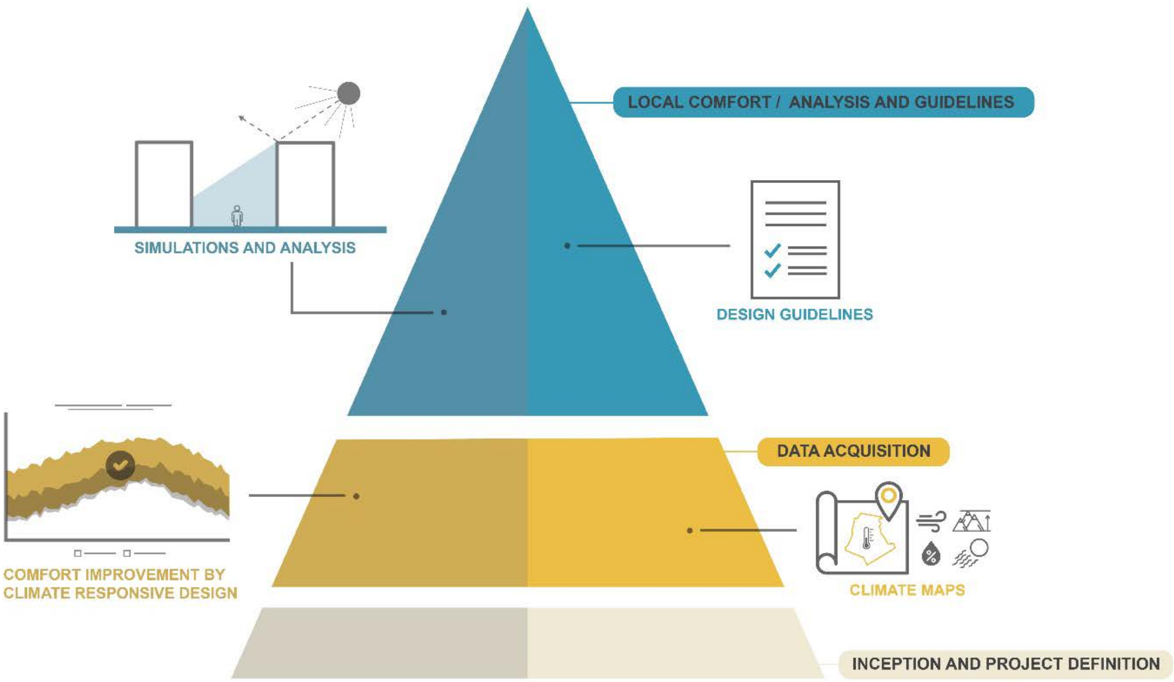


Figure 1: Background research for deriving evidence-based urban microclimate guidelines

As the above pyramid indicates, the foundation of the work is local climate data that has been acquired, statistically treated and that is summarized in the separate Data Acquisition Report. The data is represented spatially in maps as well as temporally in terms of time, diurnal swings and seasonal changes (indicated in ochre coloured base of the pyramid).

The data has then been put into an urban design context (dark blue) through computational simulation techniques, modelling the thermodynamic interaction between the environmental forces and future developments. As there is no fully developed design that can be tested, the studies have been formalized on a strategic level, testing the key design parameters with their effect on the urban micro-climate.

The results are interpreted with respect to different topics relevant from a regional planning point of view as summarized in the next paragraph, informing the regional guidelines (light blue in the pyramid).

Relationship between Outdoor Comfort & Urban Development Guidelines

The climate-relevant topics from a regional planning point of view have been explored between NEOM, Transsolar and different design teams. They are summarized in the graphic below. They address questions related to the following:

- Urban density
- Urban Morphology
- Urban Heat Island effect
- Walkability
- Shading through vegetation

Additionally, these topics are relevant for programmatic questions as well, such as the following:

- Functions in public space
- Sports
- Tourism

Figure 2: Climate-relevant topics addressed in this guideline

In order to inform the guidelines with respect to design measures such as walkability in an urban context, shading through vegetation or with respect to programmatic questions such as sports etc., the UTCI metric is used which helps to describes the value of outdoor public space from a human centric design & outdoor comfort point of view. Successful implementation of these guidelines will ensure that NEOM will provide high quality outdoor spaces – promoting a healthy and sustainable society, including an emphasis on walkability and reduced driving, enhanced social interaction in the public realm and an urban climate with reduced needs for energy consumption.

The following guidelines therefore refer to the Universal Thermal Climate Index (UTCI) to quantify the effect of design interventions on the thermal experience of citizens and visitors in NEOM.

The guidelines include the following design interventions and programmatic decision-making frameworks:

1. Climate responsive programming framework for urban design
2. Climate responsive programming framework for tourism
3. Climate responsive programming framework for sports and activities
4. Self-shaded walkways and public spaces
5. Movable shading systems for squares & plazas or partially self-shaded walkways
6. Shading using vegetation
7. Elevated Wind Speeds at pedestrian level
8. Compact urban development to promote walkability
9. ‘Cool-pockets’ at every 100m on all walkways
10. High surface albedo materials
11. Reduction of anthropogenic heat rejection from HVAC systems into street canyons
12. On-site renewable energy production

The guidelines prescribe design aspects and planning processes that can be implemented in future NEOM legislation. They should always be used in conjunction with state-of-the-art engineering considerations.

CLIMATE RESPONSIVE PROGRAMMING FRAMEWORK

Objective

Every design and planning process involve decisions about program at different scales, i.e. functional assignment of activities to different spaces, sometimes involving different times of the day or the year. Examples are for instance: shopping, dwelling, walking, sports or tourism, each related to different physical engagement.

The following guidelines for “climate responsive programming frameworks” ensures that climate responsive design thinking is part of this process, and that design and decision making assigns the appropriate activities to the right space and time. The guidelines not only consider a) the climate data and information that has been gathered, but also b) the possibilities that the augmentation of micro-climates through climate responsive design offers.

The Climate responsive programming framework making use of climate data will be described in the following three guidelines, while the climate responsive design interventions, to optimize the environmental interaction between urban form and human perception of heat, will be summarized in the guidelines to follow the programmatic aspects.

Every activity has different requirements, depending on whether they are performed in water, on water, on land, in the air, and if they involve increases physical activities like sports or resting in a café, restaurant or bus stop. Therefore, no universal rule can be established as to what activity should be performed where and when. Instead the guidelines relative to programming prescribe a process that can be adopted by designers and decision makers when exploring the programmatic opportunities for every specific activity and program aspect.

This process is described in the following, in terms of questions that should be raised, in order to create a connection to the local climate, and the possibility that design interventions have for augmenting the climate. The designers shall then demonstrate

- what the relevant questions are,
- how they have been addressed and
- what the findings are, using the acquired data and results from this study

An example framework indicating questions and climatic comfort analyses is outlined for the programmatic guideline related to sports. In principle, every activity and programmatic consideration should follow a similar approach.

1
CLIMATE RESPONSIVE PROGRAMMING FOR URBAN DESIGN

Urban Development, Master Planning and City Design involve programmatic concepts relevant for the experience of outdoor spaces. These include for instance markets, outdoor restaurants, spaces with dwelling qualities, shopping high streets, walkable streets (see Guidelines **8** and **9**). Decision making within the planning process shall take into account the microclimatic qualities and opportunities that climate responsive design thinking offers. As the variety of scenarios and activities is very diverse, a process, rather than prescriptive recommendations is described in the following.

Design Intervention:

- Align the program involving and affecting outdoor activities with climatic opportunities from a user centric design point of view.

Process:

- Form interdisciplinary team to identify the activities that programmatically should take place in outdoor public spaces irrespective of design.
- Using available climate data and climate responsive design study, summarize the microclimatic drivers and constraints for outdoor activities with respect to daytime, season and location.
- Specific for each activity and program item, identify all reasonable climate responsive design interventions summarized in set of guidelines to extend the applicable period and spatial constraints.
- Synthesize above analysis to inform program, design and spatial assignment of activities for a climate-responsive programmed masterplan.

2
CLIMATE RESPONSIVE PROGRAMMING FOR TOURISM

NEOM will be an attractive travelling destination. Due to the diversity of its landscapes, the region has the potential to host not only urban tourism but other types of it such as beach, cultural, adventure, etc. Many of the touristic activities will take place in outdoor environments, hence an approach based on the understanding of microclimates will be required to enhance the comfort of the visitors and extend tourist periods.

Design Intervention:

- Plan tourist activities and schedules according to local climatic conditions and apply all reasonable climate response design interventions to extend the period during which they can be realized in comfort.

Process:

- For each touristic activity, create a climate responsive tourism framework assessing the regional climate data, and address the following questions:

  - What are the touristic destinations and key sites in the NEOM region?
  - What design interventions can be employed in the context of these sites?
  - How can touristic programs be informed by seasonal variations?
  - How can they be matched to the diurnal swings over the day?
  - What is the most appropriate location for site independent tourist functions within the region of NEOM?

3
CLIMATE RESPONSIVE PROGRAMMING FOR SPORTS AND ACTIVITIES

NEOM will provide an environment for sports and activities, most of which will happen outside of cities. It may occur informally or organized through events, and will involve athletes, audiences, organizers and the general public engaging in activities. It will occur in water, on water, on land and in the air, and through its diversity will require a sport-specific approach to every activity.

Design Intervention:

- Chose location and time for events according to the local climate conditions. Specific for each sport, apply all reasonable climate responsive design interventions to extend the period during which sports can be safely performed. Otherwise compensate heat stress through alternative strategies such as sufficient hydration and adapted performance expectations.

Process:

- For each sport/activity, create a climate responsive activity framework assessing the regional climate data and address the following questions:
  - What is the spectrum of environmental UTCI conditions to perform the considered sport/activity?
  - What design interventions can be employed in the context of the considered sports/activity?
  - What is the right season for the considered sport/activity?
  - What is the right time of the day for the considered sport/activity?
  - What is the most appropriate location within the region of NEOM for the considered sport/activity?
  - What mitigation measures ameliorate the potentially harsh environmental conditions for the considered sport?

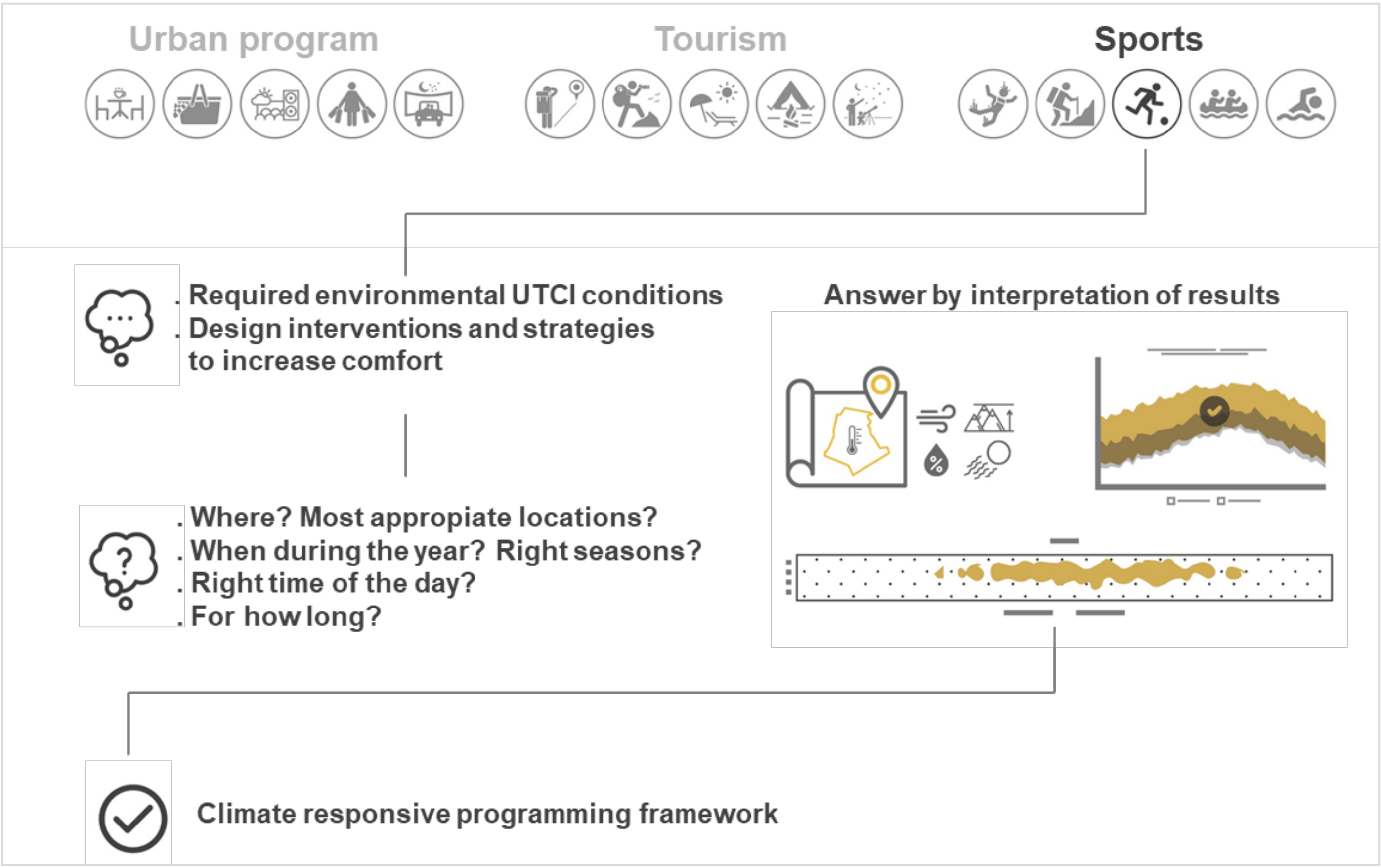
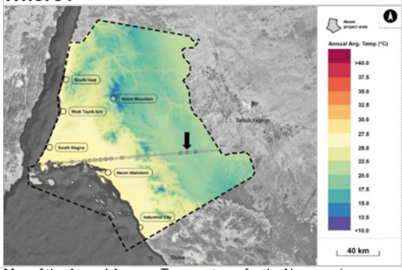


Figure 3: Workflow followed to obtain the Climate Responsive Programming Framework

How? / Define conditions

. Required UTCI range
. Design interventions
. Comfort improvement strategies

Where?



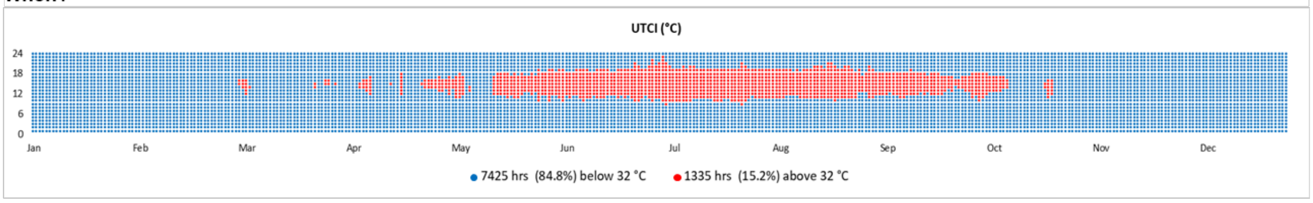
Map of the Annual Average Temperatures for the Neom region

When? / For how long?

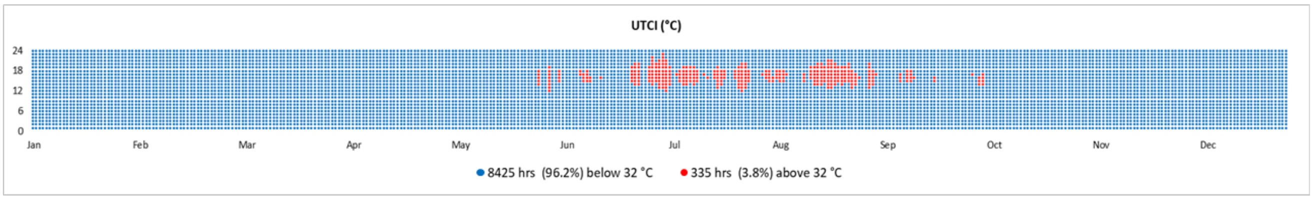
	Non-Shaded Field	Shaded Field
Favorable Months	November - March (42% of the year)	October - May (67% of the year)
Daily Schedule	All day	All day
Unfavorable Months	April - October (58% of the year)	June - September (33% of the year)
Daily Schedule	19:00 - 08:00 (12 hrs)	19:00 - 11:00 (15 hrs)
Broadcasting Time	???	???
Annual Operability*	1265 hrs (17%)	1308 hrs (18%)

Climate Responsive Activity Framework

When?



Annual Carpet-Plot of UTCI in a Non-Shaded Outdoor Space



Annual Carpet-Plot of UTCI in a Shaded Outdoor Space

Figure 4: Examples for climate data at example location NL11 to inform a Climate Responsive Activity Framework

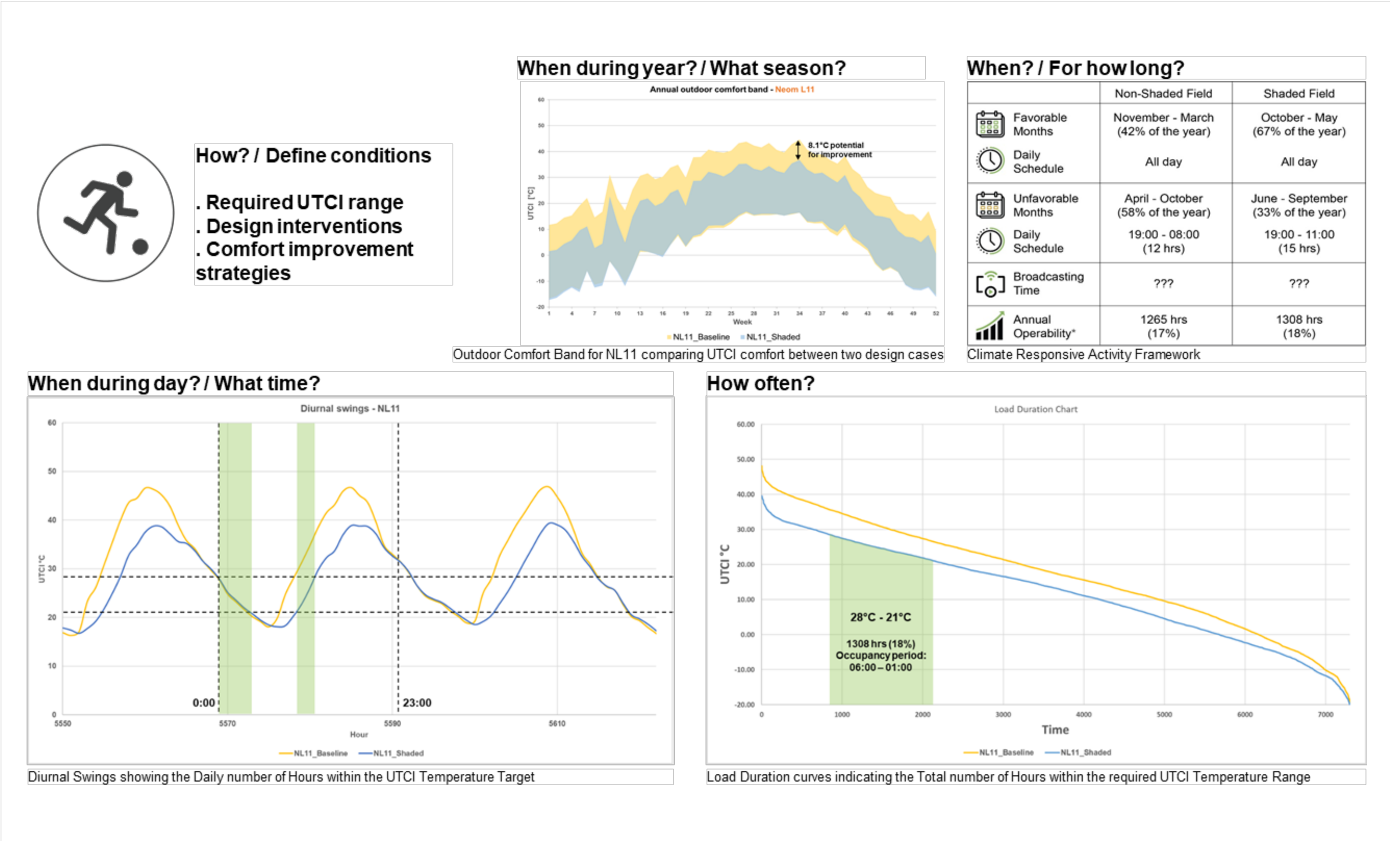


Figure 5: Examples for climate data at example location NL11 to inform a Climate Responsive Activity Framework

SHADING

Objective

Use of urban spaces and walkability is connected to the formed urban microclimatic conditions. Outdoor spaces which are not properly designed with regards to the environment, negatively alter the urban microclimate. To enhance outdoor comfort means to indirectly increase usability of public spaces and promote walkability, which can be achieved by sufficiently shading urban squares and streets.

Shading can also positively affect the environment by reducing the building cooling energy demand and related CO_2 emissions.

4
SELF-SHADED WALKWAYS AND PUBLIC SPACES

Applicable at pedestrian occupied zones of all walkways and public spaces.

Design Intervention:

- Improve the microclimate in street canyons through optimizing the relationship between building height and street width. This positively influences shading and exposure to the cold night sky.

Prescriptive Measures:

- Provide walkways and public spaces to have canyon aspect ratio higher than or equal to 2.0 as this provides optimum shading & protection from solar radiation.

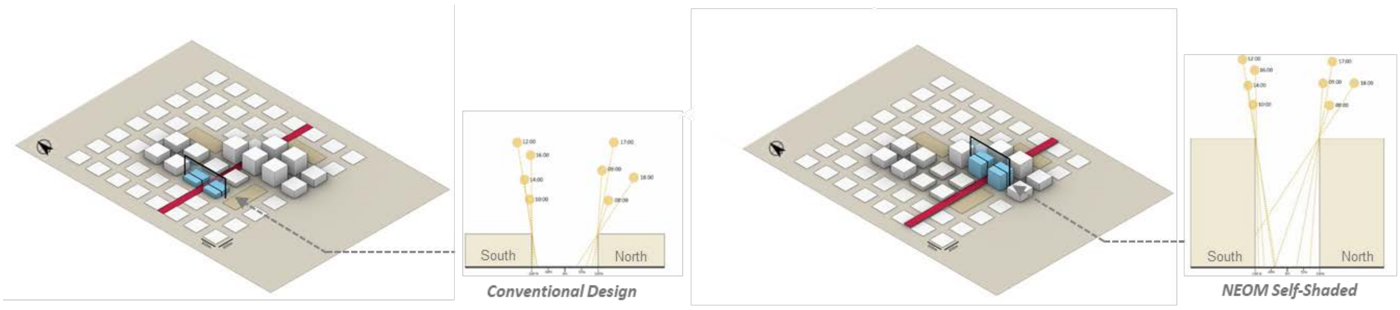


Figure 6: Generic city grid of 300 x 300m showing various possible street-canyon aspect ratios.

(L) Conventional design (aspect ratio 0.5); (R) NEOM Self-shaded (aspect ratio 2)

Evidence Based Planning – Impact of Self-Shaded Walkways: (Example of E-W Axis Street of Canyon Ratio 2)

The following example demonstrates the improvement of urban microclimate from a human comfort perspective (outdoor comfort), for an E-W Axis Street with canyon aspect ratio of 2. For the sake of brevity, the results presented here are for one location – NIC, however a similar trend in improvement of urban microclimate is observed for other locations in NEOM as well. In spring (21st March) an improvement of up to 10 °C UTCI at Noon (12:00) could be achieved by adopting self-shaded walkways and public spaces in street canyons.

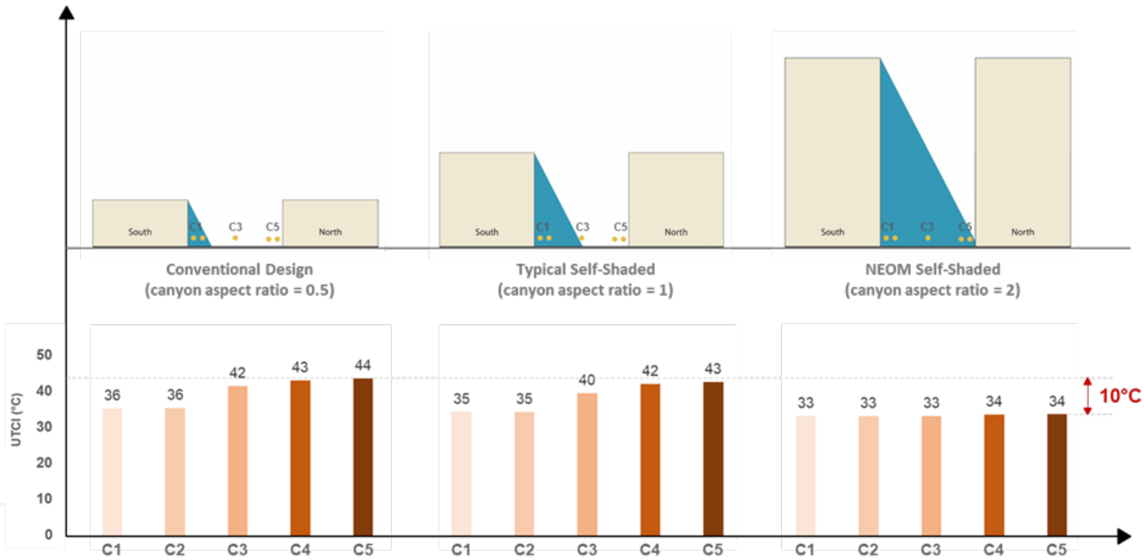


Figure 7: UTCI improvement of up to 10 °C in a street canyon of aspect ratio 2, as compared to a street canyon of aspect ratio 0.5. ***Spring Day (21st March) at Noon (12:00)***

In autumn (21st September), temperatures can reach up to 47 °C UTCI at Noon (12:00) in a conventional street canyon. Adopting self-shading street canyons (aspect ratio 2) can help reduce temperatures by up to 9 °C UTCI at the same time of the year.

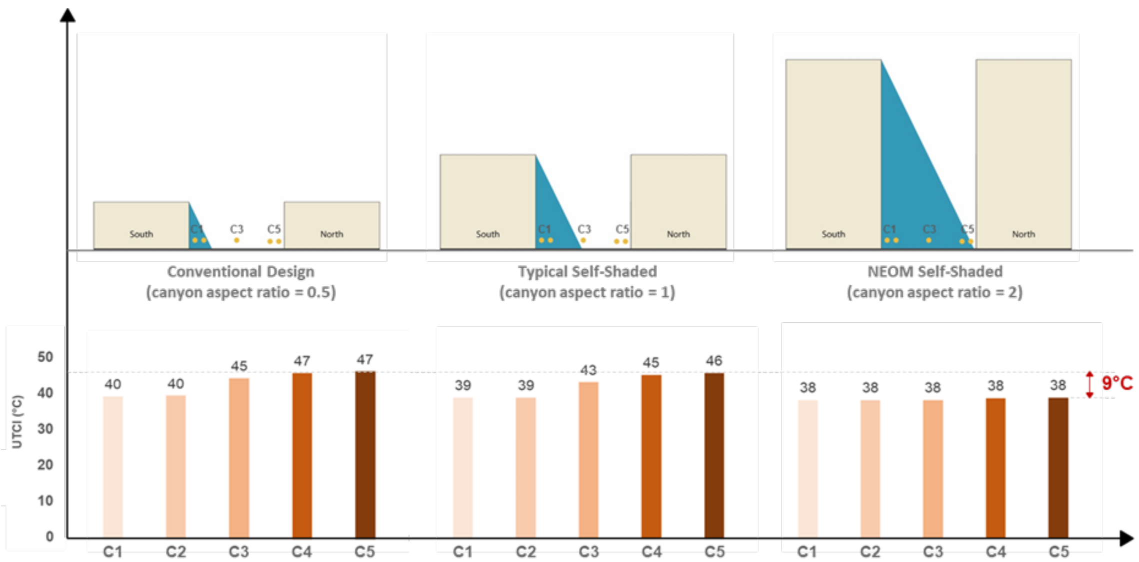


Figure 8: UTCI improvement of up to 9 °C in a street canyon of aspect ratio 2, as compared to a street canyon of aspect ratio 0.5. ***Autumn Day (21st Sept) at Noon (12:00)***

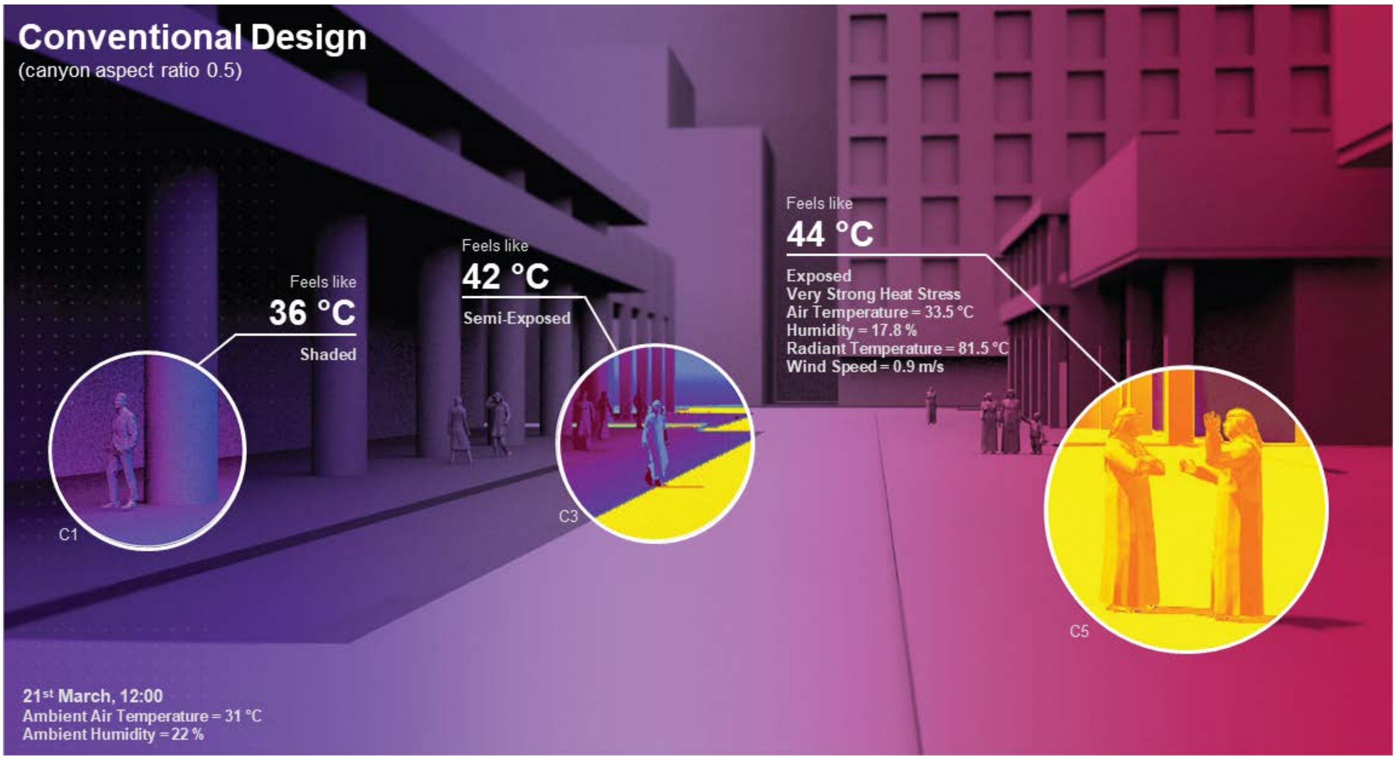


Figure 9: UTCI temperatures at three different positions in a street canyon of aspect ratio 0.5.
Spring Day (21st March) at Noon (12:00).

Figure 10: UTCI temperatures at three different positions in a street canyon of aspect ratio 2.
Spring Day (21st March) at Noon (12:00).

Self-shaded streets can improve the perception of microclimate by up to 10 °C UTCI. They also cover larger areas of the street than can be perceived as cooler compared to a sun-exposed scenario

The impact of adopting self-shading street canyons (aspect ratio 2) for the entire year shows that the naturally comfortable (outdoor) conditions can be increased by up to 4.5 months of the year, with an annual average improvement of up to 7.1 °C UTCI in urban microclimate.

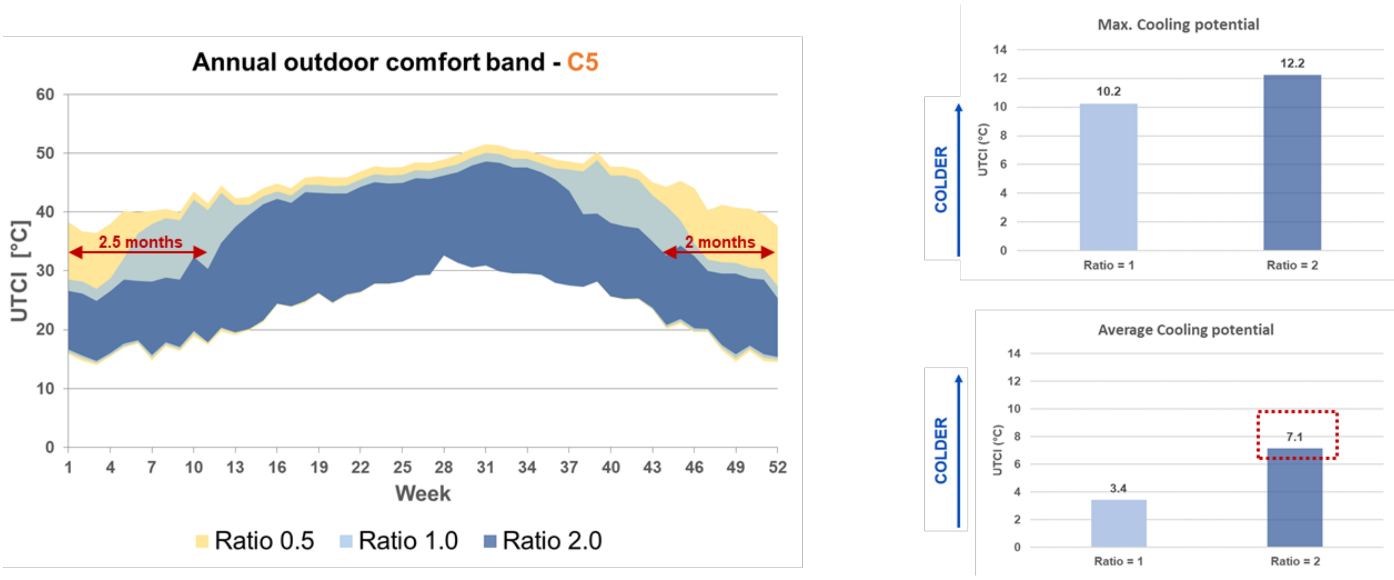


Figure 11: Annual outdoor comfort band comparing the range of UTCI temperatures experienced at the sun-exposed, unshaded side of 3 different street canyons (ratio 0.5, 1 & 2)

5
MOVEABLE SHADING SYSTEMS FOR SQUARES & PLAZAS OR PARTIALLY SELF-SHADED WALKWAYS

Applicable for squares & plazas or pedestrian walkways on partially self-shaded streets (aspect ratio < 2) where a higher standard of outdoor comfort is expected. This could also be applicable for places where people will dwell for a medium (at least 5 minutes) to a long duration.

Design Intervention:

- Improve the microclimate in squares & plazas by providing temporary shade. In retracted state this allows heat to be radiated to the cold night sky, which also improves the thermodynamic balance of people in public space.

Prescriptive Measures:

Provide moveable shading system in all applicable spaces. The shading system should remain active during the day to minimise solar heat gains and retract during the night to allow night-time sky cooling.

- Ensure the shading system should not reduce existing sky view factor by more than 15% in the retracted state at night.
- Provide shading membranes with a maximum light transmission of 15%.
- Provide shading membranes with a minimum reflectivity of 0.5.
- Provide shading systems with low emissivity (< 0.3) on downward facing (i.e. user facing) surfaces.

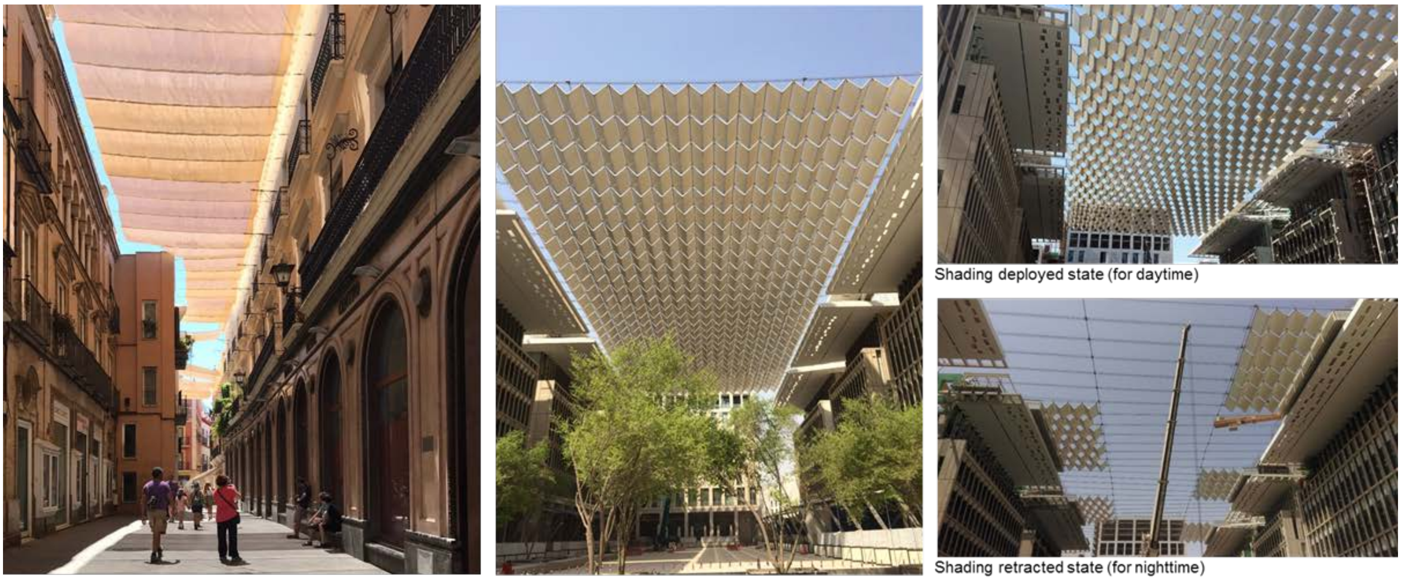


Figure 12: Examples of moveable shading systems for squares, plazas & streets.

Evidence Based Planning – Impact of moveable shading systems:

The following example demonstrates the impact of installing moveable shading systems in a plaza in NIC. An improvement of up to 7.4 °C UTCI during peak summer daytime & an additional improvement of 1.5 °C UTCI during night can be achieved by installing a moveable shading system.

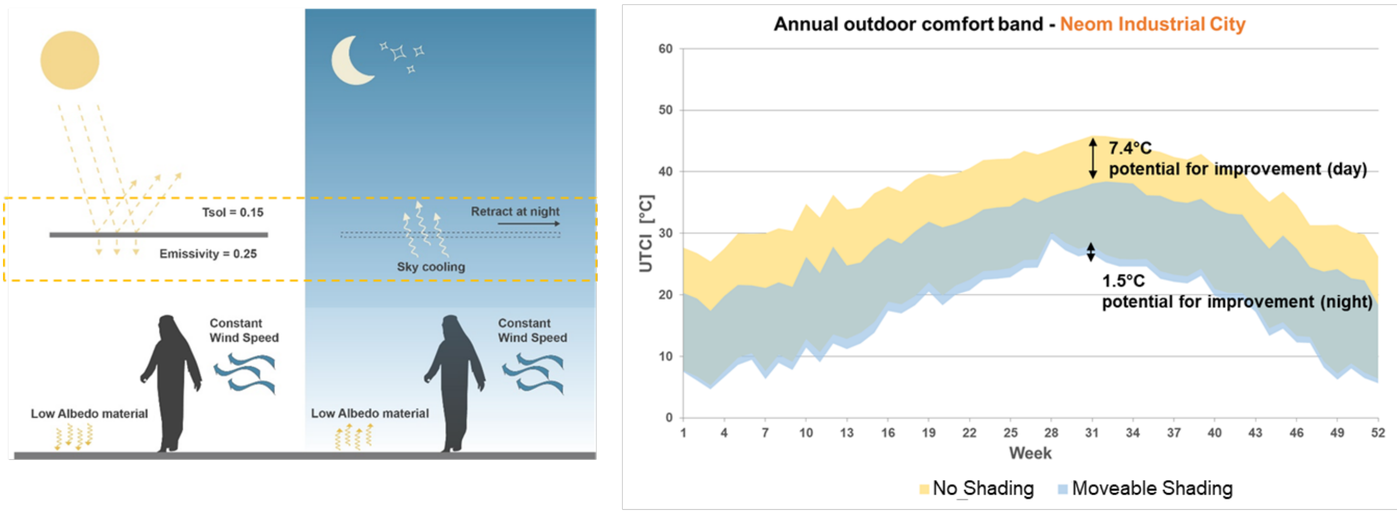


Figure 13: Annual outdoor comfort band comparing the range of UTCI temperatures experienced in a plaza – with & without moveable shading system

6
SHADING USING VEGETATION

Trees provide shade and typically tree leaves heat up less as compared to the surface of an artificial shading structures, which is attributed to the evapotranspiration cooling effect. However, this evapotranspiration is in turn associated to a large amount of fresh water demand for irrigation. Therefore, a water-sensitive strategy should be adopted for planting trees in key locations to optimize the balance between tree water consumption & human comfort. Applicable to plazas and public spaces, street canyons and alleys.

Design Intervention:

- Strategic use of trees to improve microclimate in areas of high user density & long user dwelling times (at least 15 minutes) such as plazas & public spaces.
- Discourage / prohibit use of continuous rows of trees for shading alleys & walkways. Instead, urban biophilia can be successfully integrated in the urban fabric by strategic use of vegetation in areas like ‘cool-pockets’ that will form a network throughout the city grid.

Figure 14: Poor use of trees in spaces with low occupancy functions and low-density plantation e.g. planted far apart in alleys & walkways. This provides limited shading & microclimate improvement benefit despite significant water consumption.

Figure 15: Strategic use of trees in spaces with densely occupied functions and dwelling qualities designed for longer durations of occupancy e.g. picknick in park

Prescriptive Measures:

- Provide trees in spaces with densely occupied functions and dwelling qualities designed for longer durations of occupancy (picknick in park, outdoor restaurants, markets, 'cool-pockets' (see Guideline **9**, etc.) to significantly shade the occupied public space (> 80% shading effect).
- For all other spaces (walkways, roads,) refer to Guidelines **4** / **5** to provide shading using self-shading street canyons or artificial structures without consuming water for irrigation.
- Limit use of vegetation as a means of providing shade to the top 8-12% of the most intensively occupied areas, focussing on dwelling (picknick areas, benches, seats), and prioritising spaces that are more densely occupied for a longer period. Therefore, provide 8-12% of public space with "green" shading through vegetation, the remaining relevant spaces through shading strategies using artificial structures or self-shading of buildings.
- Basis for the assignment of plants will be a use-intensity map, taking into account amount of people and occupancy time, spatially resolved over outdoor spaces.
- Demonstrate compliance by following the workflow laid in the 'Process' section below. Also see section for Evidence Based Planning to understand the intent & spirit of the guideline.

Process:

- Perform a fresh and grey water balance study to determine a reasonable amount of water available for irrigation.
- Perform outdoors occupancy analysis and prepare user density maps, highlighting the zones with maximum potential for benefitting from trees
- Demonstrate that a large number of people will benefit from & interact with the trees, for periods of long occupancy (at least 15 minutes).

Evidence Based Planning – Impact of shading by vegetation:

The following example (Fig. 16) demonstrates the water consumption of trees used for shading in a low density (alley) vs high density (plaza/urban oasis) scenario.

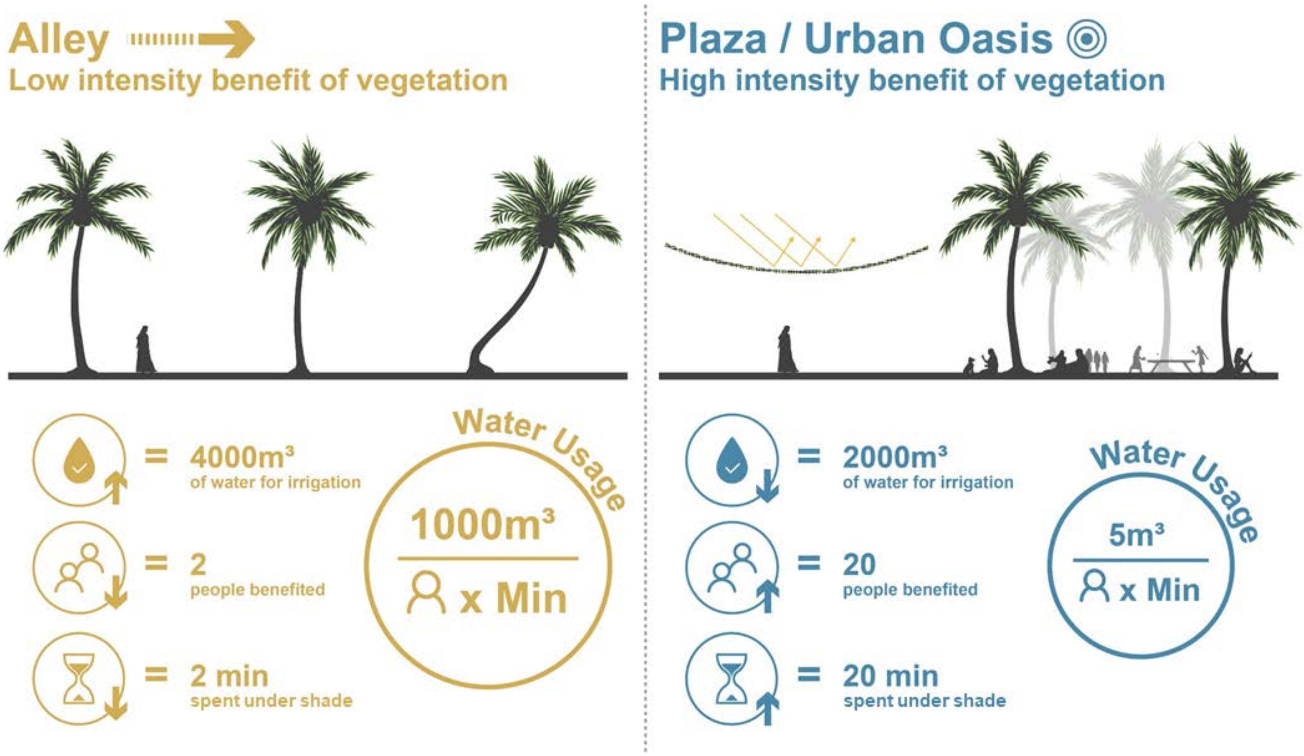


Figure 16: Effective water consumption of a row of trees in an alley in terms of shading / evapotranspiration cooling effect per person, compared to high density trees in a plaza.

In low density trees scenario, for instance, 60 trees that are planted far apart in an alley, may offer shade for roughly 2 minutes to about 2 pedestrians, but may still consume up to 4000 m3 of water for irrigation. On the other hand, 30 trees placed strategically in a plaza that shade 20 people dwelling under them for about 20 minutes, would only consume 2000 m3 of water for irrigation. Hence, strategically placed trees effectively consume 200x less amount of water in terms of shading / evapotranspiration cooling effect per person, compared to a row of trees in an alley.

The following example demonstrates the impact on microclimate using trees for shading in a low density (alley) vs high density (plaza/urban oasis) scenario. Low density trees, for instance, as planted far apart in an alley, improve urban microclimate by only 2.3 °C UTCI. This is in strong contrast to the impact of trees planted densely & close to one another (as in a plaza), which can be up to 6.8 °C UTCI improvement in plaza microclimate. The densely planted trees can block up to 80% solar radiation that hits the ground.

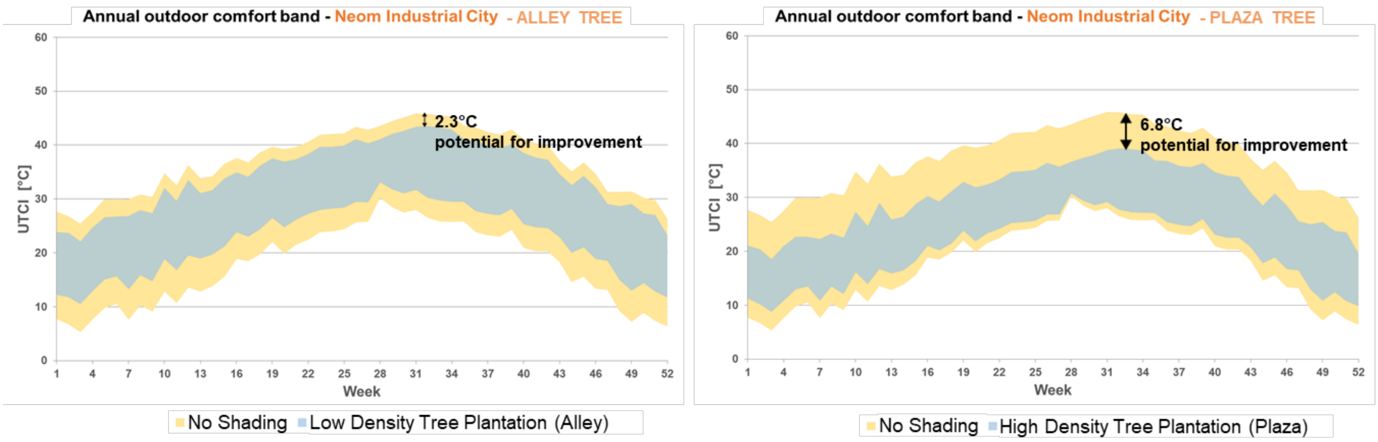


Figure 17: Annual outdoor comfort band comparing the range of UTCI temperatures experienced with & without trees in an alley (L) & plaza (R)

WIND

Objective

Wind has the capacity to increase the heat transfer between surfaces and air. As such, depending upon relative temperature differences, wind has the capacity to not only cool or heat surfaces of the urban envelope, but also the human skin. Understanding the winds and harnessing their cooling potential aid in making the right design decisions & is therefore critical in shaping urban form & microclimates for valuable spaces. The cooling effect of breezes also help to ameliorate the impact of Urban Heat Island effect.

While the dynamics of shading can be predicted in a deterministic way, wind is highly volatile and highly depends on local conditions. Therefore, the interaction between wind and the urban form can hardly be generalized. The following guideline therefore combines a performance requirement for wind with a suggested method to be employed in a site-specific design context for different locations in the NEOM region.

7
ELEVATED WIND SPEEDS AT PEDESTRIAN LEVEL

Wind speeds between 1.5 m/s – 4 m/s at a height of 2m above ground are optimum for outdoor comfort & urban microclimate in the NEOM region.

Design Intervention:

- Develop project specific wind adaptation strategies to ensure presence of recommended wind speeds in the occupied zone of pedestrian walkways, plazas and other frequently occupied public spaces.

Performance target:

- Ensure local wind speeds between 1.5 m/s – 4 m/s at a height of 2m above ground in pedestrian walkways and plazas and other frequently occupied public spaces.

Process:

- Plan street grid and orientation according to wind (e.g. align streets with prevalent wind direction). To achieve this, perform project specific Computational Fluid Dynamics (CFD) simulations or Wind-Tunnel testing during the master planning process to meet the performance target and identify areas of low, medium and high wind speed, to inform the urban design/masterplan.
- Determine appropriate boundary conditions for simulations or wind tunnel testing, based on site-specific frequency distribution of wind velocities & most significant wind directions.

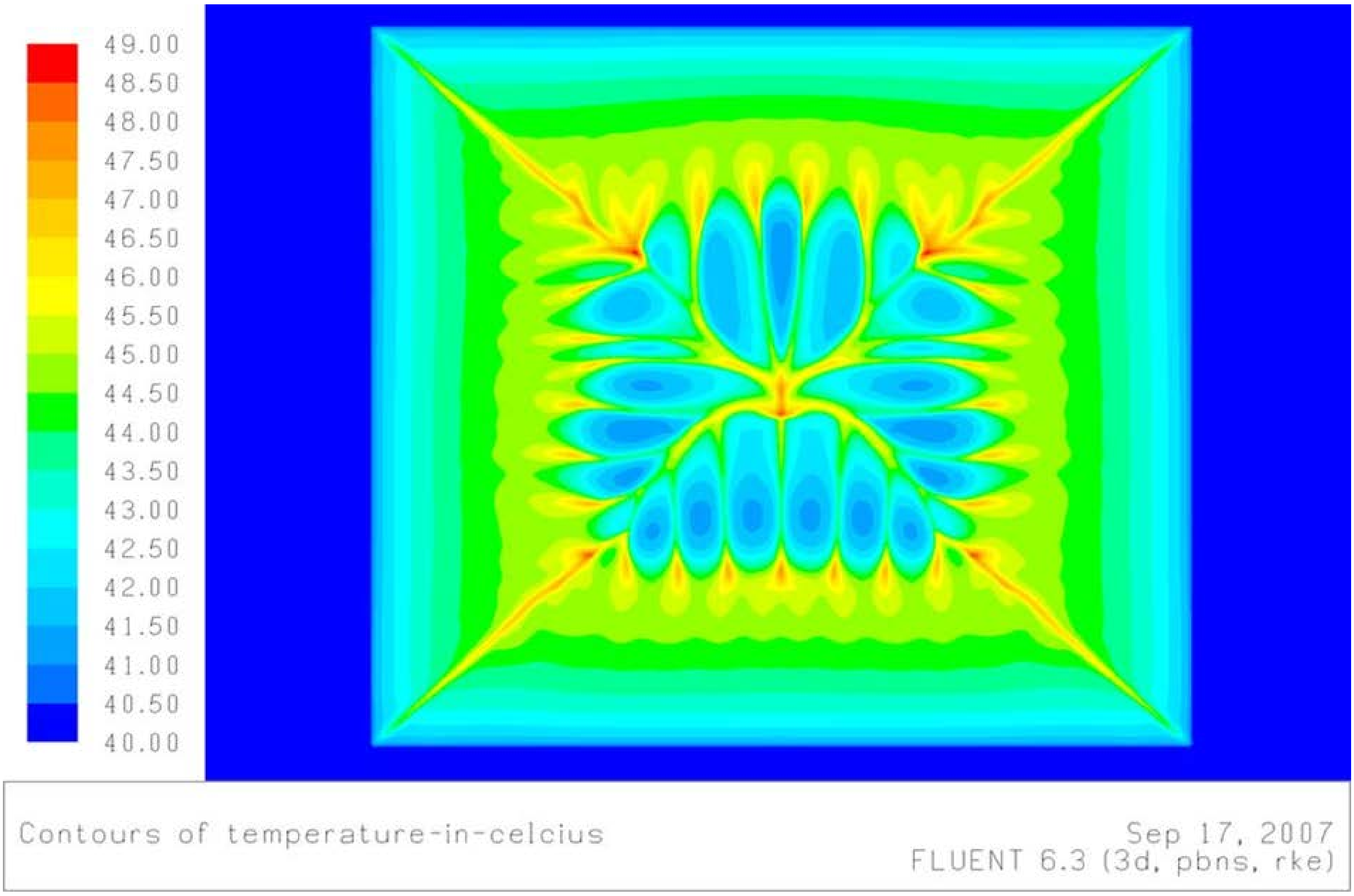


Figure 18: Example of a CFD simulation to study the impact of street grid and orientation on wind at pedestrian level in a city.

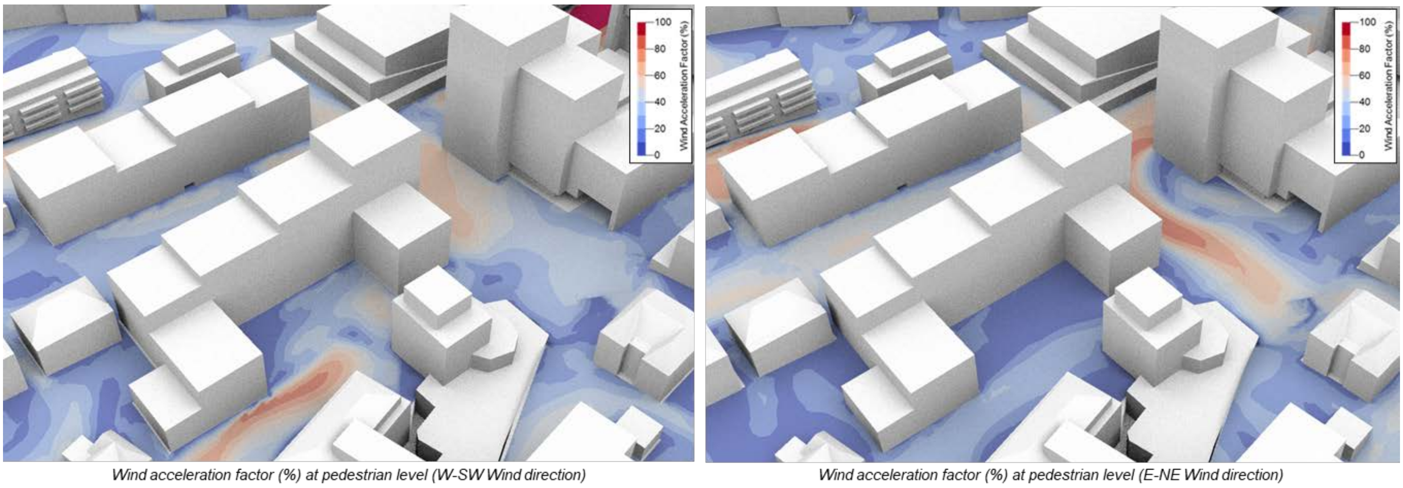


Figure 19: Example of a CFD simulation to identify areas of low, medium, and high wind speed for various wind directions to inform the urban design / master planning process.

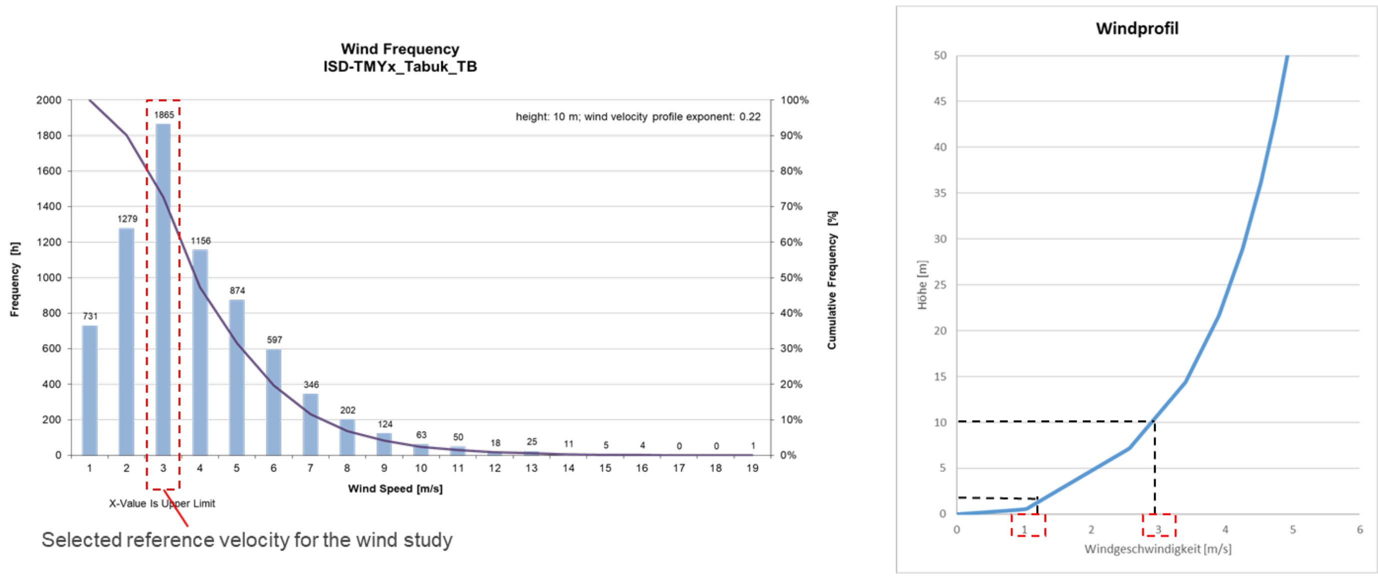


Figure 20: Example of site-specific frequency distribution of wind velocities that should be used for determining boundary conditions for the wind study simulation.

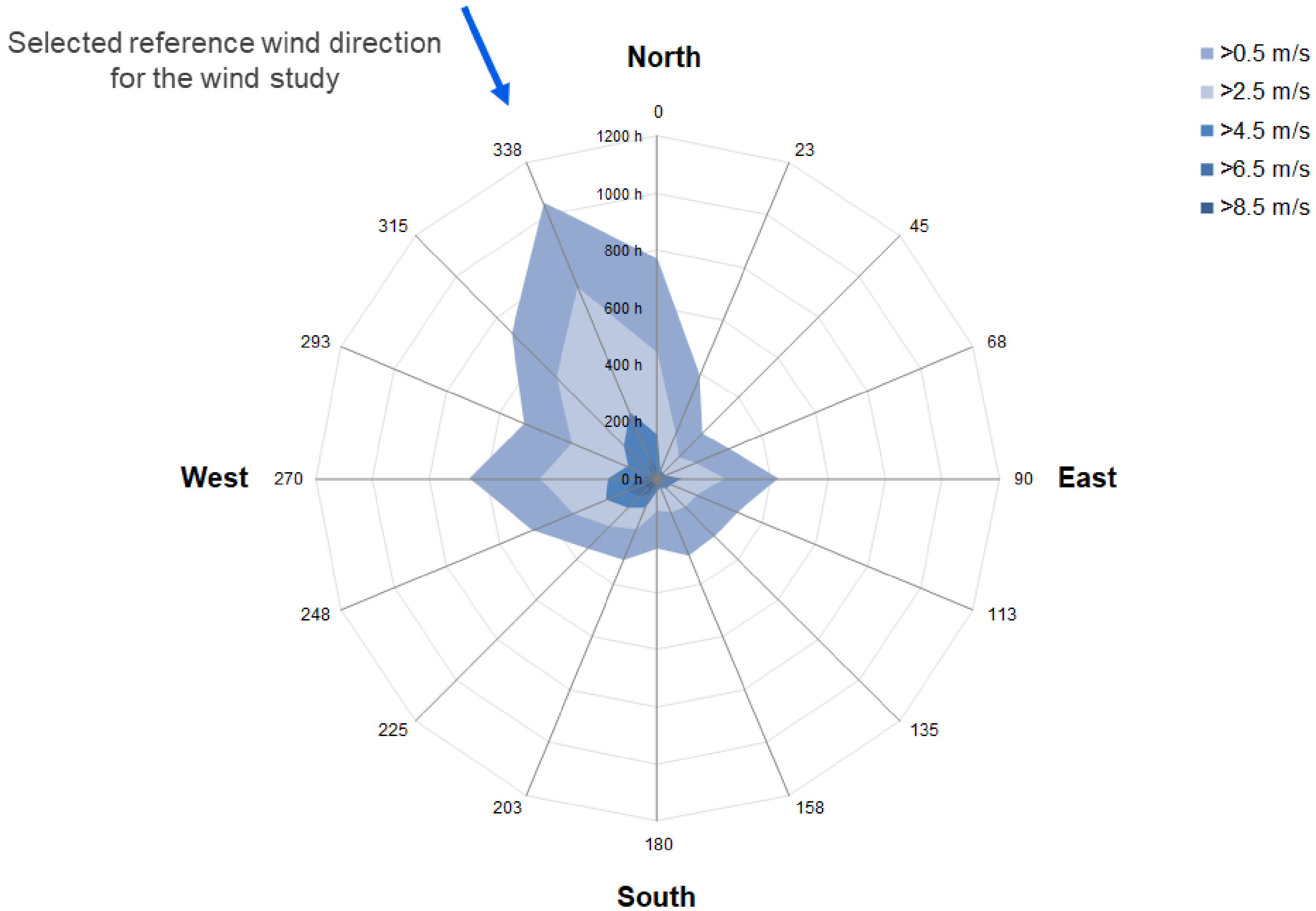


Figure 21: Example of site-specific wind direction rose that should be used for determining boundary conditions for the wind study simulation.

Evidence Based Planning – Impact of Wind Speed:

The following example demonstrates the impact of reduced wind speeds on urban microclimate in a plaza. Reduced wind speeds can increase UTCI temperatures up to 3.5 °C, thereby reducing outdoor comfort. In high altitude desert areas (e.g. location L11), reduced wind speeds have greater impact in the winter months, increasing UTCI temperatures by up to 12 °C.

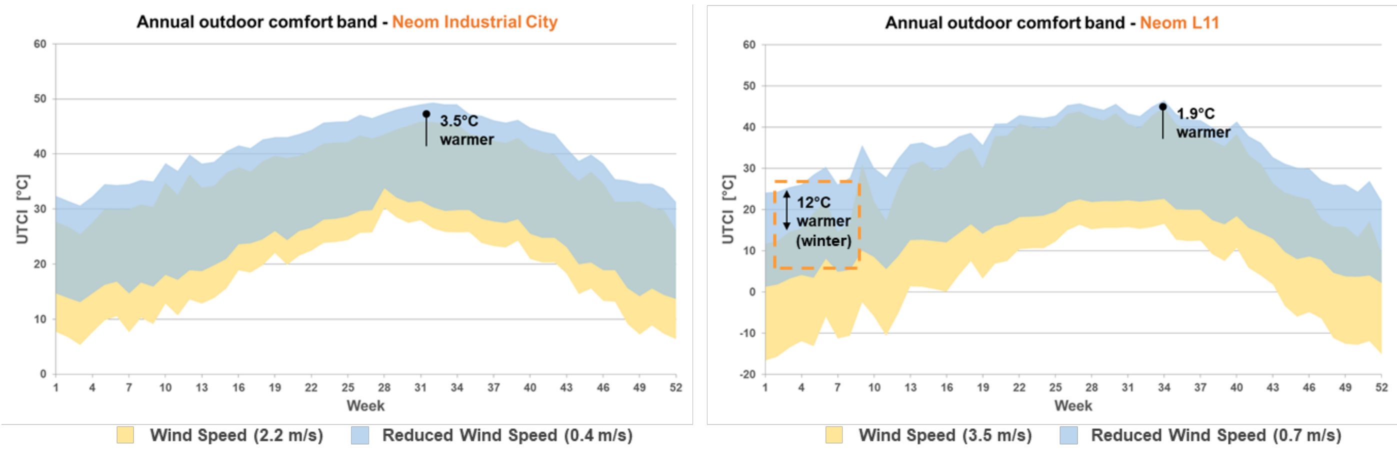


Figure 22: Outdoor Comfort band for NEOM Industrial City and NL11 showing the effect of reduced wind speeds.

WALKABILITY

Objective

Walkability can be defined as a neighborhood's capacity to support lifestyle physical activity. Several built and social environmental characteristics promote physical activity such as accessibility to various amenities (coffee shops, restaurants, grocery stores etc.) and good aesthetics of the built environment.

Additionally, the characteristics of the walking route itself contribute greatly towards enhancing walkability. Hence, presence of quality infrastructure support such as uninterrupted sidewalks, reduced number of vehicular traffic lanes crossed by a pedestrian etc. is vital. The ‘Walk-Score’ metric formalizes these requirements, as addressed in the guideline for compact urban development to promote walkability.

However, the presence of good social, building and infrastructure characteristics alone does not ensure a walkable neighborhood. Pedestrians would not prefer to walk on streets which are well planned from an urban planning perspective, if they are still exposed to the scorching summer heat of the desert. Hence, maximizing human thermal comfort is the key ingredient in creating a vibrant, walkable neighborhood – for residents and tourists alike. Shaded streets (which are addressed under the previously discussed guidelines of Shading) combined with ‘cool-pockets’ proposed under this section, provide an appropriately distributed network of comfortable spaces. Following these guidelines will extend the comfortable walking period for most parts of the year.

8
COMPACT URBAN DEVELOPMENT TO PROMOTE WALKABILITY

Urban sprawl discourages walkability & increases the use of private vehicles on the streets even for short distances. A compact urban development designed to be purposefully walkable, adds both tangible and intangible value to the character of the place, offering a more inviting environment for pedestrians.

Design Intervention:

- Develop compact urban development plan to promote walkability.

Performance Target:

- Ensure minimum Walk-Score of 90 for 75% all new developments.

Prescriptive Measures:

- Ensure daily errands do not require a car, or at least, most errands can be accomplished on foot. This can be achieved by ensuring proximity (about 5 to 8 min walking distance) to various amenities e.g. grocery stores, coffee shops, restaurants, entertainment & tourist activities, drug stores, parks, schools, clothing & hardware stores etc.
- Provide uninterrupted walking pathways / sidewalks.
- Minimize number of vehicular traffic lanes to be crossed by a pedestrian.

Process:

- Form interdisciplinary team to develop and formalize project specific integration of urban planning, transport engineering, spatial design and outdoor comfort strategies.
- Perform Walk-Score calculations at design stage to meet recommended walk-score targets (e.g. with tools like MIT Urban Modeling Interface, Urbano, etc.)

9
'COOL-POCKETS' AT EVERY 100M ON ALL WALKWAYS

Applicable to all pedestrian walkways in the urban area, with the goal to achieve cool pockets at every 100m walking distance. These hubs will offer a resting environment for a short pause while walking through the streets. Individual portable umbrellas can be borrowed and returned at these hubs, in addition to access to free & fresh drinking water.

Design Intervention:

- Provide thermal transition zones aka 'cool-pockets' that form an appropriately distributed network of thermally comfortable resting spots for pedestrians. These areas should be shaded and may utilize one or more of the following strategies:
  - Dry Mist Fans (i.e. Evaporative Cooling) with Elevated Air Speeds
  - Additional shading by dense vegetation (e.g. shrubs like Bougenvillae), as although these plants may only provide limited additional shade, but they promote biophilia & help enhance the subjective perception of comfort.

Note: Cool-pocket network must be combined with previously discussed guidelines (4 / 5) for Shading to achieve thermal comfort.

Performance Target:

- Demonstrate at least 75% of occupied hours (annually) are below 32 °C UTCI inside the cool pockets.

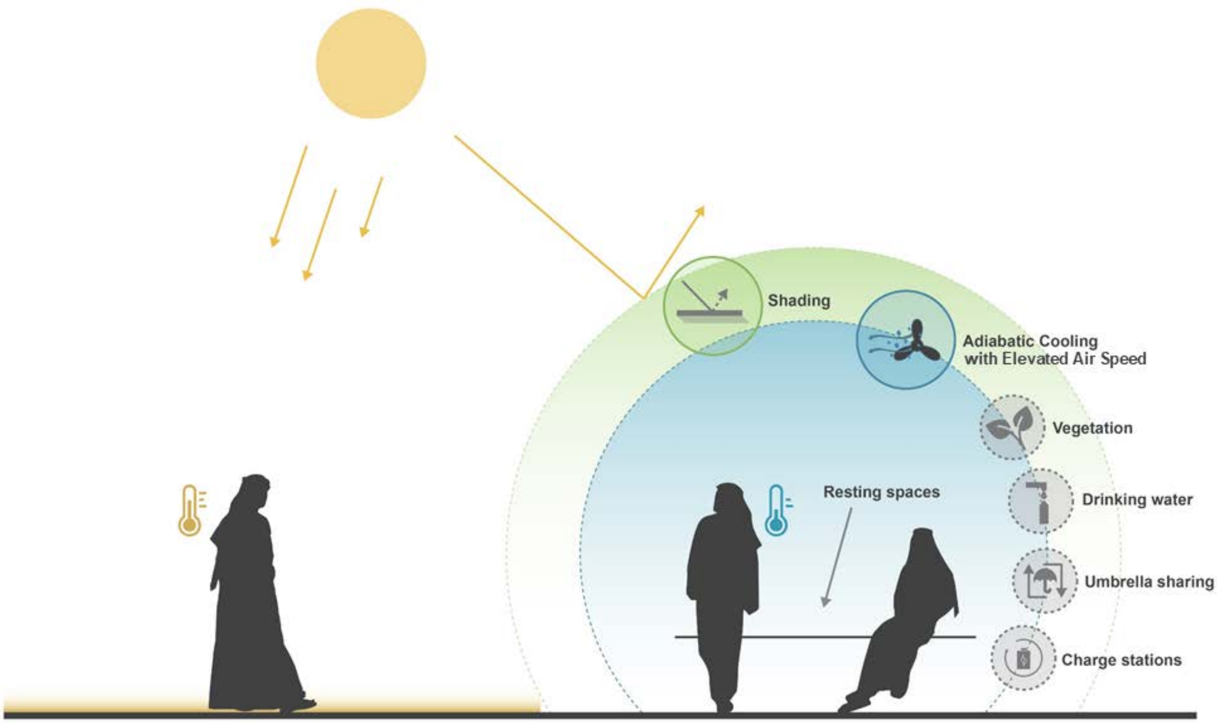


Figure 23: Conceptual sketch of potential elements that could constitute a 'Cool Pocket'

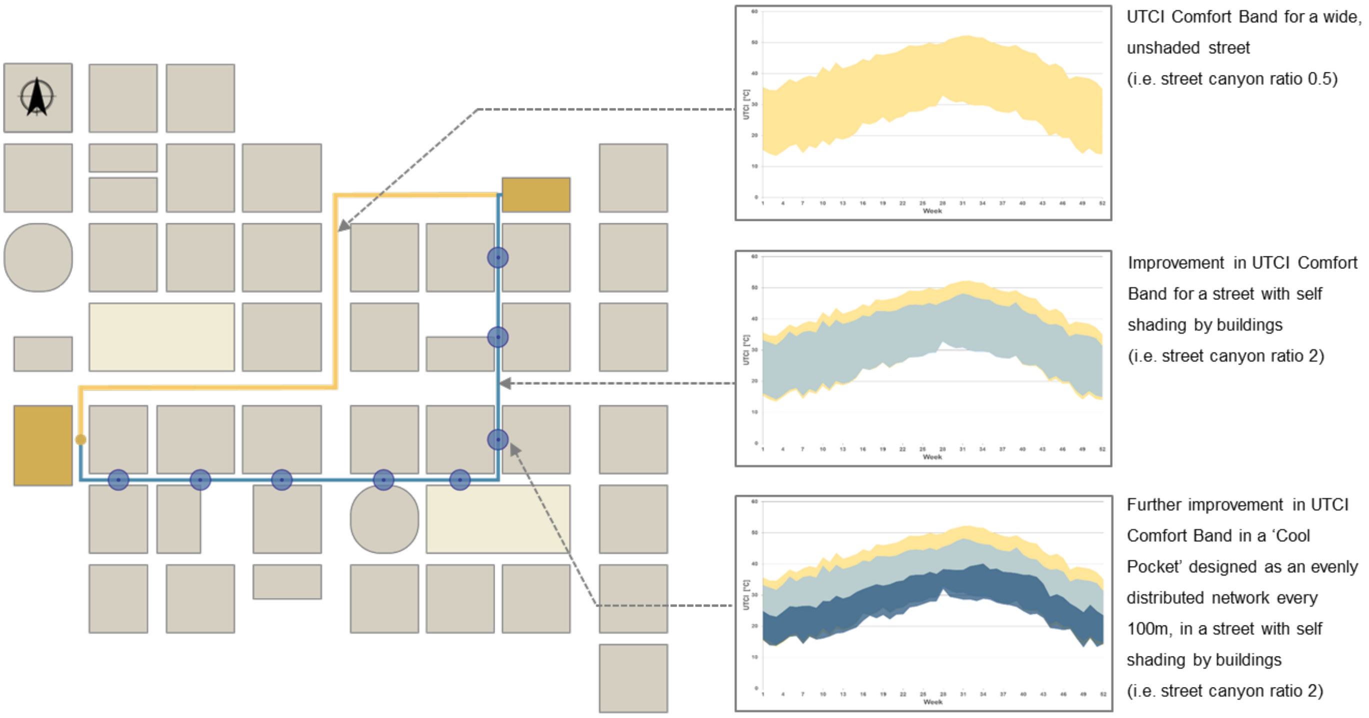


Figure 24: Conceptual diagram demonstrating the comfort enhancement potential of an evenly distributed network of 'cool pockets' at every 100 m, situated in a self-shaded street canyon (ratio 2).

Figure 25: Examples of Misting Fans with Elevated Air Speeds that could be installed in cool pockets. These could be Dry Mist (L) & Wet Mist (R). Dry Misting fans significantly enhance outdoor comfort as opposed to conventional Wet Mist fans, and therefore recommended for use in the cool pockets.

Prescriptive Measures:

- Provide an appropriately distributed network of thermally comfortable cool pockets at every 100 m on all walkways. Additionally:
    - Provide ample resting spaces / benches
    - Develop infrastructure for portable umbrella sharing
    - Provide access to free & fresh drinking water

Note: Cool-pocket network must be combined with previously discussed guidelines (4 / 5) for Shading to achieve thermal comfort.

Process:

- Form interdisciplinary team (including urban & landscape designers, environmental planners etc.) to develop design options that fulfill the performance target.

Evidence Based Planning – Impact of Cool Pockets: **(Example of N-S Axis Street)**

In the previous guideline **4** for Shading, it is demonstrated that depending on the orientation of street axis, street canyons with ratio 2 (i.e. buildings twice the height of street width) or more can help reduce the perceived UTCI temperature by up to 10 °C. In this example we present the annual carpet-plot of UTCI in such a shaded street (N-S Axis):

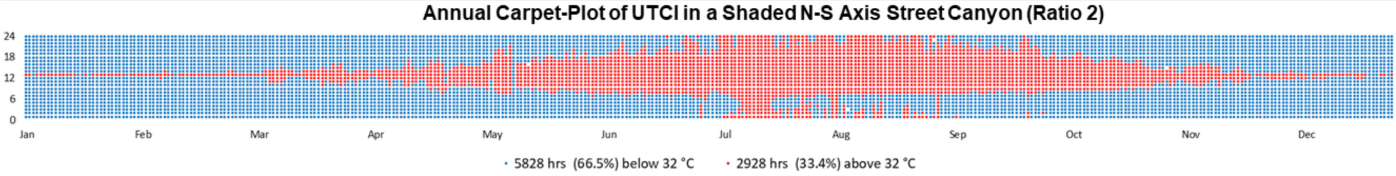


Figure 26: Annual Carpet-Plot of UTCI in a shaded N-S axis street canyon (ratio 2). The y-axis is 'Hour of the Day', the x-axis is 'Day of the Year'. Each blue dot represents an hour of the year below 32 ° UTCI (66.5% of the year).

For instance, a N-S Axis Street Canyon of Ratio 2 is comfortable for 66.5% of the total hours in a year. However, irrespective of the season, all hours around noon are above 32 °C UTCI due to direct exposure to high altitude sun. The frequency of these hours (with UTCI above 32 °C around noon & mid-day) increases with the advent of the summer season, thereby reducing the number of comfortable hours every day.

A well designed 'Cool-Pocket', situated in the same N-S Axis Street Canyon of Ratio 2, is comfortable for 85.8% of the total hours in a year. It can be further observed that in the cool pockets, even the hours around noon remain below 32 °C UTCI for more than 7 months of the year. Cool pockets also increase the number of comfortable hours in a day considerably, thereby promoting walkability.

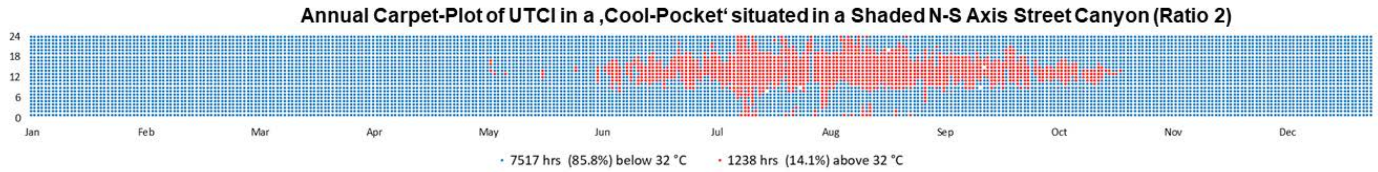


Figure 27: Annual Carpet-Plot of UTCI in a 'Cool-Pocket' situated in a shaded N-S axis street canyon (ratio 2). The y-axis is 'Hour of the Day', the x-axis is 'Day of the Year'. Each blue dot represents an hour of the year below 32 ° UTCI (90.1% of the year).

The total number of hours comfortable for walking, based on different time periods of the day, are further investigated.

Evidence Based Planning – Impact of Cool Pockets: (Morning Hours; 06:00 to 10:00) (Example of N-S Axis Street)

This graph plots the total number of comfortable hours during the Morning, for each day of the year, for different scenarios. The red line represents the number of walkable hours in a street canyon of Ratio 2. We can see that starting from Mid-April, the number of comfortable hours for walking gets reduced due to the rising of summer temperatures, and during peak summer in July, the streets could be too uncomfortable to walk even during morning hours.

On the other hand, the green line represents the number of walkable hours in a street canyon of Ratio 2 with an appropriately distributed network of cool pockets. We can observe that providing cool pockets can increase number of comfortable walking hours in the morning by up to 3.5 hours (i.e. almost entire morning), except in the peak summer month of July. This shows that adding cool pockets can ensure that almost all morning hours are comfortable for walking, for about 90% of the year.

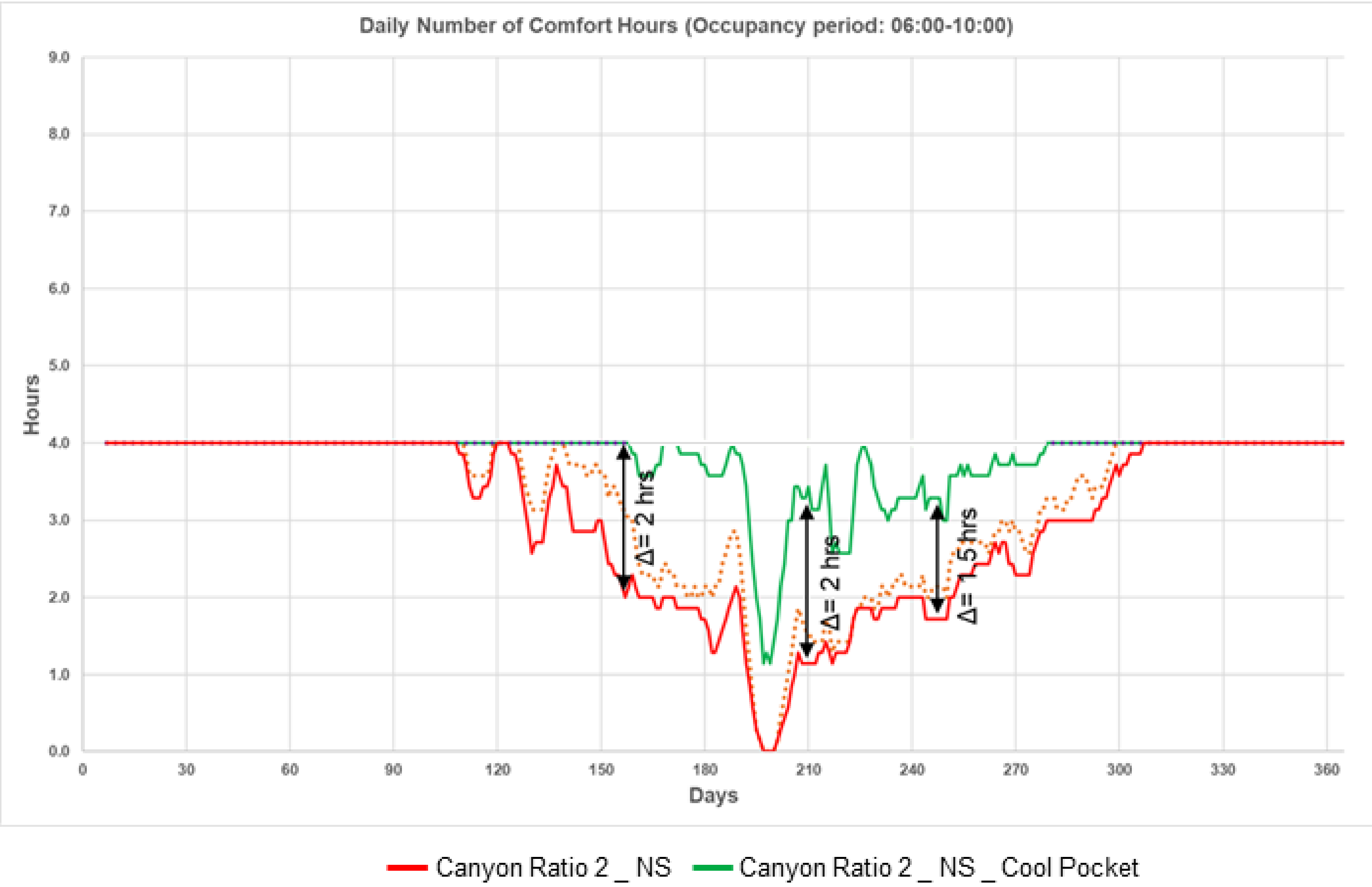


Figure 28: Graph indicating the total number of comfortable hours during the Morning, for each day of the year, for different scenarios.

Evidence Based Planning – Impact of Cool Pockets: (Mid-Day / Afternoon Hours; 10:00 to 16:00) (Example of N-S Axis Street)

This graph plots the total number of comfortable hours during the Mid-Day & Afternoon, for each day of the year, for different scenarios.

We can observe that ensuring an appropriately distributed network of cool pockets can provide comfortable walking hours for almost the entire Mid-Day / Afternoon period for up to 6.5 months (January to Mid-May & November to December). Such a network of cool pockets can also provide up to 2 hours of comfortable walking time even during the summer months in the Mid-Day / Afternoon period.

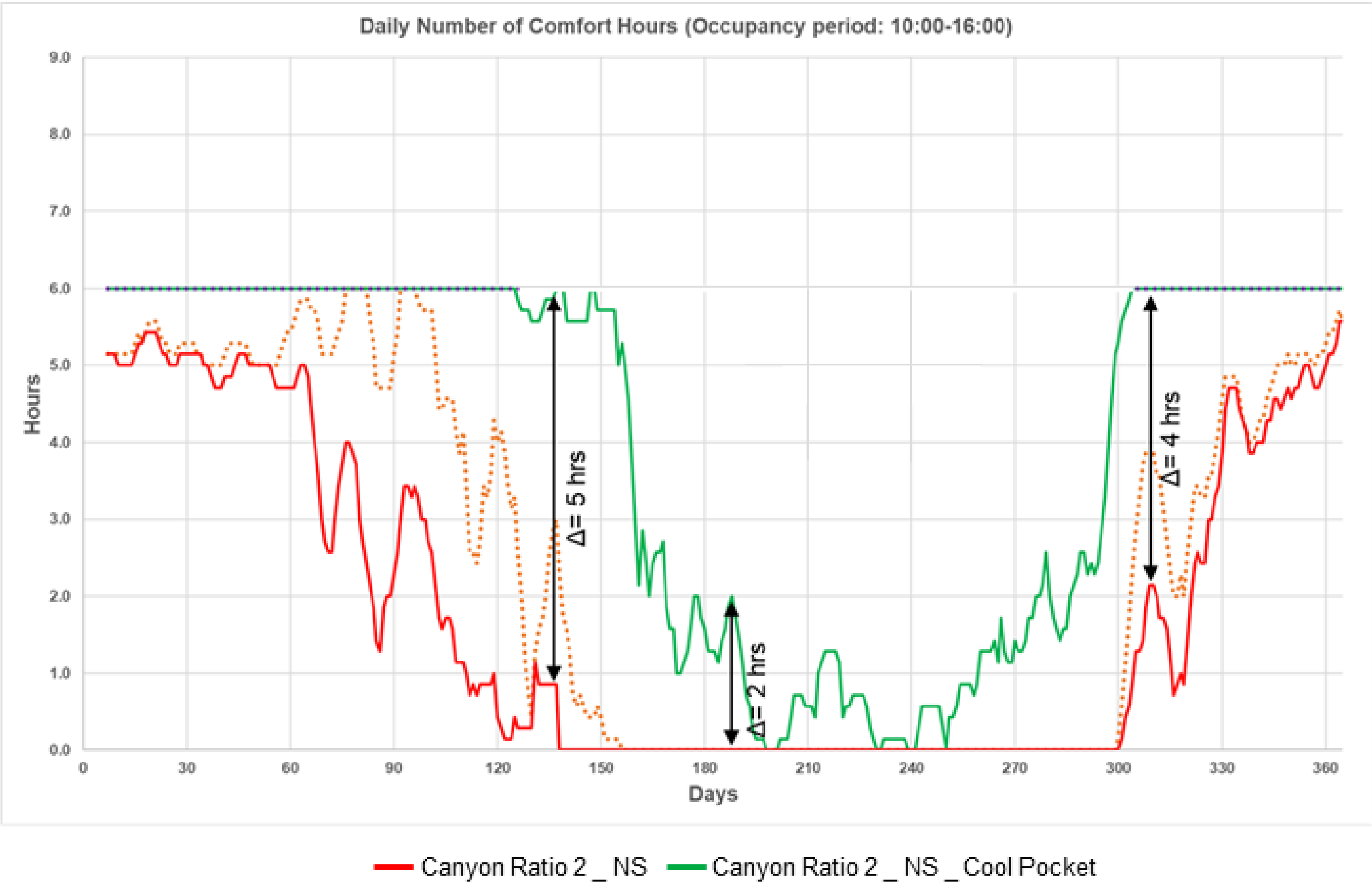


Figure 29: Graph indicating the total number of comfortable hours during the Mid-Day & Afternoon, for each day of the year, for different scenarios.

Evidence Based Planning – Impact of Cool Pockets: (Evening Hours; 16:00 to 24:00) (Example of N-S Axis Street)

This graph plots the total number of comfortable hours during the Evening hours, for each day of the year, for different scenarios. Providing an appropriately distributed network of cool pockets can increase the number of comfortable walking hours by up to 3.5 hours in the summer months.

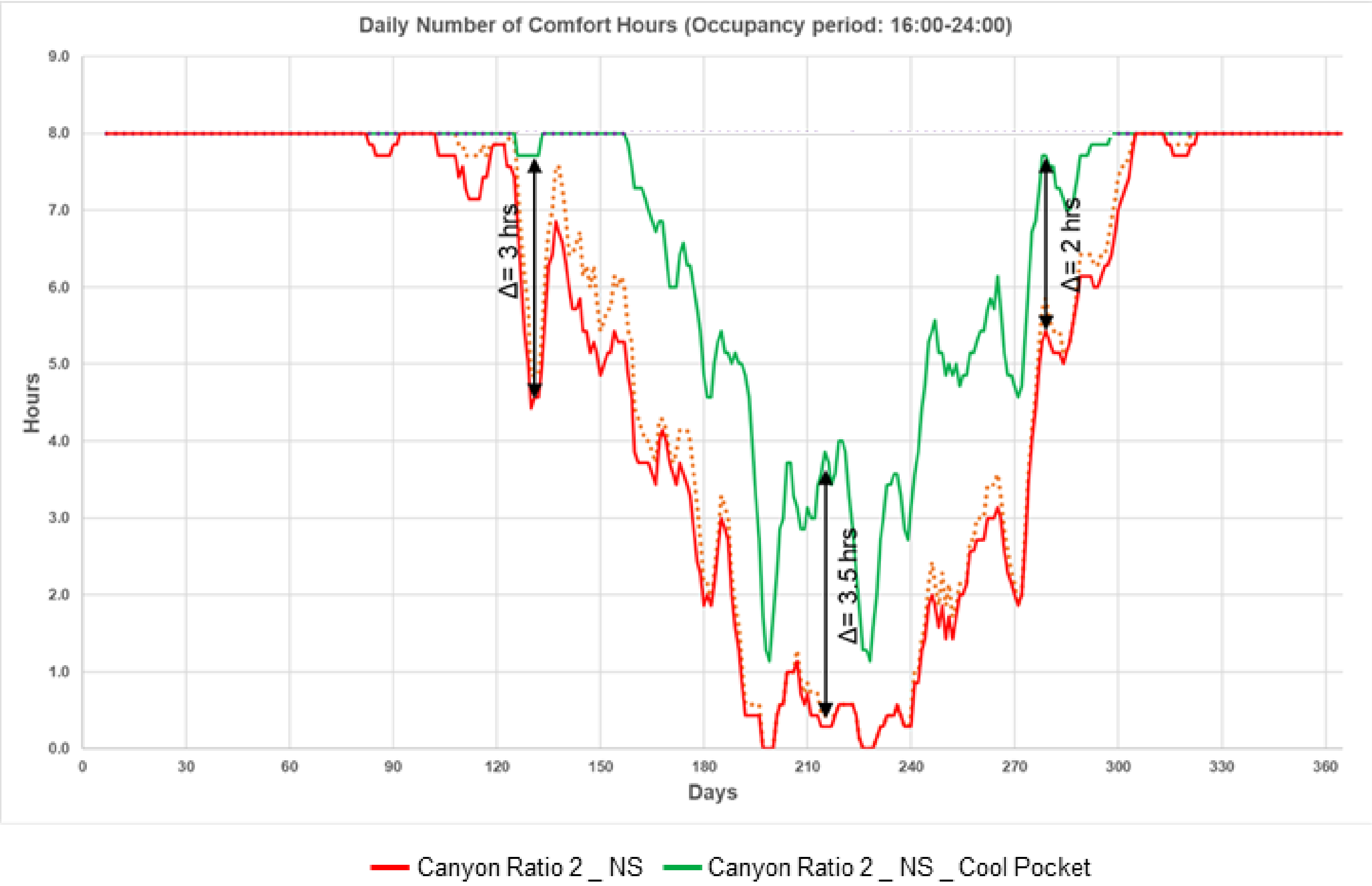


Figure 30: Graph indicating the total number of comfortable hours during the Evening, for each day of the year, for different scenarios.

URBAN IMPACT

Objective

The summer Urban Heat Island (UHI) effect is the elevation in the outdoor urban air temperature, that often occurs by the replacement of the natural landscape with buildings, roads and other heat-absorbing infrastructure. Urban heat islands can negatively affect the urban community and tourism by reducing thermal comfort.

The measures that can be adopted to mitigate UHI effect are many and multi-dimensional. These include interventions related to shading such as Self-Shaded walkways discussed in guideline **4**, shading & evapotranspiration through trees in guideline **6**, or network of cool pockets as proposed in guideline **9**.

In this section, additional measures such as those related to surface albedo, anthropogenic heat etc. that further help to reduce the UHI effect are discussed, analyzed with the vantage point of improving human comfort.

Additionally, other measures that influence, and in turn are themselves influenced by, urban level decisions such as night sky pollution, district cooling & integration of renewables are also discussed.

10
HIGH SURFACE ALBEDO MATERIALS

Outdoor materials have a significant impact on both comfort and energy consumption of urban areas. This is due to absorption of solar radiation by darker surfaces, which prevent reflection and traps heat. Cool materials have low heat conductivity, low heat capacity, high solar reflectance, high emissivity (facing the sky), and are permeable (i.e. offer greater potential for high level of embodied moisture). Building roof tops and public space horizontal surface finishes are two of the most significant contributors.

Design Intervention:

- Use materials with high albedo (i.e. low absorption) for outdoor surfaces. Not applicable for building facades.

Performance Target:

- For each tile in 1 x 1 km urban development grid with total built-up area ≥ 0.5 Km2, the area-weighted average surface albedo (at the end of 3 years) of all roofs and horizontal surfaces should be at least 40%. All surfaces with PV can be excluded from the calculation requirement.

Note: The terrestrial albedo of the natural desert ground can be assumed to be 20% for the purpose of the calculation.

Prescriptive Measures:

- Reduce solar absorption – replace dark surfaces, black roofs, and asphalt paving, with cool materials.

Figure 31: Example of high albedo surface finish – rooftops, plazas etc. in Paris, France (L) and in Santorini, Greece (R)

Process:

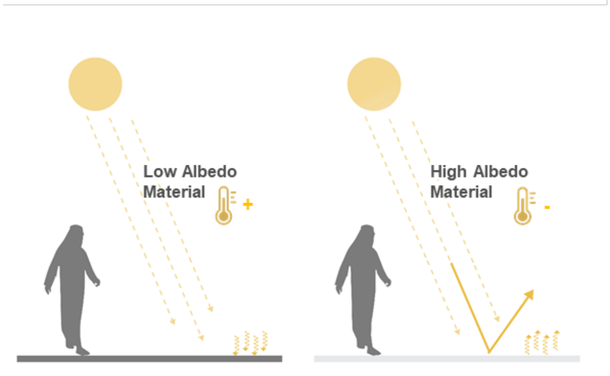
- Form interdisciplinary team (including landscape designers, environmental planners etc.) to develop and formalize integration of project specific design, landscape and comfort strategies that establish functional relationship of different elements.
- Develop a palette of cool materials to achieve a coherent urban design scheme. The below documents (see Fig. 33) provide a good database of initial reflectance of various materials for aiding the design team.

Author	Document Name	Relevant Section	Webpage
U.S. EPA	Reducing Urban Heat Islands: Compendium of Strategies. Cool Roofs	Table 02: Comparison of Traditional and Cool Roof Options	https://www.epa.gov/sites/production/files/2017-05/documents/reducing_urban_heat_islands_ch_4.pdf
Low Carbon Living CRC	Guide to Urban Cooling Strategies 2017	Table on Page 18: Cool Paving Technologies	http://www.lowcarbonlivingcrc.com.au/sites/all/files/publications_file_attachments/rp2024_guide_to_urban_cooling_strategies_2017_web.pdf
Low Carbon Living CRC	Cooling Cities: Strategies and Technologies to Mitigate Urban Heat	Table 04: Cool roofs vs warm roofs with typical values of initial solar reflectance and initial thermal emittance Table 05: Description of existing technological trends in the field of reflective pavements	http://www.lowcarbonlivingcrc.com.au/sites/all/files/event_file_attachments/discussion_paper_cooling_cities_final.pdf
Heat Island Group, Berkley Lab	Cool Roof Coatings Material Database	Table 02: Solar Reflectance and Thermal Performance of Roof Coatings (White) Table 03: Solar Reflectance and Thermal Performance of Roof Coatings (Tinted) Table 04: Solar Reflectance and Thermal Performance of Roof Coatings (Aluminum)	https://heatisland.lbl.gov/resources/roof-coatings#white
Cool Roofs and Cool Pavements Toolkit	A Practical Guide to Cool Roofs and Cool Pavements (January 2012)	Table on Page 24: Common Roofing Materials and Cool Options Table on Page 29: Cool Pavement Materials	https://www.coolrooftoolkit.org/wp-content/pdfs/CoolRoofToolkit_Full.pdf

Figure 33: A list of useful resources of cool materials to aid the design team.

Evidence Based Planning – Impact of surface albedo in plaza:

The graph shows that having a higher floor albedo allows for an improvement of UTCI temperature by 2.7°C. This can be attributed to the fact that materials of higher albedo absorb less solar radiation, hence reducing surface heat gains. This results in better outdoor thermal comfort.



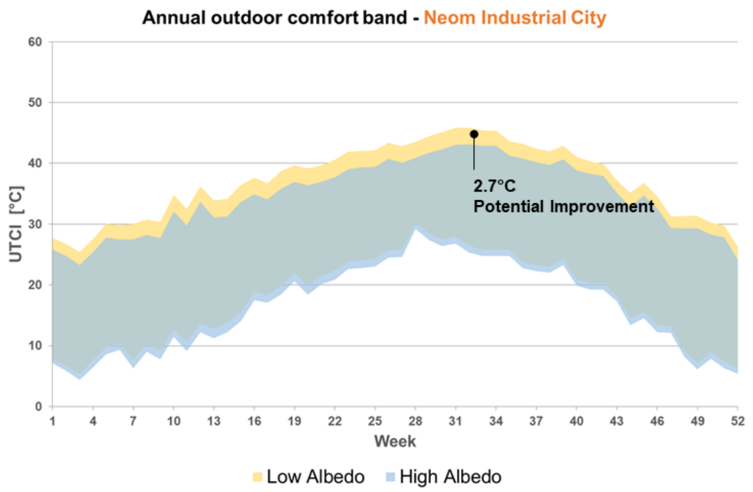


Figure 32: Conceptual sketch showing the impact of albedo on plaza (L) and Annual outdoor comfort band showing the impact of changing floor albedo in plaza (R)

11
REDUCTION OF ANTHROPOGENIC HEAT REJECTION FROM HVAC SYSTEMS INTO STREET CANYON

Anthropogenic heat, generated from stationary and mobile sources within an area, has a significant contribution to the UHI effect. A common source of anthropogenic heat are the HVAC systems for conditioning indoor spaces in buildings. The heat generated from this source can warm up the urban atmosphere and get stored inside the materials; increasing thermal discomfort and energy consumption.

Centralized district cooling systems may offer a more energy efficient solution for cooling at an urban scale.

Design Intervention:

- Ensure an efficient use of HVAC systems to reduce the generated heat.
- Prevent anthropogenic heat from building mechanical ventilation and cooling systems from being exhausted to the street canyon or public squares / plazas.
- Encourage centralized district cooling systems. These systems benefit from economies of scale due to the set-up of centralized plants (and storage technologies) instead of individual cooling units in each building. This results in reduced carbon emissions due to lower electricity consumption and reduced anthropogenic heat rejection in the street canyons and plazas.

Figure 34: Anthropogenic heat from building HVAC system that is exhausted in the street canyon increases UHI effect.

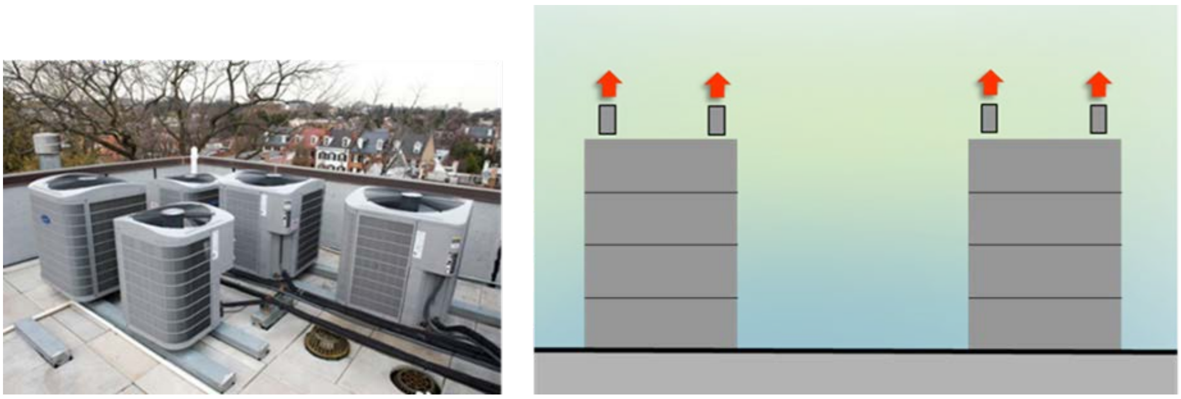


Figure 35: Placing building HVAC systems on building rooftop helps mitigate UHI effect.

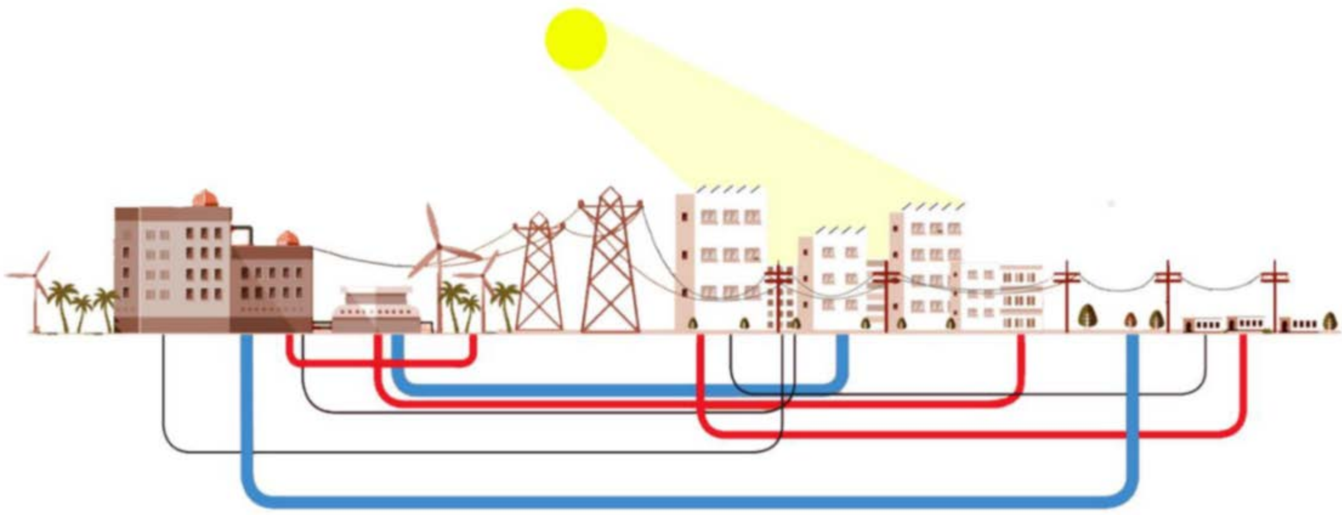


Figure 36: Schematic diagram of a district cooling system in synergy with renewable energy production. Adopting district cooling strategies helps to reduce HVAC rejection into the street canyon.

Prescriptive Measures:

- Buildings should be designed with a high climatic quality to reduce the total volume of spaces to be artificially conditioned,
- Prioritize the use of centralized cooling systems over stand-alone units,
- HVAC heat rejection units should be placed on the roof. However, these could be placed on the facades always looking out of the pedestrian street canyon or public squares / plazas only in the case of a tall building (height > 35m). Also exempted are buildings located in low density urban areas with a large set back from the main street canyons (e.g. private villas),

Process:

- Introduce policy measures to implement the prescriptive measures recommended above to prevent exhaust of anthropogenic heat from buildings to the street canyon or public squares / plazas.
- Conduct feasibility study to determine the district cooling system capacity, network and plant location on a case to case basis to assess the following (but not limited to) features:

  - Connection feasibility from district cooling plant to all targeted end users.
  - At building level, feasibility to ensure compatible terminal-units (FCU, AHU, Heat Exchangers, etc.) to avail facility of water-based district cooling systems
  - At building level, feasibility to adopt radiant cooling strategies.

12
ON-SITE RENEWABLE ENERGY PRODUCTION

Provide infrastructure for renewable energy production.

Design Intervention:

- Provide infrastructure for renewable energy feed-in to the electricity grid.
- Promote and incentivize on-site solar PV for meeting cooling energy demand in buildings.
- Promote solar thermal plants for domestic hot water generation in residential buildings.

Performance target:

- Cover 100 % cooling energy demand for the Neom region through renewable energy production.

Prescriptive measures:

- Promote building integrated PV plants with feed-in to electricity grid

Process:

- Form interdisciplinary design team to develop and formalize a set of project specific strategies to achieve the on-site renewable energy production objective.