TAYLOR'S UNIVERSITY
Wisdom • Integrity • Excellence

KHOO TECK PUAT HOSPITAL

MASDAR INSTITUTE

Assignment 1: Passive Green Building Case Studies Poster & Booklet

ARC 61804 – Green Strategies for Building Design

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1.1 INTRODUCTION

Khoo Teck Puat Hospital

YISHUN, SINGAPORE | 2010

Khoo Teck Puat Hospital is located on a 3.5-hectare site next to Yishun Lake in northern Singapore. The design revolves around creating a green environment that brings comfort to patients and boosts staff morale. Through active and passive design strategies, the hospital reduces energy costs by 50% and has the potential for natural ventilation in 40% of its floor area.

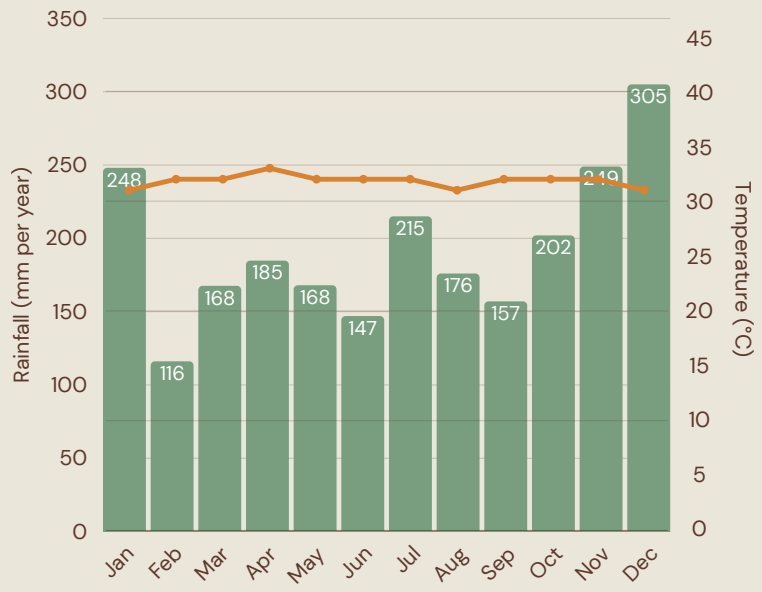
Masdar Institute

MASDAR CITY, ABU DHABI, UAE | 2010

The Masdar Institute of Science and Technology (now part of Khalifa University) was a pioneering research-driven graduate-level university focused on advanced energy and sustainable technologies. It was the first major development in Masdar City, a planned eco-city located near Abu Dhabi, United Arab Emirates.

CLIMATE OVERVIEW

YISHUN, SINGAPORE

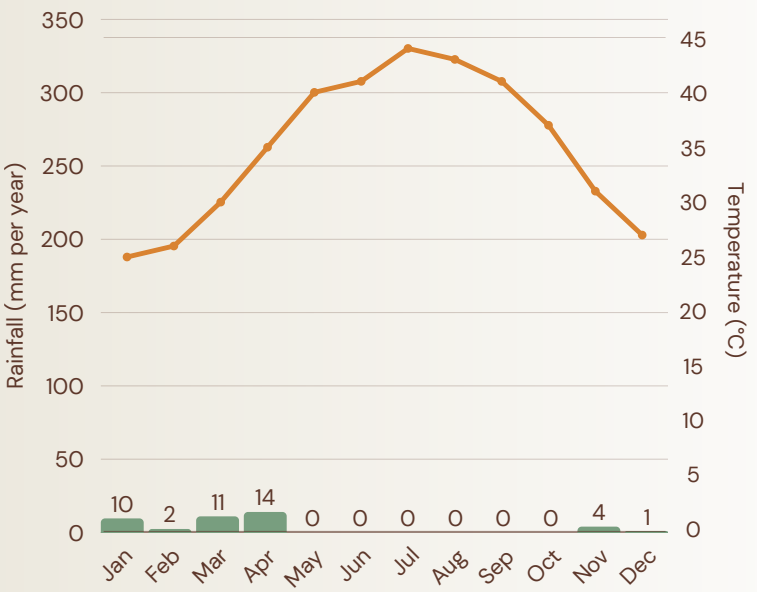


High temp: 33°C
Low temp: 24°C
Mean temp: 28°C

Precipitation: 194.6mm
Humidity: 79%
Wind: 16km/h

*KTPH is located in Singapore, in a **tropical** climate. The daily **high and low temperatures are consistent** and differ by only around 10°C, with a **mean temperature of 28°C**. It is **humid** with an average precipitation of 195mm.*

MASDAR CITY, UAE



High temp: 44°C
Low temp: 15°C
Mean temp: 29°C

Precipitation: 3.6mm
Humidity: 51%
Wind: 26km/h

*Masdar Institute is located in the UAE, in an **arid** desert climate. The **daily temperatures vary significantly**, averaging about 44°C during the day and 15°C at night. Daily temperatures peak during the summer. **Precipitation levels are very low,** with an average of 3.6mm.*

CONCLUSION: Both buildings have to deal with relatively hot temperatures, though KTPH is in a **consistently humid** climate while Masdar Institute is in **daily fluctuating temperatures** and **dry weather**.

Khoo Teck Puat Hospital

YISHUN, SINGAPORE

ARCHITECT, M&E, C&S: **CPG CONSULTANTS** (Singapore) • DESIGN CONSULTANT: **RMJM HILLIER** (UK) • LANDSCAPE: **PERIDIAN ASIA**

Key Construction Facts
Construction Start: 2005
Completion (Phase 1): 2010
Expansion (Phase 2): Yishun Community Hospital (adjacent), opened in 2015 as part of the larger Yishun Health campus

Building Height: Typically 4–6 stories (low- to mid-rise to encourage natural ventilation and integrate with surrounding landscape)

Materials Used – Khoo Teck Puat Hospital (KTPH):

- Precast concrete and reinforced concrete structure for durability and thermal performance
- Extensive use of glass to maximize natural daylight while minimizing artificial lighting needs
- Sun-shading devices (such as vertical and horizontal fins) to reduce solar heat gain
- Green roofs and vertical greenery to lower ambient temperature and improve insulation
- Energy-efficient systems and fixtures, including LED lighting and motion sensors

02 KHOO TECK PUAT HOSPITAL

2.1 SITE PLANNING

SITE ORIENTATION & SPACE PLANNING

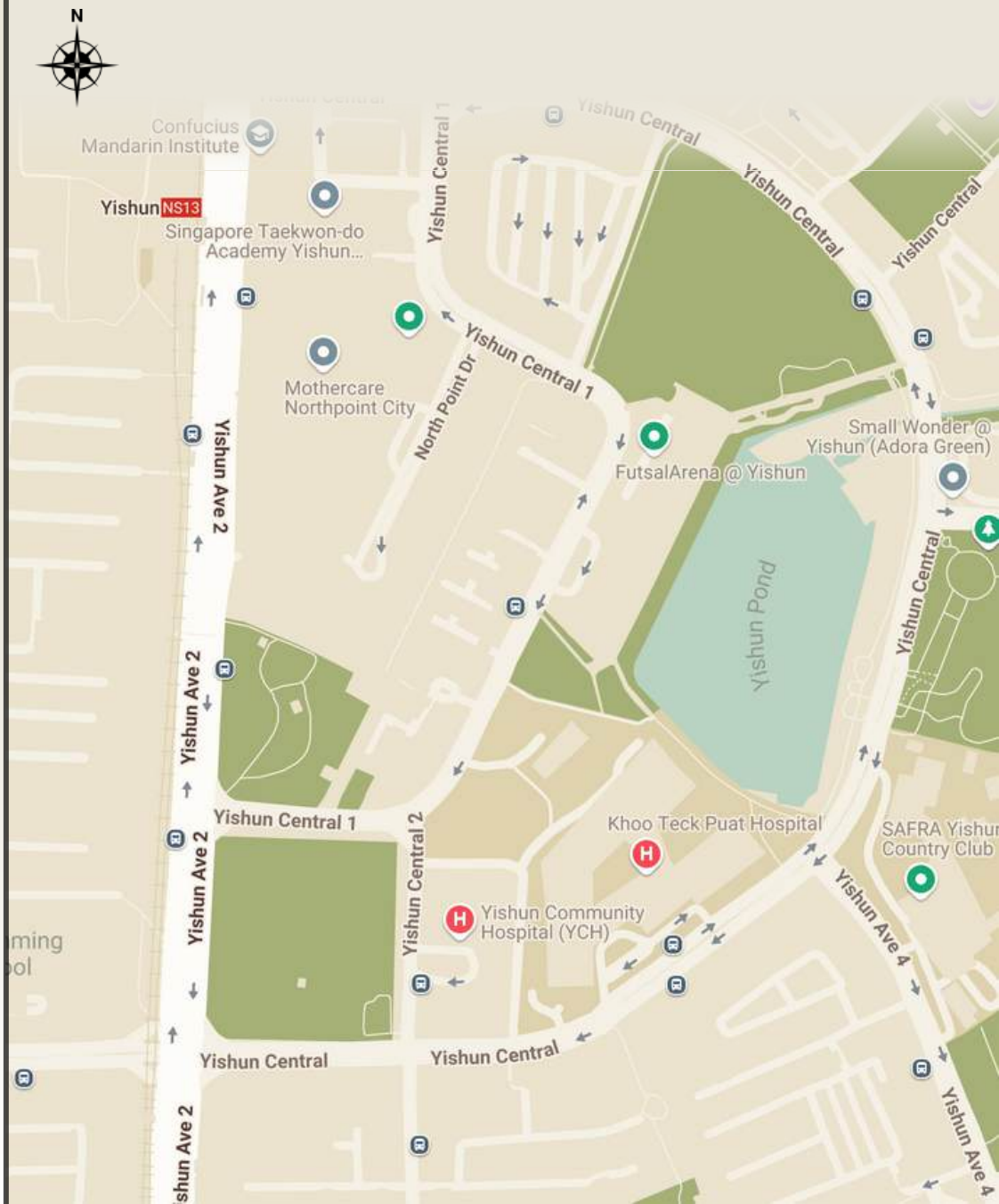
Khoo Teck Puat Hospital (KTPH) was strategically built in Yishun to address the growing healthcare demands of residents. Prior to its development, patients in this area had to travel long distances to central hospitals, leading to inconvenience and overcrowding in existing facilities. By placing KTPH in Yishun, the government aimed to decentralize healthcare services, reduce the burden on centrally located hospitals, and improve accessibility for northern residents.

ACCESSIBILITY

The chosen site is well-served by major roads and public transport networks, including bus services and proximity to Yishun MRT station. This connectivity enhances convenience for patients, visitors, and staff, contributing to the hospital's function as a regional medical hub.

NATURAL LANDSCAPE

The peaceful, green surroundings help create a healing environment for patients. Being close to nature reduces stress and encourages recovery, while also keeping the hospital cool through natural ventilation.



02 KHOO TECK PUAT HOSPITAL

2.1 SITE PLANNING

BUILDING ORIENTATION

KTPH was designed with sustainability and patient well-being in mind. The master planning and orientation of buildings reflect a deep understanding of environmental conditions and how architecture can enhance healing.

SOUTHEAST-NORTHWEST AXIS

The hospital is aligned along a southeast-northwest axis. This orientation captures cool breezes from the northeast and southwest, which flow through the naturally ventilated spaces of the hospital.

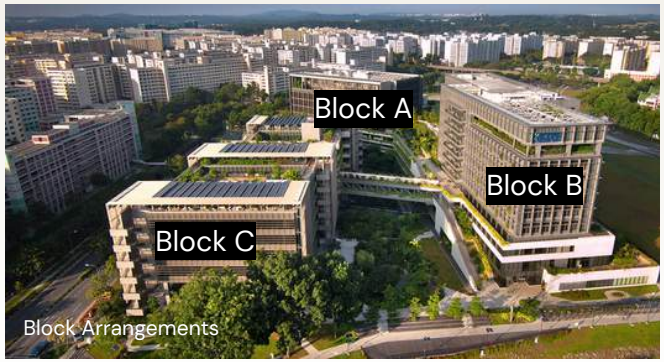
COOLING AND AIR CIRCULATION

The blocks are aligned to facilitate cross-ventilation. Open corridors, and strategically placed courtyards allow airflow to pass through public and patient areas, contributing to a naturally cool environment.

PATIENT WARDS AND VIEWS

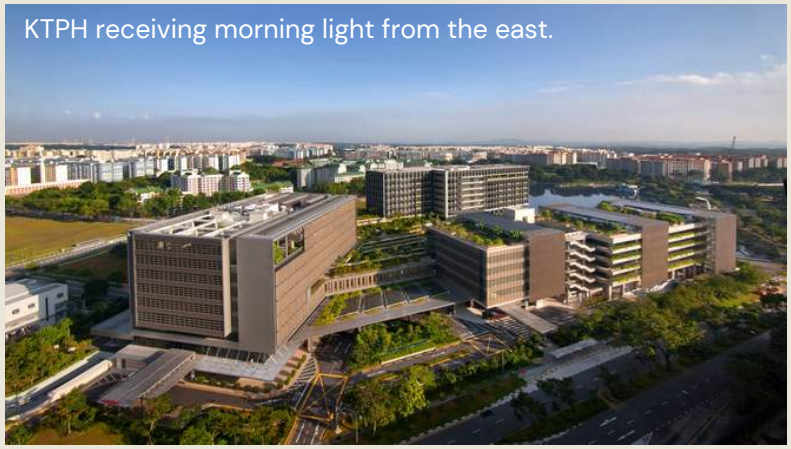
In Block C (Outpatient Clinics), wards are staggered to provide self-shading and reduce heat gain. This layout enhances energy efficiency and offers calming views of Yishun Pond and gardens, supporting a healing environment through connection with nature.

- **Block A (8 storeys):** Private wards and Emergency Department (A&E)
- **Block B (10 storeys):** Subsidized wards and Intensive Care Units (ICU)
- **Block C (6 storeys):** Outpatient Clinics (Focus of report study)



Block Arrangements

2.2 DAY LIGHTING IN BLOCK C

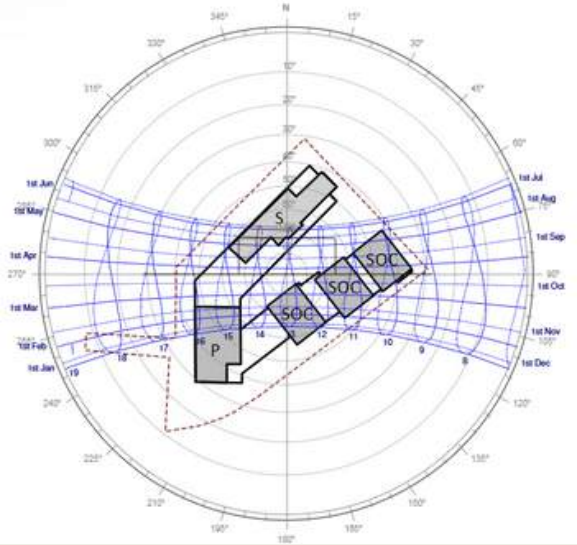

KTPH receiving morning light from the east.

DAYLIGHTING

- **Orientation and Placement:**

Block C (Specialist Outpatient Clinic Block (SOC)) is located in the southeastern part of the hospital massing.
Its orientation exposes it to **eastern sun** at an angle, depending on surrounding shading.

Sunpath diagram of KTPH



SHADING & LIGHTING LIMITATIONS

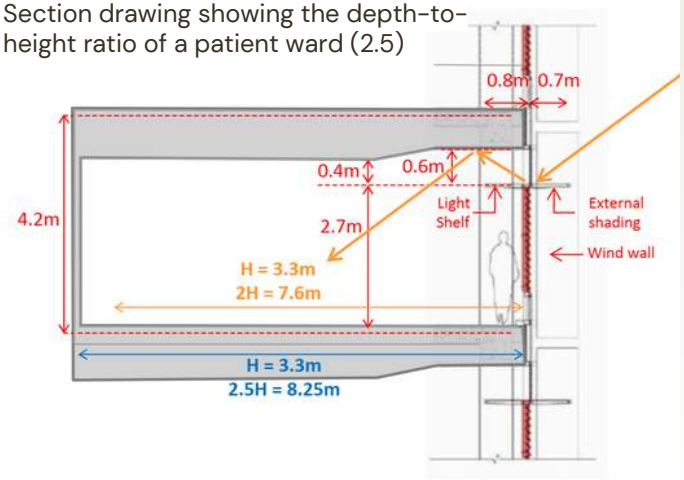
- **Shading by Adjacent Blocks:**

Surrounded by other blocks (S and P blocks), Block C receives partial shading on its western and northern sides, reducing the intensity of direct sun but still allowing diffused daylight.

- **Room Depth**

Patient rooms were designed to have a depth-height ratio of 2.5 or less to achieve natural ventilation guidelines, which were slightly below the standard daylighting depth-height ratio of 2.0.

Section drawing showing the depth-to-height ratio of a patient ward (2.5)



EFFECTS & IMPLICATIONS

- **Effect on Internal Spaces:**

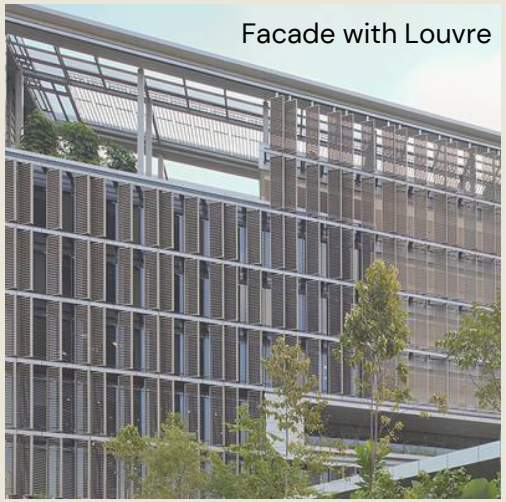
Shaded spaces facing inner courtyards or atriums may still benefit from reflected light, though ground floors or central areas may require supplemental lighting due to limited direct exposure.

- **Design Implication:**

Parts of Block C have reduced glare and solar heat gain, a key feature in tropical design to maintain thermal comfort. However, daylight levels are not uniform & some rooms do not receive sufficient natural lighting—which was compensated with light shelves enhance penetration deeper into the block.

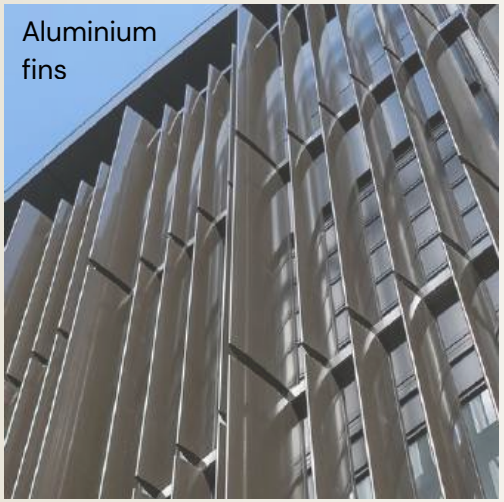
2.3 FACADE DESIGN

The façade of Khoo Teck Puat Hospital (KTPH) shows the hospital's focus on healing, nature, and energy-saving design. It was built to suit Singapore's hot, humid weather while creating a calm space for patients and staff. The façade combines shading, greenery, and airflow features to support comfort and health.


Facade with Louvre

SUN PROTECTION AND HEAT CONTROL

The building uses **sunshades, vertical fins, louvre windows and overhangs** to block strong sunlight. These help keep the rooms cool and reduce the use of air-conditioning. Light-colored materials are also used to reflect heat. The east and west sides of the building have deeper shading because they get the most sun.


Aluminium fins

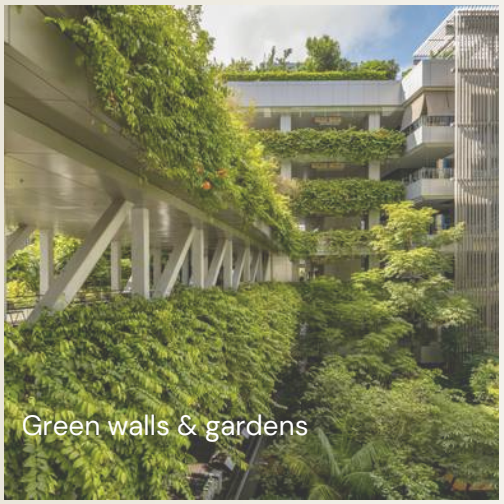
MATERIALS AND MAINTENANCE

The façade uses strong, weather-proof materials like **aluminum fins and tiles.** These materials last long and are easy to clean, which is important for a hospital building.


Louvre windows throughout entire facade

NATURAL VENTILATION AND DAYLIGHTING

The façade **allows fresh air** to flow through open corridors, air wells, large windows, and louvre windows, using the prevailing winds for natural cooling. **Large windows** in patient rooms and public areas bring in daylight and offer peaceful views of Yishun Pond. They are positioned to maximize light while reducing direct sun.

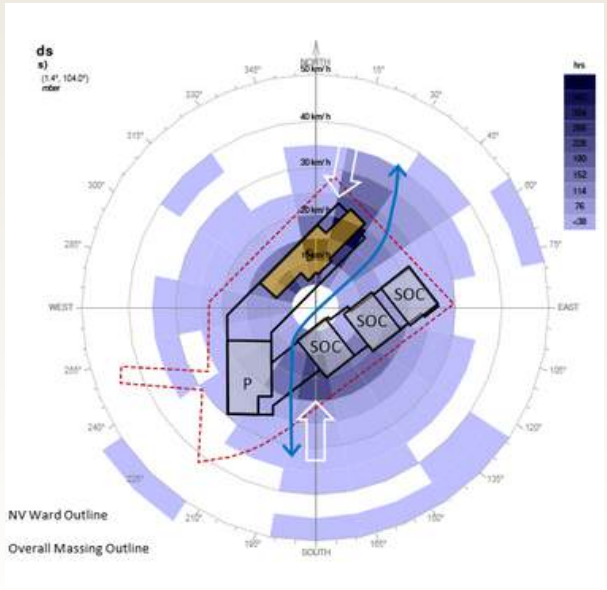

Green walls & gardens

GREEN FAÇADE DESIGN

Plants are added to the façade through green walls, balconies, and rooftop gardens. These cool down the building and improve air quality. Seeing greenery also helps patients feel relaxed and recover faster. This supports KTPH's idea of a "hospital in a garden."

2.4 NATURAL VENTILATION

Wind direction throughout the year



Key Natural Ventilation Features:

- **Architectural Fins:**

Fins along the building's walls are designed to channel prevailing northeast winds into the building, **enhancing airflow by 20–30%** (as per wind tunnel tests done at NUS).

- **Louvre Windows:**

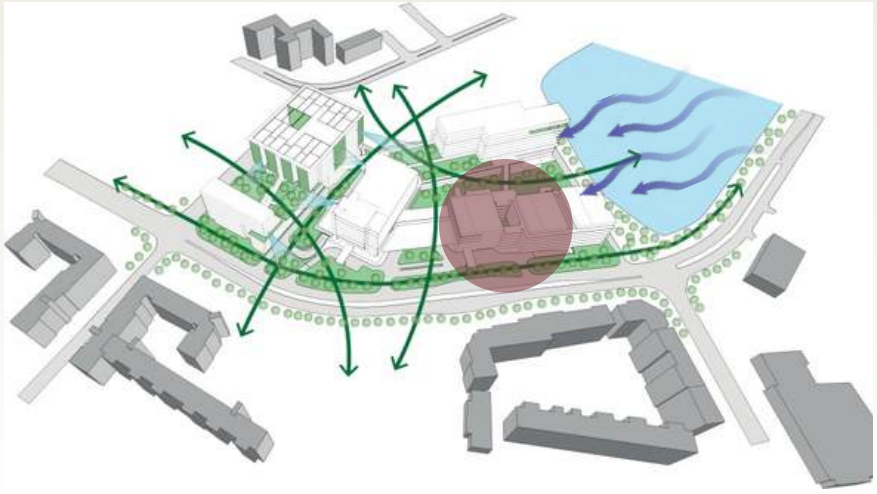
Adjustable louvre windows facilitate cross-ventilation, allowing fresh air to circulate while providing protection from rain.

- **Central Courtyard Design:**

The V-shaped configuration of the hospital's blocks creates a central courtyard that promotes natural ventilation and cooling. Common areas such as the main lobby and public corridors were specially designed for optimal natural ventilation thereby reducing the need for mechanical ventilation and energy consumption.

- **Integration with Yishun Pond:**

The hospital's orientation allows breezes that skim over Yishun Pond to flow through the building, providing cooling effects in Singapore's humid climate.



Integration with Yishun Pond:

Block C

2.5 LANDSCAPING

KTPH & BIOPHILIC DESIGN

Khoo Teck Puat Hospital integrates lush **gardens**, **water features** like ponds and waterfalls, and **natural landscaping** into its façade and site design, achieving a **green ratio of 3.92**—where the total greenery area (horizontal and vertical) is nearly four times the building's footprint.

18% of KTPH's floor area account for blue-green spaces and 40% of all such spaces are publicly accessible. The landscaping is thoughtfully integrated into the hospital environment to promote healing, wellbeing, and sustainability.

SUSTAINABILITY

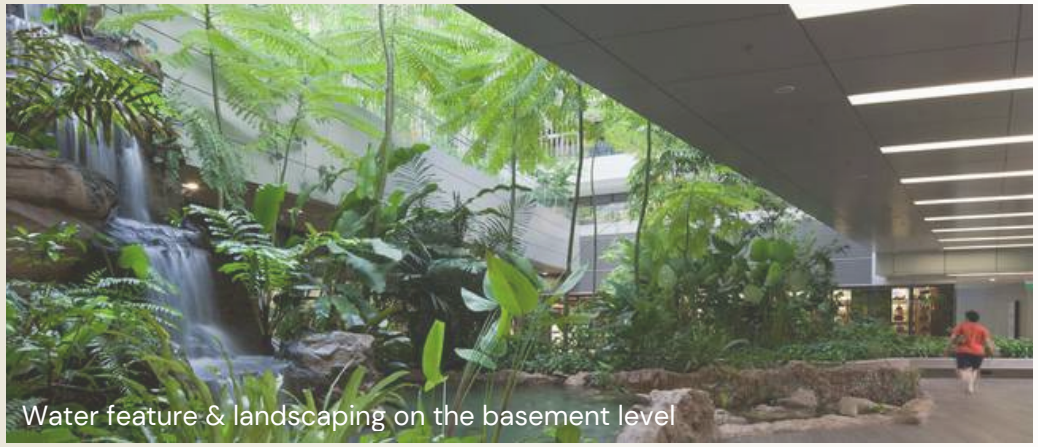
The hospital's landscaping uses **native plants suited to the local climate**, reducing the need for watering and maintenance. **Rainwater harvesting & detection systems** and **irrigation systems from Yishun Lake help conserve water**, while green roofs and vertical gardens help regulate temperature and improve air quality.

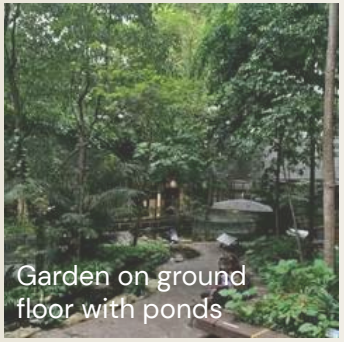
BIODIVERSITY

The landscaping at Khoo Teck Puat Hospital is designed to **attract native birds, butterflies, and other wildlife** within the hospital grounds. **Community rooftop farms** present throughout the hospital house **over 130 types of fruits, herbs, & vegetables.**

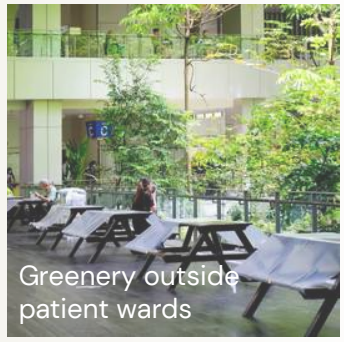
EASY ACCESS AND CONNECTION TO NATURE

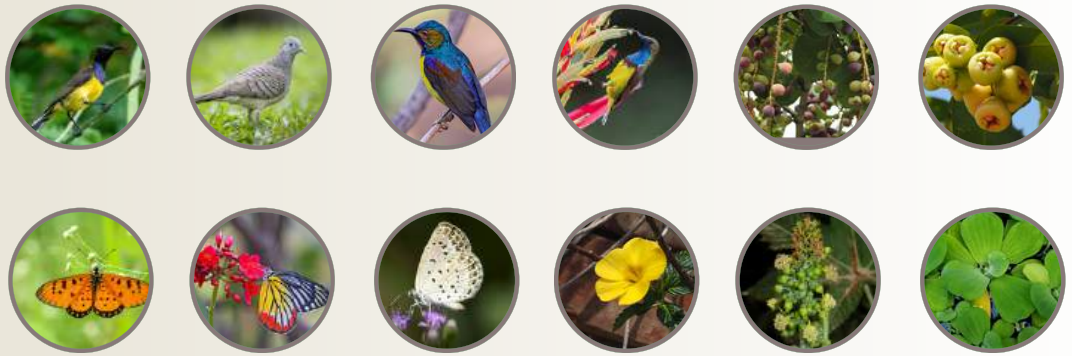
The hospital's **outdoor spaces are designed with universal accessibility in mind,** featuring wheelchair-friendly pathways and comfortable seating areas to accommodate all users. Moreover, the landscape is seamlessly connected to the hospital buildings, allowing **patients to enjoy views of natural greenery from their rooms,** creating a **calming, restorative environment** that reduces stress, **supports patient recovery,** and offers relaxing spaces for visitors and staff.


Water feature & landscaping on the basement level


Garden on ground floor with ponds


Block C Rooftop Garden


Greenery outside patient wards



2.6 ANALYSIS

EFFECTS ON SUSTAINABILITY

- ***70% of the Hospital Uses Natural Ventilation:*** The design reduces reliance on air conditioning by leveraging natural airflow, which is enhanced by the building's shape and the wing walls.
- ***High Green Ratio (3.92):*** Greenery is almost four times bigger than the land area.
- ***Open Green Areas (40%):*** Gardens and paths open to the public for relaxation and healing.

IMPACT ON SPACE AND USER EXPERIENCE

- ***Patients:*** Natural light and views of greenery create a calming, therapeutic environment, while natural ventilation improves comfort.
- ***Staff:*** Access to light and green spaces promotes a healthier, more productive working environment.
- ***Visitors:*** Public green spaces enhance social interaction and connect the hospital with the surrounding community.

In 2016, a POE revealed that KTPH's use of biophilic design (BD) elements such as greenery and water attributed to it performing better than a non-biophilic study when comparing **perceived beauty, self-reported well-being, and user awareness of and proximity to nature**. Out of six such constructs, four corresponded with biophilic design.

Over 80% of respondents said yes when asked if hospitals ought to invest in blue-green elements.

The study identified that 15% of visitors that come to the hospital do so for **social and recreational reasons**. In addition, it also pointed out that 58% of respondents who visit KTPH come from the neighborhood.

Masdar Institute of Science & Technology

MASDAR CITY, ABU DHABI, UAE

The Masdar Institute of Science and Technology (now part of Khalifa University) is a pioneering research-driven graduate-level university focused on advanced energy and sustainable technologies. It was the first major development in Masdar City, a planned eco-city located near Abu Dhabi, United Arab Emirates.

ARCHITECT, ENVIRONMENTAL ENGINEER **FOSTER + PARTNERS, JW ARMSTRONG** • LANDSCAPE **GILLESPIES**

General Information

Location: Masdar City, near Abu Dhabi International Airport, Abu Dhabi, UAE

Total Site Area: Approximately 45,000 square meters for Phase 1

Gross Floor Area (Phase 1): Around 57,000 square meters

03 THE MASDAR INSTITUTE

INTRODUCTION

The Masdar Institute of Science and Technology (Phase 1)

Key Construction Facts
Construction Start: 2007
Completion (Phase 1): 2010
Expansion (Phase 2): Planned but modified due to changes in development strategy

Building Height: Typically 3–5 stories (low-rise to reduce cooling load and enhance passive cooling)

Architects and Engineers
Architectural Design:
Foster + Partners (UK) – Led by architect Norman Foster

Master Plan of Masdar City

Masdar City was envisioned as a model sustainable city, integrating energy efficiency, walkability, and smart technologies. The Masdar Institute Phase 1 was the first built element of this plan.

The Masdar Institute, was created to develop the technology necessary for the operation of which from 2025 will be one of the most sustainable cities in the world.

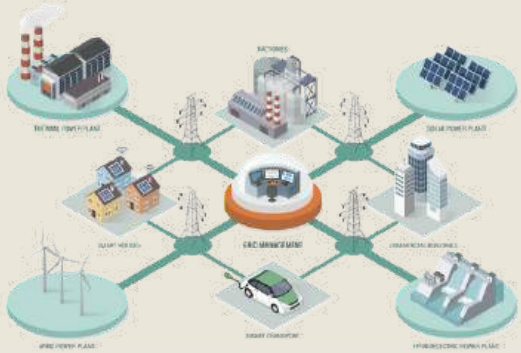
Materials Used:

- Precast concrete with high thermal mass to reduce heat gain
- ETFE (Ethylene Tetrafluoroethylene) shading systems
- Aluminum screens inspired by traditional mashrabiya (Arabic latticework) to block sun
- Recycled materials where possible
- Photovoltaic panels on roofs and carports

3.1 SITE PLANNING

WHY WAS THE INSTITUTE BUILT AT ITS SELECTED SITE?

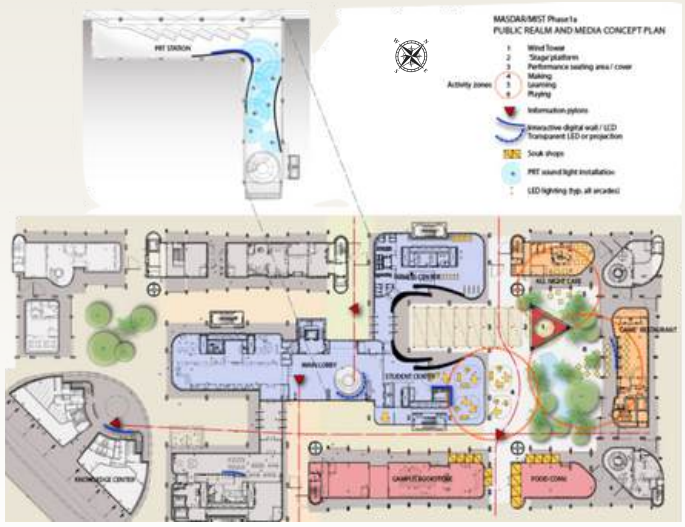
Integration with a Sustainable Ecosystem: Masdar City, a pioneering sustainable urban development and hub for clean technology, offers a unique setting where students and faculty actively engage with and contribute to real-world sustainable technology innovation.



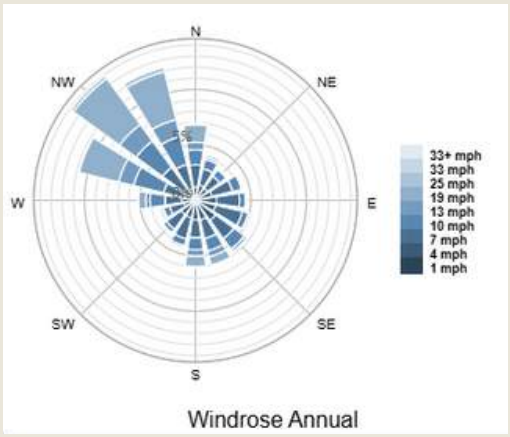
Access to Infrastructure and Resources: Masdar City's advanced sustainable infrastructure—renewable energy, smart grids, and water-efficient systems—provides the institute with direct access to key resources for research and education.

smart grid electricity supply network

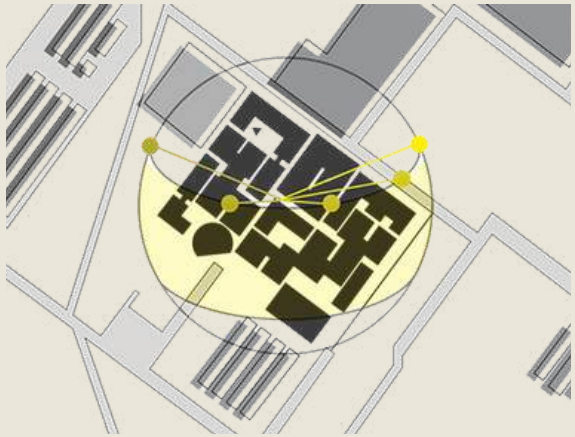
Proximity to Abu Dhabi International Airport: Masdar City's location near the airport ensures convenient access for international students, faculty, and collaborators.



Floor plan of institute



Windrose Annual



BUILDING ORIENTATION

Follows a southeast-northwest grid. This orientation is deliberate because:

- Minimizes Direct Sun Exposure: This alignment reduces the amount of direct sunlight hitting the building facades during the hottest parts of the day (mid-morning to mid-afternoon). The longer facades face north and south, receiving less intense, more diffused sunlight.
- Facilitates Airflow: This orientation helps to channel the prevailing winds through the city streets and between buildings, promoting natural ventilation and cooling

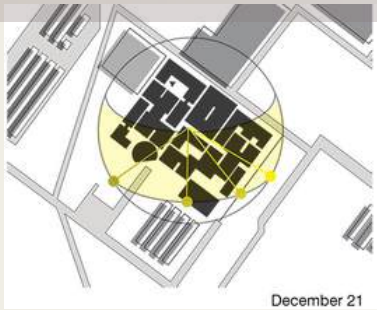
Self-Shading and Mutual Shading:

- close proximity and orientation of buildings to each other also contribute to mutual shading, creating cooler microclimates at street level for pedestrian walkways.

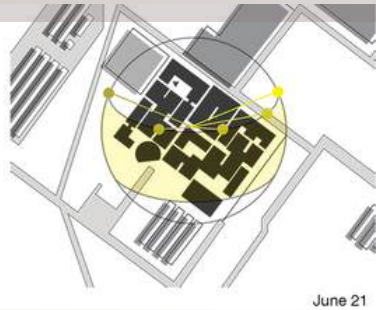
3.2 DAYLIGHTING

Solar field is built to fuilfill the energy need of the Masdar City. Untill the construction of the city is completed, it fulfills the energy need of the instute.

- Buildings located close to each other to provide sun shading to pedestrians.
- Solar panels on top of the buildings also provide sunshading for both the pedestrians and residents in the buildings



December 21



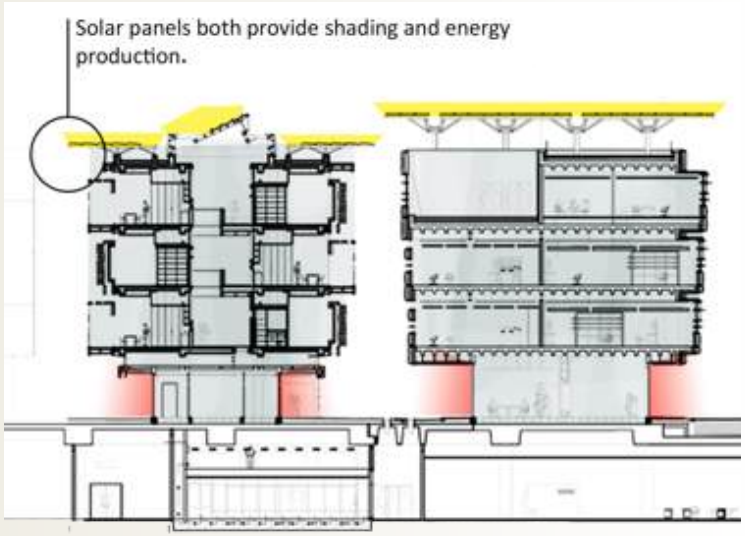
June 21

- This area receives a lot of sun shine during the year

MATERIALS

- Glass
- Reinforced concrete coloured with local sand

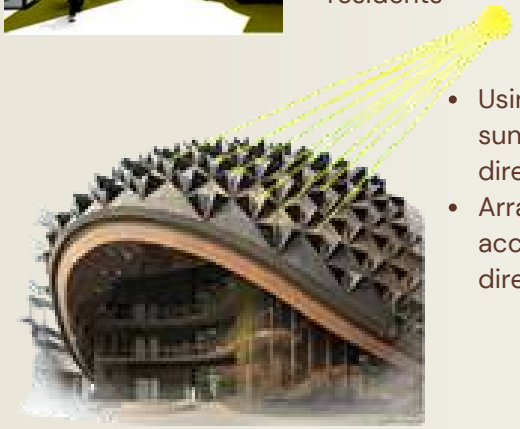
- Mashrabiya used for both sun shading and providing privacy for the residents



Buffer zones shelters the air inside the construction from the outside

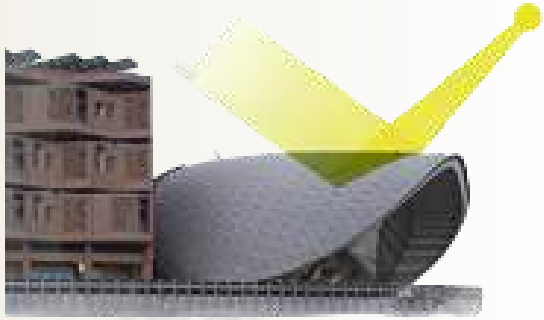
Light shelves and deep windows: Minimize glare and allow natural light penetration.

Buildings feature waving red concrete facades. These serve as insulation, and the alternating waves allow the building to shade itself.



- Using indirect sunlight instead of direct sunlight.
- Arranged according to direction of sun

- Reflecting direct sunlight



3.2 DAYLIGHTING

ROOF DESIGN

- Photovoltaic (PV) Arrays:

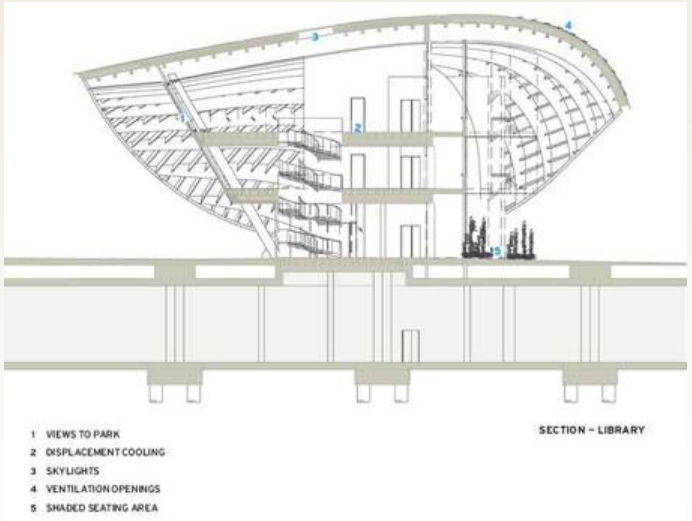
Over 5,000 m² of roof space is covered with solar panels, generating clean energy for the campus and shading roofs to reduce indoor heat gain and cooling needs.

- Green Roofs:

Some roof areas feature vegetation, which improves insulation, supports evaporative cooling, manages stormwater, and enhances air quality.

Benefits:

- Clean, renewable energy generation
- Passive solar shading
- Reduces HVAC load



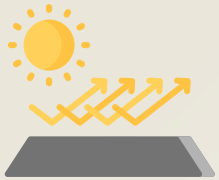
- The Institute's Knowledge Centre is perhaps the most unusual building in Masdar City. The shell-like structure shades an open atrium and glass front.

- The triangular outcroppings at one end serve as shading for windows and to maximize solar panel surface. The roof beneath the shell is made of glue laminated timber, lowering its environmental impact.

3.3 FACADE DESIGN

- Facade is modular, with a limited number of types, so majority of assembly is done offsite.
- deep openings in inner-most façade reduce heat gain while creating dramatic lighting effects.
- Glazing locations based on Ecotech calculations to determine orientation, overshading of façades, window and screen placements to reduce heat gain.
- High level shaded clerestory to maximise daylighting, penetration through bounced light deep into the apartment.
- Fully sealed envelope to provide very high level of air tightness
- Lightweight/ low thermal mass, highly insulated façade and internal finishs act as fast responsive system to suit space use / cooling.

Balconies can be lifted into place with all cladding installed on pre-assembled lightweight steel frames.



- Inner layer of 90% recycled aluminium reflects light within balcony and is lightweight enabling it to cool down quickly. The double skin allows for convection to ventilate the cavity and mitigate any additional heat gain.
- Highly insulated U-value 0.25 W/m2K for solid wall and 1.1 W/m2K for glazing
- U-value is a measure of thermal transmittance, indicating how well a building element (like walls, windows, or roofs) conducts heat. It is expressed in W/m²K (Watts per square meter per Kelvin) and quantifies the rate of heat transfer through a structure for a given temperature difference across it

- Patterned GRC (glass reinforced concrete) screens
- designed by Jean-Marc Castera provide privacy control.

3.4 NATURAL VENTILATION

WIND TOWER:

Al Barjeel

- The 45-meter Wind Tower reimagines the traditional Al Barjeel, capturing and directing cool air to the public square below.
- Sensors control louvers to face prevailing winds, enabling airflow even in low wind using passive cooling.
- LED lights indicate the Institute's energy performance, and the tower houses instruments for weather and air quality monitoring.

AIRCUITY Safe, Smart & Efficient Airside Solutions

Aircuity installed its OptiNet® system in Masdar Institute's first phase to cut initial costs and enable long-term energy savings.

Smart sensors adjust ventilation based on occupancy and air quality. Classrooms, conference rooms, and libraries use Demand Control Ventilation, while labs use real-time Demand-Based Control, reducing outside air use by up to two-thirds—to as low as 2 air changes per hour.

These strategies save about **32.5 KWh per square foot**—a **55% HVAC energy reduction**—lowering solar PV needs by nearly **1.5 megawatts**.

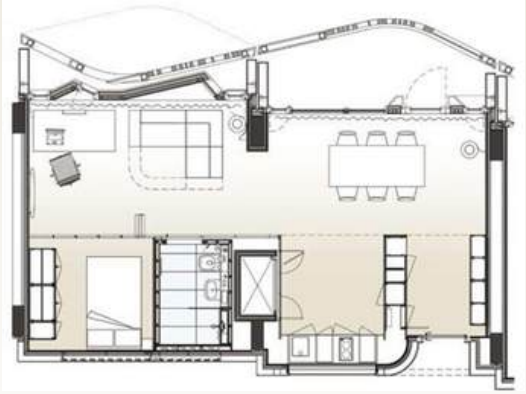
SIEMENS BUILDING (VENTILATION)

DESIGN ELEMENTS

1 Inspired by traditional Arabian design, the layout includes shaded courtyards and narrow streets. Residential buildings feature naturally ventilated atriums where cool evening air enters through podium openings, cools walls, and exits via top louvers.

2 Apartments feature screened, high windows for natural light and privacy. FSC timber-framed, low-e double glazing and well-placed openable windows enhance ventilation. Acoustic separation ensures quiet and privacy.

3
- The roofscape is intentionally irregular to channel breezes into alleys and generate airflow.
- The buildings' heavy mass slows heating and cooling, helping to balance temperature shifts between day and night.
- The green linear park adjacent to part of the buildings captures cooling night-time winds, while wind gates control hot winds.
- Wall insulation is over three times the ASHRAE benchmark, and strict air-tightness limits hot, humid air infiltration.



residential building plan

3.5 LANDSCAPING

Contributes to sustainability through various aspects of its landscaping, including promoting water conservation, enhancing biodiversity, and creating green spaces that reduce the urban heat island effect.

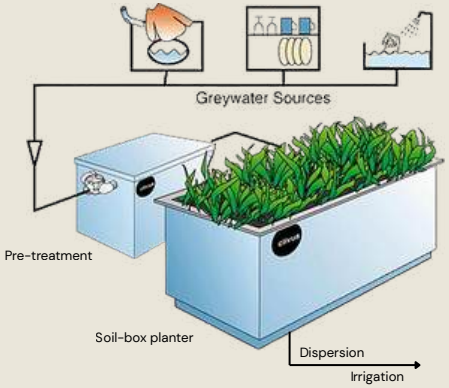
1 Passive Cooling through Landscaping

- Vegetation placed near building façades to cool surrounding air
- The vegetations incorporates native and regional plant species that are well-adapted to the local climate, promoting biodiversity and ecological balance.

- Trees and taller shrubs are strategically placed to cast shadows on walkways, reducing ground temperature.
- Encourages walking instead of vehicle use, supporting sustainable transport
- Landscaping helps reduce ambient temperature in this outdoor corridor by up to 5°C

2 Water-Efficient Irrigation

- Uses treated greywater (water from non-potable sources like showers and sinks) from the buildings for irrigating the central courtyard
- Subsurface drip systems reduce evaporation losses



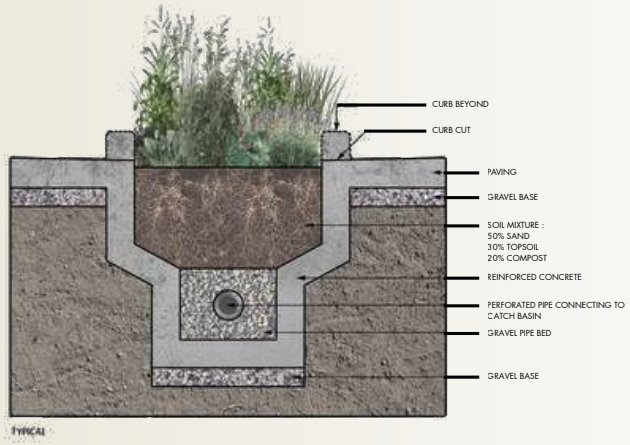
3 Use of Native and Drought-Resistant Plants

- Species like date palms, acacias, and desert grasses are planted.
- These plants thrive in harsh climates with minimal water and low maintenance needs
- The Masdar Institute primarily focuses on Salicornia (also known as samphire)

acacias | desert grasses | date palms | Salicornia

4 Permeable Surfaces and Bioswales

- Landscaping includes permeable gravel beds and bioswales that absorb water and support native plants.
- Enhances stormwater management while maintaining greenery.



3.6 ANALYSIS

The Masdar Institute of Science and Technology (designed by Foster + Partners) is the first building completed in Masdar City, which is envisioned as one of the world's most sustainable urban developments. The building sets a precedent for net-zero energy and low-carbon design in harsh desert climates.

The Masdar Institute's main sustainability strategy centers on passive design and renewable energy integration. It emphasizes reducing energy demand through passive design principles first, and then meeting the remaining needs with clean, renewable energy sources.

IMPACT ON SPACE AND USER EXPERIENCE

- **Students & Researchers:** Thermal comfort and natural daylight improve focus, productivity, and indoor well-being in learning environments.
- **Public Realm:** Shaded courtyards, wind towers, and walkways create comfortable, cool outdoor microclimates that foster community interaction.

- **Campus Identity:** The building's sustainable design acts as a "living lab," aligning with its academic mission and inspiring environmental stewardship.

KEY STRATEGIES USED

Shaded Courtyard Design & Solar Control

- Mashrabiya-inspired façades, deep-set windows, and arcades reduce direct sunlight and heat gain. The building orientation maximizes shade, while native palm trees, shrubs, and pergolas provide additional cooling. Together, these features significantly lower the need for mechanical air conditioning in the harsh desert climate.

Mashrabiya Facade

Material Strategy

- Use of recycled and locally sourced materials reduces embodied energy.
- Prefabrication techniques minimize on-site waste.
- Example: Aluminum sunshades and façade panels were prefabricated and sourced locally, lowering transport emissions and ensuring precise installation with minimal waste.

Aluminum sunshades

prefabricated façade panels

04 CONCLUSIONS

KHOO TECK PUAT HOSPITAL.

MASDAR INSTITUTE.

SITE PLANNING

- KTPH is oriented to capture prevailing winds from Yishun Pond for natural ventilation.
- Masdar Institute is laid out to reduce solar exposure and optimize walkability in a hot desert climate.

Both projects are context-sensitive, maximizing the site's environmental and climatic potential.

DAYLIGHTING

- KTPH incorporates courtyards, atriums, and skylights to reduce dependence on artificial lighting.
- Masdar Institute uses north-facing windows and shading elements to bring in diffuse daylight without heat gain.

Both reduce lighting loads while enhancing occupant well-being.

FACADE DESIGN

- KTPH features operable windows, horizontal louvers, and sun-shading fins.
- Masdar Institute's façades use high-performance materials and mashrabiya screens for thermal control.

Facade systems are tailored to their respective climates—tropical vs arid.

NATURAL VENTILATION

- KTPH is designed for cross ventilation through open corridors and operable windows.
- Masdar Institute uses wind towers and courtyards to facilitate airflow and passive cooling.

Both reduce reliance on mechanical HVAC systems.

STRATEGIC LANDSCAPING

- KTPH integrates rooftop gardens, healing gardens, and water features to create a therapeutic environment.
- Masdar uses shaded pathways, native plants, and courtyards to lower surrounding temperatures.

Landscaping plays a vital role in microclimate regulation and user experience.

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