# BETTER DESIGN FOR COOL BUILDINGS

## HOW IMPROVED BUILDING DESIGN CAN REDUCE THE MASSIVE NEED FOR SPACE COOLING IN HOT CLIMATES

PEEB Working Paper
August 2020

PEEB
PROGRAMME FOR ENERGY EFFICIENCY IN BUILDINGS

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# CONTENT

# EXECUTIVE SUMMARY

Energy needs for space cooling are predicted to triple by 2050, especially in hot and tropical countries. Nearly 70% of the increase will come from residential buildings[1]. Global sales of air conditioning (AC) systems per year have nearly quadrupled since 1990. This trend is set to continue and intensify, driven by high demand for new housing and infrastructure and rising incomes.

**Better building designs can reduce or even avoid the energy demand for space cooling**. High-performance building envelopes can reduce the cooling demand by 30% to 50%. Climate-adapted building envelopes, exterior colours, windows, natural ventilation, orientation and vegetation offer large possibilities to reduce the energy demand for cooling.

Better building designs are highly cost-efficient. The design stage is crucial, when extra effort is minimal. **Three steps** are needed for cool low-carbon buildings: **avoid** - **shift** - **improve**:

| | |
|---|---|
| AVOID | **High cooling demand** through ***building design adapted to the local climate***. |
| SHIFT | **Remaining cooling** to ***renewables***, ***thermal storage and district cooling***. |
| IMPROVE | **Conventional cooling** by increasing the ***efficiency of systems and appliances***. |

If buildings are **adapted to the local climate** and **use passive cooling techniques**, they can keep cool naturally. Variations depend on the climate zone, the local building culture and building use. While there are many variations, the following principles apply:

- In **humid climates**, light- to mid-weight structures and open, spacious layouts allow for constant natural ventilation.
- In **dry climates**, buildings should be massive to block the heat during the day and naturally cool down at night.

**Policies** should therefore address *both* **better building designs** *and* **efficient cooling technologies**. Policies to curb cooling demand often concentrate on promoting the use of efficient cooling technologies and appliances. This is not enough. There is a need to foster improved building designs which take into account the climatic and cultural context.

**Policy recommendations:**

1. Integrate building design into **cooling strategies and NDC targets;**
2. Adopt and enforce **ambitious building energy codes** for new buildings and renovations;
3. Use **financial incentives, information campaigns and capacity-building** to promote energy-efficient building design;
4. Develop minimum energy **performance standards** and labelling **for appliances**;
5. Make **low-income housing** energy-efficient to ensure **'Cooling for all'** and reduce energy poverty.

[1] IEA. 2018

To support countries worldwide to inspire ambition and accelerate action towards clean and efficient cooling, in April 2019 the **Cool Coalition** was launched at the First Global Conference on Synergies between the 2030 Agenda and Paris Agreement.

### The Cool Coalition

The Cool Coalition is a global effort led by UN Environment, the Climate and Clean Air Coalition (CCAC), the Kigali Cooling Efficiency Program (K-CEP), and Sustainable Energy for All (SEforALL).

As a global multi-stakeholder network, it connects a wide range of key actors from government, cities, international organizations, businesses, finance, academia, and civil society to facilitate knowledge exchange, advocacy and joint action towards a rapid global transition to efficient and climate-friendly cooling.

The Cool Coalition promotes an **'reduce-shift-improve-protect'** holistic and cross-sectoral approach to meet the cooling needs of both industrialized and developing countries through urban form, better building design, energy efficiency, renewables, and thermal storage while phasing down hydrochlorofluorocarbons (HFCs).

**More information:**

*www.coolcoalition.org*

**Example: Reflective 'cool' roofs in South Africa**

Supported by the 'Million Cool Roofs Challenge', a project of K-CEP, the South African National Energy Development Institute (SANEDI) deploys solar reflective coatings in a number of demonstration projects and plans large-scale roll out.

**More information:**

*https://www.coolroofschallenge.org/*
*https://www.sanedi.org.za/Cool%20Surface.html*
*https://www.seforall.org/sites/default/files/SEforALL_CoolingForAll-Report.pdf*

# 1. CHALLENGE: GLOBAL ENERGY NEEDS FOR SPACE COOLING WILL TRIPLE BY 2050

Energy needs for space cooling are predicted to triple between 2016 and 2050. Nearly 70% of the increase will come from residential buildings, mostly in emerging economies. Global sales of air conditioning (AC) systems have already been growing steadily: Since 1990, annual sales of ACs nearly quadrupled to 135 million units. There are now about 1.6 billion AC systems in use[2].

This trend is set to continue and intensify especially in hot and tropical countries, following high demand for new housing and infrastructure, driven by global population growth and rising incomes[3].

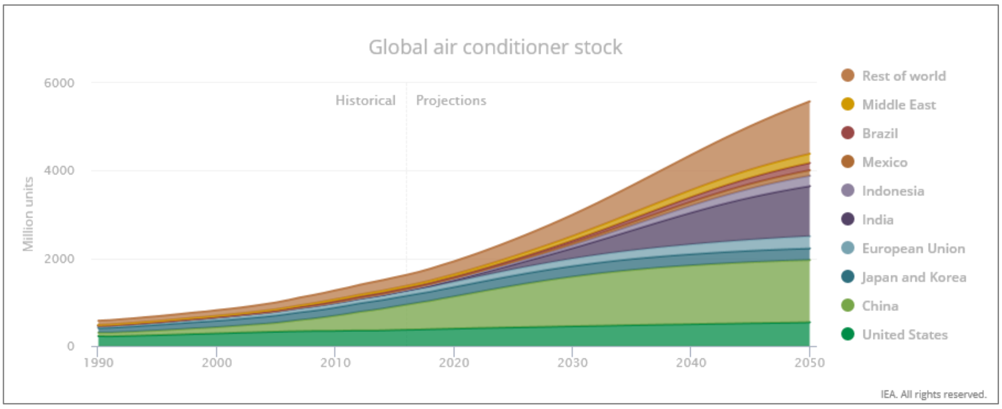


*Figure 1: Projected growth of global air conditioners (Source: IEA.2018)*

One of the main issues underpinning the trend is access to thermal comfort in buildings and its implied effects on productivity, well-being and health. The IEA[4] notes that of the 2.8 billion people living in the hottest parts of the world, only 8% currently possess ACs, compared to 90% in the United States and Japan.

## 1.1. Better building designs reduce the need for space cooling

Building design has a major impact on the need for mechanical cooling. Traditional buildings in hot climates often achieve comfortable conditions without electricity. Long roof overhangs, exterior shading elements and green courtyards provide shade to buildings and reduce solar heat gains. However, when designing buildings today, the construction cost and design requirements of clients are often much more important than energy and cooling issues. As a result, achieving thermal comfort is often ignored in the design and left to be solved by mechanical cooling.

An improved building design can significantly increase the thermal comfort and reduce or even avoid the energy demand for space cooling.

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[2] IEA. 2018

[3] IEA. 2018

[4] IEA. 2018

The following design features reduce the energy demand for cooling:

- **Roof coatings:** High-quality white roofs can reflect 80% of the sun's energy compared to black roofs that reflect only 5% to 10%[5].
- **Envelopes:** High-performance thermal building envelopes (foundations, external walls, roofs and external doors) can reduce the cooling demand by 30% to 50%[6].
- **Windows:** Low-emissivity glass reflects infrared solar radiation without affecting the entry of visible light and reduces cooling demand by at least 20% compared to conventional glass[7].
- **Ventilation:** A survey of office buildings in China shows, that the use of natural ventilation can reduce the overall number of hours of air conditioning needed by as much as 40% while achieving the same indoor comfort level[8]. Analyses in office buildings in Thailand show that natural ventilation can reduce the energy demand for cooling by 8%[9].
- **Landscape and vegetation:** In residential areas, it is estimated that well-designed landscapes could save 25% of the energy used for cooling[10].

To reduce cooling demand, there is a strong need to reinterpret traditional and climate-adapted construction methods with the technologies, tastes and design standards of our time.

## 1.2. Policies for both: better building designs *and* better technologies

Policies to curb cooling demand often concentrate on promoting the use of efficient cooling technologies and appliances. However, this is not enough. There is a need to foster improved building designs which take into account the climatic and cultural context.

Policies should focus on *both* aspects: **better building designs** *and* **efficient cooling technologies and appliances**.

**Policy recommendations:**

1. Integrate building design into **cooling strategies and NDC targets**;
2. Adopt and enforce **ambitious building energy codes** for new buildings and renovations;
3. Use **financial incentives, information campaigns and capacity-building** to promote energy-efficient building design;
4. Develop minimum energy **performance standards** and labelling **for appliances;**
5. Make **low-income housing** energy-efficient to ensure **'Cooling for all'** and reduce energy poverty.

[5] IEA. 2018

[6] IPCC. 2014 and Fraunhofer Institute for Solar Energy Systems ISE. 2017

[7] IEA. 2019

[8] IEA. 2019

[9] Fraunhofer Institute for Solar Energy Systems ISE. 2017

[10] IEA. 2018

## 2. BUILDING DESIGN: THE KEY ELEMENT TO KEEP BUILDINGS COOL

Building design that is adapted to the local climate can increase indoor comfort and reduce or even avoid the need for cooling. However, this must be applied from the very beginning.

At the **design phase**, the extra effort is minimal, while later adjustments and energetic refurbishments are much more expensive.

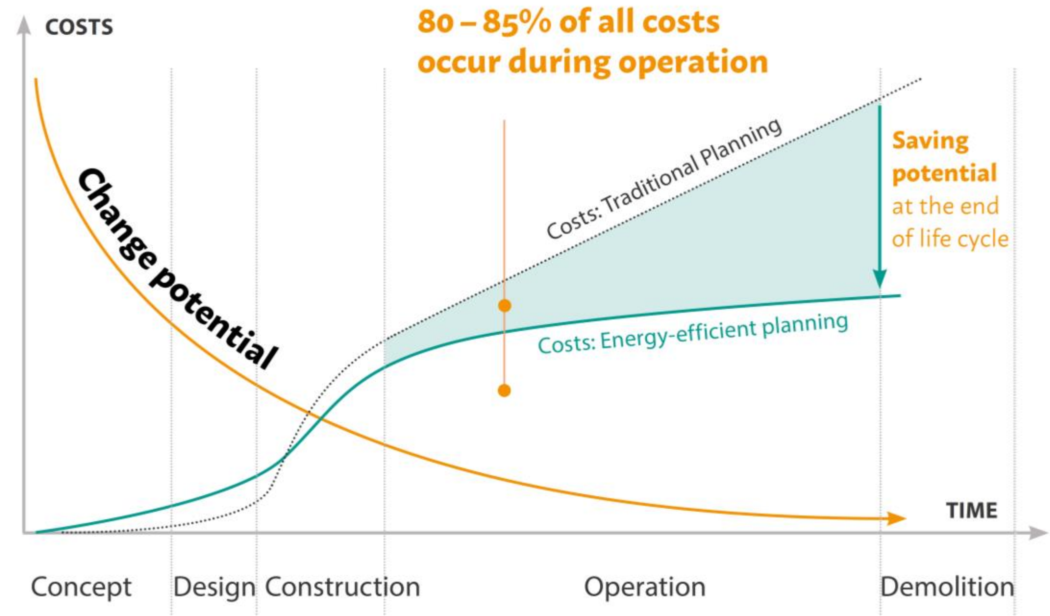


*Figure 2: Building design and change potential (Source: PEEB. 2019. Based on: Kovacic and Zoller 2015)*

### 2.1. Three steps towards cool buildings

***Three steps***[11] are needed for designing cool and low-carbon buildings: avoid - shift - improve:

| | |
|---|---|
| **AVOID** | **High cooling demand** through ***building design adapted to the local climate***. |
| **SHIFT** | **Remaining cooling** to ***renewables***, ***thermal storage and district cooling***. |
| **IMPROVE** | **Conventional cooling** by increasing the ***efficiency of systems and appliances***. |

In the following section, the three steps are introduced.

[11] Common approach based on Cool Coalition and Dalkmann and Sakamoto. Transport - Investing in energy and resource efficiency (2011).

## 1. AVOID – High cooling demand through building design adapted to the local climate

Ideally, improved building designs are based on **sustainable urban development planning** by the municipality. Sustainable urban master plans define an appropriate density of buildings and a balanced mix of building uses, which reduce urban traffic to a minimum and meet the needs of the population.

As a first step, the building design should be adapted to the local climate by applying **bioclimatic architecture**[12] and **passive building design**[13] principles.

### Site adaptation

- The design takes advantage of the **site's surroundings**, such as the surrounding vegetation, water bodies and the proximity to other buildings, which can partially or completely shade and cool both the roof and the façades of the new building.
- To reduce the **urban heat island effect**, green roofs, broad-leaved trees and bushes provide shade but do not obstruct air circulation.

### Orientation and shape

- **Orientation:** A building should be oriented from east to west along the main path of the sun, exposing only smaller façades to high solar radiation at low angles.
- **Shape:** In humid climates, larger distances between buildings allow for better air circulation. In arid climates, compact buildings that are close together expose less façade to the sun and provide shade.
- **Openings:** Most openings (doors, windows, vents) should face north or south to reduce sun exposure. The window positions should allow optimal use of daylight, but with a small surface to avoid solar radiation inside. Horizontal glazing should be avoided.

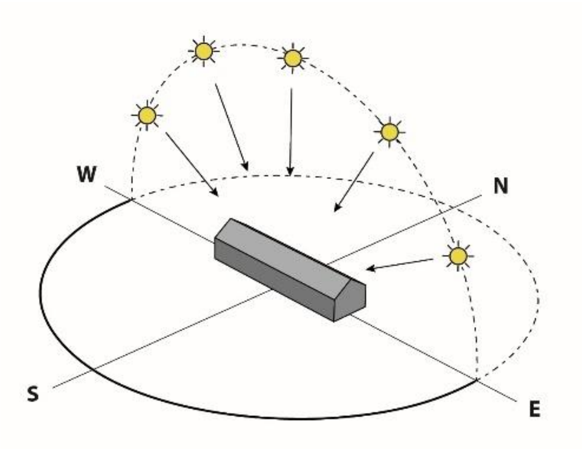

*Figure 3: Orientation according to the sun (Source: PEEB. 2019)*

- The **window-to-wall ratio** should be generally low to minimize internal heat gains while allowing for sufficient natural interior lighting. In hot climates, the total window area must not exceed 20% of the total wall area.

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[12] ***Bioclimatic architecture*** – focusing mainly on applying local building culture and tradition – refers to the design of buildings and spaces (interior and exterior) based on the local climate, aimed at providing thermal and visual comfort, making use of solar energy, natural breezes or other environmental sources or protecting from solar radiation. Very generally, it can be refered to as: "adaptation of shelter to climate" (Olgyay, Victor. 2015 and CRES. 2019).

[13] ***Passive building design*** – focusing mainly on reducing the energy demand – uses building shape, orientation, materials and layout to reduce or avoid mechanical cooling, heating, ventilation and lighting demand without the need for active systems. Passive design may include optimising spatial planning and orientation to control solar gains and maximise daylighting, manipulating the building form to facilitate natural ventilation and making effective use of thermal mass to help reduce peak internal temperatures (Designing Buildings Wiki. 2019).

**Building envelope**

- **Walls:** In dry climates, the walls are massive to keep out the heat during the day and release the slowly absorbed heat at night. In humid climates, the walls are light with many openings and vents for ventilation.
- **Roofs:** In dry climates, roofs are massive or insulated. In humid climates, roofs are light and insulated.
- **Shading:** Roof overhangs and exterior shading minimise solar radiation on façades and windows.
- **Coatings:** Bright and reflective coatings on roofs and façades reflect solar radiation and prevent it from entering the interior. Vegetation can protect façades.

**Building materials matter**

In **dry climate zones**, dense materials such as stone and brick reduce thermal fluctuations. Traditional buildings with thick earthen or stone walls rarely need to be cooled artificially. When using lighter materials, thermal insulation is needed.

In **humid climate zones** with open building layout, lighter materials, such as wood (only where sufficiently available, avoiding deforestation) and composite materials may be used.

In general, materials with **low embodied energy** should be applied, avoiding excessive use of steel, glass and aluminium.

- **Windows:** In **dry climates**, high-performance windows should be used with double glazing and solar film if no external shading is possible, optionally, with natural ventilation during nighttime.
- In **humid climates**, louvre windows should be used with insect screens for natural ventilation. Depending on the local security situation, windows might be equipped with installations for ensuring security. Optionally, high-performance windows in very hot and humid climates.

## 2. SHIFT – Remaining cooling to renewables, thermal storage and district cooling

If mechanical cooling and ventilation are still required, the required energy should be covered through **renewables**, **district cooling** and **solar powered cold chains** or similar climate-friendly approaches.

- **Renewable energy** can be purchased from the grid or produced on-site, for example, by photovoltaic systems on building roofs or, where possible, façades.
- **Solar-powered cold chains and stations** can be an innovative off-grid solution in remote or rural locations for storage and preservation of delicate goods such as fruits and vegetables.
- At certain locations a **district cooling system** can be an option to provide cooling to many different buildings, for example, using industrial waste heat.

## 3. IMPROVE – Conventional cooling through highly-efficient systems and appliances

For the remaining energy needs, the **most energy-efficient systems and equipment** should be used for cooling, lighting and household devices.

- Instead of mechanical cooling, the use of **ceiling fans** should be considered first as they consume very little energy but significantly increase thermal comfort when it is hot. A ceiling fan provides a thermal sensation equivalent to reducing the indoor temperature by at least 2°C.
- **Digital technologies** such as smart thermostats and other control devices can optimise the cooling distribution and reduce the cooling demand in a building.
- Cooling systems must not contain **refrigerants** that are harmful to the environment, such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs).

While the three steps include comprehensive measures that may not always be applicable, there are some basic **'quick wins'** that should be applied to every building in a hot climate zone:

**'Quick wins' for all buildings**

- The building **orientation** should be aligned the from **west to east** as far as possible.
- The **window-to-wall ratio** should be generally low, adapted to the climate zone.
- **External shading** should be installed above all windows, exterior doors and vents.
- **Natural ventilation** should be encouraged where possible and adapted to climate zone.
- **Vegetation** should be provided to shade to the building and provide evaporative cooling.
- **Roofs** should be built with **thermal insulation**.
- Light-coloured and reflective **coatings** should be applied on **roofs and façades**.
- Building interiors should be equipped with **ceiling fans**, before considering air conditioners.

# 3. BUILDING DESIGN FOR HOT CLIMATES

Buildings need to be adapted to the local climate to increase indoor comfort and avoid or substantially reduce the need for cooling.

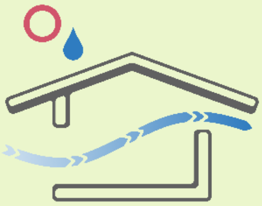
To achieve this, there are two basic **building design approaches**[14]:

1. **Open design *without* air conditioning**, with light to medium weight walls and roofs, encouraging constant air circulation or
2. **Closed design *with* air conditioning**, separating the interior from the exterior space, with massive walls and roofs.

Both design approaches are applied in **dry *and* in humid climates**. However, there are slight variations which depend on the specific temperature and humidity variants of the climate zone, the local building culture and on the specific building use and its desired thermal indoor comfort. A hospital, for example, has more demanding indoor air hygiene and temperature requirements than a residential building.

**Humid climate**

**Open *without* AC**



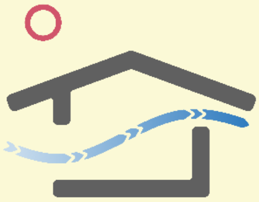
Lightweight building, encouraging constant air circulation

**Closed *with* AC**

Mid-weight building, cooling down mechanically in the most efficient way

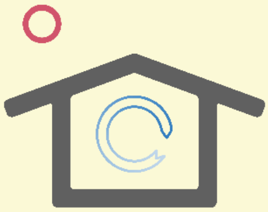
**Dry climate**

**Open *without* AC**



Massive building, blocking heat and encouraging air circulation

**Closed *with* AC**



Massive building, blocking heat and cooling down mechanically

The following section briefly introduces these building design variations.

[14] Based on iPHI. 2019 and UN Habitat. 2014

### 3.1. Humid climate – Ventilation is essential to stay cool

The traditional design approach in hot and humid countries and regions, for example in South East Asia, is to keep buildings open and constantly naturally ventilated. A building design with many openings combined with high ceilings ensures a constant air flow through the building with warmer air drifting upwards and outwards underneath the ceilings or roofs. Natural breezes can thus provide cooling for the inhabitants.

In humid climates, there are usually larger distances between buildings so that prevailing air currents can pass through more easily. Vegetation is arranged to provide maximum shade for buildings and open spaces without hindering natural ventilation[15].

Nevertheless, in very hot and humid climates, mechanical cooling may be necessary to lower the humidity of the air and thereby provide acceptable and comfortable interior conditions. For these climates, a closed design with a high-performance building envelope with highly efficient air conditioning and air dehumidification can be the solution.

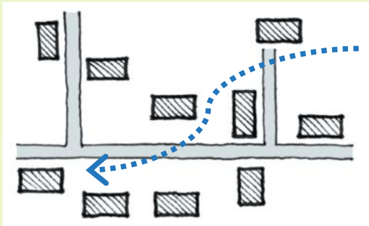
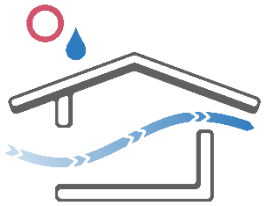


*Figure 4: Spacious settlements in hot and humid climates*
*(Source: UN Habitat. 2014)*

[15] UN Habitat. 2014

## Humid climate 1: Open *without* air conditioning



If temperatures are within the acceptable comfort range, an open building design should be applied. This is particularly the case in regions where frequent local air currents make high temperatures and humidity more bearable.

This design ensures a constant air circulation in the building, improving thermal comfort and avoiding the need for mechanical cooling.

**Building characteristics:**[16]

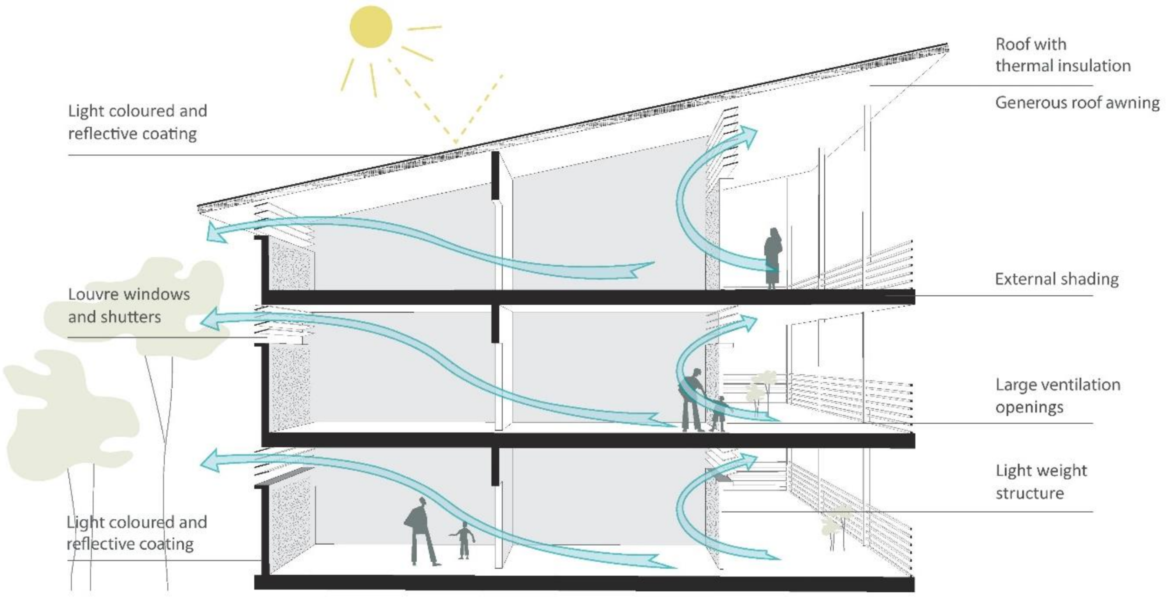



*Figure 5: Open building type in hot humid climate (Source: PEEB. 2019)*

**Shape** – The building has an open layout, is not very compact and often with an adjacent or inner courtyard, combining open and closed spaces.

**Walls** – The walls are light and have many openings and vents near the floor and ceiling, creating a pressure difference that causes air circulation and constant ventilation.

**Roofs** – The roofs are well-insulated and light-coloured with a reflective coating.

**Shading** – Generous awnings and roof overhangs and external shading elements minimise solar radiation on façades and windows.

**Windows** – Louvre windows or shutter windows are used for continuous air flow.

**Cooling** – Ceiling fans are recommended to increase comfort during temperature peaks and at times when there is no outdoor air movement.

[16] Partly based on Australian Government 2013 and UN Habitat 2014

**Example: Community Housing in Ho Chi Minh City, Vietnam**

Covered open-air corridors, ventilated roofs and fibreglass insulation provide natural light, ventilation and protection from the sun.

*Image 1: Community Housing Project in Ho Chi Minh City (Source: see below)*

**Energy saving –** while the electricity consumption of a conventional apartment in Ho Chi Minh City is around 16-20 kWh/$m^2$ a (with ceiling fan) and 29-38 kWh/$m^2$ a (with split ACs), this building does not need energy for space cooling apart from a minimum amount for ceiling fans.

**Sources and more information:**

*https://edition.cnn.com/style/article/t3-architecture-asia-bioclimatic-architecture/index.html*
*https://www.t3architecture-asia.vn*

**Example: Smart GHAR-III (Green Homes at Affordable Rate) Project in Rajkot, India**

This affordable housing project by the Rajkot Municipal Corporation (RMC) reduces internal heat gains through walls made of 230 mm Autoclaved Aerated Concrete (AAC) blocks and highly reflective roofing made of glazed tiles. The windows are partially opaque, providing sufficient daylighting. The window-to-wall ratio is low, meaning that the amount of glazed surface on the façade is kept low to avoid overheating. 90% of the windows can be opened for natural ventilation.

*Image 2: Smart GHAR-III Project in India (Source: see below)*

**Increased thermal comfort** – despite the low cost of this project, the clever building design reduces peak summer room temperatures by more than 5°C compared to conventional housing in this climate. In addition, the number of hours of thermal discomfort per year will drop from an expected 6,200 under the conventional design to 2,500.

These design improvements will avoid or significantly reduce the need for air conditioning units installed by the tenants, thus, reducing energy bills and $CO_2$ emissions.

**New low energy strategies** – in one of the blocks of 14 apartments, an assisted cross ventilation through the service shaft with a single fan on top has been installed and tested. It has demonstrated that 15 Air Changes per Hour (ACH) of fresh air can be guaranteed in each flat with a proper aeraulic design (calibrated static air exhausts) for night cooling. The electrical power for this system needs less than 1.5 $W/m^2$. It further helps to reduce overheating of the apartments during hot periods.

**Sources and more information:**

*https://www.beepindia.org/portfolio/charrette-18-affordable-housing-rajkot/*
*https://www.gkspl.in/publication/case-study-smart-ghar-iii-rajkot/*
*https://www.youtube.com/watch?v=eCZGzRQI_GM*

## Humid climate 2: Closed *with* air conditioning

Where temperatures are very high for a longer period or during daily peaks, additional mechanical cooling and dehumidification of the interior air might be needed to provide comfortable interior conditions. For these climate zones, a closed building design may be the appropriate solution to mechanically cool the interior in the most efficient way.

In a climate where the ambient temperature is very high only at a certain time of day, this closed building approach can also be combined with natural cross-ventilation for cooling at night. In this case, the building should be designed to be operated in a mixed mode with manually operated windows.

Generally, this building design is more suitable for regions with good access to technology experts and suppliers, as more advanced building systems require maintenance over time.

**Building characteristics:** [17]

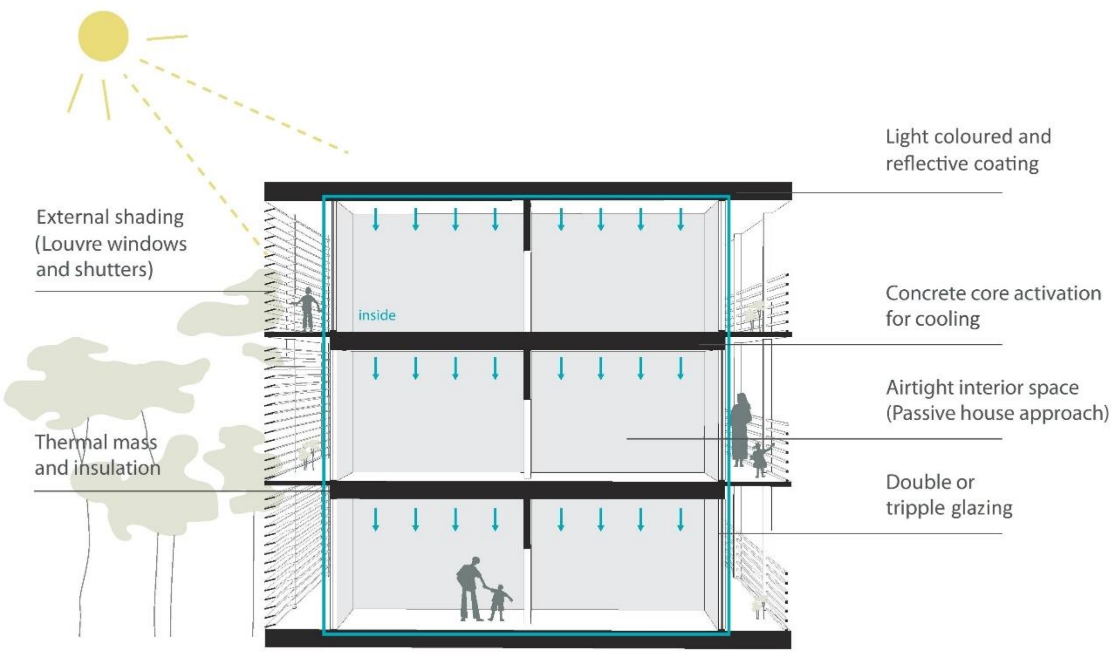



*Figure 6: Closed building type in hot humid climate (Source: PEEB. 2019)*

**Shape** – Compact building to reduce the surface area of the building envelope to a minimum to avoid excessive exposure to solar radiation.

**Walls** – The walls are airtight and light to mid-weight with thermal insulation.

**Roofs** – The roofs are light-coloured with a reflective coating and have thermal insulation.

**Shading** – Generous awnings and roof overhangs and external shading elements minimise solar radiation on façades and windows.

[17] Partly based on Australian Government 2013, UN Habitat 2014

**Windows** – The window to wall ratio is optimised to allow sufficient natural light to enter while minimizing internal heat gains. High-performance and airtight windows with double glazing are used.

**Cooling** – active measures (with energy input):

- **Earth-air heat exchangers**, also called 'earth tubes', can be used for cooling. Outside air flows through a pipe system 1.5 to 3 metres underground, using the nearly constant underground temperature of the earth to cool the outside air.
- **Concrete core cooling**, often called 'concrete core activation', can be used. Cool air passes through holes within concrete slabs to cool the building structure directly, before supplying the air into the interior spaces.
- **Photovoltaics** can generate electricity for cooling (and lighting and appliances).
- **Highly efficient AC units** are used in small buildings and central cooling systems with heat exchangers (cooling down exterior air-inflow) in large buildings. Additional dehumidification may be required.

**Example: Austrian Embassy in Jakarta**

The building envelope of this passive house consists of windows facing north and south, fixed wooden slats and concrete walls and roofs. Thermal mass, insulation and a tight building envelope provide climate protection and intelligent building systems ensure comfort.

*Image 3: Austrian Embassy in Jakarta (Source: see below)*

**Energy saving** – the total annual energy demand of this building is about 40 kWh / m$^2$ usable area while the same building with a conventional design would consume around 270 kWh / m$^2$ per year. The cooling demand is around 28 kWh / m$^2$ per year.

This represents a total energy demand reduction of 85% compared to a standard Jakarta office building, which is equivalent to a $CO_2$ emissions reduction of 73 tons per year.

**Sources and more information:**

*https://passivehouse-database.org/index.php?lang=en#d_4340*
*http://www.pos-architecture.com/projects/jakarta/*
*http://www.ecreee.org/sites/default/files/event-att/ecreee-140610-oettl-jakarta-s3.pdf*

### 3.2. Dry climate – Blocking the heat during the day, and cooling off at night

Hot and dry climate zones, like savannah or semi-arid and arid climate zones, experience very hot daytime temperatures and, depending on the altitude and latitude, huge temperature differences between day and night. Therefore, massive and heavy exterior walls and roofs are highly important to keep the temperature constant for a longer time and to create a natural barrier between the interior and exterior temperatures.

Buildings in hot arid climates are usually compact and dense with narrow streets and small squares and with tall vegetation for shading. This layout provides optimal protection against solar radiation (UN Habitat. 2014).

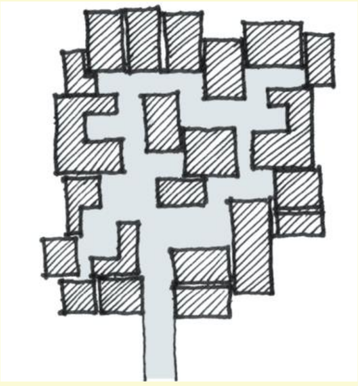


*Figure 7: Dense settlements in hot and dry climates (Source: UN Habitat. 2014)*

## Dry climate 1: Open *without* air conditioning

In dry climate zones with hot days and cool nights, this open building design is applied.

Massive walls and roofs absorb the heat slowly during the day and slowly release it during the cooler nights, thus reducing the amplitude of temperature variations between day and night. Natural ventilation during nighttime allows fresh air inside the building to cool the inner structure which can in turn absorb internal gains during the daytime, thus maintaining a comfortable indoor temperature throughout the day.

**Building characteristics:**[18]

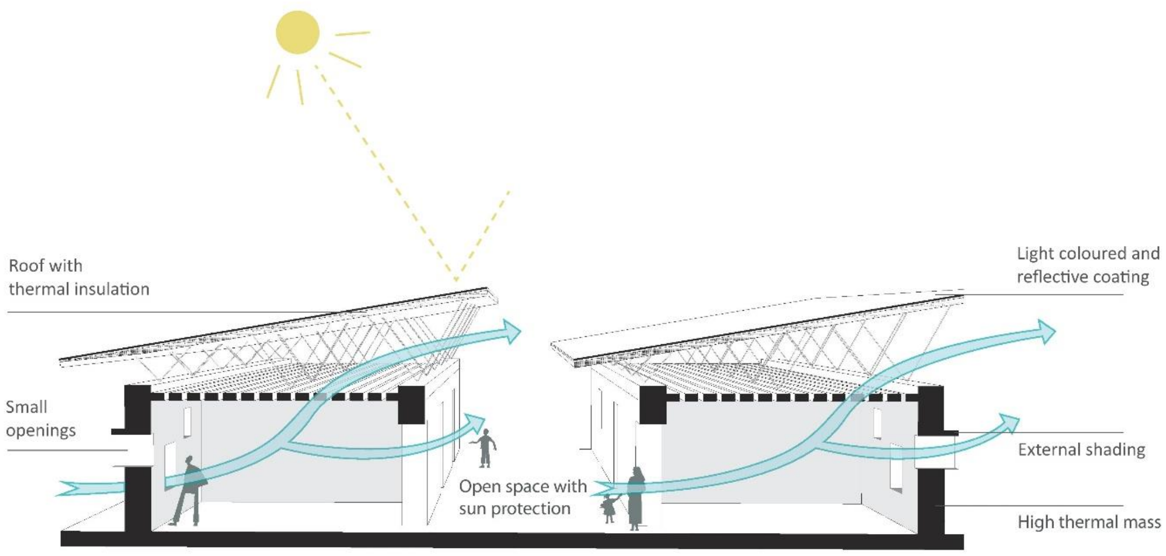



*Figure 8: Open building type in hot-dry climates (Source: PEEB. 2019)*

*Depending on the climate, it may be necessary to block natural ventilation during daytime (when the outdoor temperature is very high) and to enable natural ventilation only during the night*

**Shape** – Buildings are compact and close to each other shadowing each other's façades.

**Walls** – The walls are massive for blocking the heat during day peaks.

**Roofs** – The roofs have thermal insulation, reducing the heat flow to the interior, are light-coloured with a reflective coating and are naturally ventilated below.

**Shading** – Generous awnings and roof overhangs and external shading elements minimise solar radiation on façades and windows.

**Windows** – Small louvre windows or shutter windows allow for improved air circulation.

**Window to wall ratios** should be optimised to avoid excessive solar gains.

[18] Partly based on Australian Government 2013 and UN Habitat 2014

**Cooling** – Passive measures (without energy input) may include:

- **'Solar chimneys'** can enhance the ventilation of rooms by creating an air pressure differential. Warmed by solar radiation, chimneys heat the rising air and increase the difference in temperature between incoming and outflowing air.

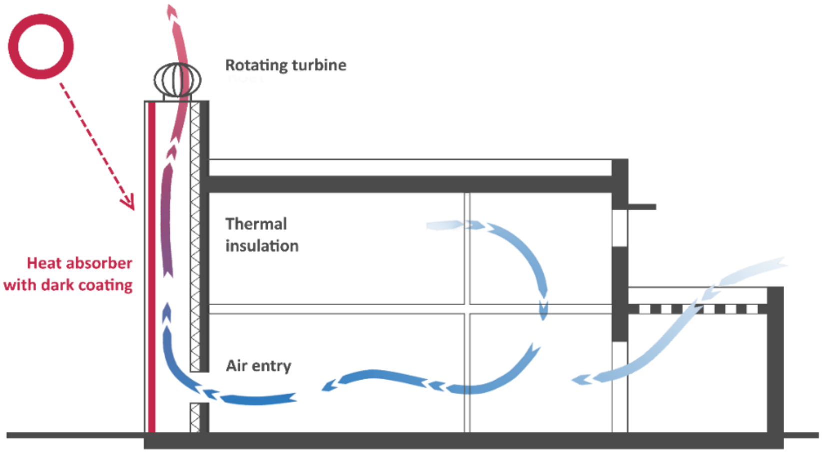



*Figure 9: Scheme of solar chimney (Source: PEEB. 2019)*

- **Direct air evaporative cooling** can be applied through spray humidifiers or fountains and ponds delivering moisture to the building surroundings.
- **Wind towers or wind catchers** – In individual houses with high day and night temperature fluctuations, wind towers absorb heat during the day and draw in cool air at night.

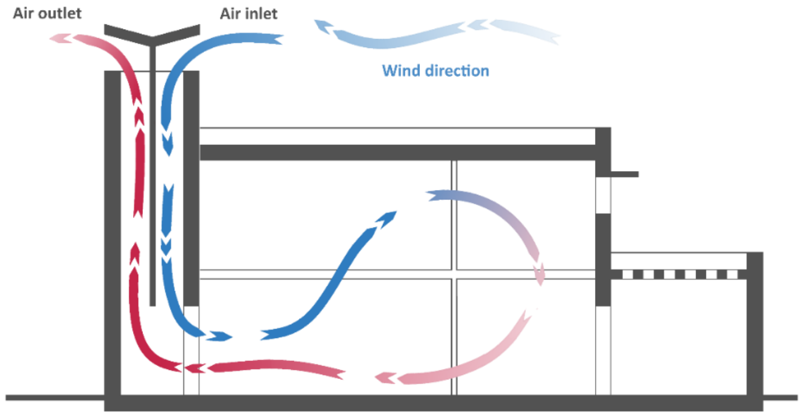



*Figure 10: Scheme of wind tower (Source: PEEB. 2019)*

**Example: Clinic and Health Centre in Burkina Faso**

The main construction material of this health centre is compressed earth bricks. Their high thermal mass absorbs the heat during the day and releases it during the night, reducing the amplitude of temperature variations between day and night and helping keep the interior spaces cool. Ten large overlapping roofs protect the clay walls during the rainy season as well as shade the interiors and surroundings of the centre from the hot daytime sun.


*Image 4: Clinic and Health Centre in Burkina Faso (Source: see below)*

**Energy saving –** This project shows how architecture adapted to the local climate can avoid mechanical cooling. It is not only about building a medical clinic but also about finding innovative uses for local materials and working with the people in the local cultural context.

**Sources and more information:**

*http://www.kere-architecture.com/projects/clinic-leo/*

*https://www.archilovers.com/projects/127540/surgical-clinic-in-leo.html#info*

## Dry climate 2: Closed *with* air conditioning

In very hot dry climate zones, mechanical cooling might be needed for comfortable interior conditions. A closed, well-insulated and airtight building design, based on the Passive House principles [19], can be an adequate solution. This building design is more suitable for regions with good access to technology experts and suppliers, as more advanced building systems require maintenance over time.

**Building characteristics:**[20]

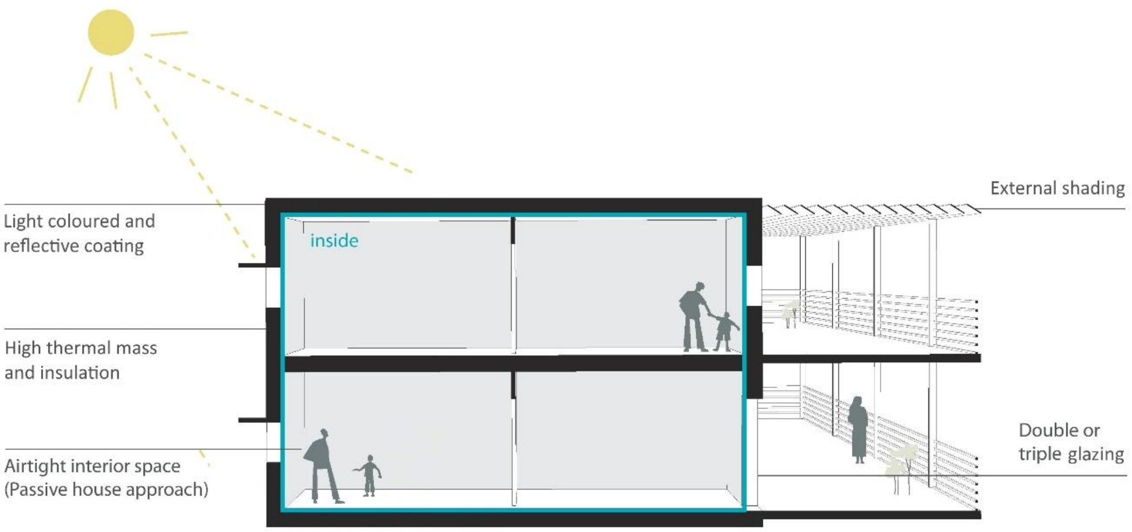



*Figure 11: Closed building type in hot-dry climate (Source: PEEB. 2019)*

**Shape** – Buildings are compact and close to each other shading each other's façades.

**Walls** – The walls are massive or with high thermal insulation and airtight.

**Roofs** – The roofs are heavy with thermal insulation and light-coloured with a reflective coating.

**Shading** – Generous awnings, roof overhangs and external shading elements minimise solar radiation on façades and windows.

**Windows** – Optimised window-to-wall ratios and high performance and airtight windows with solar films or double glazing.

**Cooling** – Active measures (with energy input) may include:

- **Earth-air heat exchangers** can be used for cooling. Outside air flows through a pipe system 1.5 to 3 metres underground, using the nearly constant underground temperature of the earth to cool the outside air.
- **Concrete core cooling** can be used. Cool air is passed through holes within concrete slabs to cool the building structure directly, before supplying the air into the interior spaces.

[19] Passive House principles according to the Passive House Institute PHI: thermal bridge free design, superior windows, ventilation with heat recovery, quality insulation and airtight construction. (PHI 2019)
[20] Partly based on Australian Government 2013 and UN Habitat 2014

- **Photovoltaics** can generate electricity for cooling (and lighting and appliances).
- **Indirect air evaporative cooling** can be applied to increase thermal comfort, using water to cool the airstream which passes through a heat exchanger.

**Example: Mohammed bin Rashid Space Centre in Dubai**

This Passive House certified office building is equipped with highly insulated walls, a 40 kWp photovoltaic field and a 25 kWh electric storage system for all its energy needs. The structure is a prefabricated timber platform frame which allowed for a very short construction time. Different cooling systems are installed for research purposes: supply air cooling or dehumidifying, recirculated air cooling, and floor cooling.

*Image 5: Mohammed bin Rashid Space Centre in Dubai (Source: see below)*

**Energy saving for cooling –** the energy demand for cooling and dehumidification of this building is around 50 kWh/m² per year which is met by the installed photovoltaic system. A conventional office building in this hot dry climate zone can easily consume three or four times the energy for air conditioning.

**Source and more information:**

*https://passivehouse-database.org/index.php?lang=en#d_5065*
*https://www.construction21.org/case-studies/h/mohammed-bin-rashid-space-centre.html*

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