GUIDANCE NOTE 4

Passive Cooling for Public Buildings

Guidance for Humanitarian Practitioners

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Abbreviations

DEC	Direct Evaporative Cooling
EPS	Expanded Polystyrene
IPCC	Intergovernmental Panel on Climate Change
MRT	Mean Radiant Temperature
O&M	Operation and Maintenance
PU	Polyurethane
SNV	Single-sided Natural Ventilation
XPS	Extruded Polystyrene

Citation

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1 Introduction

1.1 Purpose and Scope

As a result of climate change, high temperatures are an increasing threat to communities in many parts of the world. By the 2030s, the Intergovernmental Panel on Climate Change (IPCC) forecasts that the number of heatwaves globally will increase by 8 times[1] [1]. These periods of extreme heat are highly dangerous, leading to significantly increased mortality [2], [3], particularly among elderly people, people living with pre-existing medical conditions, pregnant women and infants [4]. The effects of the weather can be amplified where buildings are not adapted to address heat risks, especially where these buildings are used by people who are already vulnerable to the effects of heat. As well as the effects on health, hot indoor environments can cause lack of concentration and have a negative effect on the performance of students in school [5].

This document provides guidance to help humanitarian actors incorporate low-cost cooling elements into public buildings used in humanitarian responses, such as Primary Health Centres, schools and child-friendly spaces. Most of the elements considered are 'passive cooling' - a method to provide cooling through natural methods without relying on mechanical systems that require energy. A small number of low-cost 'active cooling' (mechanical systems requiring energy) approaches are also briefly covered.

Who is the document for?

The guidance note is written for humanitarian managers with responsibility for projects that involve the construction, conversion or maintenance of public buildings, particularly health centres and schools. It does not assume that the reader has a background in architecture or engineering and is written in non-technical language. The guidance is intended to help these managers engage with technical professionals (locally hired builders and engineers) and inform decisions around building design and budgets. Where necessary, technical details and specifications of use to engineers and builders are referenced, and wherever possible links to these documents are provided.

What sort of buildings?

The guidance covers temporary structures, such as tents, and transitional or permanent buildings made both with industrially produced materials, such as breeze blocks and corrugated sheet, and with local construction materials, such as adobe mudbrick. The main focus is on permanent buildings, as these form the majority of the public buildings in humanitarian contexts and present a wider array of opportunities for cooling.

The guidance covers retrofitting strategies for existing buildings, as well as strategies for new buildings. It contains a mix of strategies for hot climate zones (where cooling has greater priority over heating) – Tropical (Köppen classification A) and Hot-Dry Climate Zones (Köppen classification BWh and BSh). While strategies may also be applicable in other climate zones, such as Sub-tropical climates and Mediterranean climates, they are not designed to address colder climates such as Temperate, Cold-Dry, or Polar zones.

What is the document based upon?

The document is based upon peer-reviewed literature and high-quality grey literature on passive cooling strategies in hot climate zones. The guidance has been field tested by the International Medical Corps in Mali and the Central African Republic .

There have not been many studies focused on passive cooling strategies for health centres, and so literature for other buildings was also considered.

For more information on how this guidance was developed, please see the methodology section Annexe 3.3.

Additional considerations on scope

The guidance takes a multi-hazard approach. Wherever possible, strategies account for the additional risks of high winds, high rainfall, and floods in addition to extreme heat, (e.g., is a particular strategy relevant in situations where high winds can be expected?).

The guidance does not cover all passive cooling strategies; for example, strategies that may be effective but require high levels of technical expertise or significant financial resources to implement are not included. Examples of strategies that were excluded as not being generally applicable in humanitarian contexts include green roofs, passive downdraught cooling, wind towers, indirect evaporative cooling, trombe walls, earth cooling, radiant cooling and roof ponds. Weather sealing and insulating windows were also left out because these are more applicable to airconditioned buildings than passively cooled buildings.

The guidance is primarily concerned with the physical, rather than social, aspects of buildings as the latter are extremely context dependent. In some cases, the approaches outlined may not be socially or culturally acceptable. Suggestions are included for the user to ensure that any features planned are socially and culturally appropriate.

The guidance should be read in conjunction with existing national or sectoral standards and guidelines related to the construction of public buildings. The guidance is designed for humanitarian professionals but is general in nature; it does not provide specific guidance for any particular building.

1.2 How People Experience Heat

The degree to which people are comfortable or uncomfortable at a given temperature (thermal comfort) depends on both physiological factors that determine how the human body interacts with its environment, and on the specific circumstances of an individual.

In general, the human body responds to excessive heat (thermoregulates) in two ways. It uses the circulatory system to bring heat to the skin, and this heat then radiates into the air. It also uses perspiration (sweating). Perspiration on the skin evaporates into the air and, as it evaporates, the skin cools down.

Environmental factors, particularly airflow and humidity, have an important influence on how effectively these mechanisms cool the body down. *Airflow*, in the form of wind or ventilation, can increase the effectiveness of cooling because it blows away the pocket of hot air around the body (produced when the body radiates heat) and replaces it with new air. However, this only works if the wind is cooler than the air around the body that it replaces. *Humidity* in the air determines how effectively the body cools down through perspiration. If the air is very humid, perspiration cannot easily evaporate, and the body finds it much harder to cool down. This is why, if the air temperature is 35 °C and the relative humidity is 65%, it feels as hot as an environment with an air temperature of 49 °C with a relative humidity of 0% [6]. This humidity effect is only relevant at temperatures of 32 °C or higher [7] cited in [8]. **This shows the importance of humidity, as well as heat, as a threat to human health.**

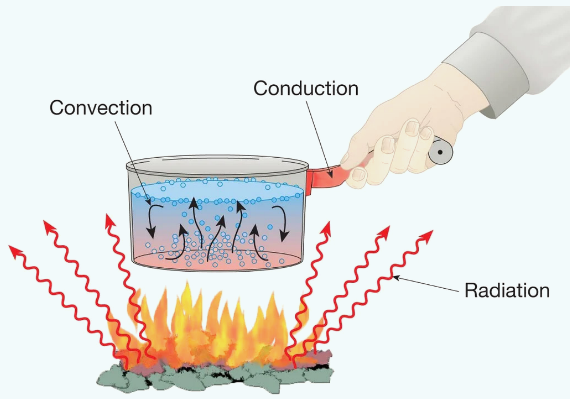
These general physiological processes are affected by individual circumstances. Different people have different metabolic rates (which influences how much heat that person's body produces). People undertaking physical activity tend to be hotter than those who are not (in one study, for example, nurses experienced thermal discomfort at a temperature where patients felt comfortable, as a result of their higher levels of activity [9]). The clothing that people wear also determines how effectively they can cool down, and different people have more, or less, effective thermoregulation systems. In general, elderly people, pregnant women and young children are less effective at losing heat. People with non-communicable diseases, such as cardiovascular conditions, diabetes, respiratory problems, renal conditions, and Alzheimer's or Parkinson's disease are also less able to thermoregulate [9]. Therefore, not all the building occupants have the same thermal comfort requirements. For more information, see *Guidance Note 12: Programmatic Response to Extreme Heat.*

1.3 Why Buildings Heat Up

Buildings are affected by different sources of heat in the environment. Heat comes from direct sunlight (direct solar radiation). But it also comes indirectly from sunlight that has been 'stored' in the environment: in the ground, other buildings, or the air. Heat can also be generated by people within buildings (metabolic processes) and by the use of machinery and lighting.

Heat is transferred from the environment to a building in three main ways:

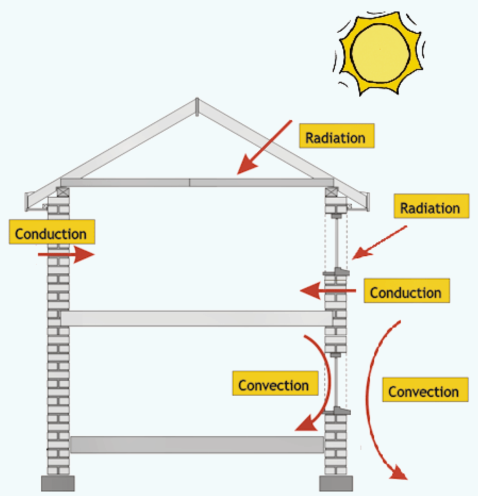
Figure 1: Conduction, convection and radiation



Source: Science Ready. HSC resources

1. **Conduction:** is the process through which heat travels through solid materials, for example, when a spoon in a hot bowl of soup transfers heat along its handle to your hand. Similarly, heat stored in the ground may be transferred to a building through conduction.
2. **Convection:** is the process by which heat moves through liquids and gases. Convection causes warmer, lighter air to rise (creating a low-pressure zone) and cooler, denser air to descend (creating a high-pressure zone). Wind circulates from an area of high pressure to areas of low pressure. In a building, heat can be transferred when hot external air enters a building.
3. **Radiation:** is the transmission of energy through electromagnetic waves (from the sun, for example). You experience radiant heat when you feel the warmth of the sun or from a fire. It travels straight and warms solid objects directly. In a building, walls and roofs absorb radiant heat from the sun. They may also absorb heat radiated from other buildings, or from the ground.

Figure 2: Conduction, convection and radiation in buildings



Source: Mohammed Salih, Tawfeeq (2016). Insulation Materials (Figure 1.4) Modes of heat transfer through the building

There are three main reasons why buildings heat up: External Conditions, Building Design and Construction, and User Behaviour and Building Usage [12]. They are discussed further below.

1. **External Conditions:**

   The location of a building is one of the most important determining factors for whether the building may experience overheating. Climatic conditions (temperatures, wind patterns and the solar path) vary for different locations and, within a given location, environmental conditions also vary.

- **Lack of Shading:** buildings exposed to direct sunlight without shade from nearby structures or trees absorb more heat (as they are exposed to more radiation from the sun).
- **Wind Barriers:** natural wind protection (such as trees) or artificial protection (from, for example, other buildings) change the airflow, disrupting the potential heating or cooling effects of airflow.
- **Orientation:** buildings with long walls facing the east and west receive low angle sun which is more difficult to shade than north/south facing walls. Unshaded south walls (Northern hemisphere) or north walls (Southern hemisphere) are exposed to sun for the whole day.

2. **Building Design and Construction:**

   The design and materials used in a building can worsen overheating:

- **Poorly Designed Openings:** on hot days, large or unshaded windows and doors can allow excessive sunlight and hot air to heat the interior.
- **Construction Materials:** lightweight, poorly insulated materials can quickly absorb heat, making the building hotter. Roofing materials that are unshaded or poorly insulated intensify heat under direct sunlight.
- **Insufficient Ventilation:** buildings with inadequate ventilation systems slow down convection processes and fail to expel hot air. Poor placement of inlets and outlets reduces airflow, trapping heat and making the interior uncomfortably warm.

3. **User Behaviour and Building Usage:**

   Overheating can also result from how buildings are used:

- **Blocked Openings:** if windows or ventilation points are closed or sealed to prevent dust, airflow is reduced, and heat accumulates.
- **Unintended Usage:** designs may not align with how occupants use the building, such as closing openings for privacy or security, which restricts ventilation and increases heat buildup.
- **Increased Energy Use:** increased use of electronic equipment, such as computers and lighting, can accumulate heat.
- **Increased Occupancy:** means more people breathing out moist air. This increases humidity which can cause discomfort. Also, heat is generated by the body so high-density occupation means additional heat.

The design of the building contributes to the degree to which it heats up. Design elements can also contribute to internal humidity and airflow, affecting the temperature and how it is felt by building users.

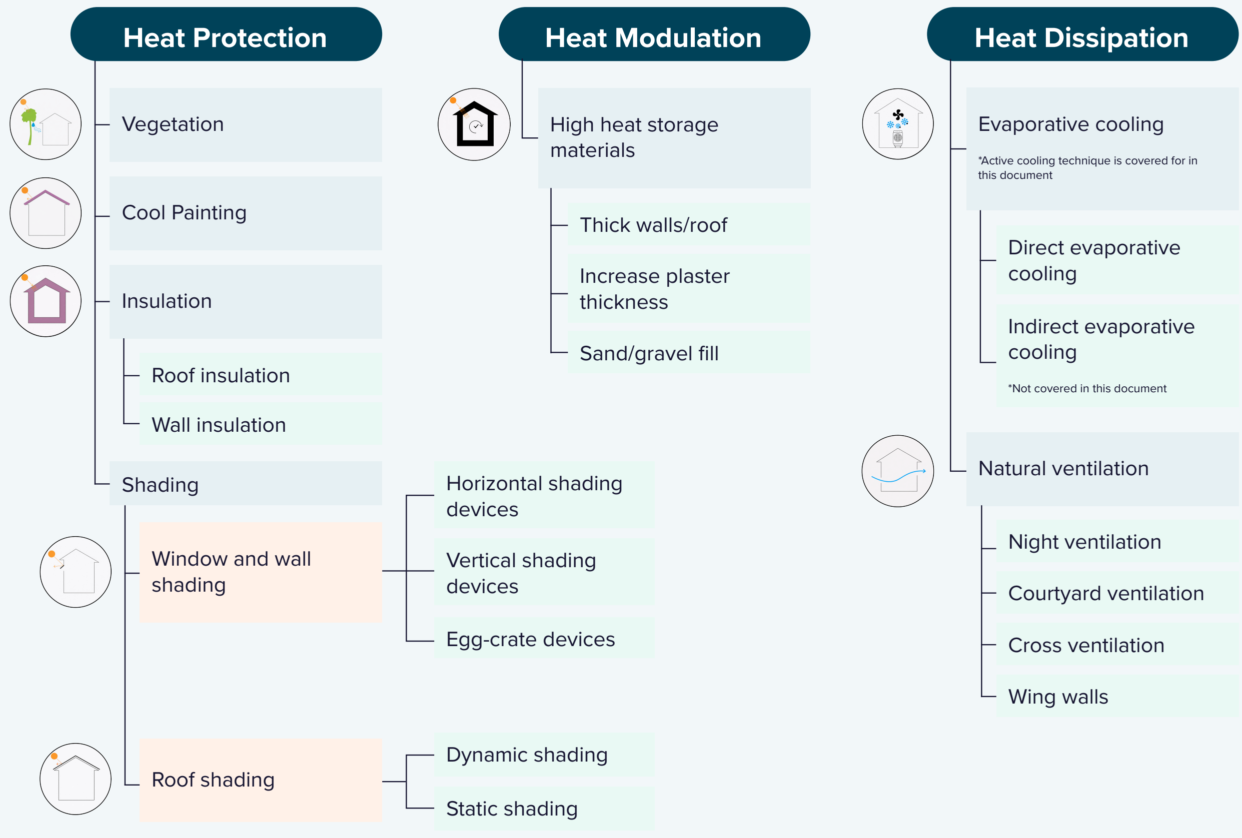
1.4 An Overview of Passive Cooling Strategies

Passive cooling strategies can be grouped into three main categories: Heat Protection, Heat Modulation, and Heat Dissipation [13].

- **Heat Protection:** involves protecting the building from gaining heat from direct sunlight (radiation). This can be done either by a protective layer, like shading or cool paint coat, or changing the microclimate by adding vegetation or waterbodies [14].
- **Heat Modulation:** this approach is suitable for places with a big difference between day and night temperatures (often in dry climates). It works by designing the building to 'even out' large fluctuations in temperature between day and night: storing the heat within the structure during the daytime, and then gradually discharging it at night [14]. Heat modulation techniques in buildings involve the use of building materials that can store large amounts of heat.
- **Heat Dissipation:** involves techniques that dispose of the excess heat of a building into a cooler area or material, which is generally called a 'heat sink'. The heat sink must be at a lower temperature than the building [14]. The environment (air, water, sky) can be used as heat sinks. For example, if a building is hot but the night sky is cooler, the heat of the building can be drained away to the sky.

Most heat dissipation techniques that are covered in this guidance document involve ventilation.

Figure 3: Categorisation of strategies



Source: Author's own work

1.5 Choosing and Implementing Passive Cooling Strategies

1.5.1 How to use this guidance

This guidance contains information on a variety of passive cooling strategies that can be used in public buildings in humanitarian contexts.

The following steps are recommended to choose and implement the most appropriate strategy or strategies for a particular building.

Step 1: Identify the context

Specifically, consider the following questions:

1. Is this a new building, or does the strategy need to retrofit an existing building?
2. Is this a temporary building or a permanent or transitional building?
3. Is it possible to use low-cost active cooling in the building (i.e., there is a reliable energy supply) or are only passive cooling techniques possible?
4. Is the building in a dry/arid area (Köppen classification BWh and BSh), or a more humid area (Köppen classification Am, Af, Aw)[2].

Step 2: Generate a longlist of potential strategies from the general information in this section

With this information, you can narrow down the possible strategies to those most appropriate for the context and read the relevant guidance (e.g., for passive cooling in dry climates or humid climates) to get a general idea of the different approaches relevant to different contexts. Then consult the strategy table to create a longlist of possible strategies.

Step 3: Selection of relevant strategies

For each strategy in the longlist, read the summary section at the start of each strategy in Section 2. If required, each strategy (such as natural ventilation, or roof shading) has additional detail on design considerations, such as how to apply the strategy, its drawbacks, situations where the strategy cannot be used, and information on its effectiveness.

Wherever possible, discuss the potential strategies with a building engineer and/or the builders who will be responsible for putting it into practice.

This guidance considers the effectiveness of each strategy in cooling a building according to several studies. As they were conducted in different contexts, they could only measure effectiveness in that specific context. Hence it is extremely difficult to make any general statement on the effectiveness of any particular strategy in all contexts. Nevertheless, the information on effectiveness in this guidance has been synthesised to inform decision-making, even if it cannot be used as the sole criterion for making a decision.

Step 4: Implementation

Each strategy has a *Further Readings* section containing additional technical guidance that can be used by builders who are implementing the adaptations (for example, guidance on the installation of insulation).

Building users and managers should be aware of any actions that they need to take to ensure the effectiveness of the strategy. The WHO [16] and the pilot testing of this guidance pointed to the importance of:

- *developing a manual related to the operation and maintenance* (O&M) of the passive cooling system, even for low-tech systems in health-care settings. This should provide information on how the passive cooling system works and guidance on activities that should or should not be undertaken to ensure the effectiveness of the system (e.g., ventilation schedules for the building, instructions on running active cooling systems (if any) may include guidance that patients should not open windows unless instructed).
- *including this information in training programmes* for staff and building users. This might include information on ventilation and opening/closing windows during heat stress/cold stress; and switching off electrical devices to reduce internal heat and save energy [92].

1.5.2 Dry Climates

Dry climates are often associated with large fluctuations between day and night temperatures and higher levels of direct solar radiation. Overall, the most effective strategies in hot-dry climates aim to shade surfaces exposed to the sun, add moisture, reduce heat gain and modulate large temperature fluctuations. This often means buildings with thick walls and roofs.

- **Using High Heat Storage Materials** (see Section 2.1): in hot and dry places the days can be very hot whilst nights can get cold. If a building has a thick outer shell (walls and roof) that can store heat (high thermal mass), it can stay cool inside during the hot day, and release the heat slowly when it is needed into the cooler night [15]. If the heat is not needed in the night (because the night is cooler than the day, but still too hot) then windows can be opened to release the heat (see Section 2.2.3 for further detail on night ventilation).

  It is recommended to have a roof that is a good reflector of heat. A solid white-painted roof (or another reflective coating) can be very effective (See Cool Painting). In areas where nights/winters are cold, additional roof insulation is desirable (See Insulation) if cool painting is applied on the roof. Alternatively, a removable roof shade can work well (see Roof Shading and Radiant barriers), using a temporary covering instead of a permanent shading/reflector layer. This can be retracted to allow heat storage when it is cold, and deployed to block the sun's heat during hot days.

  In hot-dry climates, when it is very hot outside, it is recommended to minimise ventilation during the day (see Section 2.2.3); ventilation should be sufficient only for maintaining indoor air quality. Night-time ventilation is important to allow hot air to leave the building at night.

- **Insulation** in hot, dry climates will often be low thermally conductive material with a reflective outer layer (to decrease the impact of solar radiation). Care should be taken in using a high heat storage strategy (above) as ventilation may interfere with the movement of heat at night.

- **Direct Evaporative Cooling:** water can have a cooling effect in hot-dry climates when it evaporates. However, care must be taken not to over-saturate the air as it may lead to mould and mildew – especially hazardous in clinics [16]. An effective passive Direct Evaporative Cooling strategy is to hang damp cloth in front of windows. Alternatively, if resources are available, active direct cooling methods can be used such as Desert Coolers, although humidity needs to be kept in check (see Section 2.9).

  In hot-dry climates, winter heating may also be important. Check the monthly average temperatures in the winter months for the location. Heating in winter may be desirable so wall and window shades should be designed that allow the winter sun to come in but block the summer sun. This is possible with adjustable window shades, such as blinds, or sizing overhangs appropriately on equatorial-facing facades. See Window and Wall Shading and Section 3.1 for further detail. The use of deciduous trees is encouraged for the same reason – shading in summer but allowing heating in winter.

1.5.3 Humid Climates

Humidity increases the perception and effect of temperatures. Highly humid environments can lead to health problems at lower temperatures than in dry environments (see How People Experience Heat). Overall, in hot-humid climates, the aim is to remove heat and moisture where possible (e.g., through ventilation), shade surfaces, and reduce heat gain. A lightweight, breathable shaded envelope (lightweight walls and roof) is recommended.

The difference between daytime and night time temperatures tends to be smaller in humid climates, so strategies that work on the principle of reducing fluctuations between day and night temperatures (such as using High Heat Storage Materials) are less effective (see Section 2.1). Therefore, unless the location does experience significant fluctuation, alternative strategies may be more effective.

If the building is actively cooled, then condensation inside the construction may be a risk (see Section 2.9 for further detail).

Walls should be lightweight and breathable to draw out the moisture from indoors [15]. Putting a non-breathable cover over the walls, for instance, with a tarp for rainwater protection, will trap the humidity inside causing thermal discomfort.

- **Natural Ventilation** is the main approach to passive cooling in many humid environments The presence of a breeze can especially improve comfort levels. If the orientation of the building or the windows are not aligned with the prevalent wind direction, wing walls can be used to direct airflow inside the building (see Wing Walls). In addition to removing heat, natural ventilation is very important for removing moisture from indoor air (decreasing the apparent temperature for building users and reducing the risks of mould – a particular consideration in healthcare settings [16]). Removal of moisture, however, depends on outdoor humidity being lower than indoor humidity [20].
- **Night ventilation** is less effective in humid climates than in hot-dry climates but can nonetheless flush out some heat from a building. A more flexible strategy (e.g., opening windows at any time when the outdoor temperature is lower than the indoor temperature) works better than a fixed strategy, especially in high density areas like clinic wards. However, care should be taken as humid air can be drawn indoors. Moreover, during the day, humidity builds up indoors because of the building's occupancy and usage. Passive solutions for controlling humidity are difficult where both outdoor and indoor humidity is high. In these environments, if resources are available, dehumidifiers are recommended to remove moisture as they have relatively low energy consumption [21].
- In general, **insulation** is much less effective as a passive cooling approach in hot-humid climates than in hot-dry climates [17]. If it is used it should be chosen based on managing both heat and humidity [18]. Materials such as gypsum plaster can be used in the interior to regulate moisture [19].
- **Direct Evaporative Cooling** is also generally less effective in extremely humid environments, as evaporation will not occur effectively where the air is already humid. A dehumidifier may be recommended if resources are sufficient.
- **Shading** (see Roof Shading and radiant barriers and Window and Wall Shading): these work well in buildings exposed to direct sunlight and should be used alongside natural ventilation [20].
- For areas with moderate to high rainfall, a sloping roof is recommended to drain water properly. The upper surface should be covered with a **reflective layer** or the lower surface should be covered with a **low emission layer** [15] (see Roof Shading and radiant barriers).

1.5.4 Strategy Table

Table 1 provides some basic information on all the cooling strategies outlined in the next section, to help in selecting relevant strategies for a particular context.

It shows:

- **Yellow Column:** whether the strategy can be used as a 'retrofit' for an existing building, or is only possible in new buildings, or whether it can be used in both new buildings and as a retrofit.
- **Green Column:** whether the strategy can be used in permanent buildings and bamboo/wood framed or adobe brick transitional buildings, or in temporary shelters, or in both.
- **Blue Column:** whether the strategy is effective in dry climates (Köppen classification BWh and BSh), in humid climates, (Köppen classification Am, Af, Aw) or in both.
- **Orange Column:**
  - The likely cost of using the strategy in a humanitarian context ($ signifies lower cost, $$$ signifies higher cost).
  - The level of technical skills required to use the strategy (x signifies building / engineering skills generally available in a rural community; xx signifies more specialised building / engineering skills often available in a larger town; xxx signifies specialised building / engineering skills that may only be available in larger cities).
  - The level of specialised inputs required to use the strategy (x signifies inputs commonly available in a humanitarian context; xx signifies more specialised inputs, xxx signifies inputs that may only be available in a larger city or may require importing into the country).
- **Grey Column:** the effectiveness of the different strategies.

Table 1: Strategy Table

Strategy	New or existing (retrofit)?		Permanent/ transitional[3] or temporary?		Dry or humid?		Cost and technical requirement			Effectiveness
	New	Existing	Perm/Trans	Temp	Dry	Humid	Cost	Technical skills reqd.	Specialised inputs?	
Insulation	x	x	x		x		$$	xx	xx	xxx[4]
High Heat Storage – sandbags		x	x	x	x		$[5]	x	x	xxx[6]
High Heat Storage – thick walls	x		x		x		$$	xx	x	xxx
High Heat Storage – plaster	x	x	x		x		$	xx	x	x
Wind Driven Ventilation	x	x	x	x	x	x	$	x	x	xx
Stack Ventilation	x	x	x		x	x	$$	xx	x	xx
Strategic Ventilation	x	x	x	x	x	?	$	x	x	xxx
Courtyard Ventilation	x		x		x	x	$$$	xx	x	xx
Wing Walls	x	x	x		x	x	$$	xxx	xx	x
Cool Painting (White Paint)	x	x	x	x	x	x	$	x	x	x

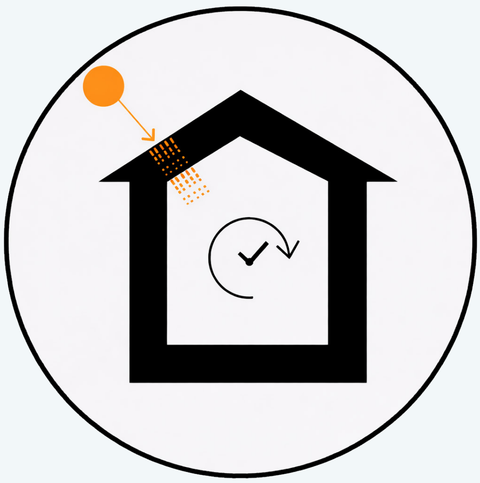
Strategy	New or existing (retrofit)?		Permanent/ transitional[3] or temporary?		Dry or Humid?		Cost and technical requirement			Effectiveness
	New	Existing	Perm/Trans	Temp	Dry	Humid	Cost	Technical skills reqd.	Specialised inputs?	
Cool Painting (Reflective Paint)	x	x	x	x	x	x	$$$	x	xxx	xx
Roof Shading	x	x	x	x	x	x	$$	xx	xx	xx
Vegetation	x	x	x	x	x	x	$	x	x	xx
Window / Wall Shading	x	x	x	x	x	x	$$	xx	xx	xx
Building Form and Zoning	x		x	x	x	x	$$$	xxx	xxx	xxx
Low Cost Active Cooling	x	x	x	xx	x	x	$$	xxx	xxx	xxx[7]

Note that the table provides illustrative, general guidance and will not be accurate in all contexts. It has been developed from a literature review and inputs from users in field trials. Costs, availability of materials and, above all, effectiveness vary significantly depending on the specific context.

2 Strategies

2.1 Using High Heat Storage Building Materials

Figure 4: Using High Heat storage materials



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings AND Retrofitting (plaster, sandbags only)
✓	Permanent AND Temporary (sandbags only)
✓	Dry

A. What is it?

This strategy involves building with heavyweight construction materials such as stone, bricks, earth, and concrete that have a high thermal mass. The thicker and denser the material, the higher its thermal mass – and so in turn, the higher its heat storage capacity. See Box 1: Thermal Mass. When retrofitting buildings, it involves adding high thermal mass materials to the building.

Box 1: Thermal Mass

Heat storage (thermal mass) refers to a material's ability to absorb, retain, and release heat. Heavyweight building materials like stone, brick, earth, and concrete generally have a high thermal mass. The denser and thicker the material, the greater its thermal mass - and therefore its capacity to store heat.

Heat builds up in these materials during hot periods and is released gradually into the air when it cools down. This helps prevent heat from entering the atmosphere inside the building during the day and releases stored heat at night or in winter to keep the interior warm. In climates with significant temperature differences between day and night, this method works well to stabilise indoor temperatures below the highest external temperatures.

The approach involves labour but is not technically complex. It can be applied in several ways such as by using sandbags, sandfill, thick layers of plaster, or having thick walls of high thermal mass materials. Sandbags, though useful, are heavy, labour-intensive, take up space, and can create obstacles in densely populated areas.

The effectiveness of thermal mass significantly reduces in climates where the difference in daytime and night-time temperatures is low. Because there is no large temperature fluctuation in these climates, the heat from the building does not dissipate at night.

A high thermal mass strategy requires effective ventilation at night time to ensure that hot air leaves the building (see Strategic ventilation).

B. How does it work?

By having components of the building (walls and roof) constructed with high thermal mass materials, the building slowly gains and stores heat when it is hot outside (often during the day). As the building envelope heats up slowly, and stores much of the heat, this prevents the heat being transferred to the building interior.

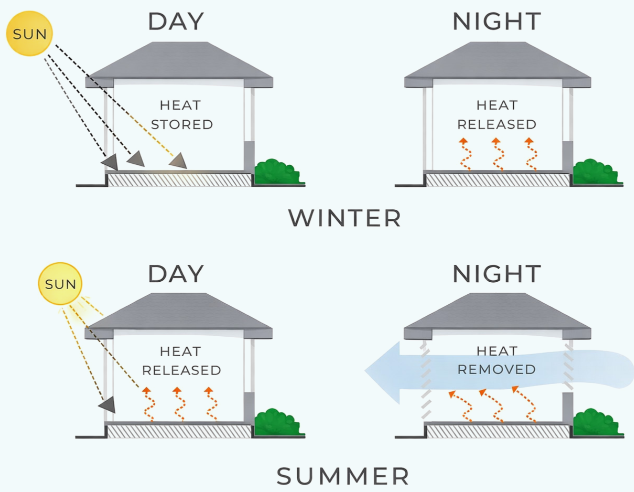
Then, when it gets cold (at night or in winter), the stored heat is released into the environment and into the interior of the building. In climates where it is cold at night, this heat then keeps occupants warm. In climates where it remains hot (although cooler than the daytime), night ventilation should be used to counteract heat buildup during the night from released heat, removing the heat to keep the occupants cool (see Figure 5).

This approach can be very effective in climates where the difference between day and night temperature is significant. The fluctuation in outside temperatures between day and night is stabilised inside the building. Heat is transferred through the material through **conduction** and then into the air inside through **radiation** and **convection**. See Section 1.3 for different heat transfer mechanisms.

Constructing a sun-facing wall (which receives more heat from radiation) with high thermal mass materials is recommended to reduce heating up the interior spaces behind that wall.

How much heat a material can store is based on its Heat Storage Capacity. The higher the Heat Storage Capacity, the greater its ability to store heat. Increases in the thickness of the material increases the heat storage capacity. See Table 2 in Section 2.1f for Heat Storage Capacities for relevant High Heat Storage materials.

Figure 5: Heat storage and release



Source: Tim Pullen: The Importance of Thermal Mass

In hot summers, cooling at night happens by opening the windows/vents at night. In cold winters, closing the windows/vents allows the thermal mass to heat up the interior.

C. Ease of application / notes on application

The approach requires labour but is not technically challenging. There are different ways it can be applied.

- **Thick walls and roof:** for new structures, construct thick walls and roof slabs of high thermal mass materials such as brick, stone, thick compressed stabilised earth blocks, adobe, cob, brick, rammed earth etc.
- **Plaster:** for existing structures, a thick layer of render/plaster of high thermal mass can be added such as gypsum plaster [19], mud plaster, or cow-dung plaster (vedic plaster) [22]. This depends on the construction material available as well as what the existing building is made from.

  Gypsum plaster can also regulate indoor humidity in humid environments and should be used in combination with insulation [19].
- **Sand and gravel fill in wall cavities:** buildings with cavities in the wall structure can be filled with sand and gravel [42].
- **Sandbags:** alternatively, walls of buildings can be clad with sandbags [42]; it may be preferable to do this on the outside so that it does not reduce the usable floor area inside the building. This strategy may also be useful in flood-prone areas to prevent the floodwater from coming indoors.

D. What are the drawbacks?

Temperature change is slow: the interior temperature does not change rapidly in response to changes in the external temperature. This means that if there are days and nights with little temperature difference (too hot or too cold) consecutively, the building will stay hot or cold for long intervals making an uncomfortable environment indoors. It also means that active cooling techniques will be less effective if the building has already stored a lot of heat.

- **Thermal discomfort at night:** in hot environments, the release of heat from the walls at night may make the interior of the building uncomfortably hot. If so, use thermal mass with night ventilation.
- **Sandbags – heavy, obstacles, and space inefficiency:** sandbags can use up a lot of space, becoming obstructions in dense areas, causing people to trip. They are heavy and require a lot of material and labour.
- **Gypsum plaster is not waterproof:** gypsum plaster is more expensive than cement plaster and cannot be used on the outer surface of walls as water will damage it. In environments prone to storms and heavy rainfall, assess whether the walls inside the building can be kept dry before using gypsum plaster.

E. Where can it not be used?

The effectiveness of thermal mass significantly reduces in climates where the difference in daytime and night-time temperatures is low. Because there is no large temperature fluctuation, little to no change occurs.

F. Effectiveness

A study compared thermal mass as a passive cooling technique in a tropical location with an arid one. It found that the cooling effect was much more significant in the arid location – the average difference between outdoor and indoor temperature was 6-8 °C in Sde Boqer (arid) while it was 2-3 °C in Maracaibo (tropical climate) [81].

In another study, in Ghana (tropical climate), a 4.3 °C maximum temperature reduction was found using a combination of high heat storage materials and night ventilation [82].

Combination and Comparison with other strategies:

- A study comparing the effectiveness of different strategies[8] based in a two-storey school in Riyadh (arid climate) showed that using high heat storage materials with night ventilation (see Strategic ventilation) proved to be one of the most effective strategies for summer cooling resulting in a 1.6 °C reduction in temperature [53]. In the same study, it was found that for hot-dry climates, night ventilation is very important to make high heat storage materials effective for cooling. Otherwise heat during daytime from glazed areas and other means can remain trapped inside. See Annexe 3.2 for further detail on the study.
- A study conducted in UNHCR's prefabricated shelters in Jordan (arid climate) found that the best performing passive cooling strategy was using high heat storage materials that resulted in a 1.3 °C reduction in average temperature and a 4.7 °C reduction in maximum temperature[9] [42]. The effectiveness of adding more material reduced beyond a certain point: as 3000 kg (sand and gravel filled inside a wall cavity) caused a maximum temperature reduction of 3.7 °C while increasing the material additionally by 11,000 kg (by cladding sandbags against the walls) resulted in just a 1 °C additional reduction [42] - not a very significant change for such a large amount of additional material.
- The effectiveness of different strategies was tested in three different climates in a study. The results showed that using high heat storage materials is the most effective strategy in Porto (Mediterranean Climate), but was less effective than other strategies in Mumbai (tropical/humid climate) and Kenya (sub-tropical climate) [19]. Due to its ability to store heat, high daytime and night-time fluctuations were stabilised[10]. Similar conclusions can be drawn for other places with high fluctuations in night-time and day-time temperatures.

- For hot-dry climates, it is recommended to have high heat storage materials on the inside and thermal insulation on the outside. However, there are practical and feasibility concerns associated with external insulation (see Insulation for further details).

Table 2: Comparison between different types of high heat storage materials

	Thermal mass type	Pros	Cons	Heat Storage Capacity / kJ/(m².K)[11]
i)	**Increase in thickness of plaster**	Can be easily applied to existing buildings Gypsum plaster provides humidity regulation in humid climates Causes negligible change in usable space of the rooms	Less effective than more material-intensive measures	These values are for 20 mm plaster: • Gypsum plaster = 20 [83] • Gypsum plaster with sand aggregate = 28 [83] • Cement plaster = 30 [83] • Cement plaster with sand aggregate = 32 [83]
ii)	**Sandbags**	Can be applied to existing buildings Performs well in regulating temperatures for extreme hot/cold cycles Applicable in temporary structures Potential for permanent buildings Potential for flood control	Take a lot of space Can become obstacles causing tripping hazards Material + labour intensive and heavy	This value is for a typical 150 mm thick sandbag: • Dry Sand = 225 [84]

	Thermal mass type	Pros	Cons	Heat Storage Capacity / kJ/(m2.K)[12]
iii)	**Thick walls**	Seamless integration with the building Performs well in regulating temperatures for extreme hot/cold cycles	Can only be applied to new buildings – may not be practical for retrofitting in most cases.	These values are for 300 mm thick walls: • Concrete block = 180 – 690 [83] • Adobe = 330 [85] • Sandstone = 480 [83] • Brick = 420 [83]
iv)	**Filling wall cavities**	Does not take additional space	Unlikely to be applicable in permanent buildings. More suitable for prefabricated structures with hollow profiles	These values are for 60 mm thick cavities: • Gravel = 96 [83] • Dry Sand = 90 [84] • Stone chippings = 108 [83]

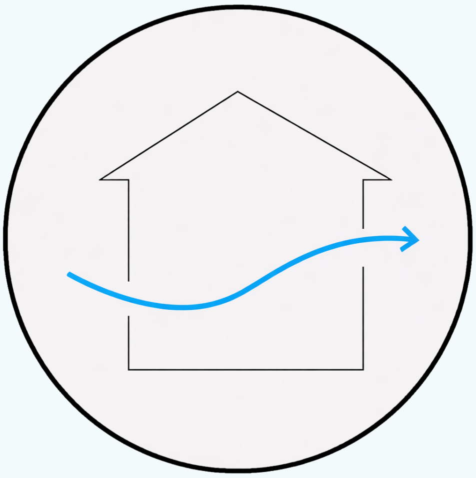
G. Further Reading

Improving thermal comfort in refugee shelters in desert environments:

Strategies for increasing thermal mass: [42, p. 35,36]

2.2 Natural Ventilation – an overview of ventilation approaches

Figure 6: Natural Ventilation



Source: Author's own work (inspired by Bill Flinn)

Note: Information that is general to all or most natural ventilation strategies is covered here. Information specific to particular ventilation strategies is covered in sub sections 2.2.1 to 2.2.5. It is recommended to read this (general) section regardless of any sub-strategy that may or may not be applicable.

A. What is it?

Natural ventilation provides a cooling effect through the flow of air through convection (see Section 1.3 for information on the mechanisms of heat transfer). This can replace hot air with cooler air. It can also provide direct cooling effects to building users by helping the body to thermoregulate, as (in lower humidity environments) air movement helps evaporate sweat which provides a cooling effect. (Section 1.2). Ventilation can also improve air quality and is important for removing moisture from the interior, preventing growth of mould and mildew in humid conditions [16] (see Section 2.7d).

People also generate heat and humidity. If the system does not allow an increase in ventilation to the minimum standard, it is recommended to reduce the maximum room occupancy if possible [86]. For minimum standards, see Section 2.2g.

Natural ventilation is one of the most important strategies for passive cooling in humid environments.

B. How does it work?

There are two main natural ventilation mechanisms. It can either be wind-driven or the result of temperature differentials (caused by hot air rising while cooler air falls)[12]. There are several strategies that make use of one, or both, of these mechanisms:

- Simple wind-driven ventilation
- Stack ventilation
- Strategic ventilation
- Courtyard ventilation
- Wing Walls

Natural ventilation strategies go hand in hand with the selection of windows, external shading, insulation, and heat absorption properties of the external surface materials [16].

C. Ease of application / notes on application

There are three basic steps for designing a natural ventilation system [16]. For more information, refer to further reading in Section 2.2g.

1. Selecting the desired airflow pattern
2. Identifying the main driving forces
3. Sizing and locating openings

Natural ventilation relies on the awareness and ability of occupants to use ventilation when conditions are favourable. For guidance on what constitutes favourable (e.g., when to open and close windows), see Section 2.2.3a.

Some other considerations that affect the quality of ventilation are:

- **Inlet and outlet height:** place the inlets at low-medium heights so a breeze is created at the occupant's level [87], and cool air (which will tend to be closer to the ground) enters the building. Place outlets high so that warmer air can leave the building.
- **Airflow limitation:** for ventilation through one inlet and one outlet, the flow of air through a building will be limited by the dimensions of the smaller opening or vent available for the air to pass through [16].
- **Inlet aspect ratio:** an aspect ratio (width/height) of around 4:1 for the inlet has been found to be particularly good for improving ventilation efficiency and indoor air quality [88]. This aspect ratio helps achieve lower indoor pollutant

concentrations, which is a key indicator of indoor air quality, especially in high-density buildings [88].

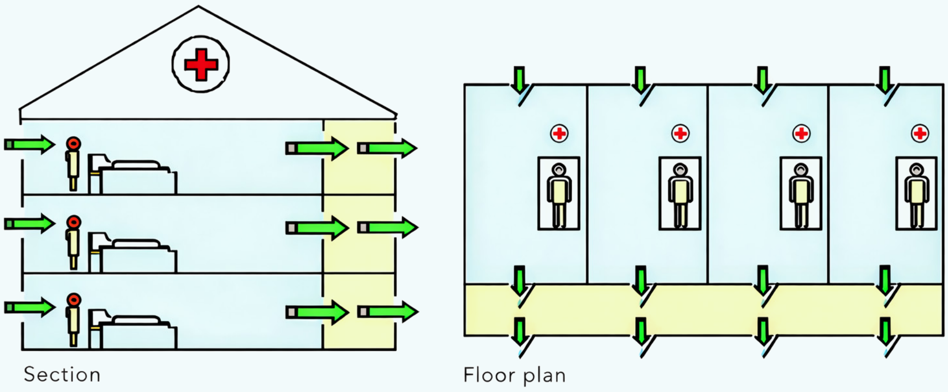
- **Outlet size:** make the outlets slightly larger than the inlets [87].
- **Breathable walls:** temporary structures, such as bamboo-based structures with breathable walls, work well in humid climates .
- **Balance wind and temperature differential:** use both wind and natural rising heat to boost ventilation. This means designing buildings to take advantage of breezes outside while also allowing for warm air inside to rise and escape, creating a circulation pattern [89].
- **Roof angle:** while primarily used for drainage in climates where rainfall is prevalent, an angled roof is also useful for enhancing airflow. In one study, it was found that a 45° roof slope can allow for better air movement inside the building compared to flat roofs [89]. In the same study, it was also found that a roof slope below 18° may have worse airflow performance than a flat roof [89]. The 45° design helps create a natural airflow, making it easier for fresh air to come in and stale air to exit [89].

Guidance for infection control:

When designing ventilation in health facilities, be aware of infection control requirements. WHO has provided natural ventilation guidelines in the form of a condensed roadmap for health-care facilities and non-residential facilities (including schools). See further reading in Section 2.2g.

- **Do not rely on wind ventilation alone:** in clinics, the design of natural ventilation for infection control should consider the worst case scenario – when wind is absent, alternative strategies for ventilation are required, such as fans (see Section 2.9) [16].
- **Wards on one side of corridor:** where there is a risk of cross-infection, natural ventilation is better where there are ward(s) on only one side of the corridor (rather than on both sides) [16] because the single directional flow reduces the likelihood of airborne pathogens moving between wards. It is better to position windows in line with the ward door to enhance cross-ventilation [90], and cited in [16].

Figure 7: Health facility ventilation



Source: Author's own work

- **Ventilation rates:** poor ventilation may increase the risk of airborne infections. Different ventilation rates are recommended for different rooms in a primary healthcare facility. Refer to Section 2.2g for guidance and how to calculate the ventilation rate.

- **Management of exhaust air:** in quarantine facilities for airborne infections, if the stale air exiting the building is not exhausted directly away from the air inlets, it is recommended to use fences to keep people away from the windows and doors at a distance of at least 4 metres [86]. This is not needed if the air is exhausted from the roofs or 2 metres above people [86].

- **Zoning rooms according to wind direction:** the main function rooms and cleaner spaces should be on the side facing the prevailing winds, while auxiliary spaces (such as corridors) should be on the sheltered side [16], [91].

  If the airflow does not flow from less clean to clean areas, and a clear airflow direction has been identified, then consider changing patient and staff areas, so that wind flows from the staff area to patient rooms, instead of the other way around, to minimise risk to health-care workers [86]. See Section 2.2g for information on how the airflow direction can be assessed.

- **Zoning respiratory wards in multiple-storey clinics:** if there are multiple storeys in the clinic, it may be preferable to locate respiratory wards on the top floors, to minimise the re-entry of exhaust air into the adjacent floors [16].

- **Creating zones to separate clean areas from dirty areas:** in rooms where aerosol generating procedures are performed, add ante-rooms to control airflow direction [86]. Double doors in ante-rooms should not open simultaneously, to maintain separation between the patient room and the clean corridor [86]. Since cross ventilation may not be possible, use alternative strategies to meet the minimum ventilation rate, such as a plastic door zipper to create the ante-room; this is a cost-effective solution [86].

Also see Section 2.2.1c *shallow room depths* for infection control guidance related to room dimensions and presence of windows.

D. What are the drawbacks?

- **Smoke and fire safety:** creating a building with interconnecting room openings can pose challenges for fire safety and smoke control. Ventilation openings might need to be sealed during a fire. However, naturally ventilated buildings can be designed to comply with compartmentalisation standards for smoke control. Special attention should be given to the fire escape route, as the design for natural ventilation also influences smoke flow patterns [16].
- **Fragility:** the presence of windows increases risk in storm-prone or strong-wind areas. Window shutters should be installed (see Section 2.2g for further detail). WHO also recommends that windows in health facilities should be able to resist wind speeds of 200 km/h, and be laminated or otherwise protected against shattering in case of disasters [92].
- **Variable nature:** natural ventilation varies significantly depending on temperature and pressure differences between the inside and outside of the building. This makes the direction and magnitude difficult to control so there can be high airflow in some locations but stagnant airflow in others. Some spots may be too cold, others too warm.
- **Variability/dependency on outdoor conditions:** effective ventilation is highly dependent on the outdoor climate. For instance, if the wind speed is too slow, hybrid ventilation may offer a solution, which combines fan-assisted ventilation techniques with passive cooling [16]. See Section 2.9 for further detail on fans.
- **Obstructions:** furniture and internal partitioning can disrupt the ventilation flow. Care must be taken to avoid restricting the intended flow path and openings [16].
- **Safety and Security:** large windows may pose a safety risk. Avoid placing windows in areas where there is a risk of falling. Otherwise, install barriers, or replace the glass with safety glass or a suitable safety film [93].

  Additionally, the UK Health and Safety Executive regulations state that if the windows are above ground floor level and large enough for a child to fall, the window opening should be restricted to 100 mm or less [93]. Window restrictors can be used which can only be disengaged with a special key/tool that is not accessible to the general public [93]. However, restricting the opening may reduce ventilation. An alternative could be fitting bars to stop children from falling out. This can also help where there are security concerns of break-ins. Local regulations should be applied where available [16].

- **Overheating:** although windows are essential for providing natural ventilation, they are the weakest part of a building in terms of thermal performance [94]. Increasing glazed areas, especially in hot-dry climates, will greatly increase the heat gain from radiation during the day – so the window area should be minimised only to provide sufficient natural ventilation and daylighting in such climates. Windows should also have wind and sun protection devices (see Section 2.6).

  The window-to-wall ratio is the ratio of the area of the window to the area of the wall. Typically, the research recommends a window-to-wall ratio of 10-20% [17], [95]. Another factor to consider is something called the 'g-value' of sun shading, which is a measure of how much of the sun's energy gets through the windows. Different types of glass have different g-values. A high g-value of 1.0 means all the solar energy gets through, while a low g-value of 0.0 means none of it does. If the g-value of the window glass is available, a common guideline is to make sure the g-value multiplied by the window-to-wall ratio remains below 5% [17].

- **Noise and pollution:** noise, dust and pollution from the outside can become practical concerns depending upon the surroundings [96]. Ventilation inlets may be placed on the sides of the buildings away from the noise or pollution source; this may only be practical for new buildings [16].
- **Restriction of ventilation rates:** the size of the openings are limited for safety reasons in clinics and schools; this restricts the ventilation rates [96].
- **Dependency on occupant control:** the effectiveness of ventilation depends upon how well the occupants can control the openings. In clinics it may not be possible to rely on occupants and nurses to open and close windows at the optimal times [96]. This can greatly decrease the performance of natural ventilation systems [96].
- **Privacy:** privacy can become an issue especially in high traffic zones. Screens can be provided in front of openings. In this case, it should be assessed whether sufficient natural ventilation and daylight are provided. Alternatively, if possible, openings/windows/vents can be provided at a higher level than the occupants.
- **Insects and pests:** insects and other pests may enter through windows and other openings spreading vector borne diseases. Where relevant, it is recommended to have semi-transparent mosquito meshes installed at openings [16].

E. When can it not be used?

Wind-related Hazards: natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

Ventilation is regularly mentioned as a key mechanism for cooling in humid environments.

Night ventilation, in particular, is an important element of high heat storage material cooling strategies (see Section 2.1)

Wind-driven ventilation is more effective than stack ventilation [12] in situations where there is reliable and steady wind, and for buildings which have a narrow layout.

It was found in a study that a roof sloped at 45° can increase the volume flow rate of air by 22-25% compared to a flat roof [89]. Sloped roofs create areas for warm area to collect under the roof. When the wind is blowing, they also create an area of low pressure on the leeward side as the air moves over the roof, which can 'suck' air out of high level outlets.

For assessing the ventilation performance in clinics, see further reading in Section 2.2g.

Comparison with other strategies:

A study tested the effectiveness of different strategies in three different climates. The results showed that natural ventilation was an effective strategy in all areas; it was most effective in Kenya (subtropical Climate), resulted in a 3.8 °C reduction in temperature, but less effective than other strategies in Mumbai (tropical climate, 2.4 °C reduction from natural ventilation), and Porto (Mediterranean climate, 2.9 °C reduction from natural ventilation)[13] [19]. For each climate, the temperature reductions quoted in the study were found using the average of the highest 5% temperatures. See Annexe 3.2 for further detail.

Comparison between different types of windows for natural ventilation:

1. Casement windows offer good airflow [87] and are especially recommended instead of sliding windows in humid climates as their openable area is twice the size. Where outwards opening shutters are added, these can steer wind inside [23].

2. Louvred windows can provide shading in addition to giving 9.2 times better airflow than awning windows (top hung windows) for the same window area[14] [21].
3. Awning windows can provide better rain protection than most windows where there are no sunshades or other rain-protection devices on the building [87].

G. Further Reading

- Assessing ventilation performance: [16, p. 8]
- Steps for designing a natural ventilation system for infection control: [16, p. 40]
- WHO roadmap for natural ventilation in healthcare facilities: [86, pp. 6–7]
- WHO roadmap for natural ventilation in non-residential buildings (schools): [86, p. 11]
- Ventilation rate for wind-driven natural ventilation system – how to estimate it? [86, p. 18]
- Ventilation rate for stack (temperature differential driven) natural ventilation system – how to estimate it? [16, p. 31]
- Airflow direction/wind direction – how to evaluate it? [86, p. 18]
- Minimum ventilation rate for non-residential buildings (schools): [86, p. 11]
- Minimum ventilation rate for different rooms in healthcare facilities:
  - Non-isolation rooms [16, p. 18]
  - Isolation rooms [16, p. 19]
  - New healthcare facilities and airborne precaution rooms [16, p. 23]
  - General OPDs, wards, corridors, and other transient spaces [16, p. 21]
- Window shutters and protection during storms and strong winds: [97]
- School safety guide for windows: [98]
- Safety for windows in healthcare and social care: [93]

2.2.1 Simple Wind-Driven Ventilation

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND Humid

Box 2: Simple Wind-Driven Ventilation

Simple Wind-Driven Ventilation is a type of natural ventilation that involves opening windows, vents and other openings to the outside to allow external air currents to move through the building.

If the opening is on one side of a space, it is called **single-sided natural ventilation (SNV)**. If the opening is on two or more (usually opposite sides of a space), it is called **cross-ventilation**. Cross-ventilation is generally more effective than single-sided ventilation.

Wind-driven ventilation depends on there being a fairly predictable and consistent wind. The wind moves warmer air from the building and can assist with the evaporation of sweat.

Its effectiveness depends on the design and placement of openings, room proportions, and wind direction. Cross-ventilation works best with openings on opposite walls, or in the far corners of perpendicular walls, while SNV is improved by using two widely spaced windows in the same wall instead of one.

Openings should be oriented to capture cool breezes but avoid undesirable hot winds. Shallow room depths are critical: cross-ventilated rooms with windows on opposite walls should be less than five times the room height in width; single-sided (stack-driven) less than 2.5 times; and single-sided (wind-driven) less than twice the height - though the latter two are ineffective for airborne infection control.

SNV is limited to shallow spaces (up to 2.5 times ceiling height) and may be ineffective in sealed rooms like clinical isolation spaces, where open windows do not guarantee adequate airflow. Cross-ventilation is generally more effective but should be avoided in wards or rooms where aerosols are generated, as it can carry contaminated air into cleaner areas and increase the risk of cross-contamination.

A. What is it?

Simple Wind-Driven natural ventilation involves opening windows, vents and other openings to the outside to allow external air currents to move through the building.

If the opening is on one side of a space, then it is called **single-sided natural ventilation (SNV)**.

If the opening is on two or more (usually opposite sides of a space), it is called **cross-ventilation**.

B. How does it work?

Wind-driven ventilation depends upon wind being directed into the building. The wind moves warmer air from the building and can assist with the evaporation of sweat. Cross ventilation uses a pressure differential – the leeward side of the building will be at lower pressure than the windward side, and this helps suck air out of the building.

C. Ease of application / notes on application

The effectiveness of simple wind-driven ventilation depends upon wind speed, wind direction, the relative position of the façade, depth of the room, and opening size [14]. There should be no obstacles to block the wind.

- **Cross-ventilation:** ideally, openings should be placed in opposite walls [23]. If they are in perpendicular walls, then openings should be placed on the farthest corner of the walls [23].
- **Single-sided natural ventilation - two windows instead of one:** if a room can only have windows on one side, it is better to have two widely spaced windows instead of one [87].
- **Placement of openings:** the placement of windows and vents can greatly impact how well air moves through a building. In the presence of cool breezes, inlets should be oriented according to the wind direction. However, this may be undesirable for hot winds in summer (in hot climates) and cold winds in winter (for climates with cold winters). Wind direction can be assessed by low-tech methods – for more information see Section 2.2g.
- **Shallow room depths:** naturally ventilated spaces must be narrow to supply adequate ventilation. There are rules-of-thumb for room depths, which are applicable to medical wards as well as general spaces [16]:
  - For cross-ventilated rooms (windows on opposite walls), the depth must be less than 5 times the height of the room.

- › For single-sided ventilation where there is no wind (only stack ventilation driven), the depth must be less than 2.5 times the height of the room. This is not effective for airborne infection control.
- › For single-sided ventilation (window only on one wall), the depth must be less than 2 times the height of the room. This is not effective for airborne infection control.

See Section 2.2.2 for more information on stack ventilation.

D. What are the drawbacks? (see also the general section Natural Ventilation)

- **SNV** – ineffective for deeper spaces: SNV is only effective up to a depth of 2.5 times the ceiling height [86], becoming ineffective for deeper spaces. Cross-ventilation is preferable.
- **SNV** – insufficient ventilation in sealed rooms: for single-sided ventilation in otherwise hermetically sealed rooms, such as isolation rooms in clinics, just because a window is open, it doesn't necessarily mean that sufficient airflow is present [16].

E. Where can it not be used?

- **Cross Ventilation** – contamination risk: cross ventilation should not be implemented in wards/rooms where aerosols are generated when there is a risk of cross contamination from the exhaust air through aerosol-generating procedures [86]. This is also the case where the airflow is from a less clean area to a clean area [86]. Natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

Cross-ventilation is recommended instead of single-sided ventilation [86] as it can play a vital role in decreasing the inside temperature [94].

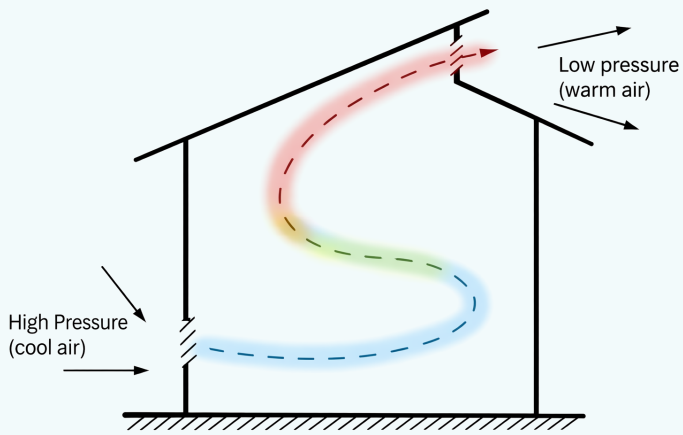
See also Section 2.2f.

G. Further Reading

See Section 2.2g.

2.2.2 Stack Ventilation

Figure 8: Stack Ventilation



Source: Civil Construction Tips [99], edited by Author

✓	New buildings AND Retrofitting
✓	Permanent
✓	Dry AND Humid

Box 3: Stack Ventilation

Stack ventilation is based on the principle that hot air rises while cooler air falls. It involves placing inlets and outlets in a building in such a way as to allow heavier, cooler air to enter the building and push out lighter warmer air.

It relies on the pressure differences between the inside and outside air due to temperature or humidity differences. This vertical pressure difference causes lighter (warmer) air to rise to the top and colder air to sink to the bottom. Stack ventilation is possible in the absence of wind.

Stack ventilation works best with high outlets and lower or medium-height inlets, allowing warm air to rise and exit. Wind can disrupt this process, so wind direction should be considered, and outlets placed on the side of the building away from the wind (leeward). Upper vents or clerestory (windows in a high section of a wall, above eye-level) help release hot air, draw in cooler air from lower vents, and improve levels of daylight. Shading or planting trees near lower vents can further cool incoming air. Roof-mounted whirlybirds, powered by wind, enhance hot air removal by creating suction, while active cooling alternatives like exhaust fans can also be used.

A. What is it?

An approach based on the principle that hot air rises while cooler air falls, stack ventilation involves placing inlets and outlets in a building in such a way as to allow cooler air to enter the building and push out warmer air.

B. How does it work?

Stack ventilation relies on pressure differences between the inside air and outside air due to temperature or humidity differences [16]. This vertical pressure difference causes lighter (warmer) air to rise to the top and colder air to sink to the bottom. Stack ventilation is possible in the absence of wind.

C. Ease of application / notes on application

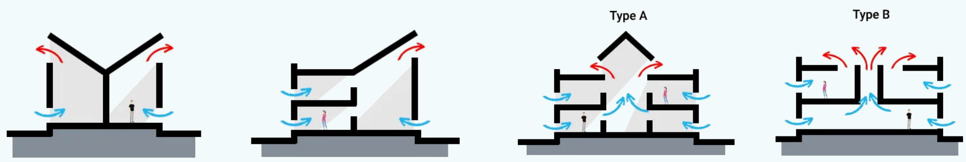
- **Outlet and inlet heights:** high outlets and lower/medium height inlets are effective for driving stack ventilation and allowing hot air to rise and exhaust out. An outlet in a tall space enhances this [23]. Where there is no wind, the higher opening will act as an outlet in most cases, as the warmer air will rise. Where there is wind, this process may be disrupted, and so the wind direction should be checked (see Section 2.2g for further detail on this) to ensure that wind does not enter the outlet, and force warm air back into the building.
- **Pitched roofs and taller buildings:** stack ventilation works more effectively in buildings with pitched roofs than in buildings with flat roofs, as pitched roofs provide greater internal height: The effectiveness of stack ventilation is directly proportional to the vertical height difference between the lower air inlets and the upper outlets.
- **Vents or clerestory windows:** vents or clerestory windows (windows in a high section of a wall, above eye-level) can be provided in upper levels of the building to allow warm air to rise and escape to the outside. Cooler air can be drawn through vents at a lower level [87]. Clerestory windows can also improve daylight

levels. It is recommended to plant trees near to the lower vent to cool the incoming air [87]. See Section 2.5 for further detail on vegetation.

- **Whirlybirds:** whirlybirds can be installed in the roofs to enhance the passive cooling effect [100] cited in [86]. Whirlybirds are rotated by wind power, and as they rotate they create an area of lower air pressure that 'sucks out' rising warm air, increasing the speed of removal of the hot stale air. Alternatively, active devices such as exhaust fans can be used in the walls for exhaust purposes. See Section 2.9 for more detail on active cooling and Section 2.2g for instructions on whirlybird installation.

  Other strategies, such as *solar chimney* and *passive downdraught cooling*, are not covered in this document due to the higher level of technical expertise required. However, they may be appropriate if sufficient reliable guidance is available elsewhere.

Figure 9: Examples of Stack Ventilation



Source: Layak Architect [101] (edited)

D. What are the drawbacks?

See Section 2.2d.

E. Where can it not be used?

Natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

See Section 2.2f.

G. Further Reading

Whirlybird: [102], [103], [104]

See Section 2.2g.

2.2.3 Strategic Ventilation

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND (limited effectiveness in) Humid

Box 4: Strategic Ventilation

Strategic ventilation is a control strategy that relies on building users actively managing (opening and closing) windows and ventilation openings to optimise airflow. It is straightforward to carry out, but its effectiveness is completely user-dependent, unless automated.

Proactive ventilation involves adjusting openings based on indoor–outdoor temperature differences as they occur.

Night or scheduled ventilation uses fixed routines - typically opening at night to release heat and closing during the day and sometimes considering local wind conditions like coastal or valley breezes. Night ventilation uses temperature differences between day and night to release indoor heat when the night sky is cooler than the building interior. It is most effective when combined with stack ventilation (See Section 2.2.2) and is particularly important in buildings with high thermal mass (See Section 2.1), which may otherwise trap excessive heat indoors at night.

Night ventilation is less effective in climates with small day–night temperature differences and may underperform if used only on a fixed night-time schedule, as cooler outdoor air can also occur during the day. In humid, densely occupied spaces, it can worsen conditions by raising indoor humidity. While it can still provide passive cooling, proactive ventilation is often more effective, and dehumidifiers are recommended where high humidity persists.

A. What is it?

Strategic ventilation is a control strategy where building users open and close windows and other ventilation openings to maximise the effectiveness of ventilation.

It can be applied to all natural ventilation principles/sub-strategies mentioned in this Guidance Note.

- **Proactive ventilation:** building users close windows and other ventilation openings if the outdoor temperature exceeds the indoor temperature, and open them if the indoor temperature exceeds the outdoor temperature.
- **Night/scheduled ventilation:** building users open and close windows and other ventilation openings according to a fixed schedule. Often this means opening windows, vents, doors and other openings to the outside at night to flush out heat and closing them during the day. Schedules may also take account of local wind conditions - such as cooling coastal breezes or katabatic winds (winds that flow downhill) in mountain valleys.

B. How does it work?

It takes advantage of the wind as well as temperature differences between the inside and outside of the building.

- **Night Ventilation:** In situations where the night sky is cooler than the air inside the building, increasing ventilation at night allows heat to be released into the night sky. This strategy can be improved by the use of stack ventilation (see Section 2.2.2) and can be particularly important where high heat storage materials have been used, as these may create unacceptably hot internal temperatures at night (see Section 2.1).

C. Ease of application / notes on application

It is as simple as opening and closing windows and other openings to the outside. This can be easily managed by staff. It is straightforward to carry out, but its effectiveness is user-dependent, unless automated.

D. What are the drawbacks?

- **Night Ventilation – low diurnal temperature difference:** it is not very effective in places where night and day temperatures are similar. However, it should be noted that it still does provide some passive cooling, as has been documented in wards in Singapore [21].
- **Night Ventilation – fixed ventilation schedule:** a fixed schedule of only ventilating during the night may not be very effective because sometimes outdoor temperatures are lower than indoor temperatures during the day as well [21]. A more effective strategy is Proactive ventilation, mentioned in Section 2.2.3a. In dense occupancies in humid climates, a study in a ward in Singapore (tropical climate) found that if only a fixed schedule of night ventilation is possible, performance can be worse than daytime ventilation [21].

- **Night Ventilation – high humidity:** humidity build-up should be considered in humid climates because, even though night ventilation may reduce internal temperatures, it can also increase humidity levels, causing discomfort[15] [105]. Passive strategies are not very effective at controlling humidity when outdoor and indoor humidity levels are both high – dehumidifiers provide a relatively low-energy solution and are recommended [21]. If dehumidification is not possible, full-day ventilation (windows open throughout the day and night) may be a better option in densely occupied spaces in humid climates [105].

Also see Section 2.2d.

E. Where can it not be used?

Natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

A test conducted in Malaysia (tropical climate) found that by using night ventilation instead of daytime ventilation (windows open during the day), there was a 2.5 °C reduction in maximum temperature and a 2 °C reduction in night temperature [105] See also Section 2.2f.

Comparison with other strategies:

1. A study comparing the effectiveness of different strategies[16] in a two-storey school in Riyadh (arid climate) illustrated the important role that night ventilation plays for cooling in hot-dry climates. This was especially significant when combined with either Insulation, resulting in a 1.9 °C reduction in temperature) or using High heat storage materials, resulting in a 1.6 °C reduction in temperature [53]. Otherwise, heat during daytime from glazed areas and other means can remain trapped inside.
2. This importance of night ventilation in climates with a high day and night temperature difference is substantiated by tests conducted in UNHCR prefabricated shelters in Jordan (arid climate) which recorded an overall rise in temperature when insulation was used only with day-time ventilation (windows were opened from 09:00-21:00) [42].

G. Further Reading

See Section 2.2g.

2.2.4 Courtyard Ventilation

✓	New buildings
✓	Permanent
✓	Dry AND Humid

Box 5: Courtyard Ventilation

Courtyards are enclosed zones that can help channel the airflow. Enhancing airflow through the design of the building is called courtyard ventilation.

A courtyard can function in two ways and can use the stack effect as well as wind-driven ventilation.

1. **Using the stack effect:** if the courtyard heats up, the stack effect will suck out the hot air from the building around the courtyard. This is true for unshaded courtyards with hard flooring.
2. **Using wind-driven ventilation:** if it is a shaded courtyard, wind-driven ventilation can push cool air inside the building. This is true for shaded courtyards with grassy floors/ trees and water bodies. Shaded courtyards, either self-shaded, vegetated, or fitted with shading devices, should be oriented to the prevailing wind to capture breezes. Multiple courtyards can be combined: green courtyards that cool incoming air and stone courtyards that heat up and draw this cooled air through connected rooms, enhancing natural ventilation.

For clinics with courtyards, corridors should be placed outside the rooms (between the room and courtyard) rather than inside, so that clean air reaches the corridor first, reducing the risk of cross-infection in at-risk spaces.

A. What is it?

Courtyards are enclosed zones that can help channel the airflow. This channelling of airflow is called courtyard ventilation.

B. How does it work?

A courtyard can function in two ways, using the stack effect or wind-driven ventilation.

1. **Using the stack effect:** if the courtyard heats up, the stack effect sucks out the hot air from the building. This is true for unshaded courtyards with hard flooring.
2. **Using wind-driven ventilation:** a shaded courtyard can use wind-driven ventilation to push cool air inside the building. This is true for shaded courtyards with grassy floors or trees and water bodies. Gardened courtyards are also beneficial to break up large enclosed spaces to provide fresh air and light [106]. If roofs are sloped towards shaded courtyards, cooler air sinks and enters the building through low openings, gets warmed up and can then exhaust out of the building through higher openings [23].

See Figure 10 for an illustration of the two types of courtyard ventilation.

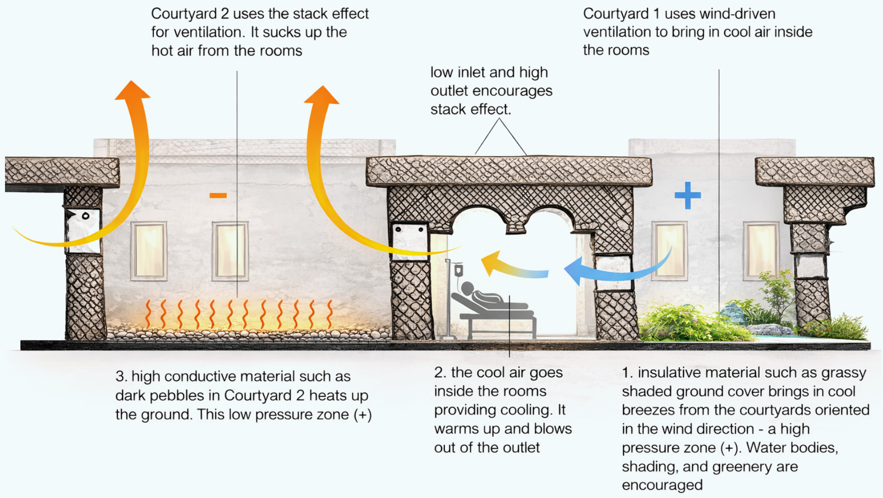
C. Ease of application / notes on application

It is only possible in new buildings where courtyards can be created, or in existing buildings with courtyards where the ventilation effects can be enhanced by, e.g., planting vegetation and adding ventilation outlets in roofs.

Shaded courtyards can be either self-shaded by the building (if they are small enough) or shaded by vegetation or shading devices. If possible, these courtyards should be oriented towards the prevailing wind, to allow for breezes [23].

A cooling strategy can use multiple courtyards utilising both stack and wind-driven ventilation: a courtyard with high conductive material, such as stone, heats up the air causing a low-pressure zone; this sucks up air from the surrounding rooms which are connected to courtyards with vegetation. These green courtyards cool the incoming air which flows into the rooms and is sucked up by the stone courtyards. This is illustrated in Figure 10.

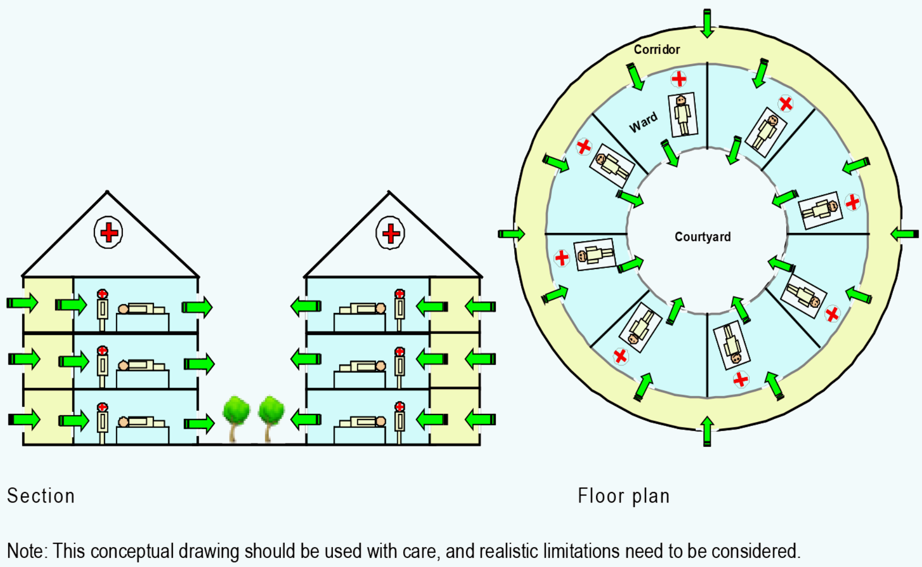
Figure 10: Courtyard ventilation: the stack effect through Courtyard 2 and wind-driven from Courtyard 1



Source: Author's own work. Patient vector image taken from http://www.freepik.com">Designed by Freepik

Guidance for clinics: where clinics use courtyard ventilation, they should be oriented so that cool air enters the corridor before entering spaces with a risk of infection; this avoids cross-infection via connected corridors by delivering clean air to the corridor first [16], as illustrated in Figure 11.

Figure 11: Combined wind and stack-driven natural ventilation in a courtyard (outer corridor) hospital



Source: [16, p. 48]

D. What are the drawbacks?

See Section 2.2d.

E. Where can it not be used?

Natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

See Section 2.2f.

G. Further Reading

See Section 2.2g.

2.2.5 Wing Walls

✓	New buildings AND Retrofitting
✓	Permanent
✓	Dry AND Humid

Box 6: Wing Walls

Wing walls are solid vertical panels that extend outward from windows at right angles to the wall. Their purpose is to capture, redirect, and accelerate airflow into a building. This is particularly effective where windows are not positioned to face prevailing winds, as wing walls can intercept winds blowing parallel to the façade. By doing so, they create suction zones on one side and pressure zones on the other, channelling air more effectively indoors. Wing walls can be incorporated into both new and existing buildings, though installing them in new buildings is more straightforward. In existing buildings, placement requires more care.

Wing walls can create uneven airflow, with stronger air movement near windows, so occupants preferring gentler airflow (e.g., patients) should be positioned centrally. The effectiveness of wing walls is also difficult to predict for specific locations.

A. What is it?

Like wings, they are vertical solid panels which project outwards next to windows and perpendicular to walls [87]. They divert and accelerate wind into the building. This is useful for existing buildings where windows are not oriented in the direction of the wind, as they can catch winds that blow parallel to the windows [21].

B. How does it work?

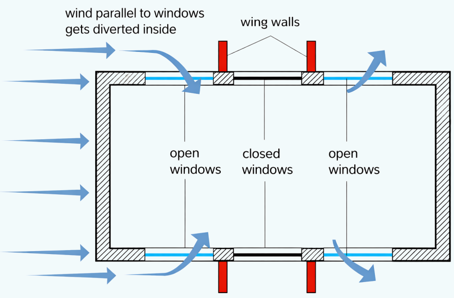
They create high pressure zones on one side and low pressure zones on the other side to accelerate and direct winds [21]. See Section 1.3 for information on high pressure and low pressure.

C. Ease of application / notes on application

Wing walls can be constructed in existing and new buildings.

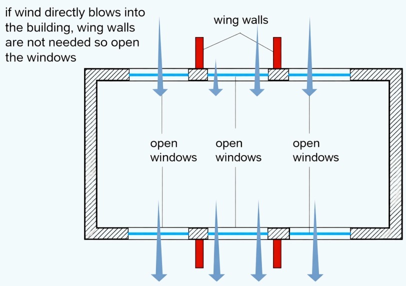
Wing walls in buildings with rows of openable windows. In existing buildings, if the wind blows parallel to the wall, opening all the windows is not an effective ventilation solution – wind coming in from one window can exit immediately through the next. In this situation, a combination of wind walls and open windows is more effective. By constructing wind walls towards each end of the row of windows, and closing the windows between the walls, the wind is channelled into the room towards one end, moves through the length of the room, and exits at the other end. The effect is enhanced by the wind walls, which guide the wind in at one end and – by creating a low pressure area away from the wind - help to suck it out at the other (see Figure 12). The arrangements works whichever the direction of wind flow (although if the direction of the prevailing wind changes and it blows directly into the building instead of alongside it, then it is recommended to open the windows in between the two wing walls [21]); see Figure 13. This strategy was employed in a naturally ventilated patient ward in Singapore (see below).

Figure 12: Using wing walls with multiple windows



Source: Author's own work, inspired by [21]

Figure 13: Opening the windows when the wind blows into the building



Source: Author's own work, inspired by [21]

D. What are the drawbacks?

Uneven distribution of comfort: airflows are higher near the windows so there is an uneven distribution of comfort. In wards, it is therefore recommended to place patients who may prefer weaker airflows in the middle of the space [21].

Effectiveness is difficult to predict: it is difficult to predict the effectiveness of wing walls in a specific location [107].

See also Section 2.2d.

E. Where can it not be used?

Natural ventilation should not be practised during wind-related hazardous conditions such as storms, strong winds, dusty winds, and high rainfall (that is likely to enter the building).

F. Effectiveness

Wing walls configuration – a case study: Wing walls proved effective in a naturally ventilated patient ward in a hospital in Singapore (tropical climate) with parallel wind [21]. Wing walls were found to increase air velocity for two different wing wall configurations by 88% and 60% respectively. It should be noted that data was collected from only a single study.

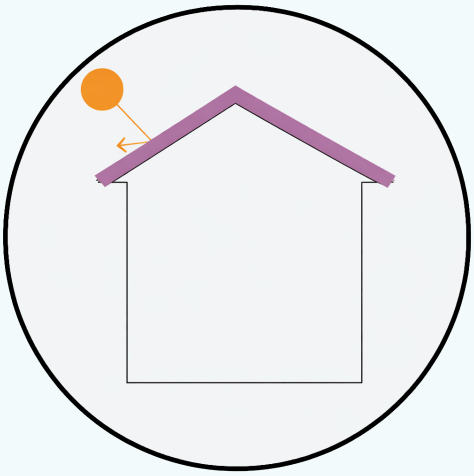
See also Section 2.2f.

G. Further Reading

See Section 2.2g.

2.3 Cool Painting

Figure 14: Cool Painting



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND Humid

Box 7: Cool Painting

Cool paints are coatings designed to reflect solar radiation, preventing heat from being absorbed by building materials - like the way light-coloured clothing keeps you cooler in summer. They are used particularly on highly conductive materials, such as corrugated metal roofs, but are also used on walls. There are two types of cool paints: renders/plasters (e.g., white plaster) and paints. Paints generally offer better adhesion and durability. Performance is measured by solar reflectance, with lighter colours reflecting more heat. Specialised heat-reflective paints further enhance this effect, but are more expensive than conventional cheaper options, such as acrylic white paint.

This is one of the simplest approaches to passive cooling and ideal for DIY application.

It may be unsuitable for climates with cold winters where the sun's heat is desirable for part of the year; retractable **roof shades** can be used instead. Cool paint's performance reduces with dust accumulation so it needs to be considered carefully for areas prone to high winds and storms. Its performance reduces with age, requiring re-application more frequently than other strategies like **insulation**.

Combining reflective (cool) roofs with internal **insulation** effectively reduces heat gain in both hot-humid and hot-dry climates.

It can be applied to both existing and new buildings. Its application in temporary structures, such as tents, is limited as problems of adhesion to the surface needs to be carefully considered.

A. What is it?

It involves using a paint that reflects the sun's radiation. This can be particularly useful for areas where overheating of corrugated metal sheet roofs is common. While cool paints are mostly applied to roofs (as they are the largest source of overheating), it can also be applied to walls.

There are two main types of cool 'paint' – renders/plasters and paints[17]. Paint coatings generally perform better in terms of adhesion and durability compared to renders [108]. White plaster is an example of a render coating; white acrylic paint is an example of a paint coating. How well a paint performs can be judged by its solar reflectance.

A lighter coloured paint will reflect more radiation than a darker one, but reflective properties can also be enhanced chemically to form heat-reflective paints. Conventional paints are cheaper but less effective than heat-reflective/ solar-reflective paints/ thermo-reflective paints. Examples of commercially available heat reflective paint products are Energy Star Paints, InfraCOOL Paints, INSULADD Paints, Thermilate Paints, Acryloc Roofcote, and LuminX. These are not recommendations; they illustrate some options available on the market.

A cost-effective recommendation is to paint two coats of glossy white acrylic paint (conventional paint) over an appropriate primer - the gloss minimises the dust accumulation [109]. It can also be spray-painted in two coats to obtain a smooth finish. If sufficient resources are available, then a heat reflective version of a pure white paint is recommended [109].

B. How does it work?

The paint reflects the solar radiation, preventing heat energy transferring to the building material. The principle is the same as wearing lighter colours on hot summer days to stay cool. This reflects heat away, preventing heat transfer through radiation (see Section 1.3 for information on different forms of heat transfer).

C. Ease of application / notes on application

This is one of the easiest approaches to passive cooling. Most commercially available products are intended for DIY applications. The surface preparation mostly involves cleaning the surface of any dust, dirt, moss, mildew, grease, oils etc. The manufacturer's instructions should be followed for application as specifications may differ. See Further Reading in this section for more detail. This is also applicable to permanent buildings. For tents, see Section 2.3f.

D. What are the drawbacks?

- **May not be suitable for climates with cold winters:** although it will work for hot summer days, it can have an adverse effect in climates with cold winters, as it will also block the sun's winter heat, which may otherwise provide comfort. If cool painting is used in these climates, proper roof insulation should also be applied (see Section 2.7 and Section 2.3f below for further detail on combining **cool paints** and **roof insulation**). Alternatively, use a removable cover with a reflective coating that can be retracted, instead of permanently (cool) painting it. See Roof Shading for more information.
- **Glare:** heat and sunlight reflected from cool painted roofs can cause glare in adjacent buildings. To avoid this, a light coloured paint can be substituted for a pure white paint [109].
- **Aging reduces performance:** like other materials, paint ages. A study in a Mediterranean climate showed a reduction of 20-25% in the solar reflectance of acrylic white paint after one year [110]. The same study found a 19% reduction in solar reflectance for California C-Paint, a type of cool paint [110]. Another study found that a roof with a white reflective paint needs to be repainted every five years [49].
- **Dirt accumulation reduces performance:** the accumulation of dirt on the roof surface may especially become a problem in areas vulnerable to storms and high winds, where dust and dirt are likely to regularly accumulate on the roof. Self-cleaning paints may present an alternate in these cases if resources are sufficient [111].

E. Where can it not be used?

As mentioned earlier, its use in climates with colder winter temperatures can be counter-productive, as the sun's heat may be desirable in winter.

F. Effectiveness

Due to its simplicity, performance, and versatility, cool painting is highly recommended. It can be applied to both existing and new buildings .

In a study in an arid climate, a 2-6.5 °C reduction in the average temperature has been found by applying cool paints [112] cited in [55] [113].

Temporary structures: applying a reflective coating to tents can provide cooling. A 7.7 °C maximum reduction in indoor temperature was found on a tent in Chengdu (sub-tropical), using a coating called a capsule retro-reflective material coating on an existing PVC tent [114]. However, it is important to consider the adherence of the coating to the tent material, so it is recommended to check with the coating manufacturer if it is to be applied on tents. For further information on the coating, see Further Reading below.

Combination and Comparison with other strategies:

i. A study in a two-storey school in Riyadh (arid climate) showed that painting the roof white was somewhat effective for summer cooling (0.6 °C reduction in temperature) but not as effective as other strategies[18].

ii. In a test in Porto (Mediterranean climate), cool painting was found to be very effective, reducing the maximum surface temperature by 8.9 °C [19]. It should be noted that surface temperature is different from air temperature as it is the temperature of the walls and roof, rather than of the air inside the building.

iii. Cool painting requires re-application more frequently than other strategies, such as insulation. A study conducted in Malaysia (tropical climate) noted that the roof had to be repainted every five years [55].

iv. Reflective coatings have been found to be more effective than a green roof at reducing cooling requirements [115] and [116] cited in [48].

v. Combining a reflective roof with internal insulation is very effective in reducing the total heat load coming from the roof [107] in both hot-humid and hot-dry climates.

Table 3: Comparison between different types of Cool Paints

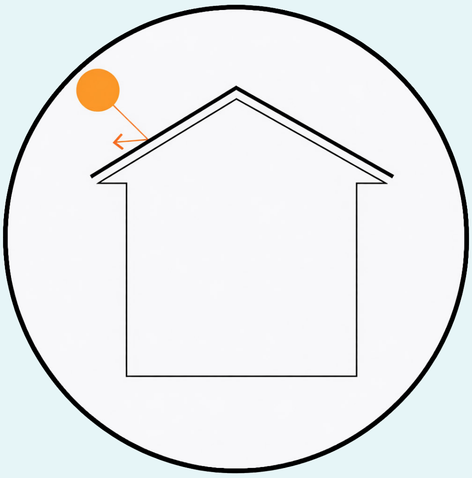
	Cool paints	Comparison
i)	Acrylic white paint vs aluminium paint [110] cited in, [117]	Acrylic white paint is more effective than aluminium paint
ii)	ASTEC's conventional paints vs ASTEC's heat reflective paints [109]	While in darker colours, the heat reflective paints perform 31% better than their conventional counterparts, for pure white, heat reflectance is only 4% better.

G. Further Reading

- Pros and cons of cool paints: [108]
- Application of cool paint: [118]
- Cool painting in humanitarian contexts: [113]
- Capsule retro-reflective coating for tents: [119]

2.4 Roof Shading and Radiant barriers

Figure 15: Roof Shading



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND Humid

A. What is it?

Roof shading involves putting covers, such as panels, metal sheets, or cloth, above the roof to block solar radiation from reaching the surface of the roof and heating it up. For the best performance these covers should reflect, rather than absorb, heat. This can be done using light coloured materials. Importantly, there should be a gap between the cover and the roof, to allow heat that is absorbed by the shading materials to be vented away by the wind. A roof cover that extends beyond the roof can also provide some shading to the walls and windows.

Ideally, the top surface of a roof shade should be durable (to withstand the weather) and the bottom surface should be made from a highly reflective, low-emissive material such as aluminium foil, to prevent heat being emitted from the cover towards the roof. If a shading net is used, then a close weave type is recommended.

Again, adding a low emissive backing to the net will make it more effective.

For climates with large temperature variations between day and night, especially when using a high thermal mass strategy, it is recommended to install a supporting structure for the roof shade so that it can be retracted during the night, allowing the roof to cool off in the cool night sky. This is also important for climates with cold winters where the sun's heat is desirable during winters. However, supporting structures for retractable roof shades may be expensive and vulnerable to wear and tear. Simple effective mechanisms are encouraged.

Retractability is unnecessary in climates with little temperature variation between day and night. However, in case of winds and storms, it is recommended that the supporting structure is strong enough and that the cover can be retracted or removed to prevent damage. If this is not possible, Cool Painting may be preferable.

Radiant barriers are layers of highly reflective foil-like material (aluminium foil or similar) that can either be used as part of a roof shade, or combined with thermal insulation (see Section 2.7), or placed inside a roof or wall. They work to prevent heat from radiation in two ways. Firstly, they reflect radiation back into the atmosphere. Secondly, because they are made from materials with low emissivity, they prevent heat that has built up in a material (such as a roof) from being emitted into the building. The most important consideration for using radiant barriers is that they are clean and free from dust, and that they face an air gap. For radiant barriers to be used in external roof shading, they need to be backed onto a durable material. Alternatively, the radiant barrier can be placed inside the roof - potentially in combination with roof shading placed outside the roof.

B. How does it work

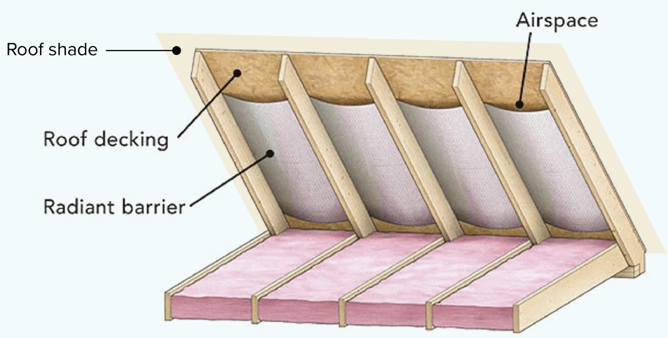
Roof shading acts as a filter or barrier against direct sunlight (blocking heat transfer by radiation). An airgap between the cover and the roof then allows any heat that was not reflected back to be vented out and away from the building through convection [42]. See Section 1.3 for information on heat transfer.

Lighter coloured materials are recommended for the shading cover materials as these reflect more radiation. Darker materials may still provide shade but will absorb heat and then re-radiate it into the building.

A cover that is white on top and reflective on the bottom is very effective [107]. On the top side, exposed to the sky, the surface should ideally be highly reflective and high emitting (similar to the properties that make Cool Painting effective [107]). The material should also be rough in texture, as this generally means it emits more heat back into the atmosphere. On the roof side of the cover, a reflective radiant barrier is effective, as the reflective surface will emit very little heat in the direction of the building.

Radiant barriers can act in two ways, as their shiny surfaces are both highly reflective (they reflect radiation back towards its source) and have low emissivity (they are bad at radiating heat themselves). When the shiny side is placed towards the source of radiation (the sun), they reflect much of this radiation back into the atmosphere. Placing the shiny side away from the source of radiation, on the other hand, prevents heat being radiated on, through the radiant barrier and into the building. However, for this to work, the shiny side needs to be facing an air gap: if it is facing solid material, the heat will be transferred by conduction (solid to solid) instead.

Figure 16: Roof shade, ceiling, insulation and radiant barrier in a roof section



Source: [121] (edited by author)

A roof cover that extends beyond the roof can also provide some shading to the walls and windows. See Window and Wall Shading.

C. Ease of application / notes on application

A cover is drawn over the roof. It can be either dynamic (retractable) or static (permanent).

1. What types of shades are there?

- **Dynamic:** removable shades are preferable in climates with large variations between day and night-time temperatures (often dry climates). Removable shades make it possible to expose the roof so it can release its heat to the cool night sky. A lightweight structure is fixed onto the roof, housing a mechanism that can be used to retract the cover or fold the panels [122].

  There are different mechanisms for opening/retracting the cover, depending on the availability of resources [24]. An example is a pipe motor which is a motorised mechanism that controls the rotation of a pipe, typically to wind or unwind a rope that supports the shading cover, to either roll up or release the rope, allowing for the opening and closing of a system. For more information on the different mechanisms see Section 2.4g.

› **Static:** for regions where there is little variation between the day and night temperatures there are limited benefits to retracting the cover and a fixed cover is more appropriate.

2. What makes a good roof shade?

› **Colour and texture:** shades should be light coloured - to reflect as much radiation as possible - and (on the top side, at least) dull, matte and textured, to emit as much heat as possible back into the atmosphere. Painted surfaces and fabric are better than shiny metal surfaces.

› **Radiant barrier:** if possible, covers should include a radiant barrier on the bottom side, to prevent heat being radiated towards the roof. Alternatively, a radiant barrier can be placed under the roof, with the shiny side facing downwards to prevent heat being radiated from the roof to the rest of the building. Avoid placing the shiny side upwards as, while it will reflect more radiation, this will typically lead to the barrier becoming dusty, which decreases its effectiveness. Ensure also that the shiny side faces an air gap. A roof cover that is made with aluminium foil will also act as a radiant barrier in addition to a roof cover, and the shiny side should face downwards facing an air cavity (see Section 2.4g for information on why an air cavity is needed).

› **High knitting density shading net:** if a shading net is used, then a high knitting density (close weave) shading net is recommended. For further information on this, see Section 2.4f where a tent was shaded using this material.

3. What about tents?

› Adding an additional roof covering over the tent can provide cooling. If there is high exposure to radiant heat from the side of the tent, then a shading strategy may also be used, such as screens or a shading net vertically positioned to block the low angle sun (see Section 2.6 for wall shading). See Section 2.4f for further details on tent studies.

D. What are the drawbacks?

- **Not effective without an air cavity:** radiant barriers are only effective when facing an air cavity [107], [123]. Roof covers should also include a gap between the cover and the roof, to allow hot air to vent away.
- **Dynamic mechanisms – wear and tear:** dynamic mechanisms for retracting

covers may be susceptible to wear and tear over time and would need replacing.

- **Weathering:** covers that are exposed to the weather are susceptible to weathering. Weathering can be aggravated by harsh weather conditions, such as rainfall, dust, and strong winds.
- **Pipe motor mechanisms – use energy/more expensive:** though an effective mechanism for dynamic shading, they use a motor and energy which can increase costs.
- **Winter heating considerations:** in climates with cold winters where heating is required, the shading devices may block solar radiation. A removable cover is recommended in such cases. It is important to design shading taking winter, as well as summer use, into consideration.
- **Strong winds:** if the climate is prone to storms and high winds, a cover that can be completely stored away so that it does not blow away in the wind is recommended. The connection of the lightweight structure should also be sturdy and routinely checked to avoid damage. If this cannot be done, cool painting the roof may be more suitable (see Section 2.3).

E. Where can it not be used?

It can be used in both hot-dry and hot-humid conditions but may not be suitable in contexts that experience strong winds.

F. Effectiveness

A study found that in a tropical climate a reduction of Mean Radiant Temperature (MRT) of 3.7 °C could be obtained [124]. MRT is the average temperature of all surfaces surrounding a person, including walls, floors, and objects, and so is different from, and generally higher than, air temperature.

Temporary structures:

A 46-49% reduction in cooling requirements has been found in an arid climate (near Makkah, Saudi Arabia) using a canvas canopy during clear sky conditions [125] cited in [126].

A study found an 8 °C reduction in the maximum indoor temperature of a tent using a 6-pin (high knitting density) shading net; a 5 °C reduction was obtained using a 3-pin shading net.

Figure 17: Tents shaded by shading nets

Source: [127]

Comparison with other strategies:

A study in a two-storey school in Riyadh (arid climate) showed that although roof shading was somewhat effective, there were better performing strategies when compared with other strategies for summer cooling[19] [53]. See Annexe 3.2 for further detail on the study.

For climates with cold winters, when heating is desirable, dynamic roof shading may be more appropriate than cool painting as it can be removed to allow the roof to heat up during the day.

Also see Section 2.6f iii.

G. Further Reading

- Retractable roof shading mechanisms: [24, pp. 1-7]
- Why an Air Gap is needed for radiant barriers: [123]
- Difference between Radiant Barriers and reflective insulation: [77]

2.5 Vegetation

Figure 18: Vegetation

Source: Author's own work (inspired by Bill Flinn)

✔	New buildings AND Retrofitting
✔	Permanent AND Temporary
✔	Dry AND Humid

Box 8: Vegetation

Planting vegetation around buildings - such as trees, shrubs, grass, or creepers - cools the environment in several ways. Vegetation provides direct shade, reducing radiation. It decreases air temperatures through the process of evapotranspiration, cooling air moving by convection. Finally, it can also funnel or protect from wind. Soft-scaping (replacing hard surfaces with vegetation) can reduce heat conduction by replacing heat-absorbing hardscapes with grass.

Deciduous trees are particularly useful for shading in climates with cold winters where the winter sun is desirable - they perform the same shading function as retractable roof shades but have other added benefits, such as improving air quality, providing cooling through evaporation, and sheltering from strong winds.

Planting is straightforward but requires water to sustain, so it may not be possible in water-scarce regions where the only alternate may be paving. Light colours for paving are recommended. While trees and vegetation generally provide shelter from strong winds, branches can also become projectiles during storms. Planting trees with large roots, such as eucalyptus, near infrastructure such as waterpipes is not recommended. Check that the plants do not cause allergic reactions, especially those planted near clinics.

A. What is it?

Planting vegetation, such as trees, shrubs, grass, or creepers, near and around the buildings to cool the environment.

B. How does it work

For vegetation, cooling happens in a number of ways:

1. As plants transpire, they produce water. As this water evaporates, it lowers the air temperature (evaporative cooling) allowing **convection** to take away the heat (see Section 1.3). This is especially beneficial in drier climates.
2. Trees can also shade outdoor spaces as well as providing shade to the building (blocking **radiation**).
3. Plants can also be used for diverting wind into the building, in a similar way to wing walls (see more about wing walls in Section 2.2.5).
4. Plants are also poor **conductors** of heat. Surfaces covered with vegetation are cooler.

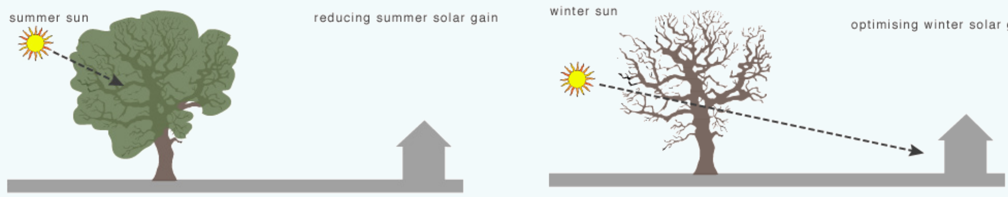
C. Ease of application / notes on application

Vegetation strategies are simple to implement as they do not require additional expertise.

- **Vegetation near windows:** the air can be cooled before it enters the building by growing plants near the windows planted in the prevailing wind direction.
- **Planting shading trees:** planting deciduous trees is highly recommended for climates with cold winters as they provide shade during the summer whilst shedding their leaves in winter, allowing the building to heat up when it is needed [53]. See Figure 19.

- **Soft-scaping:** is recommended in spaces outside, such as planting grass instead of hardscape/ pavement around schools and clinics and in the courtyards [53]. This can reduce the heat gained and anchor the soil against floods and storms.
- **Planting vegetation to divert wind:** vegetation can also influence wind patterns through wind deflection, funnelling, and air acceleration [16]. Increasing airflow can improve thermal comfort. Vegetation can also provide shelter from strong winds [16]. Tree canopies also improve air quality, especially underneath the canopies [16].

Figure 19: Deciduous trees providing shade in summer and allowing winter solar gain



Source: [129]

D. What are the drawbacks?

- **Obstructions and projectiles:** high winds can uproot trees and shrubs, and turn branches into projectiles [130].
- **Water usage and maintenance:** plants can require a lot of water, which may be problematic in dry regions with water scarcity.
- **Impracticality of soft-scaping:** soft-scaping is not possible or practical everywhere - such as on access routes or in areas of water scarcity. Paving, therefore, must be used instead. Design paving in a way to minimise heat gain, for example using light-coloured asphalt or concrete, relying on the same principles as Cool Painting (see Section 2.3) [131]. Permeable materials are recommended to allow water to infiltrate and provide direct evaporative cooling, and simultaneously help manage stormwater [131].
- **Allergens:** some plants can also trigger allergic reactions. See Section 2.5g for guidance on identifying these plants. This is particularly important to consider in clinics.
- **Infrastructure damage:** trees with extensive root systems, such as eucalyptus and poplar [132], can damage infrastructure such as foundations, footpaths, underground water pipes, and electrical and communication cables [133]. For further detail on which plants to avoid and measures to adopt, see Section 2.5g.

The likelihood of conflicts between trees and infrastructure is high when the following conditions are present [132]:

- Tree species that are large at maturity
- Fast-growing trees
- Trees planted in limited volumes of soil
- Shallow topsoil with hard-pan underneath
- Sidewalks with shallow foundations or minimal base materials
- Shallow irrigation systems
- Trees planted less than 2.0-3.0 metres from the infrastructure
- Trees older than 15 to 20 years

E. Where can it not be used?

Trees planted close to buildings, infrastructure, and along access routes should be assessed so that they do not impede traffic if they fall due to climate-related disasters [92] [130].

F. Effectiveness

Planting vegetation near windows and planting vegetation covers on walls have resulted in a temperature reduction of 7 °C [134] cited in [14] in a tropical climate. Additionally through tree shading, a 6-29% reduction in cooling requirements (the need for mechanical cooling) has been found in the same climates [135] cited in [14] and [136] cited in [14]. Note this is not a 6-29% reduction in temperature. For further detail on the studies, see Annexe 3.1.

Comparison with other strategies:

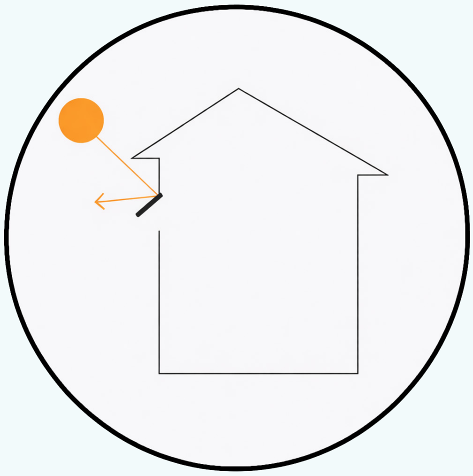
A study in a two-storey school in Riyadh (arid climate) showed that using grassy courtyards and deciduous trees shading walls proved to be effective for summer cooling (a 1.2 °C reduction in temperature) but not as effective as other strategies [53]. See Annexe 3.1 for further detail on the study and Section 2.2.4 for Courtyard Ventilation.

G. Further Reading

- Landscape Plant Selection Criteria for the Allergic Patient: [137]
- Avoid Pipe Problems Caused by Invasive Plants: [138]

2.6 Window and Wall Shading

Figure 20: Window and wall shading



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND Humid

Box 9: Window and Wall Shading

Window and wall shading aim to prevent the sun's heat (radiation) from heating walls or entering a building through the windows. There are a range of different shading devices, such as louvres, egg crate devices, overhangs, fins, and shutters.

Shading is especially important for buildings with large windows, where solar radiation is transferred directly to the inside of the building. In the Northern hemisphere, shading is needed on south, east, and west façades; in the Southern hemisphere, on north, east, and west. The equatorial-facing façade (south façade in the Northern hemisphere, north facade in the Southern hemisphere) receives the most solar exposure, followed by the west, which is harder to shade due to low-angle sun.

Near the equator, simple overhangs can provide sufficient shading to the walls and windows, to an extent. In addition to sun protection, shades can also provide rain protection.

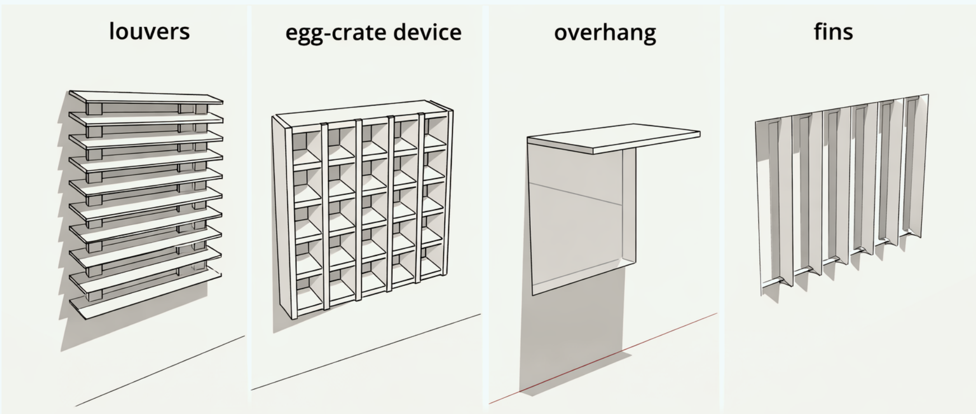
For north and south-facing facades, the aim is to keep out the high angle sun through overhangs, fins, deeply recessed windows or a combination. For east and west-facing facades (due to the lower sun angle in the morning and evening) practical solutions include multiple louvres or egg-crate devices.

Shading should balance heat control with needs for daylight and winter heating. Adjustable devices like blinds offer flexibility, while overhangs should be sized to block summer sun but admit winter sun. In windy or storm-prone areas, permanent shading devices (e.g., overhangs) are safer than fragile or temporary devices.

A. What is it?

It involves putting shading devices on windows and walls to prevent sunlight entering through windows or heating walls. See Figure 21.

Figure 21: Deciduous trees providing shade in summer and allowing winter solar gain

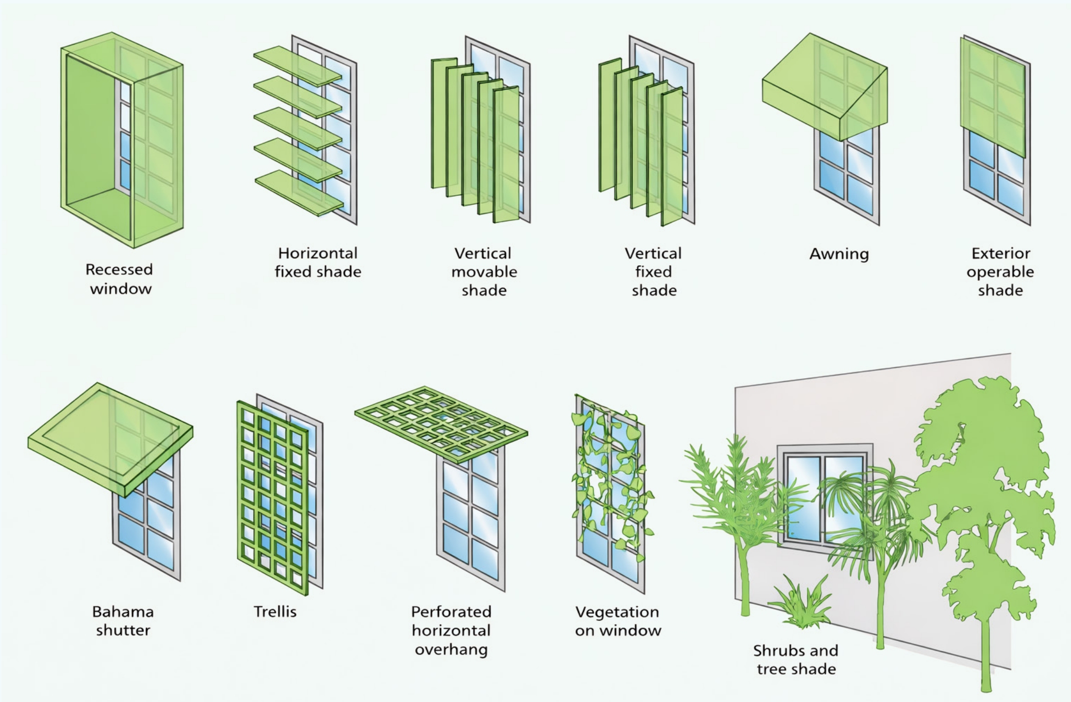


Source: [139], [140] (edited by author)

- **Louvres:** are slatted structures that are typically installed on windows or, less commonly, on facades or roofs to control sunlight and air. They consist of blades that are angled to allow light and air to pass through, while blocking direct sunlight and rain. This design helps reduce heat gain inside buildings while allowing for ventilation and maintaining visibility. Louvres can be made from various materials such as wood, metal, or plastic, and can be fixed, or adjustable to control the amount of light and air that enters. Materials that heat up less or reflect solar radiation are ideal.

- **Egg crate devices:** are similar to louvres but have a grid-like structure that resembles an egg carton, hence the name. They are often made from lightweight materials and are used to diffuse sunlight and reduce heat gain on walls and windows. The open grid pattern allows air and light to flow through while creating shade. They are particularly effective on east and west-facing surfaces, where the low-angle sun needs shading; breeze blocks can be effective at this. Screens, such as those made from wooden latticework, work in a similar way. Finer screens can be used for privacy.
- **Overhangs:** are extensions of the roof that protrude beyond the walls of a building. They provide shade for windows and walls, helping to block direct sunlight and reduce heat inside the building. Overhangs can also protect entrances from rain.
- **Fins:** are vertical structures attached to the exterior of a building, usually extending out from walls. They are designed to block sunlight and shade windows and walls. They can be made from various materials, like metal or concrete, and be positioned at different angles to maximise their shading effect. They can potentially function as wing walls (see Section 2.2.5).
- **Shutters:** top hinged shutters are also low cost options.

Figure 22: Other window and wall shading devices



Source: [141]

B. How does it work?

The shading devices act as a barrier against direct sunlight, blocking heat transfer by radiation (see Section 1.3 for types of heat transfer). They are especially important where the window sizes are large. A study conducted in a Mediterranean climate found that a building with a window-to-wall ratio of 30% without shading performs (in terms of heating and cooling) similarly to a building with a 60% window-to-wall ratio with shading [142].

If the building is in the Northern hemisphere, sun shading will be required on the south, east, and west facades. In the Southern hemisphere, sun shading will be required on the north, east, and west facades.

East facades have sun exposure in the mornings, while west facades have exposure in the afternoon. Usually the equatorial-facing façade has the greatest solar exposure and requires the highest protection. The west facing façade also requires protection, but is harder to shade due to the low angle sun. Close to the equator, the south and north facades have no large solar exposure – it can easily be blocked by overhangs as indicated in Section 2.6c [107].

C. Ease of application / notes on application

- **North and South facing facades:** the aim is to block the high angle sun. This is best achieved with overhangs, fins, deeply recessed windows or a combination [139].
- **East and West facing facades:** due to the low sun angle, single overhangs are not suitable as they would be too deep. A more practical solution is to use multiple louvres or egg-crate devices.
- **Sizing shading devices:** sizing and orientating shading devices depend upon the location of the building, façade orientation (e.g., west window) and the window heights. Where a series of horizontal shading devices are placed one above the other, the length of the projection of each device can be reduced by decreasing the spacing between consecutive shades (see Figure 23).

  Online tools are available to calculate the dimensions of sun shading devices. See Section 2.6g for further detail. Alternatively, documentation is available for sizing shading devices for windows in different orientations, at different latitudes, at selected cut-off times - but the sizing is only applicable to latitudes close to the equator between 0° (equator) and 10° S (see Section 2.6g).
- **Overhangs:** a roof shading device (see Section 2.4) or extended roof can provide shading to the walls and windows to an extent and can also provide rain protection.

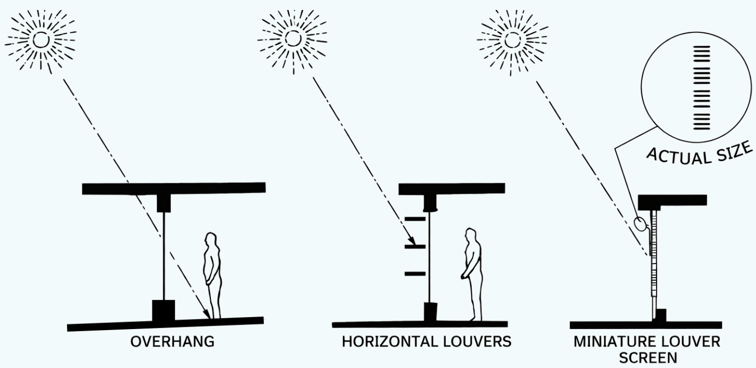
For information regarding tents, see Section 2.4c iii.

D. What are the drawbacks?

- **Lighting:** as sunlight is blocked, daylight in the building reduces. So, window shading should be done carefully so that adequate daylight can still enter. Multiple shading devices, such as louvres, block more sunlight than single ones such as sunshades. See Section 2.6g for guidance on shading.
- **Winter heating considerations:** in climates with cold winters, when heating is desirable, the shading devices may block solar radiation, an important design concern.

  Adjustable shading devices, such as blinds, can be easily controlled. If overhangs are used, they should only be deep enough to block the summer sun, whilst allowing lower angle winter sun. See Section 2.6g for more information.
- **Overhangs too deep:** in some cases, the length of horizontal shading devices required is too deep and impractical. If multiple horizontal shades are used, the required length it projects from the building reduces. This is why multiple louvres project much less than a single overhang. However, as a result, daylight inside and visibility to the outside is reduced. See Figure 23.

Figure 23: Multiple horizontal shading devices



Source: [143] cited in, [144]. Edited by Author.

For the same sun-angle, deep overhangs can be avoided if multiple horizontal shading devices are used. The depth required to shade is reduced if the spacing between multiple shades is reduced.

E. Where can it not be used?

Strong winds, storms: care should be taken in areas subject to strong winds and storms. Permanent, sturdier window shading devices, such as overhangs, may not cause problems, but ones that are temporarily fixed and more fragile (such as louvres) may.

F. Effectiveness

Tests conducted in Nicosia (Mediterranean climate) have shown that window shading resulted in a 7% reduction in cooling requirements [145] cited in [55]. In a study in Palermo (Mediterranean climate) shading was found to be highly effective when combined with insulation [142]. In New Asuid City (arid climate), shading led to a 2 °C average temperature reduction in all four orientations (north, east, south, west) [146].

Comparison with other strategies:

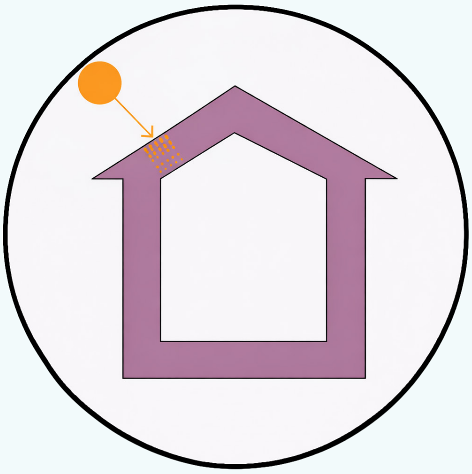
1. A study in a two-storey school in Riyadh (arid climate) showed that window shading had lower effectiveness when compared with other effective strategies for summer cooling [53] (see Annexe 3.2 for further details).
2. A study tested the effectiveness of different strategies in three different climates. The results showed that window shading is the most effective strategy in Mumbai (tropical climate), resulting in a 2.9 °C reduction in temperature, but was less effective than other strategies in Nairobi (subtropical climate) and Porto (Mediterranean climate)[20] [19]. See Annexe 3.2 for further details.
3. In tests conducted in a pre-fabricated house for disaster relief in Chengdu City (sub-tropical climate), different shading strategies were compared and wall shading was found to be the most effective one [126]. The shading used thin, highly reflective fabrics that could be removed in winter. An 18% reduction in unacceptable hours (when the temperature was above 28 °C) was achieved, which was twice the reduction found using roof shading. When both roof shading and wall shading using the fabric were used, the reduction was 28.6%. Combined with window shading using blinds, a 38.2% reduction was reached. See Annexe 3.2.

G. Further Reading

- Design Tools: sun shading device online calculator: [147]
- How Solar Screen Shades Work: keeping out the sun but bringing in light: [148]
- Sun Shading Catalogue: sun shading device dimensioning (latitudes between 0° and 10° S): [139, pp. 8-23]

2.7 Insulation

Figure 24: Insulation



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings AND Retrofitting
✓	Permanent
✓	Dry AND (less effective in) Humid

Box 10: Insulation

Insulation adds a layer of material to the building that inhibits the transfer of heat. The insulating material is made from substances with low thermal conductivity, which act as barriers to heat flow - reducing the ability of heat in the environment to enter the building through the walls or roof (and also reducing the ability of heat to leave the building). It does this primarily by reducing heat transfer due to **conduction**. By sealing gaps and cavities, it also decreases heat transferred through **convection**.

Where reflective foil is added to the insulation, the combination can prevent heat transfer due to **radiation** by acting as a mirror to the heat, as well as preventing transfer by conduction

Insulation is predominantly used as a passive cooling strategy in dry climates; it has less utility in humid climates. Care should also be taken when using insulation with high thermal mass materials, as it can disrupt the movement of heat out of the building at night. It is important to pair insulation with strategic ventilation (see Section 2.2.3) to ensure that heat is not trapped inside the building and can be released at appropriate times.

Insulation comes in different forms, including rigid boards and rolls of material that can be applied to roofs and/or walls. They are made from different materials, including mineral wool, fibreglass wool, cellulose, reflective insulation, extruded polystyrene (XPS), expanded polystyrene (EPS), and sheep-wool insulation. The choice of material depends on availability, physical form, cost, toxicity, environmental friendliness, performance, water-resistance, acoustic resistance, mechanical strength, resistance to vermin and fungus and maintenance. Fire safety is particularly important to consider.

The thermal performance of an insulation material is judged by a metric called its R value. The higher the R value, the better it performs as an insulator.

Insulation can be applied to existing buildings as well as new buildings. In most cases, a frame is created and attached to the walls or roof to mount the insulation. If reflective foil insulation is used, it should be positioned with the shiny side facing out, facing an air space or cavity.

A. What is it?

Insulation is a layer of material that prevents heat from spreading. Materials that are poor conductors of heat (low in thermal conductivity) are used to create this barrier.

Different materials can be chosen depending on availability, physical form, cost, toxicity, environmental friendliness, performance, water-resistance, acoustic resistance, mechanical strength, resistance to vermin and fungus, maintenance and fire safety.

High performing synthetic materials include XPS, EPS, and polyurethane (PU). Where resources are limited, cost-effective and sustainable alternatives are also present which can promote opportunities for employment and local industry [22]. Depending on the material, insulation comes in a variety of forms, including rigid boards and rolls of material.

Wall insulation can also be made from biomass panels created from fibres of different pulps, such as sugarcane, fenugreek, cow dung, sugar apple and wood [22]. Sheep's wool and straw are also options. These naturally sourced options are context-dependent; not all options will be relevant in all contexts.

Roof insulation can also be installed with materials such as bricks, inverted earthen pots in lime concrete, and by putting a layer of tiles on top of clay pots [23], [24]. Roof insulation is particularly important for corrugated metal roofs, as these roofs become very hot. Insulation can also be placed on the ceiling.

Reflective foil insulation can be made of single or multiple layers of reflective foil (to prevent heat transfer by radiation), combined with materials that prevent heat transfer by conduction (such as foam or plastic bubbles). See also radiant barriers in Section 2.4b and further reading in Section 2.4g. For guidance on installation, see Section 2.7c.

B. How does it work?

Insulation reduces the ability of heat in the environment to enter the building through the walls or roof. It does this primarily by reducing heat transfer due to conduction and convection. However, reflective foil insulation also stops heat transfer due to radiation. See Section 1.3 for types of heat transfer.

C. Ease of application / notes on application

Insulation can be applied to existing buildings as well as in new buildings. In most cases, a frame is created and attached to the walls or roof to mount the insulation. For more information on installation, see Further Reading in Section 2.7g.

Whether the insulation is applied on the outside (externally) or on the inside (internally) is determined by several factors. Studies generally suggest that external insulation is more effective for preventing heat transfer, but internal insultation is easier to apply and less exposed to damage from the elements.

Roof insulation in a hot dry climate should be placed on the attic floor, directly above and outside the part of the building that is used, but below the roof space. This provides a barrier between the used area of the building and the unused roof space and allows hot air in the roof space to vent out at night.

Where the main passive cooling strategy is the use of thermal mass to store daytime heat and release it heat at night (see Section 2.1), insulation may not be appropriate as it can interfere with the loss of night-time heat.

Insulation is less effective as a passive cooling strategy in humid climates but, in areas with bright sunshine, it can prevent heat gain (radiated heat) from transferring through solid roofs or walls. If insulation is used in these environments, care should be taken to prevent moisture building up.

If EPS or XPS are to be used, fire-retardant materials, such as mineral wool belts, should be used as barriers where there is risk of fire spreading (such as at joints between building materials, between storeys and spaces around windows and doors and especially near potential sources of fire-risk such as electrical boxes). Inorganic wools like mineral wool and fibreglass are fire-safe options - mineral wool showing better fire performance [25]. Organic options are also available with a low fire risk, like compressed straw [26], cork [27], and hempcrete [28]. For further detail on fire-safety see Section 2.7d and Section 2.7f.

Reflective insulation: the shiny side should face a minimum enclosed air cavity of 19 mm thickness [29] (see Section 2.7g for information on why an air cavity is needed). In walls, reflective insulation should be placed with the shiny side facing outwards and facing the air cavity, to act as a 'mirror' to radiant heat. In roofs, the shiny side should face downwards, again facing an air cavity (normally the attic space). Here, it is not the reflectiveness of the insulation, but the fact that the reflective surface is also a low emitter of radiation, that helps the cooling effect (see Section 2.4 for more information on this effect). Placing the shiny side down also prevents it from becoming covered with dust [17]. For further guidance on installation, see Section 2.7g. In one study, food packaging with an aluminium layer (that would otherwise end up in landfill) was repurposed as reflective insulation. They were layered for strength (three layers were used in the study) and their seams ironed for joining them. They were then fixed onto a backing material, such as jute cloth, cardboard, or tarpaulin [124]. Another study proposed covering the internal surface of tents with an aluminium film [126] to form a radiant barrier, although the study did not provide any evidence of effectiveness.

Wall-insulated assemblies with the insulation directly fixed to the wall are suitable for warm climates where there is no risk of condensation. Insulation in the form of batts/blankets, such as mineral wool, can be friction-fitted between wooden joists while rigid boards of insulation such as EPS can be directly fixed onto the wall. They are then covered by a finish, such as gypsum board or plaster.

A ventilated roof with insulation placed on the ceiling/attic has been known to work in all climates in both pitched and flat roofs.

D. What are the drawbacks?

- **Reduced effectiveness in hot-humid climates:** when there is almost no temperature difference between indoors and outdoors, thermal insulation has little-to-no effect, unless the façade or roof is exposed to the sun. This is why, in general, thermal insulation is not useful in hot-humid climates when the building is passively cooled [17].

- **Reduced performance due to moisture/trapping moisture:** sources of moisture, such as water pipes, should be carefully checked before insulation is installed, so water does not leak into the insulation, damaging it and reducing its efficiency. In humid climates, to allow moisture inside the building to pass through to the outside, vapour permeable materials, such as mineral wool, should be used for insulation [45] which do not feed mould growth [46]. Reflective foil also prevents the movement of moisture, and where the inside of a building has high humidity (as a result, for example, of high occupancy in a dry climate), it can trap moisture inside the building. In these circumstances, consider using permeable reflective insulation.
- **Vermin infestation:** mice and other vermin may infest the insulation cavity if they find a way in. This is particularly true for some types of insulation. See Section 2.7g for further detail on which insulations are susceptible. It is recommended to seal all cracks and crevices, and install vermin-proof perforated mesh, especially in the lower areas of the wall [42].
- **Overheating:** a well-insulated building that is not well ventilated can also prevent heat spreading from the inside out, trapping heat inside. Heat can be generated from the building occupants' activity and from electronic equipment, especially in densely populated areas such as wards, causing overheating. Therefore, when outside temperatures are lower than indoor temperatures (as is often the case at night, particularly in dry climates), insulation should be used in combination with natural ventilation to remove heat. See Section 2.2.3 for further guidance on when to open and close windows for natural ventilation.
- **Fire Hazards:** fire safety should be assessed when selecting insulation. Polystyrene-based insulations such as EPS and XPS are combustible and pose fire hazards [43]. In terms of smoke and toxicity, EPS is a greater risk than XPS after catching fire [44]. There are biobased fire-safe options such as sheep wool.

E. Where can it not be used?

Insulation can be used in all climates but is generally much more effective in dry climates. Care should be taken when dealing with moisture and preventing condensation.

F. Effectiveness

Wall insulation is one of the most frequently discussed strategies in the literature [48] and is effective in many contexts.

Various studies suggest that insulation is effective at decreasing internal temperatures by 1-3°C [49], [42], [50] cited in, [49]. Some studies found that insulation can decrease the amount of heat that needed to be removed from a building to retain a comfortable temperature by 30-40% [51] cited in [49] and [52] cited in [49]. However, these studies were generally using better insulating materials, such as polystyrene or polyurethane insulation.

The thermal performance of an insulation material is judged by a metric called an R value. The higher the R value, the better it performs as an insulator e.g., an R value of 4 performs better than R3. The R value increases with the thickness of the material. For information on R values of different insulations, see Table 4.

The studies also demonstrated the importance of using night ventilation (see Section 2.2.3) in combination with insulation in dry climates. This was because, in some cases, although the maximum temperatures in the building decreased when insulation was added, the average temperatures (which included night temperatures) increased. This was due to heat being held inside the building by the insulation and no effective ventilation [42].

For further detail on the different studies/strategies and their effectiveness, see Annexe 3.1.

Comparison with other strategies:

1. A study comparing the effectiveness of different strategies[21] in a two-storey school in Riyadh (arid climate) showed that insulation with night ventilation (see Section 2.2.3) was one of the most effective strategies for summer cooling, resulting in a 1.9 °C reduction in average temperature [53]. The same study found that, in hot-dry climates, night ventilation is very important to make insulation effective for cooling (otherwise heat from the daytime can remain trapped inside). See Annexe 3.2 for further detail on the study. The finding was substantiated by tests conducted in UNHCR prefabricated shelters in Jordan (arid climate), which recorded an overall rise in temperature when insulation was used with daytime-only ventilation (windows were opened from 09:00-21:00) [42]. See Annexe 3.2 for further details on the study.
2. Tests in patient rooms in hospital buildings in Illam (Mediterranean climate) showed that roof insulation was the most effective of all strategies, resulting in a nearly 25% reduction in cooling requirements [54]. See Annexe 3.2 for further details on the study.
3. A study in Malaysia (tropical climate) found insulation to be the most effective strategy for reducing temperatures and for cost effectiveness[22] [55]. See Annexe 3.2.

Table 4: Comparison of different types of insulation

	Insulation type	Pros	Cons	R value[23] in (ft²·°F·h)/ BTU
i)	Mineral wool and fibreglass wool	• Highly effective fire performance and doesn't require additional fire-retardant chemicals. Mineral wool is more fireproof than fibreglass wool • Can also be used as fire-stops unless it is faced/ finished with flammable material • Non-carcinogenic and thoroughly tested for health [46] • Does not feed mould growth [46] • Non-corrosive • Good for Do-It-Yourself projects [56]	• Thermal performance is not as good as PU foam, XPS, or EPS. Similar in performance to cellulose and sheep wool • Can cause irritation so requires gloves and mask for handling • Susceptible to pest infestation	Fibreglass wool = R2.9 - R3.8 [57] Mineral Wool = R3.7 - R4.3 [58]
ii)	PU foam (poly-urethane)	• Very high thermal performance • Seals cracks and crevices very effectively as it is sprayed on • Does not provide food for vermin, making it less likely to attract pests	• Expensive • Difficult to apply as it requires specialised spraying equipment • Needs fire-retardants to be considered fire-safe [59] • No conclusive evidence of health safety [46] • Rodents may chew through it to reach other areas. If foam is not installed properly and there are gaps, it could become a point of entry for pests	R6 - R7 [57]

	Insulation type	Pros	Cons	R value[23] in $(ft^2 \cdot °F \cdot h)$/ BTU
iii)	Cellulose insulation	• Eco-friendly	• Untreated cellulose insulation has issues such as fire-safety, feeding mould growth, and attracting pests like termites, rodents, and insects. It requires proper treatment with chemicals such as fire retardants and pesticides to prevent these issues. While appropriate off-the-shelf options may be available in some markets, it is not the case in many places. e.g., it may be corrosive if treated with corrosive chemicals for fire retardation [46]	R3.6 – R3.9 [57]
iv)	Reflective insulations	• Good for Do-It-Yourself projects [56] • Suitable for standard framing [56] • Bubble form works well with irregular framing or obstacles [56] • Most effective for preventing downward heat flow; effectiveness depends on spacing and number of foils [56] • Cost generally depends on market availability but cheaper than PU foam	• Requires an air cavity and correct orientation to be effective. See Section 2.7g and Section 2.7c for further detail	The R value is not a good indicator of effectiveness for reflective insulation. Its reflectivity is a better indicator [60]

	Insulation type	Pros	Cons	R value[23] in (ft²·°F·h)/ BTU
v)	Sheep wool	• Healthy [61] • Eco-friendly [61] • Doesn't require gloves in installation. Easy to install • Fire-safe. It does not burn, but instead singes away from fire and extinguishes itself [62]	• Thermal performance is comparable to fibreglass [61] • Can be 2-3 times more expensive than fibreglass if not readily available [61] • May not be readily available [61] • Potential for odours, especially in humid climates [61] • Pest infestation is a risk [61] • Thermal performance reduces over time due to compression [61]	R3.6 - R4.3 [63]

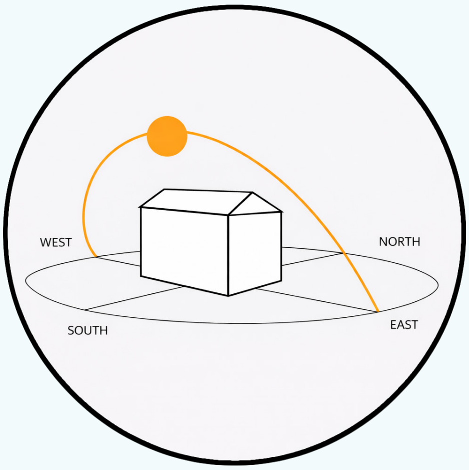
Note: The table is not a complete overview of possible insulation materials.
For further guidance on comparing different insulation types, and a brief overview of methods of installation, see [56].

G. Further Reading

- Insulation selection guide: [46]
- Insulation installation guide (includes mineral wool, sheep wool, XPS, EPS, reflective insulation) (pdfs + videos) : [64], [65], [66], [67], [68], [69], [70], [71]
- Rendering on insulation guide: [72]
- Installation of roof insulation on a flat roof: [41]
- Insulation renovation guide: [73]
- Where is firestopping required: [74], [75]
- Technical Guide on designing a wall section in hot-humid climates with insulation: [76]
- Guidance on installation of Reflective foils: [77]
- Why an Air Gap is needed for reflective insulation and guidance on airgaps: [78]
- Condensation issues due to insulation: [79]

2.8 Building Form and Zoning

Figure 25: Building Form and Zoning



Source: Author's own work (inspired by Bill Flinn)

✓	New buildings
✓	Permanent AND Temporary
✓	Dry AND Humid

This section deals with strategies specifically for new buildings.

Box 11: Building Form and Zoning

If creating new buildings, optimise the shape and placement of buildings at the design stage to reduce solar heat gain and enhance ventilation. Zoning and layout organise interior spaces to maximise cooling, daylighting, and comfort in key functional areas like classrooms or wards.

Long sides of the building should face north and south to reduce low-angle sun exposure (in the morning and evening) on walls and windows: the long wall facing the equator (south wall in Northern hemisphere) is shaded to reduce high-angle exposure.

Orientation should also consider prevailing winds, capturing cooling summer breezes while protecting against hot winds using trees or wing walls.

Self-shading can be achieved by breaking up large buildings into narrower forms, incorporating courtyards, deep balconies, or recessed windows.

Shallow room depths improve natural ventilation and daylighting, while high ceilings enable stack ventilation by allowing hot air to rise and exit. However, if rooms are too shallow, they may not function properly so they should be carefully designed.

Zoning strategies include placing auxiliary areas, such as toilets, storage, and staircases, on equatorial-facing or west façades, to act as thermal buffers for the main functional spaces.

Courtyards enhance both ventilation and daylighting, and major functional areas should be separated from auxiliary spaces if active cooling is used, with priority given to spaces with less solar exposure. Layouts that encourage courtyards and narrow linear rooms support better ventilation and daylighting than deep, massive spaces.

A. What is it?

- **Building Orientation and Form:** orienting the building and designing its shape and size in a way to minimise solar radiation or improve ventilation.
- **Zoning and Layout:** uses strategies to layout and zone areas within a building to make use of cooling strategies and provide better environmental conditions (cooling, daylighting), at least to the main functional areas, such as classrooms, wards etc.

B. How does it work?

- **Building Orientation and Form – orientation in relation to sun:** the long side of the building should face north/south - while this increases the amount of time that the façade faces the sun, it decreases the amount of time that it faces low angle sun, which is more difficult to avoid through shading [23]. For simple diagrammatic representations of recommended forms, see Section 2.8g for further detail.

  Extended east and west facing elevations should be avoided due to high solar gains that may be difficult to shade [106].
- **Building Orientation and Form – orientation in relation to wind:** assess the prevailing wind direction on site in summers and winters and orient the building

to receive more summer winds - unless winds are too hot (such as Foehn and Sirocco winds), in which case orient the building to receive protection from winds. Winter wind protection can also be achieved using deciduous trees; summer winds can also be cooled and funnelled by trees and wing walls. See Section 2.5 for details on trees and Section 2.3.5 for wing walls. Note that, in some areas (for example, near coasts and in mountain valleys), cool winds may occur at particular times of day.

- **Building Orientation and Form - self shading:** by breaking up larger, deeper forms (in top view) into smaller narrower buildings, self-shading and daylighting can be achieved: This can be done by introducing courtyards, which should be proportioned to be shaded and/or contain cooling features such as trees, water, and soft paving. For more information on courtyards, see Section 2.2.4. Self-shading can also be created by deep balconies or deep window recesses.
- **Building Orientation and Form – shallower depth of rooms:** although deep plans are often favoured in clinics over shallow linear plans (due to greater and closer medical adjacencies), rooms with shallower depths are preferred for effective natural ventilation and daylighting [91].
- **Building Orientation and Form – high ceilings:** tall spaces, such as those with high ceilings, double storey heights or stairways, enable stack ventilation by providing space for the hot air to rise and exhausting out. See Section 2.2.2 for further information on Stack Ventilation.
- **Zoning – auxiliary areas as thermal barriers:** auxiliary areas, such as toilets, storage, and staircases, placed in areas with high solar radiation (equatorial facing façade and the west façade) can act as thermal barriers to buffer the inner areas holding the main functions. However, this is only recommended if daylight and natural ventilation in the main areas is sufficient. This may be possible through courtyards.
- **Zoning – courtyards:** courtyards are recommended for ventilation and daylighting. See Section 2.2g for further detail on courtyard ventilation.
- **Zoning – separation of major function spaces if active cooling is involved:** separating the major function spaces (e.g., outpatients and inpatients in clinics, classrooms in schools) from auxiliary spaces, such as corridors, is recommended. It is important to reduce the energy required for the active cooling system, so only the major function spaces are cooled [91]. Areas that are actively cooled should also be those that receive less direct solar radiation. For further information on active cooling see Section 2.9.
- **Layout:** a comb-style or compound style layout is recommended, instead of a centralised layout, especially in healthcare facilities [91]. This is because narrow rooms (in comb-style) and courtyards (in compound style) are effective for ventilation and daylighting, instead of deeper rooms in a massive construction (in a centralised layout).

Table 5: Comparison of layouts

	Style	Characteristics
i)	**Comb style**	• Linear construction • Narrow rooms provide good natural ventilation and daylighting • Effective for natural ventilation
ii)	**Compound Style**	• Less affected by solar radiation • Cooler air in courtyards flows towards otherwise hot, medical functional areas • Vegetation and water provide cooling • Effective for natural ventilation
iii)	**Centralised style**	• Massive construction • Lacks natural ventilation, and needs high energy consumption • Not effective – should be avoided

C. Ease of application / notes on application

All the strategies in Section 2.8b are applicable to new buildings.

D. What are the drawbacks?

If rooms are too shallow, they may not function properly so they should be carefully designed.

E. Where can it not be used?

Building siting in climate-hazard-prone areas: the siting of new buildings and new infrastructure should take climate risk scenarios into consideration, such as increasing drought, floods, storms, prolonged rainfall, strong winds, heat waves and sea-level rise [92]. Siting should be the first area of consideration and can prevent catastrophic damage [92].

F. Effectiveness

Studies conducted in tropical and Mediterranean climates have shown that a 6-11% reduction in cooling requirements is possible by orienting the long side of the building to face north and south instead of east and west [55], [142]. See Annexe 3.1.8 for further detail on the studies.

G. Further Reading

- Building orientation and Form - diagrammatic representations of forms: [23, pp. 21–25], [149]

2.9 Active Cooling and Direct Evaporative Cooling

Figure 26: Active Cooling Systems

Source: Author's own work

✓	New buildings AND Retrofitting
✓	Permanent AND Temporary
✓	Dry AND Humid (Not applicable for Evaporative Cooling)

Box 12: Active Cooling

Active Cooling Systems need energy to function. Systems include: cooling fans blowing air to provide a cooling effect by evaporating perspiration from the skin (ceiling fans and pedestal fans); blowing out hot, stale air from the building to the outside (exhaust fans); or reducing the temperature of the air through Direct Evaporative Cooling (Desert Coolers). Desert Coolers have been found to be very effective in hot-dry climates

Direct Evaporative Cooling (DEC) can also happen through passive methods, such as hanging damp cloths near windows to cool the incoming air. DEC is only suitable for dry climates.

With the exception of ceiling fans, because of their portability most active cooling systems can be used in both temporary and permanent structures, as long as a power source is available. DEC, including do-it-yourself desert coolers, is also suitable for both temporary and permanent buildings, because it is simple to implement.

Active cooling systems require continuous electricity, which may be supplied by solar panels but can be costly. Large fans can be difficult to install and noisy; fans are also ineffective - and can even be dangerous - in high temperatures. Portable fans cool only small areas, requiring multiple units for larger spaces. Ceiling fans can mix air but may reduce air quality and interfere with natural cross-ventilation, especially in healthcare settings; they should be used carefully alongside exhaust fans.

DEC increases humidity: this can be uncomfortable for occupants in humid climates and can lead to mould and mildew if humidity levels get too high. DEC requires water and that can be problematic in water-scarce regions. Desert coolers can breed mosquitoes if poorly maintained, lose efficiency with high-calcium water, high winds, or under humid conditions, and may cause condensation in humid climates resulting in mould and mildew.

A. What is it?

Active Cooling consists of strategies for cooling which require energy.

Direct Evaporative Cooling uses evaporation to cool the air.

B. How does it work / notes on application

Fans:

- **Portable fans:** can reduce body temperature by replacing the hot air 'envelope' around a person (produced as an individual radiates heat into the air) with cooler air from the environment, and by enhancing the evaporation of sweat. They can enhance overall natural ventilation if they are positioned next to windows on the side of the building facing the wind. They can also provide cooling for specific people, which may be desirable in, for example, clinics where patients and staff under different conditions may have different cooling requirements. Cooling fans with controls for multiple speeds should be used, so people can adjust the speed as needed [16].
- **Exhaust fans:** to improve airflow in a room, hot air can be pushed out of the room, usually with an exhaust fan or similar. It works best if the fan is placed near

a window on the side of the building sheltered from the wind. This way, fresh air from outside gets pulled in to replace the hot air, helping to cool the room naturally. This can be used for increasing ventilation rates in rooms housing patients with airborne infections [86]. Exhaust fans should be installed where the air can be exhausted directly to the outside either through the wall or the roof.

- **Ceiling fans:** by increasing the movement of air over the skin (such as done by portable fans) a ceiling fan circulates air within a room, making occupants feel cooler in the same way as a portable fan. Ceiling fans can improve the air-mixing in the room to prevent hot and cold spots. This is only recommended once the minimum ventilation rates have been met [86]. See Section 2.2g for minimum ventilation rates.

Direct Evaporative Cooling:

- **Direct Evaporative Coolers/desert coolers/swamp coolers:** other active cooling systems, such as ceiling fans, portable fans, and exhaust fans, can provide cooling to the occupant and bring in relatively cooler air from the outside, but are not able to cool the air itself. Desert Coolers can cool the air [42], and are highly effective in dry climates. They are not effective in humid environments. They work by drawing warm dry air through a damp surface, transferring the heat to the water which leads to the water on the surface evaporating: the evaporation cools the air in the same way that evaporation of perspiration cools the human body. The mechanism usually requires a pump, tray, fan, suitable surface, water, and an electricity source. An example of a desert cooler made for desert environments can be found in Section 2.9g. Examples of surfaces include cellulose pads that are treated to resist degradation - with a cross-fluted design increasing the surface area to hold water, and aspen pads. For further detail on the different materials of filter pads, see Section 2.9f.

  There are also passive methods for achieving Direct Evaporative Cooling:

- **Damp cloths:** warm air is drawn through fabric saturated with water. Cloths can be placed at ventilation openings such as windows. As the air passes through the damp fabric, the water evaporates, absorbing heat from the air and thereby reducing its temperature [150].

- **Spraying water:** water is sprayed onto surfaces near ventilation openings (like window screens) at intervals to induce evaporative cooling [150].

If active cooling techniques are used, the WHO recommends ventilation systems with an energy backup arrangement to satisfy demands for at least three days [92]. Emergency backup generators should be periodically checked, even if they are rarely used [92].

C. Ease of application?

All Active Cooling systems discussed above (except for ceiling fans) can be used in temporary and permanent structures, due to their portability. Solar panels can be used for electricity supply. Pedestal fans can also be used as exhaust fans near windows, if they are oriented to blow air out of the window.

Direct Evaporative Cooling can also be implemented in temporary and permanent buildings because it is simple. Desert Coolers are ideal DIY solutions and can be constructed out of readily available, local hardware materials [24]. For further detail, see Section 2.9g.

D. What are the drawbacks?

- **Active Cooling – Electricity supply:** all active cooling techniques require a continuous electricity supply. Although electricity may be provided by solar panels, it can become costly.
- **Active Cooling – Installation difficulty:** especially for large exhaust fans.
- **Active Cooling – Noise:** may become an issue with high-power exhaust fans.
- **Active Cooling – Effectiveness in higher temperatures:** when the temperature rises above 30 °C, cooling fans are not sufficient to keep the building cool enough for occupants [16]. Fans should NOT be used in temperatures over 35 degrees, where they may actually increase the temperatures of building occupants. Low-cost Direct Evaporative Cooling is recommended for this, particularly in drier climates; it is relatively low cost compared to air-conditioning mechanisms.
- **Active Cooling – Portable fans – Cooling for small areas:** portable fans can only cool small areas. While this has the benefit of targeted cooling (see Section 2.9g), multiple fans would be needed for a bigger space.
- **Desert Coolers – mosquitoes:** poorly maintained evaporative coolers can become breeding grounds for mosquitoes or some harmful microorganisms [151].
- **Desert Coolers – reduced efficiency in water with high calcium content:** if the water has a high concentration of calcium, calcification can block up pores in the evaporative cooler pads and reduce efficiency [151].
- **Desert Coolers – reduced efficiency due to high winds:** in areas of high winds, the face of some filter pads may become damaged in such a way that they fold over the pores, reducing efficiency [151].
- **Direct Evaporative Cooling – reduced performance in wet seasons and humid climates:** in humid conditions, effectiveness of evaporative coolers decreases. If the relative humidity increases to over 80% for an extended period it can lead to

uncomfortable and potentially unhealthy conditions [107]. The moisture content of air can be reduced by air dehumidifiers.

- **Active Cooling/ Desert Coolers – Condensation in humid climates:** if the building is in a humid climate and uses active cooling to reduce the indoor temperature (such as Desert Coolers), care must be taken to avoid creating condensation [47]. Where active cooling is used, it is recommended not to keep the indoor temperature too cool to prevent this.
- **Direct Evaporative Cooling – discomfort due to increase in humidity:** DEC can contribute to increased humidity levels that can become uncomfortable.
- **Direct Evaporative Cooling – mould and mildew:** if DEC increases the humidity levels, it may cause problems such as mould and mildew.
- **Active Cooling – Ceiling fans – effect on air quality:** ceiling fans can help mix the air. However, if windows and other openings are closed, the air will become more polluted over time and be circulated by the ceiling fans. This is more significant in healthcare settings where the risk of cross-infection may increase.
- **Active Cooling – Ceiling fans – hampers cross ventilation:** ceiling fans can hamper cross ventilation (see Section 2.2.1 for cross ventilation) as they can disturb natural wind-flow patterns. Ceiling fans may try to push air out of a window through which outside fresh cool air is trying to blow in. In such cases, turning off the ceiling fans and using exhaust fans to enhance wind-flow, can work to improve cross-ventilation.

E. Where can it not be used?

- **Active Cooling – Portable fans and ceiling fans – temperatures above 35°C:** the WHO advises that fans should not be used in temperatures over 35 °C, particularly in humid conditions [152] as, in these conditions, they heat people up, rather than cooling them down.
- **Direct Evaporative Cooling– moisture issues in humid climates:** if the air is already too humid, DEC may not be possible in indoor areas where moisture cannot be effectively vented. An alternative is Indirect Evaporative Cooling, which does not bring in any moisture, but it is expensive and technically specialised, so it is outside the scope of this guidance.

F. Effectiveness

Comparison with other strategies:

A study, conducted in UNHCR's prefabricated shelters in Azraq, Jordan (arid climate) on different cooling strategies, found that the best performing strategy was a desert cooler. It resulted in a 2.4 °C reduction in average temperature and a 5.2 °C reduction in maximum temperature[24] [42]. See Annexe 3.2 for further detail on the study.

Table 6: Comparison between different types of Desert Cooler pad materials

	Desert Cooler filter pad material	Pros	Cons
i)	Aspen	• Less expensive [153] • Provides a balance between air and water, ensuring effective cooling inside the house [153] • The pads allow more air to pass through a slightly saturated cushion, resulting in cooler indoor air [153]	• Short life [153] • Not as effective as cellulose [154]
ii)	Cellulose	• Highly absorbent [153] • Recyclable and biodegradable [151] • Efficient water and air mixing [151] • Efficient when evaporation happens quickly (either due to a drier climate or faster fan) [153] • Greater lifespan than Aspen [151] • Best balance between how easily water can pass through and the size of the pores [154]	• More expensive than Aspen [153]
iii)	Plastic	• Only useful in the shorter term [153]	• Not very effective [153] • Not absorbent [153]

Comparison between different types of Direct Evaporative Cooling methods:

In a study in Jeddah (arid climate), tests were done in an old building with mashrabiya installed in the windows of a room [150]. Mashrabiya are traditional wooden lattice-work screens. For further information, see Annexe 3.1.

Table 7: Comparison between different types of Direct Evaporative Cooling methods

	Direct Evaporative Cooling Technique	Pros	Cons
i)	Damp cotton cloth placed on mashrabiya	• High Cooling Effectiveness: achieved up to 6.8 °C reduction in indoor temperature, making it the most effective of the three methods [150] • Low-Cost: requires minimal materials and no mechanical systems • Simple Implementation: easy to set up and remove as needed	• Maintenance: needs regular re-wetting to maintain cooling efficiency • Potential building damage due to moisture
ii)	Spraying water on mashrabiya	• More effective than earthen pots • Relatively easy to implement: can be manually or mechanically operated	• Limited Duration of Effect: cooling only lasts as long as spraying and evaporation continue • High Water Consumption: 4.9 litres of water were used over 2.4 hours • Potential building damage due to moisture • Less effective than damp cloths

	Direct Evaporative Cooling Technique	Pros	Cons
iii)	Porous clay or earthenware pots are placed along the inlet of mashrabiya		• Minimal effectiveness

G. Further Reading

- Direct Evaporative cooler/Desert cooler: Improving thermal comfort in refugee shelters in desert environments [42, pp. 31–33]
- Direct Evaporative cooling pad sample: [155]

3 Annexes

3.1 What studies said about the effectiveness of specific strategies

The following section provides more information on studies that considered the effectiveness of specific cooling strategies: the full studies are referenced in Section 5.

Note that the effectiveness of any given strategy differs depending on local circumstances. Note also that different studies use different metrics for effectiveness which are not directly comparable. These include:

- Reduction of average air temperature
- Reduction of maximum air temperature
- Reduction of surface temperature of walls/ceilings/roofs
- Reduction of radiant temperature (the average of multiple surface temperatures) and
- Reduction of cooling load. This is a measure of the degree to which the strategy decreases the amount of unwanted heat entering the building (often, but not always, this is in a situation where active cooling strategies (such as air conditioning) will then be used to address the unwanted heat).
- Energy Saving. This is the measure of how much less energy was used by active cooling systems as a result of the passive cooling strategy being put in place.

3.1.1 Using High Heat Storage Materials

Table 8: High Heat Storage Materials Effectiveness

	Strategy Detail	Temperature reduction	Climate	Location
i)	Increase in thickness of interior gypsum plaster by 2 cm [19]	Reduction of maximum temperature by 2.1 °C / 5% of maximum average temperature decrease by 0.9 °C	Mediterranean	Porto, Portugal / transitional building
ii)	Filling the wall cavity with sand and gravel (3000 kg) (6 cm wide in main walls, 3 cm wide in gable ends) [42]	Reduction of maximum temperature by 3.7 °C / average temperature decrease by 1.2 °C	Arid	Azraq, Jordan/ transitional shelter
iii)	Sandbags (14000 kg) on the inside of external walls[25] [42]	Reduction of maximum temperature by 4.7 °C / average temperature decrease by 1.3 °C	Arid	Azraq, Jordan/ transitional shelter

Disclaimer: ii) and iii) are comparable as they are from the same study while i) is not comparable to either.

3.1.2 Natural Ventilation

Table 9: Natural Ventilation Effectiveness

	Strategy Detail	Compared with	Energy savings %	Temperature reduction / increase	Climate	Location
i)	Night Ventilation [105]	Daytime-ventilation	-	Reduction of maximum temperature by 2.5 °C and reduction of nocturnal temperature by 2 °C, as compared to daytime ventilation	Tropical	Malaysia/ residential
ii)	Night Ventilation + louvred windows (fixed schedule) [21]	Daytime ventilation + louvred windows	-	Increase of annual average temperature by 0.3 °C	Tropical	Singapore / ward
iii)	Night Ventilation + louvred windows (ventilation whenever internal temperature is lower than external temperature, even during the day) [21]	Daytime ventilation + louvered windows	-	Reduction of annual average temperature by 0.6 °C	Tropical	Singapore / ward

3.1.3 Cool Painting

Table 10: Cool Painting Effectiveness

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
i)	Double skin roof with heat-reflective paint [172] cited in [117]	Reduction of temperature by 5 °C	Reduction of cooling energy requirement by 66% - 572 kWh over a year	Arid	Beni Isguen, Algeria/ home
ii)	Reflective white paint on roof [112] cited in [55]	Reduction of temperature by 6.5 °C on average	-	Arid	-
iii)	Cool paint on roof [19] (equivalent of white paint)	Reduction of maximum surface temperature by 8.9 °C	-	Mediterranean	Porto, Portugal / transitional building
iv)	Solar reflective white paint on roofs [113]	Reduction of temperature by 2 °C	-	Arid	Badi Bhil Basti, India / home

Disclaimer: Due to the different variables in the different studies, the figures in the table above are illustrative, so they cannot be used to draw comparisons.

3.1.4 Roof Shading

Table 11: Roof Shading Effectiveness

	Radiant barriers Detail	Temperature reduction	Climate	Location
i)	MLP panel made from 3 layers with cardboard backing [124]	Reduction of radiant temperature by 3.73 °C	Tropical	Pune and Chennai, India
ii)	MLP panel made from 3 layers with tarpaulin backing [124]	Reduction of radiant temperature by 3.68 °C	Tropical	Pune and Chennai, India
iii)	MLP panel made from 2 layers with cardboard backing [124]	Reduction of radiant temperature by 2.57 °C	Tropical	Pune and Chennai, India
iv)	MLP panel made from 1 layer with cardboard backing [124]	Reduction of radiant temperature by 2.34 °C	Tropical	Pune and Chennai, India
v)	Aluminium foil – bubble insulation [124]	Reduction of radiant temperature by 4.19 °C	Tropical	Pune and Chennai, India
vi)	Aluminium foil – double sided foam [124]	Reduction of radiant temperature by 2.04 °C	Tropical	Pune and Chennai, India

The test results in the table above are comparable as they are all part of the same study.

3.1.5 Vegetation

Table 12: Vegetation Effectiveness

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
i)	Tree shading [14] [174]	-	10.3% reduction of cooling load	Subtropical	Nanjing, China
ii)	Tree shading [175] cited in [14]	-	14.4% reduction of cooling load	Subtropical	Auburn, USA
iii)	Tree shading [135] cited in [14]	-	6.1% reduction of cooling load	Mediterranean	Sacramento (California), USA / residential
iv)	Planting vegetation near window [134] cited in [14]	Reduction of temperature by 7°C	-	Hot-humid	Japan / residential
v)	Modification of tree canopy density and quantity + albedo values (reflectivity) of ground materials [136] cited in [14]	-	29% reduction of cooling load	Tropical	Putrajaya, Malaysia

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
vi)	Deciduous and evergreen vegetation cover on building walls [176] cited in [14]	Reduction of temperature by 5°C during summer and 3°C during winters	-	Mediterranean	Pretoria, South Africa
vii)	Tree shading and cool high albedo (reflective surfaces) of roofs and pavements [131] cited in [14]	-	20% reduction of cooling load	Mediterranean	Los Angeles, USA

3.1.6 Window and Wall Shading

Table 13: Window and Wall Shading Effectiveness

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
i)	Horizontal shading device - 1.5 m overhang [145] cited in [55]	-	7% annual reduction of cooling load	Mediterranean	Nicosia, Cyprus/ house
ii)	Horizontal shading device - 1.0 overhang on south façade [142]	-	14% energy savings in uninsulated building, 24% energy savings in highly insulated building	Mediterranean	Palermo, Sicily
iii)	Horizontal shading device	-	2.62-10.13% energy savings	Tropical	Singapore/ Residential
iv)	Fixed horizontal and vertical shading devices [178] cited in [14]	-	6% energy savings	Arid	Abu Dhabi/ Residential
v)	Fixed vertical louvres [146]	Reduction of temperature of 2°C	-	Arid	New Assuit City, Egypt / Residential

3.1.7 Insulation

Insulation in arid climates: For arid climates such as in Riyadh, through a study, the recommendations for insulating schools have been found to be 5 cm thick wall insulation (polystyrene) and 10 cm thick roof insulation (polystyrene) [53]; it should be noted that the effectiveness varies for different materials and different climates.

Table 14: Insulation Effectiveness

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
i)	Polyurethane roof insulation with aluminium reflector [171] cited in [49]		88% heat flow reduction	Hot	
ii)	Polyethylene aluminium single bubble insulation on walls [50] cited in [49]	Reduction of temperature by 2.7 °C		Tropical	Selangor, Malaysia / lecture hall
iii)	5 cm thick polystyrene on external + internal walls [51] cited in [49]		38% cooling load reduction	Subtropical	Hong Kong / apartment building
iv)	2 cm thick polyurethane on external walls [52] cited in [49]		28% cooling load reduction	Arid	Qatar / house
v)	5 cm thick polystyrene on walls [49]	Reduction of temperature by 0.81 °C	6.7% monthly savings on energy	Tropical	Malaysia / room in typical office building

	Strategy Detail	Temperature reduction	% reduction	Climate	Location
vi)	4 cm thick XPS (extruded polystyrene) insulation + roof shade 30 cm above existing roof [42]	Reduction of maximum temperature by 3.3 °C, average temperature rose by 0.6 °C[26]		Arid	Azraq, Jordan/ transitional shelter

Disclaimer: Due to the different variables in the different studies, the figures in the table above are illustrative, so they cannot be used to draw comparisons between different insulations.

3.1.8 Building Orientation and Form

Effectiveness table:

Table 15: Building Orientation and Form

	Strategy Detail	Compared with	% reduction	Climate	Location
i)	Orientation of buildings facing north and south [55]	Orientation of buildings facing east and west	8.6% - 11.5% reduction of cooling load	Tropical	Malaysia and Singapore
ii)	Orientation of buildings facing north and south [142]	Orientation of buildings facing east and west	6-10% energy savings	Mediterranean	Palermo and Milan

3.1.9 Direct Evaporative Cooling Strategies in a study in Jeddah (Arid)

Tests were carried out in an old building with mashrabiya installed in the windows of a room. Mashrabiya are traditional wooden lattice-work screens.

Mashrabiya and Water Pots: (see Section 2.6 for more information on screens and other Window Shading devices).

- In this approach, porous clay pots (or jars) filled with water were strategically placed along the inlet of the mashrabiya panels to allow air from the outside to cool as it passed over the pots.
- The setup included pots with varying exposure to airflow: two pots were almost entirely exposed (about 80% of the surface area), one was partially exposed (50%), and one was shielded from direct airflow.
- The water temperature was maintained between 25 °C to 27 °C. However, the results showed that this method did not provide significant cooling, especially during peak afternoon heat, indicating a need for further adjustments to pot placement, size, or environmental conditions.

Evaporative Cooling Sprays:

- This method involved spraying water directly onto the mashrabiya at specific intervals during the hottest part of the day.
- During the testing period, a total of 4.9 litres of water was used for evaporation, contributing to increased humidity and slightly decreased indoor temperatures.
- The study noted that the maximum temperature reduction observed was up to 8.6 °C lower indoors compared to outdoor temperatures during peak heat, indicating the effectiveness of this technique in achieving better thermal comfort.

Damp Cloths:

- This method placed wet cloths on the mashrabiya. The cloth absorbed water, increasing the surface area for evaporation and thus enhancing the cooling effect as warm air passed through the damp fabric.
- Although not detailed extensively, this method aims to utilise evaporative cooling by adding moisture to the air, without relying heavily on water spray systems, which may cause potential damage to the wood structure of the mashrabiya from excessive hydration.

See reference [150] for further detail on the study.

3.2 What studies said about Strategy Comparisons and Combinations

Some studies explicitly compared different strategies to establish their relative effectiveness (in the particular context). As in the section above, different measures of effectiveness are used. The names of the strategies are the same as those in Section 2.

3.2.1 Comparative study of different strategies (Arid)

Multiple strategies including: Window Shading, Vegetation, Natural Ventilation, High Heat Storage Materials, Improved Windows, Insulation, Cool Painting and Roof Shading.

- **Climate (Location):** Arid (Riyadh, Saudi Arabia)
- **Reference:** [53]
- **Background:** The study was carried out in a two-storey school. The school is a concrete, square-shaped building with a courtyard surrounded by a 4 m wide corridor.

Strategies are tabulated in order of effectiveness ((i) being the most effective).

Table 16: Comparison of different strategies in an arid climate, Riyadh

	Strategy	Detail	Average Temperature reduction
i)	Combination of all strategies	-	3.2 °C
ii)	Wall and Roof Insulation with Night Ventilation	50 mm thick polystyrene for walls and 100 mm thick polystyrene for the roof	1.9 °C
iii)	High Heat Storage Materials with Night Ventilation	External wall thickness increased from 200 mm to 300 mm + roof thickness increased from 300 mm to 400 mm	1.6 °C

iv)	Natural Ventilation	Night ventilation	1.3 °C
v)	Vegetation	Grass cover in courtyards and deciduous trees shading external walls	1.2 °C
vi)	Cool Painting	White painting on walls and roof	0.6 °C
vii)	Roof Shading	Placed 1000 mm above existing roof	0.4 °C
viii)	Window Shading	Overhangs and fins	0.3 °C
ix)	Improved Windows	Double Glazing	0.1°C
x)	High Heat Storage Materials without Night Ventilation	External wall thickness increased from 200 mm to 300 mm + roof thickness increased from 300 mm to 400 mm	0.0 °C
xi)	Wall and Roof Insulation without Night Ventilation	50 mm thick polystyrene for walls and 100 mm thick polystyrene for roof	-1.3 °C (increase in temperature)

Conclusions:

- In hot-dry climates, winter heating is also important.
- Best performing strategies for summer cooling: insulation with night ventilation, high heat storage materials with night ventilation, and vegetation.
- Best performing strategies for winter heating: insulation without night ventilation, high heat storage materials without night ventilation.
- For hot-dry climates, night ventilation is very important to make insulation and high heat storage materials effective for cooling. Otherwise heat during daytime from glazed areas and other means can remain trapped inside.
- White paint was also effective for summer cooling.

3.2.2 Comparative study of insulation and High Heat Storage (Mediterranean)

- **Climate (Location):** Mediterranean (Ilam, Iran).
- **Reference:** [54]
- **Background:** The study was based in patient rooms in two hospital buildings. The criteria for strategies were affordability, practicality, simplicity, and availability.

Strategies are tabulated in the order of effectiveness ((i) being the most effective).

Table 17: Comparison of different strategies in a Mediterranean context

	Strategy	Detail	% reduction of cooling load
i)	Combination of all strategies	Cavity-wall with insulation + floor thermal mass + roof insulation + double glazing	27.1%
ii)	Roof Insulation	50 mm thick polystyrene (rigid)	24.7%
iii)	Roof insulation	200 mm air + 10 mm thick polystyrene (rigid) suspended	16.4%
iv)	Wall insulation	60 mm thick polystyrene (rigid)	8.6%
v)	Cavity-Wall insulation	220 mm brick (inner) + 50 mm thick polystyrene (rigid) + 110 mm brick (outer)	8.3%
vi)	Cavity-Wall insulation	220 mm brick (inner) + 50 mm air + 110 mm brick (outer)	1.5%
vii)	Improved Windows	Double glazing (6 mm glass + 30 mm air + 6mm glass)	0.1%
viii)	Floor Insulation + High Heat Storage Material in Floor	100 mm concrete existing + 150 mm additional concrete + 50 mm thick polystyrene (rigid)	-3.9%

Conclusions:

- Most effective overall solution: combination of all strategies
- Most effective single strategy: roof insulation (50 mm thick polystyrene)
- Double glazing was ineffective

3.2.3 Comparative study of multiple strategies (Arid)

- **Climate (Location):** Arid (Azraq refugee camp, Jordan).
- **Reference:** [42]
- **Background:** The study was carried out in UNHCR prefabricated shelters where one was kept as the control while 11 were tested with different passive cooling strategies. Windows were opened from 09:00-21:00, except those with high heat storage materials which were opened from 21:00-09:00 to benefit from night ventilation cooling the massive materials. See Section 2.1 and Section 2.2.3 for further detail on night ventilation and high heat storage materials.

Strategies are tabulated in the order of effectiveness ((i) being the most effective).

Table 18: Comparison of different strategies in an Arid context, Jordan

	Strategy	Detail	Average Temperature reduction	Maximum Temperature reduction
i)	Desert Cooler	Run on a solar panel. Consumes 0.6 l water/hour when in operation	2.4 °C	5.2 °C
ii)	High Heat Storage Materials	Wall cavity filled with 3000 kg sand and gravel + 11000 kg sandbags cladded internally	1.3 °C	4.7 °C

	Strategy	Detail	Average Temperature reduction	Maximum Temperature reduction
iii)	High Heat Storage Materials	Wall cavity filled with 3000 kg sand and gravel	1.2 °C	3.7 °C
iv)	Roof Shading + Roof Cowls + Ground Cooling + Wall, Roof, and Door Insulation	Roof shading placed 150 mm above the existing roof. Fan driven under floor vents. Wall and roof Insulation (15 mm thick existing + 30 mm thick foil-faced EPS additional). Door insulation (45 mm foil-faced EPS)	-0.1 °C (increase in temperature)	3.7 °C
v)	Wall and Roof Insulation + Roof Shading	40 mm XPS insulation. Roof shading placed 300 mm above existing roof	-0.6 °C (increase in temperature)	3.3 °C
vi)	Wall, Roof, and Door Insulation	15 mm thick existing + 30 mm thick foil-faced EPS additional for walls and roof. 45 mm foil-faced EPS for door.	0.3 °C	-1.3 °C (increase in temperature)
vii)	Roof Shading	150 mm above existing roof	0.3°C	-1.2°C (increase in temperature)
viii)	Natural Ventilation	Roof and low-level vents fitted	0.0°C	0.2°C

Conclusions:

- Best performing: desert cooler
- Best performing passive strategy: high heat storage materials
- Shading techniques were not adequately explored for better results
- Shading techniques work well when used with other techniques, such as insulation

3.2.4 Comparative study in three different climates

Window Shading, Natural Ventilation, High Storage Materials and Cool Painting

- **Climate (Location):** Tropical (Mumbai, India), Subtropical (Nairobi, Kenya), Mediterranean (Porto, Portugal).
- **Reference:** [19]
- **Background:** The study was based in three different climates for a prefabricated building.

Table 19: Comparison of strategies in three different climates

	Strategy	Detail	Temperature reduction of average 5% highest temperatures		
			Tropical	Subtropical	Mediterranean
i)	Window Shading		2.9 °C	2.6 °C	2.8 °C
ii)	Natural Ventilation	Wind-driven and stack ventilation. Windows were opened	2.4 °C	3.8 °C	2.9 °C
iii)	High Heat Storage Materials	Increase in thickness of gypsum plaster (10 mm thick existing + 20 mm additional)	1.0 °C	1.0 °C	0.9 °C
iv)	Cool Painting	Painting roofs and walls (reflectance of paint was similar to white paint)	1.2 °C	0.9 °C	1.0 °C
v)	Combination of all strategies		5.2 °C	5.7 °C	5.5 °C

Conclusions:

- The best performing strategy was a combination of all strategies
- The best performing strategy for each climate is:
  - **Tropical:** window shading
  - **Subtropical:** natural ventilation
  - **Mediterranean[27]:** increase in thickness of gypsum plaster
- Cool painting was found to be very effective in reducing the surface temperature - the maximum surface temperature was reduced by 8.9°C in Porto – data for other climates is not available. It should be noted that values in the table represent air temperature.

3.2.5 Comparative study of insulation and cool painting (Tropical)

Wall insulation, Improved Windows, Cool Painting

- **Climate (Location):** Tropical (Malaysia).
- **Reference:** [55]
- **Background:** The study was based in an office seminar room with air-conditioners on and 20 occupants.

Strategies are tabulated in the order of effectiveness ((i) being the most effective).

Table 20: Comparison of strategies in a tropical context

	Strategy	Detail	Temperature reduction	Return on Investment / months
i)	Combination of all strategies		0.98 °C	
ii)	Wall Insulation	50 mm thick polystyrene	0.81 °C	25
iii)	Improved Windows	Low-e glazing	0.36 °C	25
iv)	Cool Painting	White painted roof	0.11 °C	58

Conclusions:

- **Effectiveness** in reducing temperature: a combination of all strategies > Wall insulation > Low-e glazing > White painted roof
- **Lowest cost of implementation:** combination of all strategies > White painted roof > Low-e glazing > Wall insulation >
    - White paint needs repainting every 5 years
    - **Most cost effective and highest temperature reduction:** wall insulation
    - **Best performing:** combination of strategies

3.2.6 Comparative study of four strategies in China (Subtropical)

- **Climate (Location):** Subtropical (Chengdu City, China).
- **Reference:** [126]
- **Background:** The study was based in a prefabricated house for disaster relief.

  The study used four strategies: external window blinds, shading screens on north and south walls, roof shading and wall shading using thin, highly reflective fabrics that could be removed in winters.

Strategies are tabulated in the order of effectiveness ((i) being the most effective).

Table 21: Comparison of four studies in a subtropical context

	Strategy	Detail	% reduction in unacceptable hours (when temperature is above 28 °C)
i)	Window Shading + Wall Shading + Roof Shading	Window Blind + Screen + Wall fabric + Roof fabric	38.6%
ii)	Window Shading + Wall Shading + Roof Shading	Window Blind + Wall fabric + Roof fabric	38.2%
iii)	Wall Shading + Roof Shading	Screen + Wall fabric + Roof fabric	35.9%

	Strategy	Detail	% reduction in unacceptable hours (when temperature is above 28 °C)
iv)	Wall Shading + Roof Shading	Wall Fabric + Roof fabric	28.6%
v)	Window Shading + Wall Shading	Window Blind + Screen + Wall fabric	27.7%
vi)	Window Shading + Wall Shading	Window Blind + Wall fabric	26.4%
vii)	Wall Shading	Screen + Wall fabric	25.3%
viii)	Window Shading + Wall Shading + Roof Shading	Window Blind + Screen + Roof fabric	20.0%
ix)	Wall Shading + Roof Shading	Screen + Roof fabric	17.3%
x)	Window Shading + Roof Shading	Window Blind + Roof fabric	17.3%
xi)	Wall Shading	Wall fabric	18.6%
xii)	Window Shading + Wall Shading	Window Blind + Screen	12.3%
xiii)	Roof Shading	Roof fabric	9.1%
xiv)	Wall Shading	Screen	9.1%
xv)	Window Shading	Window Blind	8.6%

Conclusions:

- **Best performing strategy:** combination of all strategies
- **Best performing single strategy:** wall shading (with wall fabric)

3.3 Methodology

Overview:

A thorough literature review was conducted that consisted of published literature (primarily researched through the Google Scholar search engine) and grey literature from reputable sources. The reputable sources were organisations such as the World Health Organization (WHO), UN-Habitat, Global Alliance for Disaster Risk Reduction & Resilience in the Education Sector (GADRESS), and the Intergovernmental Panel on Climate Change (IPCC), among others. Other sources also include those shared by experts in the expert group (see Acknowledgements).

As a result, the document benefits from a diverse array of sources including peer-reviewed journal articles and conference proceedings that present empirical research (e.g., Energy and Buildings, Applied Thermal Engineering), and documents from governmental (e.g., US Department of Energy) and non-governmental organisations providing guidelines on energy consumption and health impacts. Additionally, it includes online resources and tools for performance analysis (e.g., Ubakus, ShelTherm), and industry guidelines from professional organisations.

Over 170 sources are cited, some of which are indirect citations referenced in other sources. Excluding web pages, at least 60 direct citations have been thoroughly studied and referenced. The resources were organised using Zotero and on a Miro board for analysis.

Research process:

1. The initial scope was expanded to briefly include active cooling strategies as well as those for temporary facilities. At the initial stages keywords were targeted to cast a wide net to get a general idea of all passive cooling strategies that were mentioned in the literature. This approach did not aim to go into specifics of the strategies but only to provide an overview of the different strategies. The approach was to look at review papers of passive cooling. Some of the initial keywords were (but are not limited to) the following: *Passive, cooling, strategies, methods, schools, clinics, hospitals, healthcare facilities, guidance, review, guidance, low-cost.*
2. Then the search criterion was specified according to specific strategies and other constraints such as climatic, low-cost etc. *e.g., Natural ventilation in hospitals.*
3. As clarity was developed for different strategies, further research was required that targeted specific questions based on the strategy. *e.g., Condensation in hot-humid climates*

4. The output of this literature review was a draft document. This was reviewed by an expert advisory group, with specific reference to the accuracy of the content. Suggestions of the advisory group were incorporated into the draft.
5. The revised draft document was then field tested in two locations (Mali and Central African Republic) by a medical organisation (International Medical Corps) through a project in which they chose passive strategies and incorporated them into buildings. The field test was primarily to test relevance, comprehensibility and utility. Suggestions from the pilot group were then incorporated into the final version of the document.

4 Glossary

Cooling requirement	the amount of cooling that is required to provide a comfortable environment in a building. In this document, the cooling requirement has been used mostly as an indicator of how effective the cooling strategy is.
Conduction	the process by which heat energy is transmitted through collisions between neighbouring molecules, requiring direct contact between materials.
Convection	the transfer of heat through a fluid (liquid or gas) caused by molecular motion, often occurring in the air within buildings.
Diurnal temperature difference	the difference between the night-time and day time temperatures
Emissivity	the ability of a material to emit thermal energy.
Heat Transfer	the movement of thermal energy from one object or medium to another, typically through conduction, convection, or radiation.
Heat sink	something that absorbs and removes heat to keep things cool.
High pressure zone	characteristic of cool air. Air in a high-pressure zone is denser and heavier, so it sinks toward the ground.
Insulation	materials used to reduce the rate of heat transfer between the inside and outside of a building, enhancing energy efficiency and comfort.
Low pressure zone	characteristic of warm air. Air in a high-pressure zone is lighter and less dense so it rises.

Mean Radiant Temperature (MRT)	the average temperature of all surfaces surrounding a person, including walls, floors, and objects.
Radiant Barrier	a highly reflective material that is used to reflect radiant heat.
Radiant Heat	heat that travels in waves, like sunlight warming your skin or a campfire making you feel warm without touching it.
Radiation	the transfer of heat in the form of electromagnetic waves, which can occur even in a vacuum (e.g., heat from the sun reaching the Earth).
Solar Gain / Heat Gain	the increase in temperature in a space resulting from solar radiation.
Thermal Mass	the ability of a material to absorb, store, and release heat. High thermal mass materials (like concrete and brick) can stabilise indoor temperatures by moderating temperature swings.

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End notes

1. The IPCC AR6 report forecasts a more than 8 times increase in extreme heat events (that in the pre-industrial period would have occurred once in 50 years) when global average temperatures reach 1.5 degrees above the pre-industrial average - this is currently projected to occur at some point in the 2030s. IPCC 2021.
2. Maps of the world showing the different Koppen areas are easily found on the internet, for example at https://koppen.earth/.https://koppen.earth/
3. Transitional considers bamboo framed/adobe brick transitional buildings.
4. High heat storage and insulation are both particularly effective when combined with strategic ventilation. Note, however, that insulation may not be compatible with high heat storage.
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6. High heat storage and insulation are both particularly effective when combined with strategic ventilation. Note, however, that insulation may not be compatible with high heat storage.
7. Sandbags are generally low cost. However, in field tests in Mali hessian bags were not available, so in this context were a 'specialised input' and very expensive.
8. Although not a passive cooling strategy, Desert coolers (see Section 2.9) have been found to perform very well in hot dry climates.
9. The strategies compared were window shading, vegetation, natural ventilation, using high heat storage materials, improved windows, insulation, cool painting, and roof shading.
10. The only strategy that performed better was an active cooling strategy, a direct evaporative cooler/desert cooler.
11. The different strategies compared were window shading (best performance in Tropical climate), natural ventilation (best performance in Subtropical climate), using high heat storage materials (best performance in Mediterranean climate), and cool painting.
12. The higher the Heat Storage Capacity of a material, the better the material is at storing heat. The table provides values for typical thicknesses for ease of comparison. In case a different thickness than the typical one provided is required, divide the Heat Storage Capacity with the typical material thickness provided and multiply it with the required thickness (in millimetres). E.g. If, instead of 20 mm cement plaster (typical thickness mentioned), 10 mm cement plaster is required. Heat Storage capacity = 30 kJ/(m^2.K) x 10 mm / 20 mm, which gives 15 kJ/(m^2.K) for 10 mm cement plaster. The units are kJ/(m^2.K) which measures how much heat energy, in kilojoules (kJ), is required to change the temperature of a square meter of a material (m^2) by 1 Kelvin (K).

13. Hot air creates an area of low pressure while cool air creates an area of high pressure. Wind flows from an area of high pressure to an area of low pressure.

14. The different strategies compared were window shading (best performance in Tropical climate), natural ventilation (best performance in Subtropical climate), using high heat storage materials (best performance in Mediterranean climate), and cool painting.

15. In the study, the awning window had a maximum opening angle of 30 degrees.

16. High humidity can be caused by two main reasons, humid outdoor air drawn in at night in humid climates, and heat and moisture from the occupants trapped inside during the day when the windows are closed [21] – the latter is particularly true for dense occupancies such as wards

17. The strategies compared were window shading, vegetation, natural ventilation, using high heat storage materials, improved windows, insulation, cool painting, and roof shading.

18. More precisely, the *paints* are elastomeric coatings while plaster/renders are cementitious coatings. For further detail see [108].

19. The strategies that performed better (in order of effectiveness) were insulation with night ventilation, using high heat storage materials with night ventilation, (only) night ventilation, and vegetation.

20. The strategies that performed better (in order of effectiveness) were insulation with night ventilation, using high heat storage materials with night ventilation, (only) night ventilation, vegetation, and cool painting.

21. The strategies that performed better (in order of effectiveness) were insulation with night ventilation, using high heat storage materials with night ventilation, and (only) night ventilation.

22. The strategies that performed better (in order of effectiveness) were insulation with night ventilation, using high heat storage materials with night ventilation, (only) night ventilation, vegetation, cool painting, and roof shading.

23. The different strategies were compared were window shading (best performance in tropical climate), natural ventilation (best performance in subtropical climate), using high heat storage materials (best performance in Mediterranean climate), and cool painting.

24. All the strategies compared in the study were shading strategies. These were wall shading by a wall fabric, external window blinds, shading screens on north and south walls, and roof shading using thin, highly reflective fabrics that could be removed in winters.

25. The strategies compared were window shading, vegetation, natural ventilation, using high heat storage materials, improved windows, insulation, cool painting, and roof shading.

26. The strategies compared different types of roof insulation and wall insulations, improved windows, and floor insulation combined with high heat storage material in the floor.

27. The strategies compared in the study were insulation, cool painting, and improved windows.

28. The R values given in this document are R values for a material thickness of 25 mm (1 inch). Although the R value is an imperial unit, and this document uses metric units, the R value is a more globally recognised unit than its metric counterpart (the RSI value) and is more likely to be encountered by humanitarian workers. The units are $ft^2 \cdot °F \cdot h)/BTU$, where ft^2 = square feet (area), °F = degrees Fahrenheit (temperature), h = hours (time), BTU = British Thermal Units (energy).

29. For example, see [159], Study on moisture condensation on the interior surface of buildings in high humidity climate.

30. All the strategies that were compared in the study were insulation, high heat storage materials, roof, shading, and an active cooling system.

31. There is only a slight improvement when thermal mass is increased by 4 times from 3000kg (ii) to 14000kg (iii) - so the return on investment is better for 3000kg than the 14000 kg.

32. Insulation increased the average temperature because it reduced the effectiveness of night ventilation (Section 2.2.3) which highlights the importance of combining different strategies [42].

33. Semi-arid climates may be comparable to Mediterranean climates as they similarly have a higher diurnal temperature variation and cold winters, so although high heat storage materials did not produce the highest reduction in temperature, they also contributed to winter comfort.

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