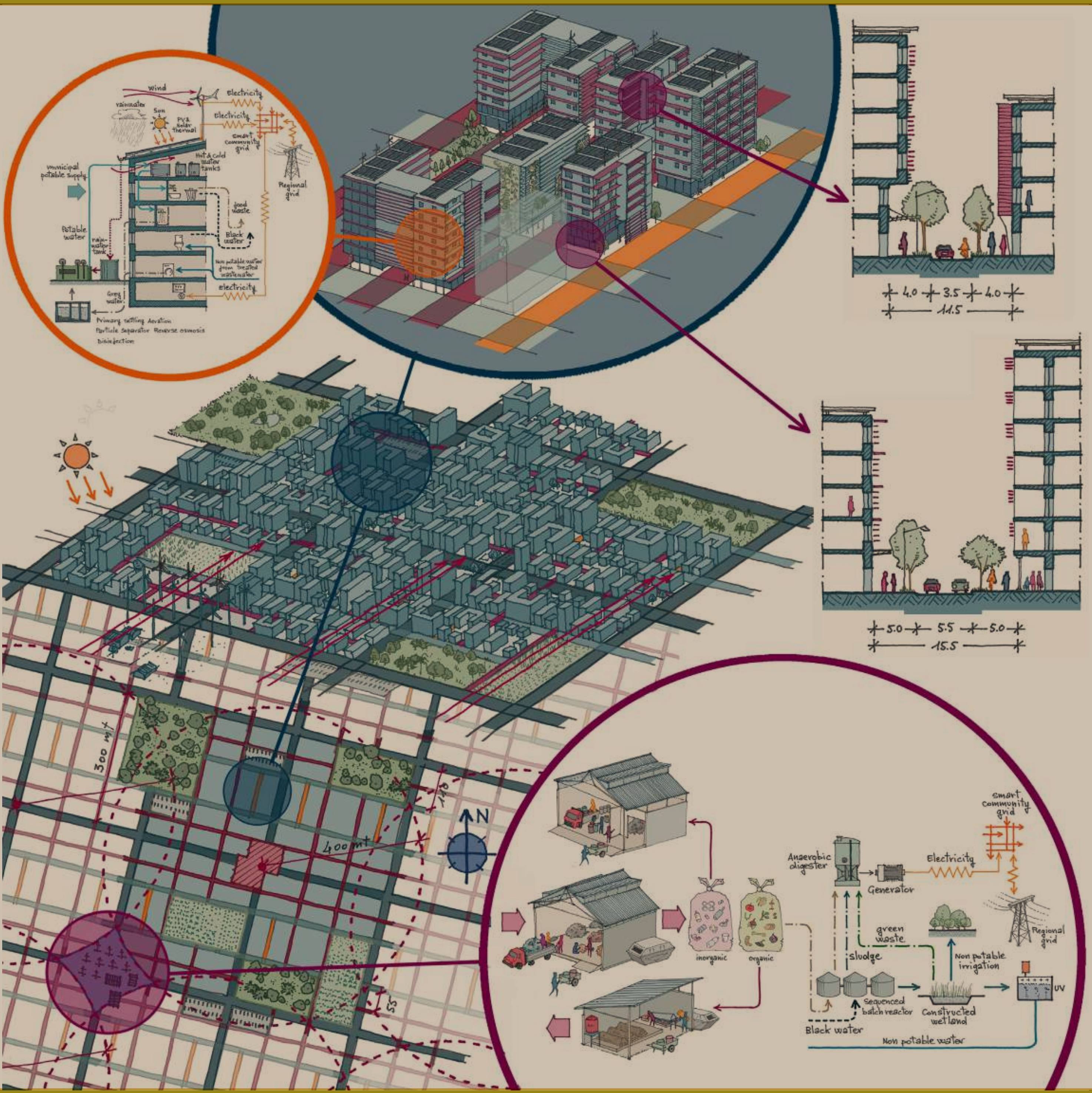
# ENERGY AND RESOURCE EFFICIENT URBAN NEIGHBOURHOOD DESIGN PRINCIPLES FOR TROPICAL COUNTRIES

## Practitioner's Guidebook



UN-HABITAT
FOR A BETTER URBAN FUTURE

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# THE CITY WE AIM FOR

A city reducing emissions of greenhouse gases from all relevant sectors, consistent with the goals of the Paris Agreement adopted under the United Nations Framework Convention on Climate Change, including holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.

A city with equitable and affordable access to sustainable basic physical and social infrastructure for all, without discrimination, including affordable serviced land, housing, modern and renewable energy, safe drinking water and sanitation, safe, nutritious and adequate food, waste disposal, sustainable mobility, health care and family planning, education, culture, and information and communications technologies.

A city supporting sustainable management and use of natural resources and land, polycentrism and mixed uses, appropriate compactness and density to prevent urban sprawl and reduce mobility challenges and needs.

A city with safe, inclusive, accessible, green, good quality public spaces, including streets, sidewalks and cycling lanes, squares, waterfront areas, gardens and parks, which are multifunctional areas for social interaction and inclusion, human health and well-being, economic exchange, and cultural expression and dialogue among a wide diversity of people and cultures.

A city resilient to disasters and climate change, including floods, drought and heat waves.

A city achieving the conservation and sustainable use of water by rehabilitating water resources within the urban, peri-urban and rural areas, reducing and treating wastewater, minimizing water losses, promoting water reuse and increasing water storage, retention and recharge, taking into consideration the water cycle.

A city achieving environmentally sound waste management and substantially reducing waste generation by reducing, reusing and recycling waste, minimizing landfills and converting waste to energy when waste cannot be recycled or when this choice delivers the best environmental outcome.

A city supporting urban agriculture and farming, as well as responsible, local and sustainable consumption and production, and social interactions, as an option for contributing to sustainability and food security.

A city adopting a smart-city approach, which makes use of opportunities from digitalization, clean energy and technologies, as well as innovative transport technologies, thus providing options for inhabitants to make more environmentally friendly choices, boosting sustainable economic growth, and enabling cities to improve their service delivery.

A city prioritizing smart-grid, district energy systems and community energy plans to improve synergies between renewable energy and energy efficiency.

A city facilitating a social mix through the provision of affordable housing options with access to good quality basic services and public spaces for all, enhancing safety and security, favouring social and intergenerational interaction and the appreciation of diversity.

A city of well-designed networks of safe, accessible, green, good quality streets and other public spaces that are accessible to all, allowing for the best possible commercial use of street-level floors, fostering both formal and informal local markets and commerce, as well as not-for-profit community initiatives, bringing people into public spaces, and promoting walkability and cycling with the goal of improving health and well-being.

A city ensuring accessible and sustainable infrastructure and service provision systems for water, sanitation and hygiene, sewage, solid waste management, urban drainage, reduction of air pollution and storm water management.

*According to: Habitat III Conference, New Urban Agenda Quito Declaration on Sustainable Cities and Human Settlements for All, Oct. 2016*

# 01 INTRODUCTION

Roughly half of the world's population lives in urban areas, and this proportion is projected to increase to 66% by 2050, adding 2.5 billion people to the urban population. Over the next two decades, nearly all the world's net population growth is expected to occur in urban areas, with about 1.4 million people – close to the population of Stockholm – added each week (New Climate Economy 2014). With the current trend in urban density, this is equivalent to building a city the size of Greater London every month for the next 40 years (UN-Habitat 2013a). If current development trends continue, by 2030 cities in developing countries are expected to occupy triple the land area they occupied in 2005 (UN-Habitat, 2012).

Almost 90% of the global urbanization between now and 2050 will occur in Asia and Africa (United Nations, 2014); in sub-Saharan Africa the proportion of urban dwellers is projected to increase from 37% of the total population in 2010 to nearly 60% in 2050 (OECD-FAO, 2013). This means that in Eastern Africa for example, the total number of urban dwellers in 2040 is expected to be five times that of 2010 (UN-Habitat 2014).

Urban areas generate around 70% of global energy use and energy-related Green House Gas (GHG) emissions (IEA 2009), thus cities in the developing world, where most of the growth will take place, will have a significant impact on GHG emissions, seriously threatening any effort to reduce them – unless new urban developments are designed to minimise their impact.

Current models of human settlements are not designed to cope with the environmental challenges and are not sensitive to the rapid technological advancements from which our built environment could benefit. New real estate developments at the neighbourhood scale are producing a silent and uncontrolled urban revolution. Taken alone, small-scale housing developments might not be perceived as relevant, but if added together these new urban estates are shaping the image of the majority of megalopolises and cities in developing countries. In fact, new developments often happen to be simply "add-ons" to existing cities, with neither coherent integration into the city plan nor the principles that should lead to a sustainable urban future. Recent developments of new neighbourhoods and districts are here to stay and will affect energy patterns, the image of society and lifestyles for many decades.

The design of new urban developments is a key issue for coping with global warming and the quality of urban life, and, bearing in mind that urban design principles that apply to cities in tropical climates differ significantly from the principles that apply to cities in temperate climates, it is a burden shared by both developed and developing countries.

## 1.1 CITIES AND GREEN HOUSE GAS EMISSIONS

Urban density is a critical but controversial factor in sustainable urban design, as the issue of its impact on Green House Gas (GHG) emissions is a complex one.

On the one hand, it is recognised that urban density is inversely correlated with transport energy consumption, and $CO_2$ emissions: the higher the density the lower the energy consumption (Kenworthy 2008; Lefèvre 2009; UN-Habitat 2013a). Density is also inversely correlated with energy consumption for space heating and cooling, because the higher the density, the lower a building's surface to volume ratio. Furthermore, density is related to land consumption, which affects $CO_2$ emissions: the higher the density, the lower the land consumption, i.e. the lower the amount of land converted from green to built, with consequently lower emissions, because vegetation acts as a carbon sink by absorbing $CO_2$.

On the other hand, urban density is also positively correlated to the Urban Heat Island (UHI) (Oke 1973): the higher the density, the more intense the UHI, decreasing outdoor comfort and increasing energy consumption, and $CO_2$ emissions for space cooling. Also, the greater the number of people who live in an area, the higher the energy consumption due to domestic appliances and hot water use.

The challenge for the urban designer is to recognise these contradictions, and find the optimum balance. Factors affecting GHG emissions that can be controlled by appropriate urban design are:

- *Transportation*, which is affected by density and land use. Mixed land use is a prerequisite for reducing transport-related GHG emissions, as it improves walking and cycling mobility and promotes public transport, thus reducing the use of private cars. Mixed land use could also provide other benefits, such as greater accessibility to services for more people, diversification of the social and economic texture (i.e. social inclusion and no spatial segregation), reduction of land used for roads and parking, enhancement of local economic activities and employment, etc. The issue of mixed land use is closely correlated with the social and economic mix.

- *Urban texture and layout* (building height, street width and orientation, colour of materials, amount and spatial distribution of green areas, etc.), which affect the UHI. Green areas are important not only because they contribute to the mitigation of the UHI, but also because they are carbon sinks. Green areas include urban and peri-urban agriculture, which can play a major role in promoting soil carbon sequestration, recycling of organic waste through composting, and in encouraging the reuse of wastewater. This could also contribute to energy savings as locally grown food reduces the need for transport and refrigeration requirements.

### 1.1.1 URBAN SERVICES

GHG emissions in a city derive not only from the building, transport, and industry sectors, but also from solid waste, water and wastewater management[1]. Appropriate focus on these issues is the key to designing low emission cities.

When a new urban development in a developed country is being designed, it is taken for granted that it will be connected to the existing city's electric grid, water network, sewage system, gas network, solid waste collection and disposal system, and transport system.

The existence of such facilities makes it easier to build and inhabit the new development progressively and leaves the responsibility of providing the services to the utilities.

In cities in developing countries, on the other hand, these facilities are often not efficient or reliably available, or are not available at all, thus a new development should be planned and designed with these issues in mind and distributed energy generation, local water supply and local stormwater, wastewater and solid waste treatment systems should be included in the design.

The integration of the energy issue into urban design affects the entire metabolism of the settlement, i.e. energy consumption of buildings, mobility, water and waste cycles.

In a new settlement (whether it be a planned city extension or infill development or urban transformation) located in a developing country, the new approach of distributed generation of energy, maximising the use of renewable sources and supported by smart grid technologies, is going to be a viable alternative to the centralised approach characteristic of the energy supply system of existing cities, because it may well suit rapidly expanding cities. The fast decreasing cost of both PV panels and batteries is making the production of renewable-based decentralised energy cheaper than the fossil-fuel-based centralised production found in developing countries as it avoids the need for new transmission lines and the construction of power stations. In the coming decades the balance between energy demand and renewable energy supply at neighbourhood or district scale will be a prerequisite for sustainable (environmentally, economically and socially) urban development both in developing and developed countries.

Since the past century a linear, centralised approach has been applied to all the resource flows feeding cities. Energy is produced in distant power stations, transported and then distributed. Water is piped from far away sources[2] to a treatment plant to make it potable and is then distributed to all the users, regardless of whether the final use requires it to be potable. So, precious potable water is used for watering plants, for flushing WCs, for washing laundry, cars and streets.

Once used, water becomes blackwater and greywater. These two flows are usually mixed and often when it rains runoff water is also added, and it all goes to a single, large wastewater treatment plant, which can be nearby or far away, to make the water clean enough to be poured into a river, a lake or the sea.

Food is produced somewhere, either nearby or far away, transported to the main vegetable, fish, or meat markets and from there distributed. Some of the food entering the city is wasted, both before and after cooking. This waste constitutes the organic part of the municipal waste which, in the majority of cities in developing countries, is sent to landfill, where it undergoes a natural process of anaerobic fermentation, releasing methane into the atmosphere and so contributing to global warming, since methane is a powerful greenhouse gas[3].

Decentralised energy, water and waste management systems, and decentralised food production are being more and more recognised as prerequisites for sustainable urban development, for many reasons; inter alia (Parkinson 2003):

- decentralised approaches may also offer increased opportunities for local stakeholder participation in planning and decision-making;
- decentralised planning and decision-making offers potential benefits relating to increased responsiveness to local demands and needs and, hence, increased willingness of communities to pay for improved services;
- decentralised management systems may achieve a better distribution of benefits than more centralized management approaches.

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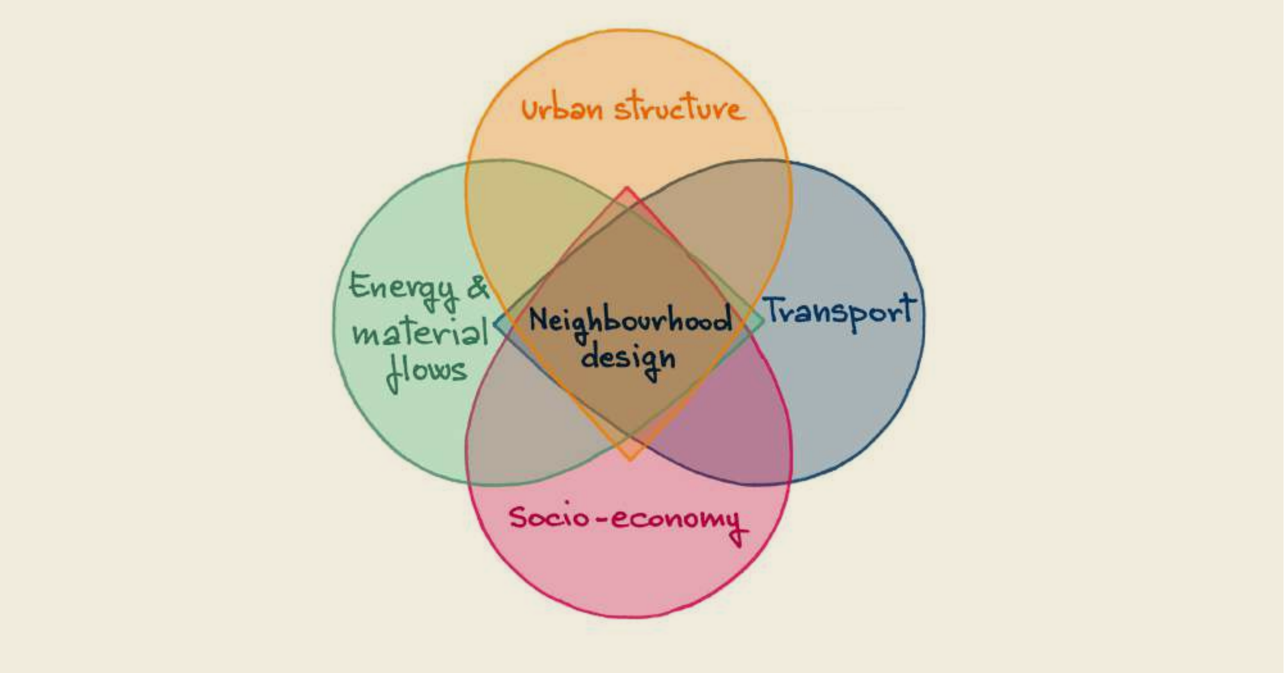
[1] *Water and wastewater services are a key component of urban areas, and could represent a large share of the energy consumption of a city, and consequently of its budget. The elements in water and wastewater systems that require energy are raw water extraction and treatment, distribution of clean water, collection and treatment of wastewater*

[2] *In some places water pumped from wells around the city is also added.*

[3] *Methane from waste disposal in landfills represents 12% of total global methane emissions (The World Bank 2010).*

FIGURE 1.1 **INTEGRATED DESIGN COMPONENTS OF A SUSTAINABLE NEIGHBOURHOOD (ADAPTED FROM: GAFFRON 2005)**



### 1.1.2 SUSTAINABLE URBAN DESIGN: CONCEPTUAL PILLARS

When designing a sustainable urban development, the designer should bear in mind that:

- a prerequisite for reaching the goal of limiting global temperature increase to 2 °C by the year 2050 is that new developments should aim for zero emissions;
- key drivers of GHG emissions are density, urban layout and texture, land use mix, energy, water and waste management systems, food production;
- form and infrastructure[4] significantly affect not only direct (operational), but also indirect (embodied) GHG emissions[5]; and that
- a systems perspective must be adopted, as all these factors are interrelated and interdependent.

But this is not enough, because the pressure of a growing urban population on natural resources such as water and ecosystems is so high that future development must be more than just "zero emissions": they must be sustainable and resilient.

## 1.2 THE NEIGHBOURHOOD SCALE

As decentralisation is a prerequisite for sustainable urban development, the incorporation of sustainability principles in neighbourhood design becomes crucial, for several reasons. First, the neighbourhood is the basic unit of the urban organism. Second, the problems presently encountered at city level are the cumulative consequences of poor planning at the neighbourhood level (Engel-Yan 2005). Third, neighbourhood scale development is also a relatively typical form of development, both for private real estate developers and for public interventions. Fourth, efficient and sustainable urban infrastructure, including buildings, transportation, urban vegetation, and water (i.e., water supply, wastewater, and stormwater) systems require detailed design at neighbourhood scale, not at the city scale. Fifth, decisions made at the neighbourhood scale are highly pertinent to quality of life.

### 1.2.1 FEATURES OF A SUSTAINABLE NEIGHBOURHOOD

According to UN-Habitat's Five Principles (UN-Habitat 2013c), a sustainable neighbourhood is characterised by:

1. Adequate space for streets and an efficient street network
2. High density
3. Mixed land-use
4. Social mix
5. Limited land-use specialization

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[4] *Infrastructure comprises services and built- up structures that support the functions and operations of cities, including transport infrastructure, water supply systems, sanitation and wastewater management, solid waste management, drainage and flood protection, telecommunications, and power generation and distribution.*

[5] *The production of infrastructure materials such as concrete and metals is energy and carbon intensive. For example, the manufacturing of steel and cement, two of the most common infrastructure materials, contributed to nearly 9% and 7%, respectively, of global carbon emissions in 2006. (IPCC 2014).*

When the Five Principles are followed, the urban structure is appropriately shaped, and both the transport and the social issues are addressed. To complete the picture, features related to energy and materials, to water and waste must also be added (see Figure 1.1), to encompass the metabolism of the whole neighbourhood, as shown in the next section.

### 1.2.2 INTEGRATED NEIGHBOURHOOD DESIGN

The realisation of a sustainable neighbourhood relies on a multifaceted and integrated design approach.

Infrastructures are usually designed independently by specialists in the individual areas (e.g., transportation, water distribution, wastewater treatment, or building design), without any mutual interaction. Sustainable neighbourhood design, however, requires the understanding of such mutual interactions, i.e. it requires a different, integrated, design process where the infrastructure systems are designed as a whole, and where the connections between the neighbourhood and the greater urban region are also considered, as several design constraints have roots beyond the neighbourhood scale. Neighbourhoods do not exist in isolation, but rather have many interactions with the larger urban system to which they belong.

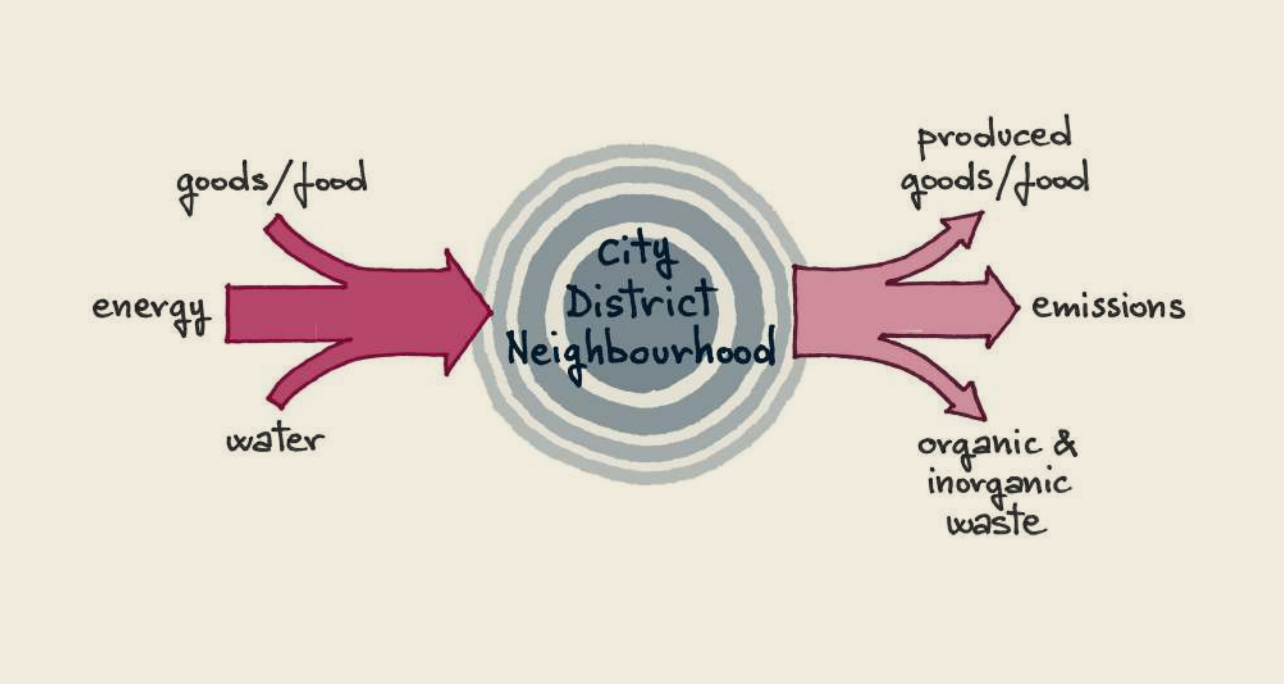
Sustainable neighbourhood design is a holistic concept requiring the integrated design of energy, transportation, water, and building infrastructures, as well as urban greening; but this is not all. An optimal solution must also aim for social equity and economic viability, and both must be included in the sustainable neighbourhood design process, which should promote social inclusion and economic activities, while bearing in mind that urban infrastructures last for decades, and so their economic viability cannot be evaluated in short time spans.

Designing such a neighbourhood requires an interdisciplinary design team. It requires the collaboration of landscape architects, engineers, urban planners, ecologists, bacteriologists, transport planners, physicists, psychologists, sociologists, economists and other specialists, in addition to architects and urban designers. In designing a sustainable neighbourhood, "every effort must be made to minimize the use of energy, water and materials at each stage of the city's or district's life-cycle, including the embodied energy in the extraction and transportation of materials, their fabrication, their assembly into the buildings and, ultimately, the ease and value of their recycling when an individual building's life is over" (Lehmann 2010).

## 1.3 FROM LINEAR TO CIRCULAR METABOLISM

"The notion of urban metabolism is loosely based on an analogy with the metabolism of organisms, although in other respects parallels can also be made between cities and ecosystems. Cities are similar to organisms in that they consume resources from their surroundings and excrete wastes.

FIGURE 1.2 **THE METABOLISM OF A HUMAN SETTLEMENT (ADAPTED FROM: ROGERS 1997)**



Thus, the notion that cities are like ecosystems is also appropriate. Indeed, the model of a natural ecosystem is in some respects the objective for developing sustainable cities. Natural ecosystems are generally energy self-sufficient, or are subsidized by sustainable inputs, and often approximately conserve mass, through recycling by detritivores. Were cities to have such traits, they would be far more sustainable" (Kennedy 2010).

A human settlement, in order to live, grow and prosper, needs to be fed with energy, goods, food and water. These flows are processed and consumed, i.e. metabolised, in the city, and the products of the metabolism are emissions, inorganic and organic wastes, and wastewater.

The metabolism of today's cities is generally linear, i.e. the inputs crossing their borders are distributed inside them and used to keep all the functions working; then, after their use, they are disposed of as waste (inorganic, organic and emissions) outside the borders; in this model, the development and the growth of cities is accompanied by a corresponding increase in the inputs and, consequently, in waste. It should be noted, however, that not all the products of the metabolism are waste: in a city some productive processes take place, and some goods and/or food cross the borders towards the outside environment, to become input for other settlements.

This linear production path of inputs and outputs, as shown in Figure 1.2 is not sustainable as cities continue to grow. The linear "Take - Make – Dispose" lifestyle of our cities increasingly depletes finite natural reserves producing wastes in quantities that the environment is not capable of absorbing without damage.

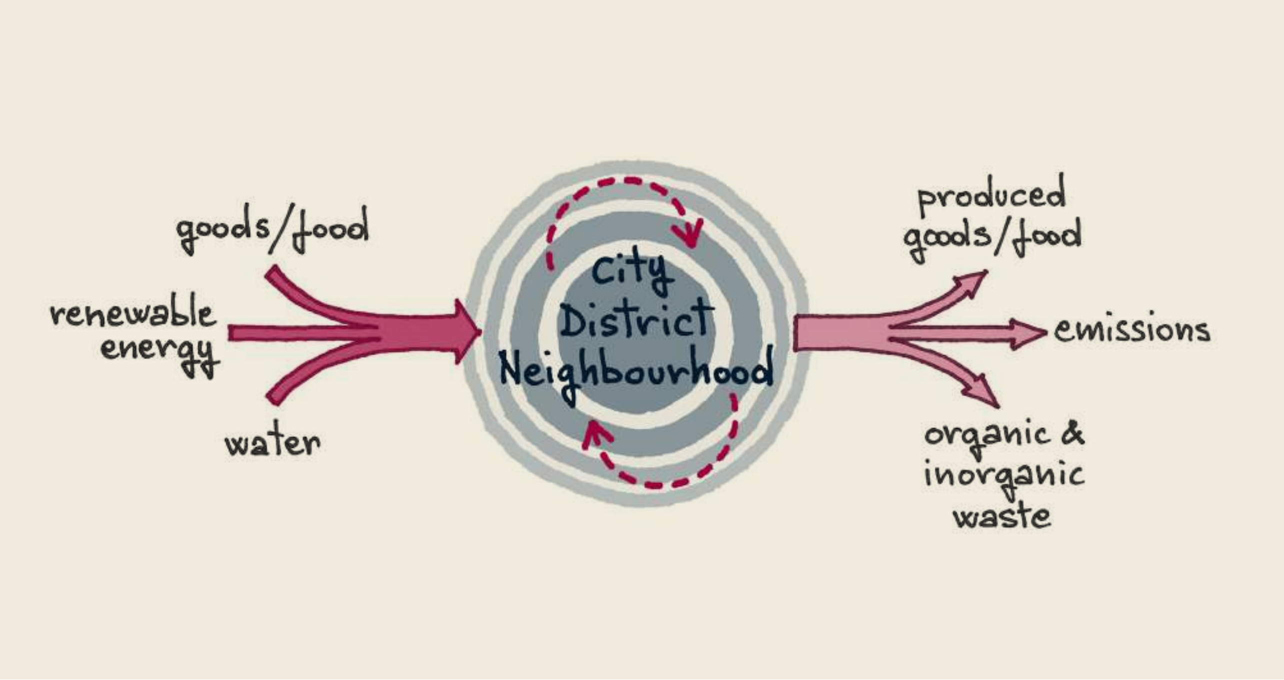
A new model of urban metabolism is needed that reduces resource consumption and waste production simultaneously, it needs to be the metabolism of a sustainable city.

A sustainable city should reduce to a minimum dependence on the input flows by maximising dependence on local, small scale, reliable production of energy and food, and by maximising reuse/recycling (Figure 1.3) of water and goods. This implies: decentralised energy production mainly from renewable energy sources coupled with energy efficient buildings and appliances; improved efficiency of the transport system for goods and people, substituting private-car-based mobility with a mobility based on public transport, car sharing, bicycles and walking (supported by a "mixed use" planning policy); urban and peri-urban gardens for food production; optimised water cycle coupled with energy production from wastewater; reduction of the flow of goods through their maintenance, repair and reuse, according to the concept of a circular economy - with the consequent reduction of waste; all this in a polycentric urban structure, which allows a more efficient management of material and people flows around local centralities (based, for example, on transit oriented developments and local energy production and distribution systems).

### 1.3.1 THE CITY AS A NEGENTROPY PROCESSOR

The most comprehensive way of analysing a complex system, such as an ecosystem or settlement, is to consider it as a thermodynamic system far from equilibrium (Allen 1998; Butera 1998).

FIGURE 1.3 **SUSTAINABLE PHYSICAL URBAN METABOLISM CIRCULAR (ADAPTED FROM: ROGERS 1997)**



In a settlement seen as thermodynamic system, its complex metabolism, diversified into several components, is reduced to a process in which high-grade, high quality energy (negentropy) is transformed into low grade, low quality waste (high entropy).

The advantage of the thermodynamic approach is that the concept of negentropy (high grade, low entropy flows) degraded into high entropy ones, applies not only to the energy flow entering the urban system or subsystems, but can be extended to the water flow and to the flow of goods and food.

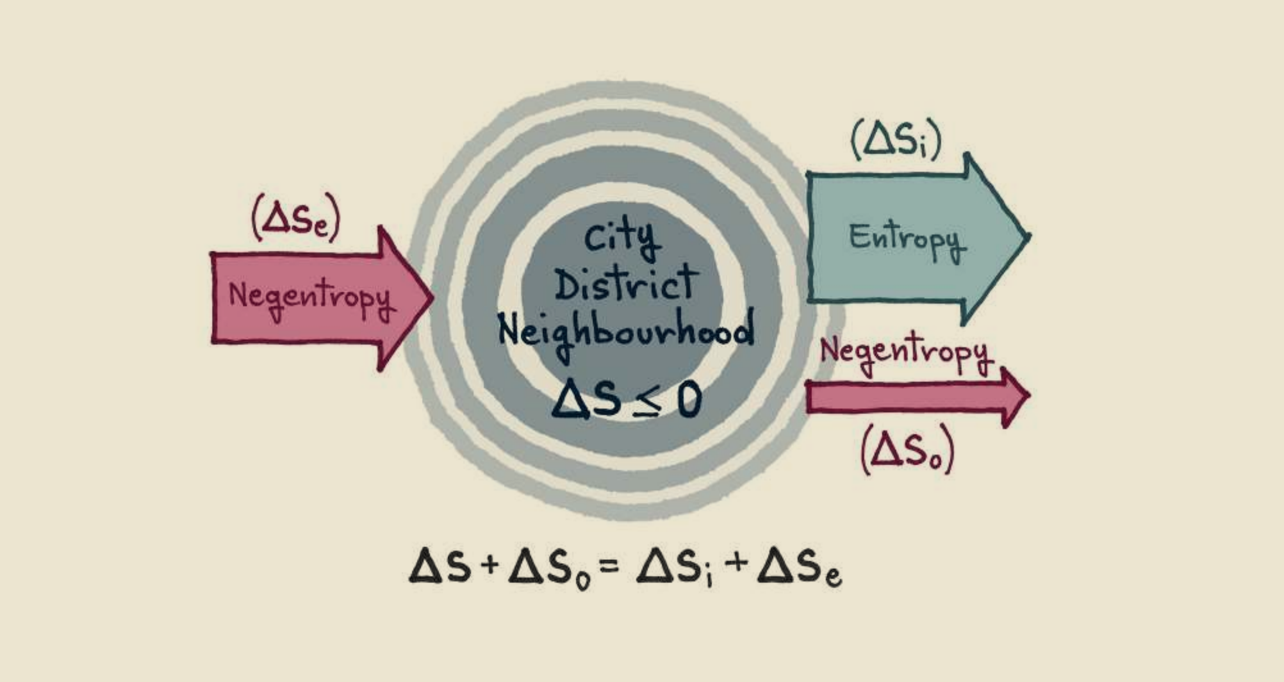
In the thermodynamic approach, useful water is fresh, clean and non-contaminated, i.e. high-grade water with a high degree of negentropy. After its use, water is no longer useful as it is dirty, and full of other components: it is waste, high entropy (low grade) water. Manufactured goods are a low entropy flow, or a negentropic flow, as they are useful and contain pure metals or plastic material and information. After use, they are worn-out, useless, contaminated, high entropy waste. Food is a low entropy flow as is the result of a process, the biological growth, that transforms solar energy (negentropy flow) into a highly structured and sophisticated system: it is a negentropy storage. After use (i.e. after it is eaten), food is transformed by our organism into excreta, a high entropy flow (actually the entropy flow of food is not so low, as some room for further exploitation exists, as shown later).

According to this approach, the most synthetic scheme of the relationship between an urban system and its environment is the one depicted in Figure 1.4, where the city is described as a negentropy processor, i.e. an open system whose negentropy inputs from the environment are matter, energy and information ($\Delta S_e$) and whose outputs are waste ($\Delta S_i$) and a negentropy flow ($\Delta S_O$) made of matter, energy and information at higher quality (and smaller quantity), if the city produces energy, goods, food or information that are exported outside its boundaries.

Within this conceptual framework, designing a sustainable urban development means designing it in such a way that its metabolism is capable of:

- minimising its entropy production ($\Delta S_i$), implementing the concepts of circular economy;
- keeping its entropy variation ($\Delta S$) equal to zero o – better – negative, by appropriately managing the negentropy input ($\Delta S_e$) and output ($\Delta S_0$). $\Delta S<0$ means that the entropy of the urban system is decreasing, i.e. its organisation increasing;
- maximising the share of renewable resources that are part of the input negentropy flow $\Delta S_e$.

FIGURE 1.4 **URBAN METABOLISM: CITY, DISTRICT, NEIGHBOURHOOD AS THERMODYNAMIC OPEN SYSTEMS**



## BOX 1.1 **ENERGY, EXERGY, NEGENTROPY**

According to physics, when you burn a litre of oil or a kg of coal or a m$^3$ of gas, you do not consume energy, as the energy contained in it is all in the fumes; in general, energy cannot be consumed as its amount in the universe is constant. What we actually consume is energy quality (with a litre of gasoline I can make the car move but no car could move with the energy contained in the exhaust gas).

When, in layman's terms, we say energy, we implicitly mean high-grade, useful energy. The degree of usefulness of energy is measured by its capability to be transformed into mechanical energy, or work, which represents the highest grade that energy can achieve because it can be totally converted into any other type of energy. Low temperature heat, for example, like the one stored in the sea or a lake, is low grade energy as is it cannot be converted into mechanical energy, so is not useful energy. High temperature heat, such as the heat that can be produced by burning a fuel, is useful energy, because it can be converted into mechanical energy with an engine. The low temperature heat resulting from this conversion, in turn, is low-grade, and is defined as waste heat, unable to produce further mechanical work. Electricity used for activating a motor is high-grade energy.

High-grade energy is also called available energy or exergy or negentropy (negative entropy). Exergy is a measure of the quality of energy. In thermodynamics exergy can be defined as the maximum theoretical work that can be obtained from a quantity of energy or matter by bringing this energy or matter into equilibrium with a reference environment. The term negentropy derives from the fact that, in any system (ecological, biological, in general thermodynamic system), there is a flow of highly ordered, organised matter used for maintaining the system's organisation, which is degraded into disorganised matter, i.e. waste, entropy. Any system, to keep itself working, alive, produces a flow of entropy, counterbalanced by an equivalent entering flow of negentropy.

Goods, being worn by use, after some time become useless, waste. Their negentropy (usefulness) content is lost and they become a flow of high entropy matter. This is true for both inorganic and organic (food) materials. Food is that part of the negentropy flow that is used for maintaining our body's organisation (i.e. keeping our entropy low) and is transformed into our biological waste, which goes into the sewage; part of the food flow, the one discarded, in our current urban systems is generally treated as waste (even if here is still some unused negentropy in it) and its negentropy content is in this way disposed of without any use[6]. The same happens, in most cases, for goods: appliances that no longer work because of a minor failure are discarded as waste, even if they still contain a lot of negentropy[7] that could be usefully recovered and used if the failure was repaired.

Thus, the urban metabolism seen from a thermodynamic perspective (Filchakova 2007) represents an open system, constantly importing negentropy, in the form of goods, energy, water and food, and exporting entropy and some negentropy, the output invariably being less ordered than the input due to irreversible internal processes.

For such a system the equation is (see also Figure 2.3):

$$\Delta S + \Delta S_0 = \Delta S_i + \Delta S_e \qquad \text{eqn. 3.1}$$

Where $\Delta S$ is the system's entropy variation per unit of time, $\Delta S_i$ is the system's production of entropy (always positive because maintenance of internal organization involves an unavoidable degradation of energy and matter), $\Delta S_e$ represents the flow of negative entropy (high grade energy, organized matter) coming from the external environment and it is the flow of organization balancing the production of entropy $\Delta S_i$; $\Delta S_0$ represents the possible negentropy flow coming out from the system (goods, energy, information produced in the city and exported). In order to maintain its organization, the system must keep $\Delta S = 0$; if $\Delta S > 0$ the system's organization is decaying; if $\Delta S < 0$ an evolution process is going on (the organization of the system is improving).

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[6] *Once, in both rural and urban communities, food waste was rarely discarded unused: its negentropy content was exploited to feed animals.*

[7] *Such as rare metals, electric motors, mechanisms, etc.*

### 1.3.2 DIRECT AND INDIRECT EMISSIONS

The calculation of urban energy consumption and consequent GHG emissions, according to the current approach, includes all the energy consumed for the "operation" of the city, i.e. the energy necessary for heating, cooling, lighting, cooking, domestic appliances, moving people and goods from one place to another and producing goods in the factories within the boundaries of the city. These are called "direct emissions", to distinguish them from "indirect emissions", which are the GHG emissions caused by the production – that takes place elsewhere – of the materials and goods entering the city and consumed by its inhabitants.

Studies of the direct and indirect emissions at city level show:

1. indirect emissions are higher than direct emissions in cities in developed countries and lower in cities in developing and emerging countries (Dhakal 2004);
2. indirect emissions grow with a city's wealth (Lenzen 2008), as the wealthier a household, the greater the number of goods entering it.

These outcomes are not surprising, and highlight the impact of consumerism on climate change.

A comprehensive study (EEA 2013) was carried out for 9 EU Member States (Czech Republic, Denmark, Germany, France, Italy, Netherlands, Austria, Portugal and Sweden) aiming to evaluate direct and indirect emissions at national level in 2005. It was found that:

- the average per capita direct + indirect GHG emissions associated with household consumption in the 9 EU Member States in the year studied were just under 12 tonnes $CO_2$-eq. — 4 to 5 times the estimated global per capita average which would keep global temperature rise below the critical 2 °C target
- direct emissions from households (due to electricity consumption, heating and hot water production) amount to about 33%, i.e. only one third of the total, the remainder being embodied in the material and food inflow.

As 73 per cent of European inhabitants lived in urban areas in 2011, the above figures can be used for cities with a fair degree of accuracy. Thus, it can be stated that, if indirect emissions are not significantly reduced, even if all cities become "zero fossil", i.e. do not require any fossil fuel to function, the +2 °C target cannot be reached, as only a minor share (33%) of total emissions would be involved.

We must shift from an "operating" consumption perspective to a "total consumption" perspective. The operating perspective focuses only on direct emissions due to the local combustion of fossil fuels, in buildings, in transport and in industrial activities, plus the emissions due to the production of the electricity used in the city. The total consumption perspective, instead, includes all emissions, direct and indirect.

The shift from the operating to the total consumption perspective will need both improvements in eco-efficiency and changes in consumption patterns. In other words, new values and lifestyles must be developed. And this is the challenge that cities in both developed and developing countries face.

## 1.4 FROM "WHAT" TO "HOW"

When it comes to "what" a sustainable city, town or neighbourhood should be, there is a wide choice of literature, and guidelines and recommendations are available. There is much less literature on "how" the urban designer should put into practice the general guidelines and recommendations proposed, i.e. there are fewer tools, indicators or figures allowing him/her to achieve the desired aims. The main reason for this is that the literature usually refers to urban planning, not to urban design that would allow the designer to translate into practice the indications given by urban planning. Some literature, however, is available for the urban designer. It addresses individual, specific, aspects of sustainability, such as urban structure and density, street design, green areas, energy, water and waste systems etc., but generally fails to integrate all these aspects into a holistic vision that evaluates the practical interconnections between them. What appears to be the best choice if the subsystem is considered in isolation may not be (and usually is not) the best when the subsystem is treated as a part of the whole system, as it affects other subsystems and is affected by them.

Infrastructures such as electricity grids and power generators, water piping, sewerage, solid waste management are usually left by the urban designer, to somebody else, who will add them on, hiding them as much as possible. This is similar to what, for far too long, has been going on with buildings: the architectural design first, and then the building services engineer comes in to make the building liveable, with water, sewerage, gas and electricity networks – with no or very little interaction with the architect. In recent years we have learnt that this approach is not consistent with sustainable building design, as architectural choices are affected by the technological services, and vice versa. Architect and building services engineer must work together, sharing their expertise in energy efficiency; this is especially necessary when designing zero energy buildings.

It is time to realise that, if the aim is sustainability, the same has to be done in urban design, especially at neighbourhood scale, which implies the maximisation of energy self-sufficiency with renewable resources, efficient use of energy and water, decentralised energy, water and waste systems, minimisation of motorised mobility, and so on. Decentralised energy, water and waste infrastructures have a significant impact on urban form and structure, as it has mobility, and vice versa.

## BOX 1.2 **RESILIENT CITIES**

A major challenge that urban systems will face in future years is climate change, which will create perturbations of unprecedented intensity and will have a profound impact on the urban metabolism, i.e. on the life itself of the urban system, with unavoidable consequences for the economic system.

In order to increase urban resistance to the perturbations of climate change it is necessary to act primarily on the urban metabolism.

This means that, even if both the non-renewable negentropy input flow and the consequent entropy output flow are minimised (for example, a zero-fossil energy city), this will not be enough to ensure sustainability. A city, likewise ecosystems, must be resilient to be sustainable, i.e.it must be capable of absorbing disturbance, of undergoing change, and of retaining the same essential functions, structure, identity, and feedbacks.

This does not mean that its degree of functionality remains constant, but that functionality will return in one form or another in a relatively short period of time. To be resilient, the city must have both the resources available and the ability to apply or reorganize them in such a way as to ensure essential functionality during and/or after the disturbance.

"Resilient cities" is a label more and more fashionably used among urban planners, but too often within the same paradigm that has led urban planners to design unsustainable and un-resilient cities. It is an approach which only looks at the measures that should be taken when facing catastrophic events, interpreting the word "resilience" in engineering terms, i.e. the ability to return to the steady state following a perturbation. "Resilience" is confused with "resistance".

Instead, resilience does not necessarily mean that the system will look just as it did before a disturbance or shock. It will maintain its functions, but individual parts of the system may have changed (adapted) to new conditions in the environment. Thus, a strategy for resilience does not guarantee short-term stability, but rather survivability of the system's essential functions in the long term.

What, in practical terms, does it mean?

Cities with a highly robust pool of resources and a high degree of adaptive capacity will be the most resilient (Longstaff 2010).

Robustness of resources depends on:

- Performance (how efficiently and effectively resources accomplish their function)
- Diversity (reliance on a rich set of different types of available resources to perform particular functions).
- Redundancy (measures the amount of resources capable of performing the same or similar function[8])

When combined, performance, diversity, and redundancy of available resources determine a system's overall robustness; i.e. its ability to provide critical functions under a variety of conditions.

Adaptive capacity is a function of the ability of individuals and groups to:

- store and remember experiences (institutional memory)
- use that memory and experience to learn, innovate, and reorganize resources in order to adapt to changing environmental demands (innovative learning)
- connect to others inside and outside the community to communicate experiences and lessons learned, self-organize or reorganize in the absence of direction, or to obtain resources from outside sources (connectedness).

Thus, institutional memory, innovative learning, and connectedness determine the foundation of adaptive capacity on a city level.

Robustness is a property shared with resilient ecosystems, while adaptive capacity – as defined above - is specific to social-technical systems.

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[8] *The terms redundancy and diversity derive, respectively, from the Information Theory (Pierce 1980) and from ecology (Odum 1983).*

This guidebook deals with urban design, and is intended as an upscaling of architectural design. Whereas architecture focuses on individual buildings, urban design addresses the larger scale of groups of buildings, of streets and public spaces, whole neighbourhoods and districts, and entire cities, to make urban areas functional, attractive, and sustainable. As architectural design provides all the information necessary for the construction of a building (geometry, materials, internal distribution, services, etc.), in the same way urban design provides construction information at urban scale (geometry of buildings and their distribution, street layout, materials, greening size and position, services, etc.). Urban design deals with the physical form of cities, being related to but different from urban planning that deals with policies shaping urban development.

This guidebook aims to make a contribution to a holistic approach to sustainable neighbourhood design, helping to integrate the metabolism of a sustainable neighbourhood into its form, shaping it in such a way that it will provide efficient energy, water, wastewater and solid waste systems, and low energy mobility. It provides background information and rules that do not aim to revolutionise urban design, but to provide guidelines which will be a starting point for the evaluation (and self-evaluation) and negotiation around new design schemes by the players involved in the process (designers, developers and public authorities) and to future generations (students of urban design and planning).

## 1.4.1 THREE-PRONGED APPROACH

In the eighties and nineties of the last century many guidebooks and handbooks on sustainable building design were published. At that time the rules and the process for designing a sustainable building were already well established, effective design tools were available, and a certain degree of awareness of the need to minimise energy consumption in buildings was also quite widely shared. Despite all that, only a very few low energy buildings were built in developed countries, even though the energy bill of the building sector was as high as 40% or more of the total.

The enforcement of a legislative framework was necessary to change this scenario, and in all developed countries appropriate regulations, based on the previously little used handbooks and guidebooks, were issued, making energy efficiency in buildings mandatory.

The same applies to sustainable neighbourhood design: without the development and enforcement of an appropriate legislative framework, i.e. a set of rules to be mandatorily followed by designers and developers, it is very difficult for even a single sustainable neighbourhood to be implemented voluntarily. And the lack of a legislative framework is not the only problem. As happened at the start of the implementation of the regulations for energy performance in buildings in Europe, the issue of the extra cost deriving from the application of the regulations arose. True that in the long run the total (capital + running) cost of the building was lower, but where were the financial resources needed for covering the increased initial cost to be found? Again, the same applies to the implementation of sustainable neighbourhoods: their initial cost is very likely to be higher than that of conventional ones, even if the overall benefits by far exceed the costs in the long run.

This triad of problems, i.e. urban planning and design, urban legislation and urban finance and economy, is addressed by the Three-Pronged Approach, promoted by UN-Habitat (UN-Habitat 2017), that states: "Any action of a Planned City Extension programme has to be implementable in each of the three areas of the Three-Pronged Approach for the action to have positive consequences. Interventional actions to tackle any arising issue are difficult to undertake without the existence of an efficient legal framework. The provision of any public service, any public property or institution requires a minimum of financial funding to keep on functioning or to be maintained. Any physical development or addition to the existing urban fabric also requires investment. Urban design, finally, is central and has to be taken into account as the development of a city requires planning activities to ensure the development of a spatial layout that enables dense and diverse development and the maintenance or improvement of a city's accessibility, liveability and environmental quality".

This guidebook deals only with one of the three branches of the Approach, the design branch, but indirectly provides some support for implementing the other two, being aware that local authorities should balance actions on all three components and avoid focusing on optimal performance in only one or two of the areas, as UN-Habitat advises (UN-Habitat 2017).

### 1.4.1.1 URBAN LEGISLATION

Urban legislation can be developed by applying to the specific urban context the rules and the guidelines proposed in this guidebook. The design tips (see Section 3) can be applied to a specific settlement and transformed into regulations, and the checklist in the same section used as a framework for project evaluation. On the basis of this guidebook, municipalities can develop either prescriptive and/or performance-based urban and building regulations, which can be integrated into the existing ones. In fact, the regulations that municipalities should individually develop depend not only on the site's physical specificity and socio-economic context, but also – and significantly – on the pre-existing legal framework.

### 1.4.1.2 URBAN FINANCE AND ECONOMY

The third branch of the Three-Pronged Approach deals with basic concepts such as proper financial management and sustainable revenues (land value capture, private participation in local investment, property taxes, titling), which should be incorporated in the financial plan from the start (UN-Habitat 2015).

Financial resources can be used for specific investments (such as a sewage treatment plant), or for an investment plan or a programme of investments that vary in size and sector. In the former, local governments would repay the investment from revenues associated with the investment itself (sewerage fees); while in the latter, repayment would be from all municipal taxes, fees, tariffs, or other sources.

For most cities, gaining access to capital financing at a reasonable cost is difficult because of their lack of creditworthiness, which makes it difficult to gain access to the national and international institutions that specifically finance projects dealing with sustainable urban development.

As an alternative option to external funding, municipalities can issue municipal bonds, which enable local governments to raise money to fund public projects, paying bondholders interest for the loan. The issuing of municipal bonds is an attractive option because it would enable the city to borrow a large amount in a lump sum and at a cheaper rate than commercial borrowing.

Several middle-income economies are seeking to develop dynamic municipal green bond markets to raise investment for environmentally sustainable development projects (Hurley 2016). Green bonds are debt instruments that are linked to projects producing a positive environmental impact; sometimes, investors accept a lower return because there is a commitment to use funds raised in a socially or environmentally responsible manner.

Unfortunately, "in most African countries sub-national entities are not allowed to borrow. Few municipalities are able to establish creditworthiness based on cash flow, debt profile and credit history to allay investor concerns about repayment of the loan. Few can show an adequate record of strategic planning, debt management and competent administration" (Paice 2016).

One of the reasons for the lack of creditworthiness for financing infrastructures for public services, such as water and sewage networks with their related treatment systems, derives from the fact that municipalities are often unable to provide adequate operation and maintenance. This leads to an inadequate service, making final users reluctant to pay the due fees and, in turn, making the municipality unable to repay the loan, or provide maintenance. A vicious circle is created. This phenomenon is quite common in cities in developing countries, and applies not only to water, sewage and solid waste: bad service and related theft of electricity derive from a similar vicious circle (Butera et al. 2016).

Decentralised electricity, water and waste systems, mutually interconnected, which characterise a sustainable neighbourhood as conceived in this guidebook, open a window on a different approach to their financing and management.

If the local legal framework allows, decentralised energy and the construction and operation of water and waste systems at neighbourhood scale could be financially supported either by a public-private partnership, or by private only investment, where the private entity could be a cooperative whose shareholders are the final users of the services themselves.

The cooperative approach to electricity production and distribution has been and is currently successful in many parts of the world, wherever the utilities were unable or unwilling to provide the service. The co-operative electrification model is one in which a group of people or the entire community takes out a loan to build proper electrical infrastructure and then provides electricity to the surrounding community. Co-ops are usually non-profit making.

A similar cooperative-based approach could be extended to the decentralised, neighbourhood scale water system (provision, treatment, reuse) and to the decentralised solid waste collection and treatment system.

The advantage of such an approach is that users are motivated to pay the fees, because they are also providers that, being also users, are motivated to give a good service. Moreover, being decentralised systems, they also provide an opportunity for further enterprise and job creation in the neighbourhood.

Sustainable neighbourhoods advocate the engagement and participation of citizens for the common good.

## REFERENCES

Allen, P. M. (1998), Cities as Self-Organising Complex Systems, in C.S Bertuglia, G. Bianchi, A Mela (eds.), The City and Its Sciences, Physica-Verlag.

Butera, F. M. (1998), Urban development as a Guided Self-Organisation Process, in C.S Bertuglia, G. Bianchi, A Mela (eds.), The City and Its Sciences, Physica-Verlag

Dhakal, S., (2004), Urban energy use and greenhouse gas emissions in Asian mega-cities, http://www.globalcarbonproject.org/global/pdf/MegacitiesAsia&GHGs.IGES2004.pdf accessed on 19/12/2016

EEA - European Environment agency (2013), Environmental pressures from European consumption and production, EEA Technical report No 2/2013

Filchakova, N., Robinson, D., Scartezzini J.L. (2007), Quo Vadis Thermodynamics and The City: a Critical Review of Applications of Thermodynamic Methods to Urban Systems, International Journal of Ecodynamics. Vol. 2, No. 4.

Gaffron, P., Huismans, G., Skala, F. (eds.) (2005), Ecocity, Facultas Verlags- und Buchhandels AG, Vienna - http://www.eurosolaritalia.org/documenti/pubblicazioni/book_1_kap2.pdf

http://www.eea.europa.eu/publications/environmental-pressures-from-european-consumption accessed on 19/12/2016

IEA (2009), Cities, Towns & Renewable Energy, - http://www.iea.org/publications/freepublications/publication/cities2009.pdf

IPCC (2014), Climate Change 2014 - Mitigation of Climate Change - Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 12, http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter12.pdf

Kennedy, C., Pincetlb, S., Bunjeb P. (2010), The study of urban metabolism and its applications to urban planning and design, Environmental Pollution.

Kenworthy, J. R. (2008), Energy Use and $CO_2$ Production in the Urban Passenger Transport Systems of 84 International Cities: Findings and Policy Implications, in: Droege P. (ed.) Urban Energy Transition: From Fossil Fuels to Renewable Power, Elsevier

Lehmann, S. (2010), Green Urbanism: Formulating a Series of Holistic Principles, S.A.P.I.E.N.S, 3.2, Vol. 3 / n. 2 - http://sapiens.revues.org/1057#tocfrom2n1

Lenzen, M., Wood, R., & Foran, B. (2008), Direct versus Embodied Energy – The Need for Urban Lifestyle Transitions, in P. Drodge (ed.), Urban Energy Transition, Elsevier, 2008

Longstaff, P. H., Armstrong, N. J., Perrin, K., Parker, W. M., & Hidek, M. A. (2010), Building resilient communities: a preliminary framework for assessment. Homeland Security Affairs, volume VI, no. 3.

New Climate Economy (2014), Better Growth Better Climate - www.newclimateeconomy.report

Odum E. P (1983), Basic Ecology, CBS College Publishing

OECD/FAO, (2013). Agricultural Outlook 2013-2022 http://www.oecd.org/berlin/OECD-FAO%20Highlights_FINAL_with_Covers%20(3).pdf

Oke, T.R. (1973), City size and the urban heat island. Atmospheric Environment 7: 769- 779

Perera, N.G.R., Samanthilaka K.P.P. (2014), Effect of Street Canyon Materials on the Urban Heat Island Phenomenon in Colombo, in R. Dayaratne and J. Wijesundara (eds.), Second International Urban Design Conference on Cities, People and Places, ICCPP- 2014 Colombo, Sri Lanka, Department of Architecture University of Moratuwa, Sri Lanka.

Pierce J. R. (1980), An Introduction to Information Theory, Dover Science Books

Rogers, R. (1997), Cities for a small planet, Faber & Faber, London

The Charter of the New Urbanism (2016), https://www.cnu.org/who-we-are/charter-new-urbanism

The World Bank (2010), A City-Wide Approach to Carbon Finance – http://documents.worldbank.org/curated/en/2013/01/17635279/city-wide-approach-carbon-finance

UN- Habitat (2013b), State of the World's Cities 2012/2013, Routledge, - http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3387

UN- Habitat (2013c), A New Strategy of Sustainable Neighbourhood Planning: Five Principles - http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3518

UN-Habitat (2013a), Urban Planning for City Leaders – http://unhabitat.org/books/urban-planning-for-city-leaders/

UN-Habitat (2014), The state of African cities 2014 - http://unhabitat.org/books/state-of-african-cities-2014-re-imagining-sustainable-urban-transitions/

United Nations (2014), Department of Economic and Social Affairs, World Urbanization Prospects -The 2014 Revision - https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf

# WHAT A SUSTAINABLE NEIGHBOURHOOD SHOULD AIM FOR

A sustainable neighbourhood is a neighbourhood whose design integrates into a holistic vision the following aims:

**1: Climate responsiveness and context**

Aim for a neighbourhood based on the climatic conditions, with appropriate responses to location and site context. Find out what the unique site constraints, climatic conditions and opportunities are.

**2: Renewable energy for zero GHG emissions**

Aim for a neighbourhood as a self-sufficient on-site energy producer, using decentralized energy systems. Find out how energy can be generated and supplied emission-free and how to minimise energy demand in buildings and in transport

**3: Zero-waste**

Aim for a zero-waste neighbourhood as a circular, closed-loop eco-system. Find out how to turn waste into a resource, aspiring to nature's zero-waste management system.

**4: Water cycle**

Aim for a neighbourhood with closed urban water management and high-water quality. Find out how to promote rainwater collection, wastewater recycling and storm water harvesting techniques, which are also for flood management, and how to avoid the consumption of potable water for uses not requiring its purity. Try to obtain energy from wastewater.

**5: Landscape, gardens and urban biodiversity**

Aim for a neighbourhood that integrates landscapes, urban parks and gardens and urban agriculture to maximize biodiversity and to minimise the urban heat island effect. Find out how to introduce inner-city gardens, trees in the streets, and urban farming/agriculture.

**6: Sustainable transport and good public space**

Aim for a neighbourhood of eco-mobility, with a good public space network and an efficient low-impact public transport system for post-fossil-fuel mobility. Find out how can we get people out of their cars, to walk, cycle, and use public transport.

**7: Local and sustainable materials with less embodied energy**

Aim for a neighbourhood construction using regional, local materials with less embodied energy. Find out what kind of materials are locally available and which appear in regional, vernacular architecture.

**8: Liveability, healthy communities and mixed-use programmes**

Aim for a neighbourhood with affordable housing, mixed-use programmes, and a healthy community. Find out how urban design recognizes the particular need for affordable housing, to ensure a vibrant mix of society and multi-functional mixed-use programmes. Land use development patterns are the key to sustainability. A compact, mixed-use (and mixed-income) city delivers more social sustainability and social inclusion.

**9: Local food and short supply chains**

Aim for a neighbourhood with high food security and urban agriculture. Find out which strategies can be applied to grow food locally in gardens and in small spaces in the neighbourhood, using natural fertilisers obtained from neighbourhood's organic waste.

A neighbourhood designed according to these ten aims is not only a sustainable neighbourhood, but it is also resilient, as it incorporates the three main elements of resilience: efficiency, diversity and redundancy (see Box 3.2 and Box 4.2 for more details). It is also a neighbourhood capable of creating employment, because of the economic activities generated.

***Source: Lehmann, S. (2010), Green Urbanism: Formulating a Series of Holistic Principles, S.A.P.I.E.N.S, 3.2, Vol. 3 / n. 2 - http://sapiens.revues.org/1057#tocfrom2n1***

# 02

# DESIGN FOR A SUSTAINABLE NEIGHBOURHOOD

According to the conceptual framework depicted in Chapter 1, designing a sustainable built environment means, first of all, maximising its thermodynamic efficiency, i.e. minimising the amount of entropy generated by the urban metabolic process and enabling the reduction of the negentropy flow entering the system without impairing its functions.

The fulfilment of this aim involves several combined actions, namely:

1. Minimise energy demand of buildings;
2. Minimise energy demand for transport;
3. Maximise efficiency of energy conversion technologies;
4. Fulfil the remaining energy consumption with renewable energy sources;
5. Optimise the water cycle;
6. Enhance solid waste reuse and recycle;
7. Close energy, water and waste cycles on site;
8. Minimise indirect GHG emissions.

The items 1), 2), 3), 4) and 8) deal only with energy (and GHG emissions) and urban design has a direct impact on these; items 5), 6) and 7) are also indirectly influenced by the urban design, as they require provision for appropriate land use and infrastructures.

Minimising energy demand by appropriately manipulating the options offered by the urban design is a crucial step for minimising the entropy production of the neighbourhood (thus the contribution to global warming), but it must be remembered that urban design also affects other aspects of sustainability, such as health, liveability, social inclusion, equity and economics.

The design parameter that most greatly affects the three spheres of sustainability, i.e. environmental, social and economic, is density, because high density:

- reduces energy consumption for transport and this in turn affects $CO_2$ emissions, air pollution and mobility costs (i.e. climate change, health, social equity and inclusion, and economics);
- reduces soil consumption, preserving natural areas and thus affecting the amount of $CO_2$ sinks and the functionality of ecosystems (affecting in turn global warming and biodiversity);
- reduces the extent of infrastructures - such as water, sewer, and electricity facilities - to serve the same number of people, affecting economics and making access to these services easier, thus promoting social equity

This does not mean, however, that the higher the density the better, because it needs to be optimised by taking into account other factors for sustainability, as shown in the following paragraphs.

## 2.1 MINIMISE ENERGY DEMAND IN BUILDINGS BY MEANS OF CLIMATE RESPONSIVE URBAN DESIGN

Energy is required in buildings for heating or cooling, hot water production, lighting and domestic appliances. Energy for hot water production and domestic appliances depends on the user's behaviour and cannot be controlled by the urban designer. Energy for heating, cooling and lighting, on the other hand, depends significantly on the urban designer, as the amount of energy required, i.e. the energy demand for obtaining thermal and visual comfort, depends not only on building design, but also on the capability to control local climate and microclimates with appropriate neighbourhood design, as the more uncomfortable it is outdoors, the more uncomfortable it is indoors, and the more energy is required for heating or cooling.

Control of local climate and microclimates, in turn, also affects the inhabitants' health and the neighbourhood's liveability. Given the complexity of the interactions between urban design, local climate, outdoor and indoor thermal comfort, energy consumption, environmental impact, health and liveability of outdoor spaces (Figure 2.1.1) and the importance of local climate control, a basic knowledge of urban climatology and thermal comfort principles is necessary for the urban designer, whose task is to design the urban layout in such a way as to create comfortable outdoor conditions through an appropriate control of energy balances on three levels: building, street delimited by buildings (canyon), neighbourhood (Figure 2.1.2).

FIGURE 2.1.1 **COMPLEX INTERACTIONS BETWEEN FACTORS IN URBAN DESIGN**

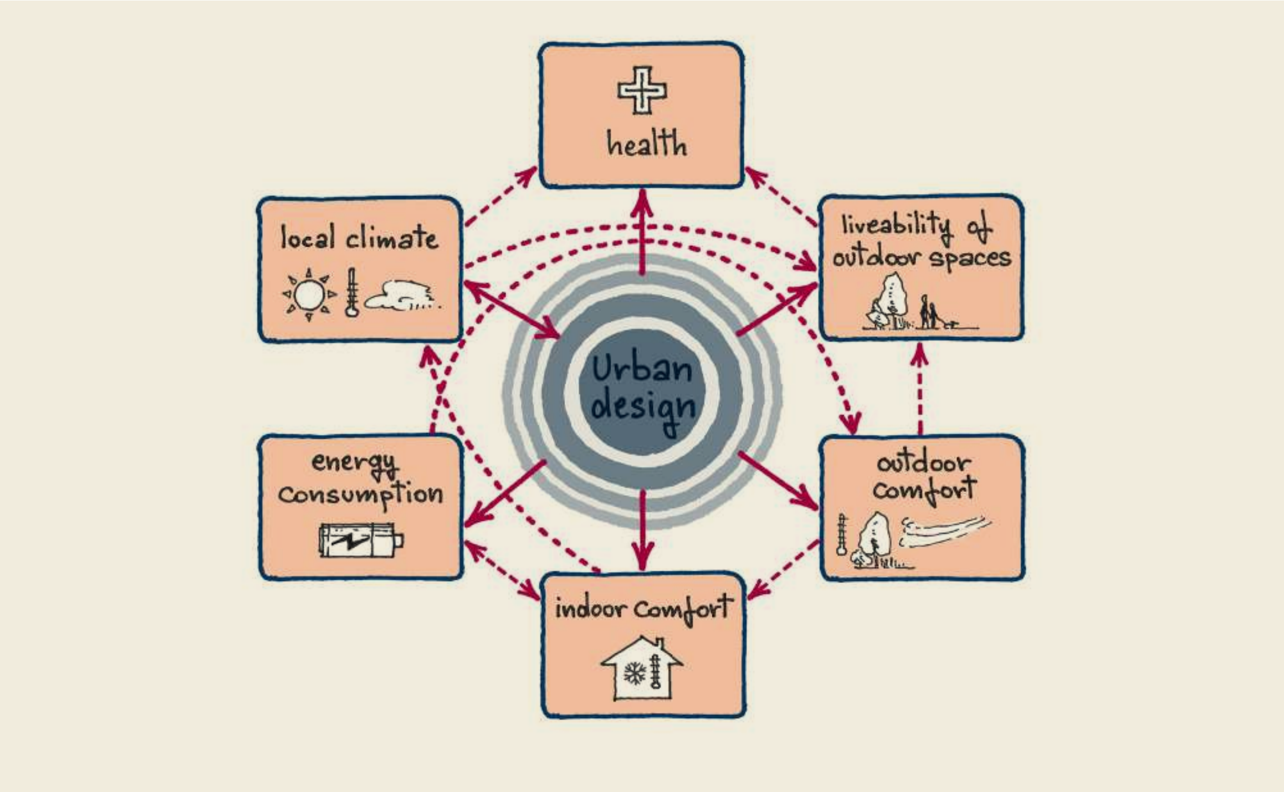


FIGURE. 2.1.2 **THE URBAN THERMAL ENVIRONMENT NEEDS A BALANCED UNDERSTANDING OF AIR TEMPERATURE, SOLAR AND SURFACE RADIATION AND WIND (ADAPTED FROM: MOCHIDA 2007)**

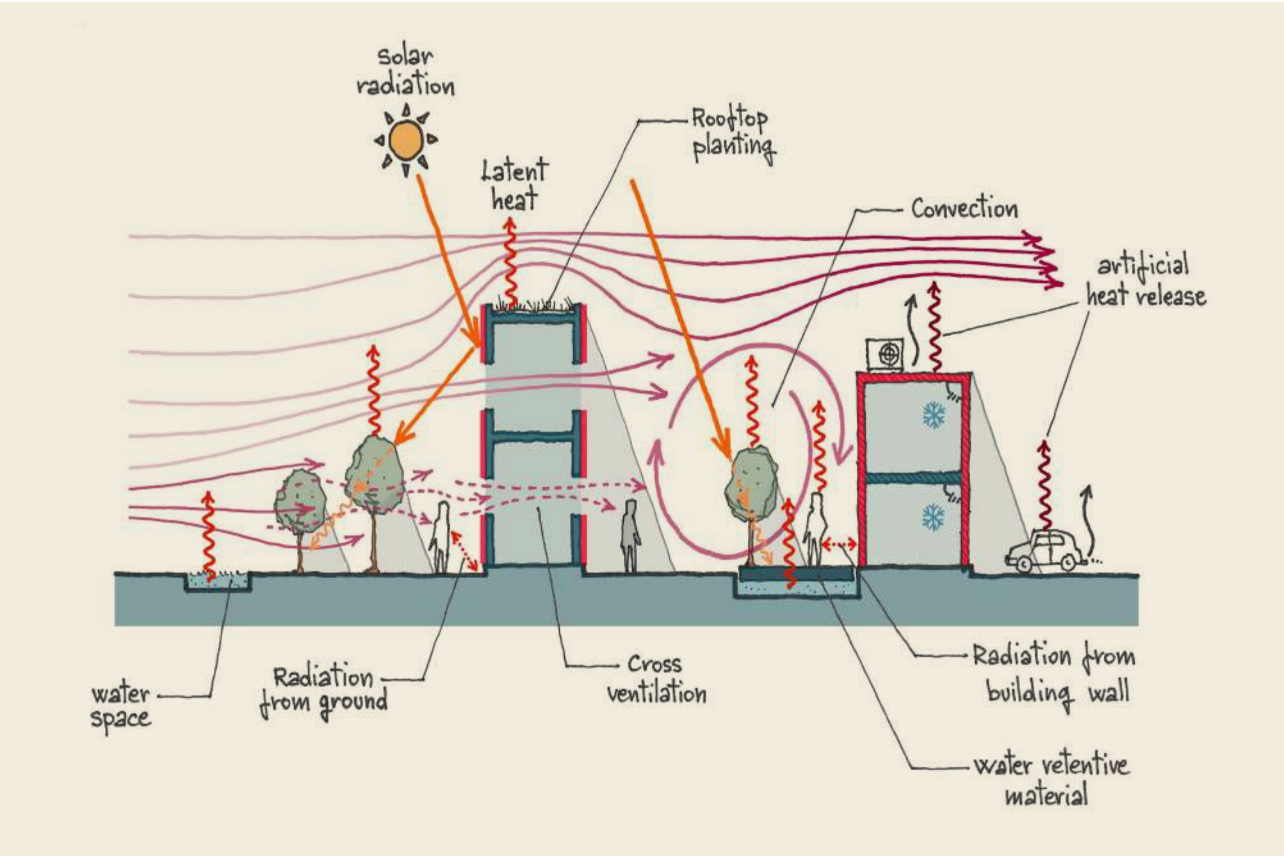
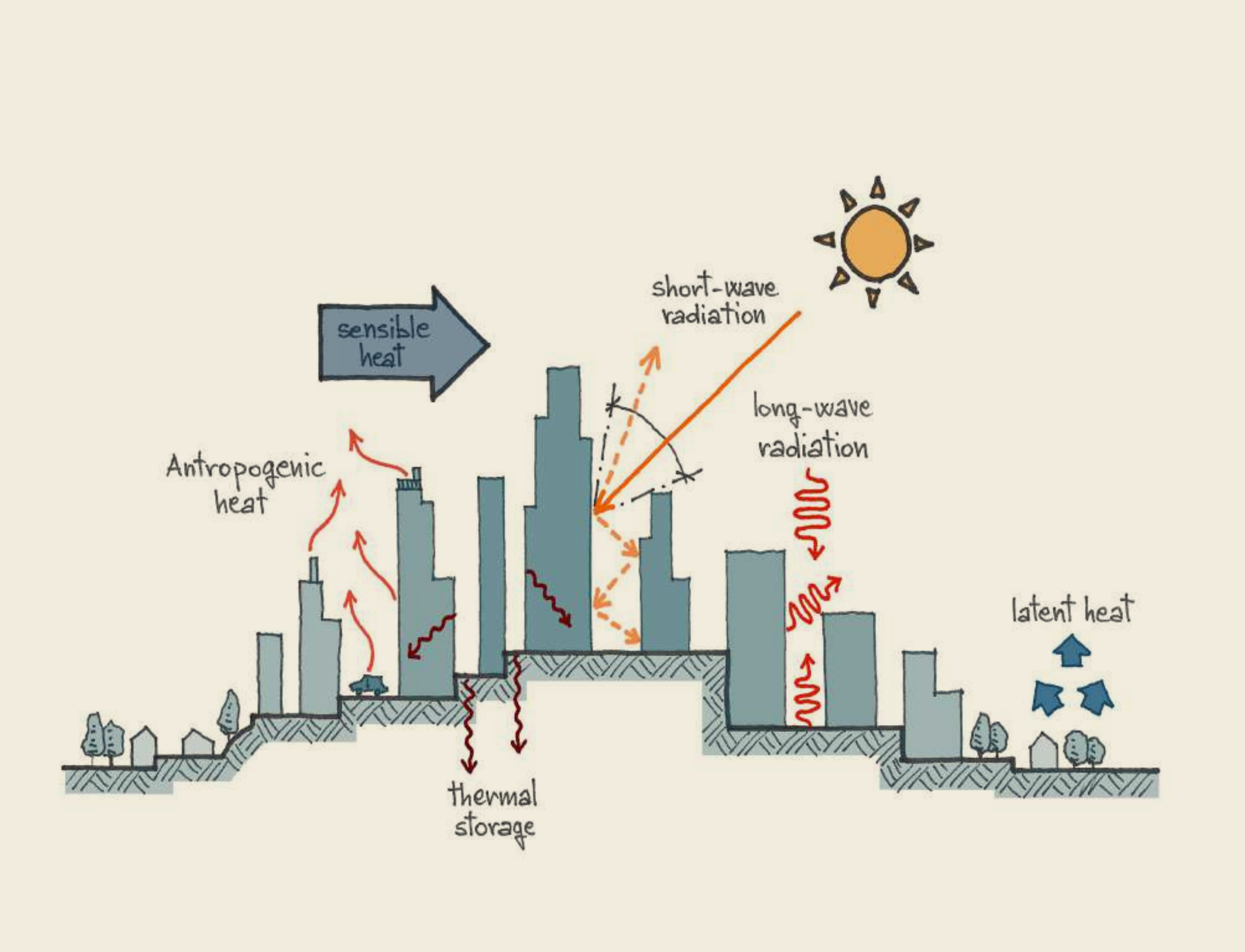


FIGURE 2.1.3 **URBAN SURFACE ENERGY BUDGET (ADAPTED FROM: EPA 2008)**



Climate responsive urban design is the prerequisite for sustainable urban development: its aim is to enhance outdoor comfort, thus reducing the need for heating and cooling in buildings.

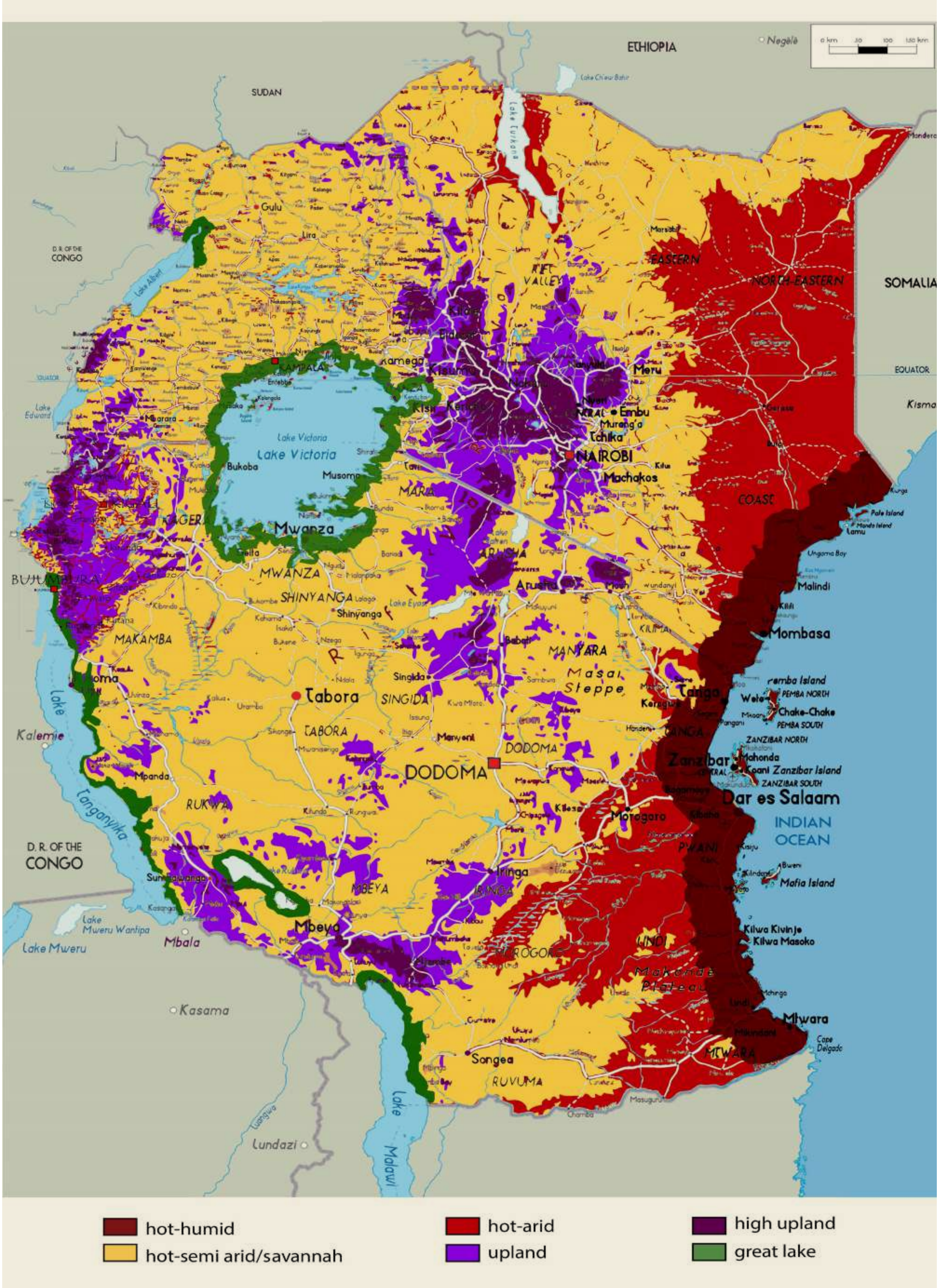
Climate responsive urban design is most effective at neighbourhood scale, where the geometry of the built areas can be manipulated for enhancing shadows, where the materials used for buildings and streets and their colour must be carefully chosen to maximise the albedo and optimise the thermal mass, and where the appropriate control of street orientation and of green areas can lead to more comfortable outdoor conditions.

In a tropical climate, the primary aim of energy-efficient urban design is to minimise heat gains and to maximise heat losses. This implies controlling the short and long-wave radiation in urban canyons, as the goal should be to find an urban geometry that is self-shading, using an intelligent combination of building heights and geometry, if necessary complemented with horizontal shading elements such as canopies, awnings and urban vegetation, and favouring air movements, by manipulating the geometry and relative positions of the buildings according to the prevailing winds.

In light of the above, the main factors to control in climate responsive building design are (Figure 2.1.3):

- The three-dimensional volume formed by buildings that abut streets (so called 'canyon geometry' effect), to control solar radiation;
- The thermal properties of urban surfaces, i.e. heat storage and reflection of solar radiation;
- The anthropogenic heat;
- The evapotranspiration, by means of green areas;
- The wind patterns.

FIGURE 2.1.4 **MESO-CLIMATES, OR CLIMATE ZONES OF EAST AFRICAN COMMUNITY (SOURCE: UN-HABITAT 2014)**



## 2.1.1 CLIMATE, COMFORT AND ENERGY

Climates on the Earth can be classified at different scales. A first classification is based on "macroclimates", as in Figure 2.1.5.

When we look more closely at a macroclimate, a more detailed classification appears, and we can see that the area is subdivided into meso-climates, as shown, for example, in Figure 2.1.4. The meso-climate represents the average of a relatively narrow range of climatic conditions. Thus, a closer examination of one of the meso-climates would reveal a number of different local climates, each deriving from various properties of the ground surface, such as location, exposure, colour, heat capacity, moisture content, permeability of the soil, characteristics of the vegetation cover, albedo and roughness of the ground surface (see Figure 2.1.6 as an example).

Local climate is generally related to an area ranging from a few square metres to a few hectares, such as the side of a hill, a valley or a portion of the built area. It is characterised by more or less marked changes in environmental parameters with respect to the surrounding context (temperature differences, relative humidity, wind, sunshine, etc.), due to the specificity of the places defined by topography, urban morphology, orientation, nature of materials, proximity to water, presence or absence of vegetation, etc. (see Table 2.1.1). The anthropogenic heat loads (traffic, heating and cooling of buildings, etc.) may also have a significant impact.

FIGURE 2.1.5 **MACROCLIMATES**

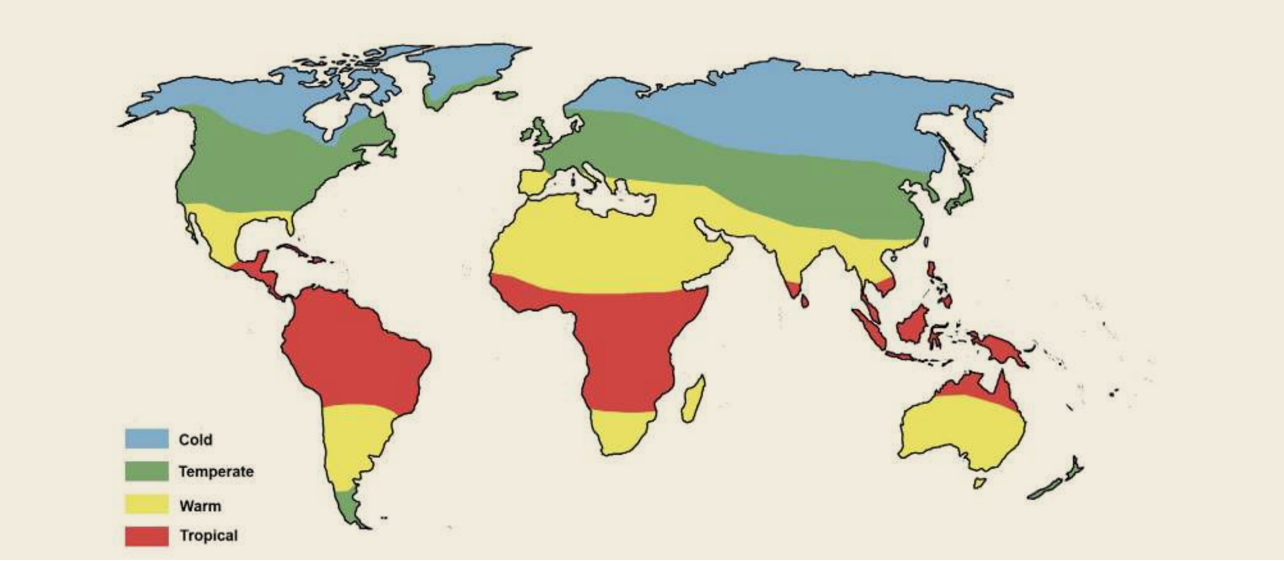


FIGURE 2.1.6 **HORIZONTAL PROFILE OF SURFACE RADIATION TEMPERATURE OVER A DIVERSE PRAIRIE LANDSCAPE (ADAPTED FROM: OKE 1978)**

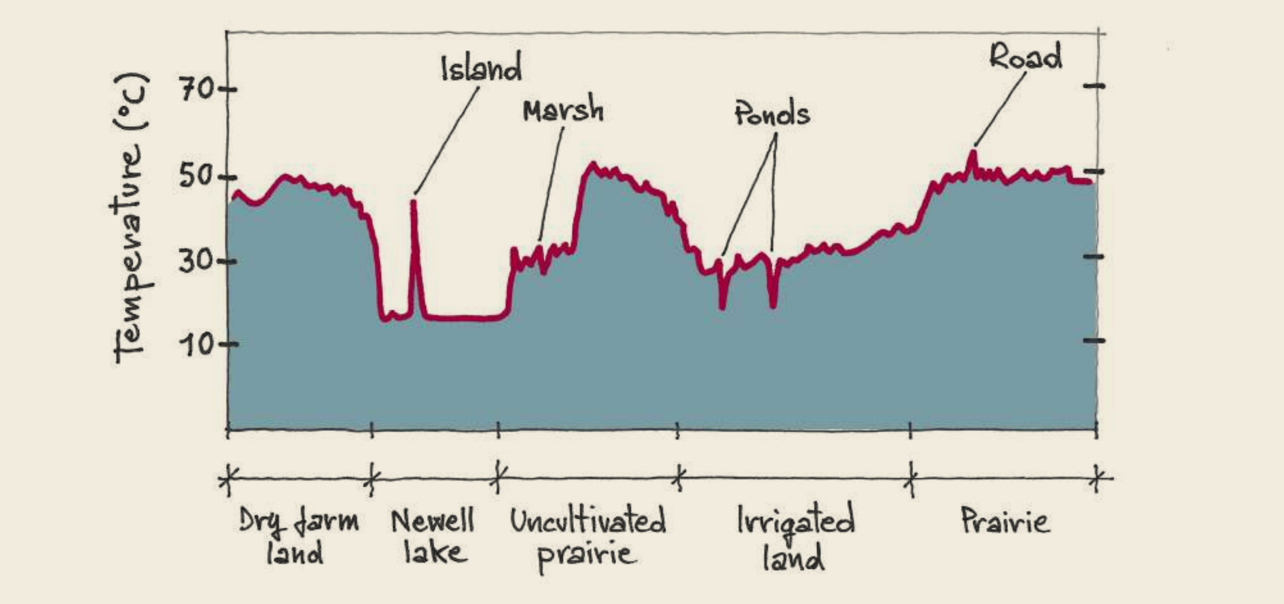


TABLE 2.1.1 **GEOGRAPHICAL FACTORS PRODUCING LOCAL CLIMATES (SOURCE" YOSHIMO 1975)**

| FACTOR | ITEM TO BE CONSIDERED |
|---|---|
| **Type of surface** | |
| Rock | Type, colour, thermal conductivity. |
| Soil | Type, texture, colour, air and moisture content, thermal conductivity. |
| Water | Surface area, depth, movements. |
| Vegetation | Type, height, density, colour, seasonal change. |
| Agricultural | Fallow land; type, height and colour of crops; seasonal change. |
| Urban and industrial | Material (concrete, asphalt, wood, metal, etc.), colour, thermal conductivity; sources of heat, moisture, pollution, etc. |
| **Properties of surface** | |
| Geometrical shape | Flat, convex, concave, etc. |
| Energy supply | Latitude and altitude, degree of screening of natural horizon, aspect, slope, exposure. |
| Exposure | Shelter provided by macro and micro-orographic features; shelter provided by buildings, trees, etc. |
| Topographic roughness | Rural areas: extent of woodland, grassland, arable; location of windbreaks and hedges; degree of agglomeration or dispersal individual buildings. |
| Urban areas: | distribution of average height of different types of built-up zones; orientation and exposure of streets, blocks and individual buildings; density of parks, gardens and other open spaces; vertical profiles across area. |
| Albedo | Type of surface. |
| Radiating capacity | Type and maximum temperature of surface; observed earth radiation. |

Finally, within the same local climate, a number of microclimates can be found: surface and air temperatures may vary by several degrees in very short distances, even millimetres, and airflow can be greatly perturbed by even small objects.

Outdoor comfort, which in a given place depends on the local climate, determines indoor comfort, which, in turn, is the driver of the energy consumption deriving from the need for heating or cooling; thus, there is a nexus between local climate and $CO_2$ emissions.

On the other hand, local climate, and its microclimates, is strongly influenced by urban design, as evidenced by the so-called urban heat island, and by the common experience that there may be hotter or cooler spots or areas in the same neighbourhood, or around the same building. Thus, there is a nexus between urban design and $CO_2$ emissions.

Climatic analysis must be an integral part of the urban design process and it should be carried out as early as possible in that process: it is very unlikely that appropriate climatic strategies can be applied retroactively to rectify errors made in the initial stages of the design process. The inclusion of an urban climatologist in the design team is strongly advisable.

Some basic information on urban climatology is given in Appendix 1, where we refer to the approach followed by Oke, in his milestone book Boundary layer climates (Oke 1978): one of the most comprehensive analyses of the urban climate.

### 2.1.1.1 URBAN HEAT ISLAND (UHI)

Urban heat islands refer to the higher temperatures in developed areas compared to more rural surroundings.

Air temperature depends significantly on that of the surface below it, and urbanized land has a greater capacity to absorb solar radiation because of the morphological configuration and characteristics[9] of the materials it is made of; thus, these surfaces are hotter than non-urbanised ones, and the temperature is higher.

Buildings in cities are mostly constructed of concrete and other man-made materials. They have higher thermal capacity than the natural environment, and therefore store more heat during daytime. The heat stored will increase nighttime urban temperatures, especially if tall buildings block the urban area's sky view and so limit release of the heat back to the atmosphere.

In addition, there is little or no cooling effect due to vegetation, and there is heat due to the mechanical cooling of buildings and to vehicular traffic. For these reasons, temperatures in urban areas are higher by several degrees than in rural surroundings, particularly at night (Figures 2.1.7, 2.1.8 and 2.1.9). This phenomenon, called the urban heat island, increases with urban size (Figure 2.1.10) and towards the centre of the city (Figures 2.1.7 and 2.1.8).

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[9] *Urban areas typically have surface materials, such as roofing and paving, which have a lower albedo than those in rural settings. As a result, built up communities generally reflect less and absorb more of the sun's energy.*

FIGURE 2.1.7 **SURFACE AND ATMOSPHERIC TEMPERATURES VARY OVER DIFFERENT LAND USE AREAS. SURFACE TEMPERATURES VARY MORE THAN AIR TEMPERATURES DURING THE DAY, FAR LESS DURING THE NIGHT. THE SURFACE TEMPERATURES OVER THE POND, ALMOST THE SAME DAY AND NIGHT, SHOW THE EFFECT OF THE HIGH HEAT CAPACITY OF WATER (ADAPTED FROM: EPA 2008).**

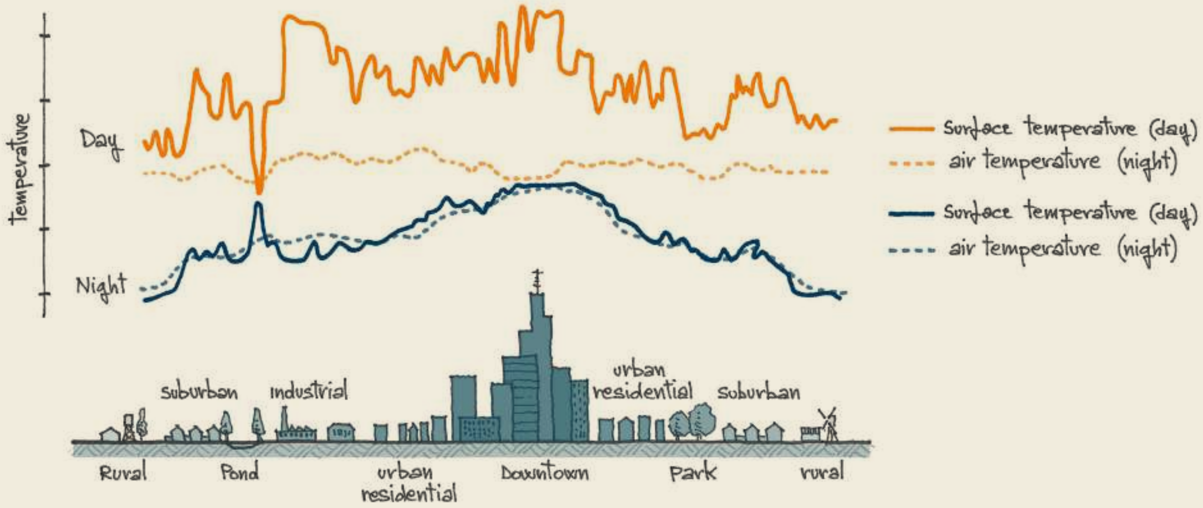


FIGURE 2.1.8 **CONCEPTUAL ISOTHERM MAP THAT DEPICTS A FULLY DEVELOPED NIGHT-TIME ATMOSPHERIC URBAN HEAT ISLAND (ADAPTED FROM: EPA 2008)**

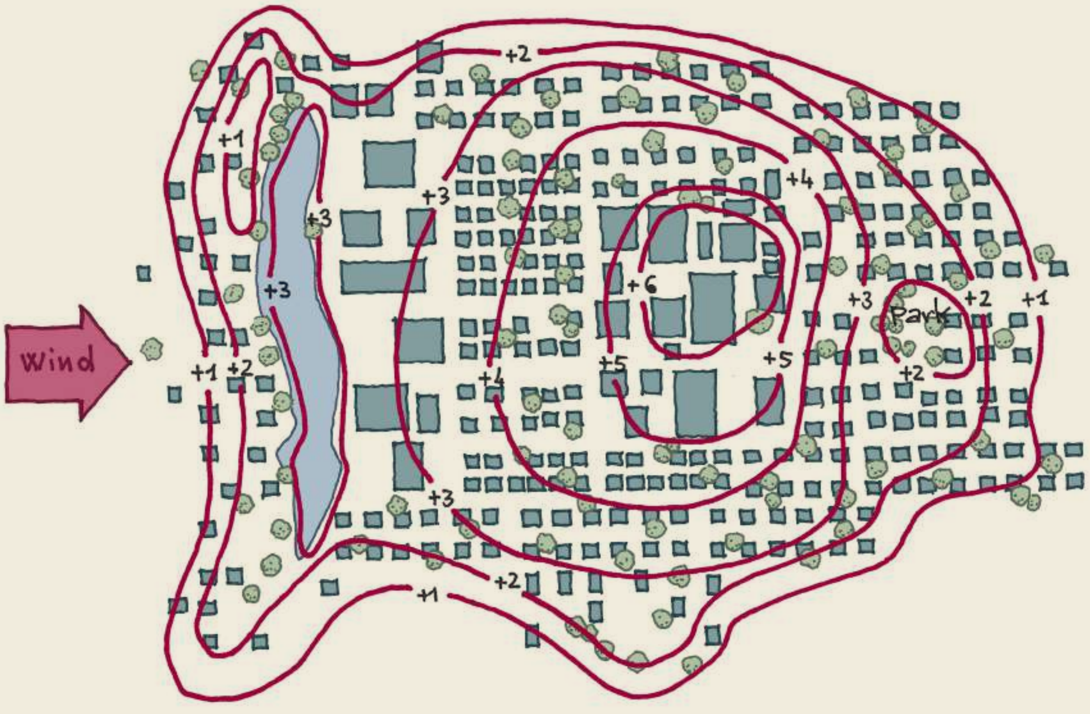


FIGURE 2.1.9 **CONCEPTUAL DRAWING OF THE DIURNAL EVOLUTION OF THE URBAN HEAT ISLAND DURING CALM AND CLEAR CONDITIONS. $\Delta T_{UR}$ = URBAN-RURAL TEMPERATURE DIFFERENCE (ADAPTED FROM: EPA 2008)**

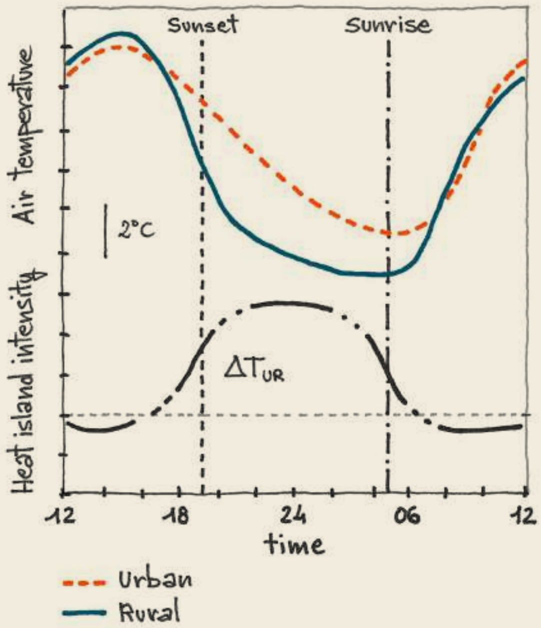
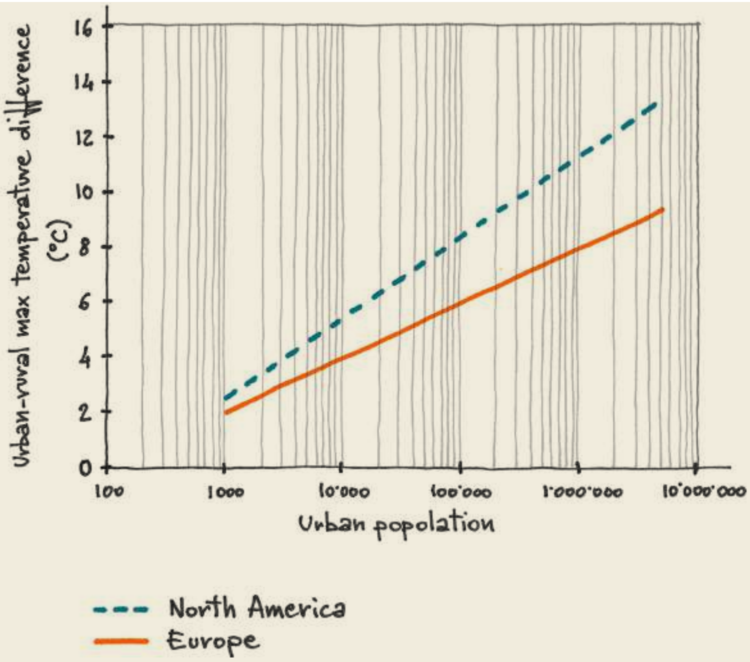


FIGURE 2.1.10 **EFFECT OF URBAN SIZE ON HEAT ISLAND (ADAPTED FROM: OKE 1973)**

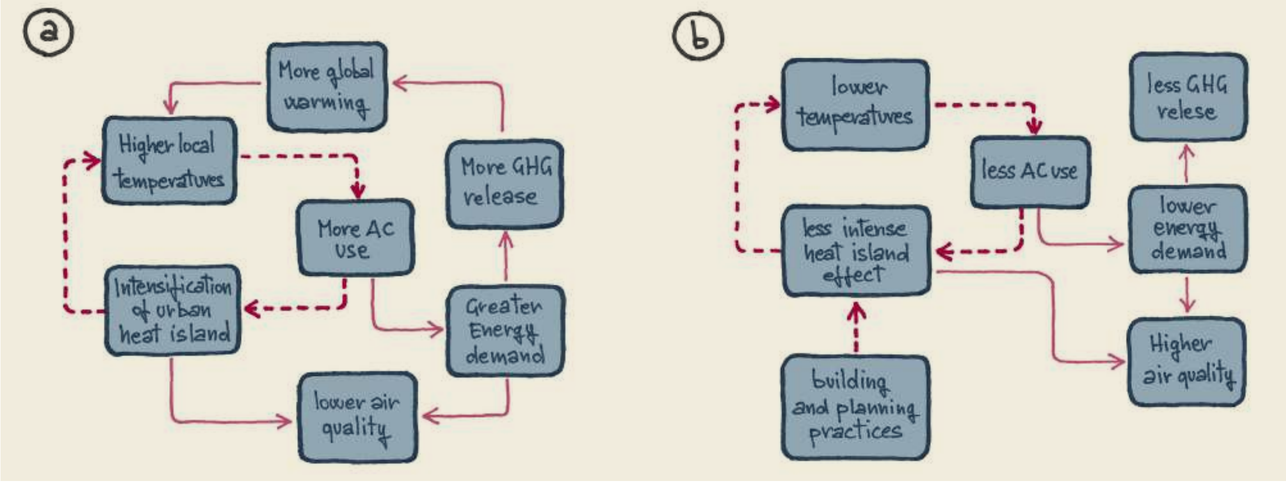


The heat island effect in warm to hot climates exacerbates energy used for cooling: electricity use in cities increases 2–4% for each 1°C increase in temperature, due to air conditioning (IPCC 2014). Moreover, higher ambient temperatures and heat waves increase the peak electricity demand and oblige utilities to build additional power plants that operate for reduced time periods. Also, they make it necessary to have additional electricity transmission infrastructures. This results in an increased cost of energy supply (Santamouris 2016).

The reduction of the heat island effect, by increasing the albedo and by applying sunscreens (e.g. vegetation) in the most critical areas, reduces energy requirements for air conditioning (which results in decreasing GHG emissions from electricity generation, see Figure 2.1.11), reduces smog levels, and reduces the health risks due to heat and poor air quality.

The urban heat island effect can be minimised with appropriate urban design at neighbourhood scale.

FIGURE 2.1.11 **A) - THE VICIOUS CYCLE OF BUSINESS AS USUAL; B) -THE VIRTUOUS CYCLE OF SUSTAINABLE URBAN DESIGN (ADAPTED FROM: OECD 2010)**



As discussed in Appendix 1, the strategies to mitigate the UHI in a tropical climate are:

- Manipulate the geometry of the neighbourhood to minimise trapping of solar radiation;
- Manipulate the street layout and the building heights to favour wind access, i.e. ventilation;
- Control the thermal properties of urban surfaces, i.e. colour and mass;
- Minimise anthropogenic heat, minimising motorised traffic and mechanical cooling;
- Maximise evapotranspiration loss with vegetation and water bodies.

### 2.1.1.2 IMPACT OF OUTDOOR THERMAL COMFORT ON URBAN ENERGY CONSUMPTION

One of the functions of a building should be to modify external environmental conditions not perceived as comfortable, in order to create a liveable indoor environment. The extent of the modification required depends primarily on the distance between the outdoor environmental conditions and the ones required to reach a comfortable status. Thus, the outdoor environmental conditions determining thermal sensation are the ones that should first of all be controlled by urban design, as they are the main drivers of indoor thermal sensation. The more uncomfortable the outdoor environment, the more uncomfortable the indoor one or – if cooling or heating is available – the higher the energy consumption.

Night-time comfort must receive special attention in the equatorial tropics, as nights in the urban context are typically too warm, as a consequence of the heat island effect.

The impact of outdoor thermal comfort on energy consumption at urban or neighbourhood scale is not linked only to its connection to indoor comfort, as comfortable urban spaces can encourage the use of more sustainable forms of transport – including walking, cycling and public transport.

Furthermore, outdoor thermal comfort directly affects health and people's behaviour and usage of outdoor spaces and can contribute to social, economic and cultural vitality. Therefore, a sustainable urban design strategy should give a high priority to the urban microclimate and its implications for thermal comfort.

Some basic information on thermal comfort, with special reference to outdoor conditions is provided in Appendix 2.

### 2.1.1.3 CLIMATE SENSITIVE DESIGN IN THE TROPICS

A hot humid climate is characterised by abundant rainfall, near constant temperatures, seasonal variations in wind speed and direction, and high humidity. A hot arid climate, on the other hand, is characterised by scarce rainfall, a high day-night temperature difference, generally weak but persistent winds, and low humidity, especially in the hottest hours. Tropical climates range between these two extremes, as shown in Figure 2.1.5, which shows the East African Community.

While in temperate climates the increased summer discomfort derived from urbanisation is somehow compensated by the reduction of winter discomfort (thus energy consumption), in tropical climates, urbanisation leads to increased discomfort (and energy consumption) all year round[10].

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[10] *With the exception of the relatively few urban developments located above 2000 m above sea level.*

If the consequences of global warming are added, climate responsive urban design becomes a must for new developments in tropical climates.

## 2.1.2 SOLAR EXPOSURE: STREET WIDTH AND ORIENTATION; BUILDING HEIGHT AND SHAPE; MATERIALS

Because of the multiple reflections on canyon walls (Figure 2.1.12), part of the incident solar radiation reaches the bottom, contributing to the heating of the canyon's floor; moreover, the walls also heat up because of the radiant energy absorbed, with the ultimate consequence of both heating the air and increasing the mean radiant temperature – thus affecting the outdoor comfort and the heat transmitted to the building's interior.

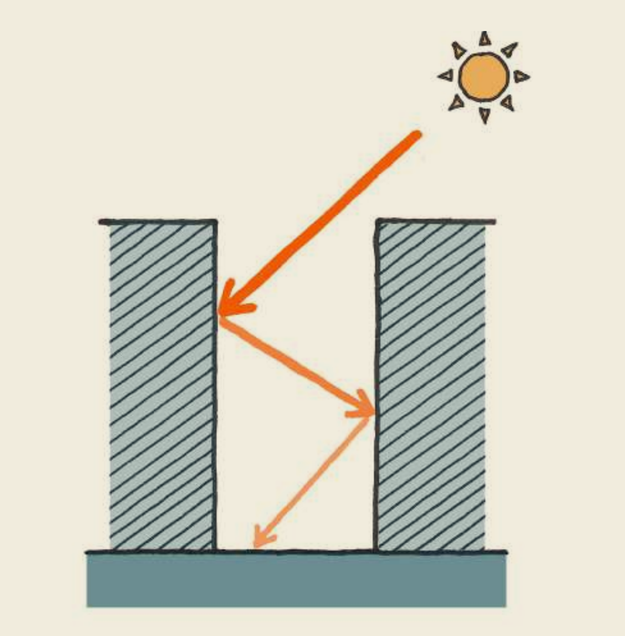
The narrower and deeper the canyon, i.e. the higher the value of the aspect ratio (building height/street width, H/W), the more reflections take place and the more radiant energy is trapped. The amount of reflected energy reaching the bottom of the canyon also depends on the albedo of the wall's surface: the higher the absorption coefficient (= the lower the albedo), the more the radiant energy is absorbed by the upper part of wall and the lower the amount reaching the bottom of the canyon. Thus, low albedo walls should be beneficial to the thermal comfort of the street; the drawback is that the energy absorbed is partly transmitted to the internal part of the building, creating indoor discomfort, and is partly released as long-wave radiation towards the canyon, affecting outdoor comfort.

TThe design of urban canyons plays an important role in creating the urban climate.

Urban canyons are characterised by their height/width (H/W) and length/width (L/W) ratios and by their orientation; the aspect ratio H/W, in turn, affects the Sky View Factor[11] (SVF) – as shown in Figure 2.1.15 - and the airflow. Therefore, street design influences both thermal comfort at pedestrian level and the global energy consumption of buildings.

As the sun is high in the sky in the tropics, much of the short-wave radiation on building facades is generally reflected onto the surface of the street, and this adds to the already large amount of direct radiation it receives and absorbs. For this reason, the control of solar gain is the first aim of urban design in a tropical climate, and the most critical parameter to consider is the aspect ratio H/W, because the H/W ratio also affects the Sky View Factor, thus the amount of long-wave radiation emitted towards the sky, which in turn affects the overall energy balance of the canyon.

FIGURE 2.1.12 **MULTIPLE REFLECTIONS ON THE CANYON WALLS**



In a street in which H/W is high, the ground surface and the lower portions of walls may remain in shade for part of the day (how long it depends on the latitude and on the orientation), so that most of the time they are exposed only to diffuse radiation coming from the limited part of the sky vault seen from ground level, and to reflected radiation from other surfaces; the amount of the latter depending also on their albedo.

As ground and walls are not heated up, the role of long-wave emission towards the sky is negligible and the air at ground level remains cooler than it would be in spaces with higher solar exposure.

The inverse relationship between a canyon's heat gain (and thus outdoor thermal comfort and indoor energy needed for achieving comfort) and a canyon's aspect ratio has been confirmed by many studies. It was found that in Colombo, Sri Lanka (hot humid climate), outdoor thermal comfort in north-south oriented streets is higher than in east-west oriented ones (Emmanuel 2007) and that comfort increases with an increasing H/W ratio (Perera 2014).

The orientation affects comfort because east-west oriented streets are exposed to sun all day, almost irrespective of the canyon's aspect ratio, while the north-south oriented streets are exposed only in the central hours of the day.

Similar results derive from a study (Erell 2012) carried out for the summer period of the city of Eilat, Israel (hot arid climate, latitude ≈ 30° N). In this case the best street orientation was also north-south and comfort improved with the increased H/W ratio.

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[11] *The sky view factor (SVF) denotes the ratio between the fraction of sky seen from an observation point.*

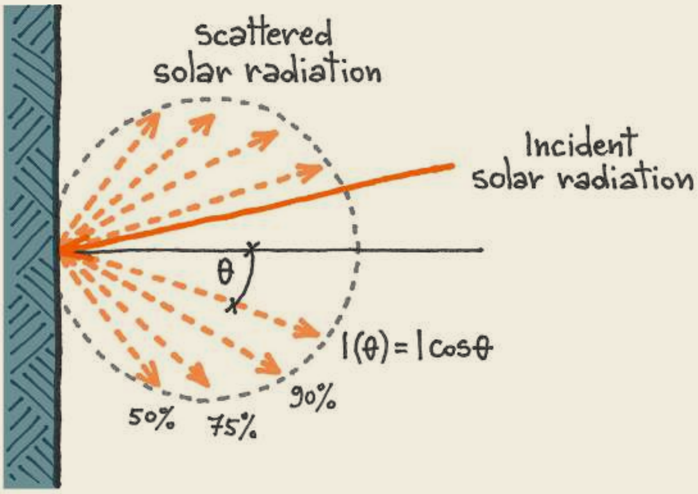
## BOX 2.1 GLAZED WALLS CANYONS

Special cases are the urban canyons whose walls are the facades of highly glazed buildings.

When sun rays hit a rough surface, as a plastered wall, they are subject to diffuse reflection and, as first approximation, follow the theoretical so called cosine law, i.e. the reflected energy in a particular direction is proportional to the cosine of the angle between that direction and the surface normal (Figure 2.13). Thus, the energy reflected downwards is attenuated by both the albedo and the cosine law:

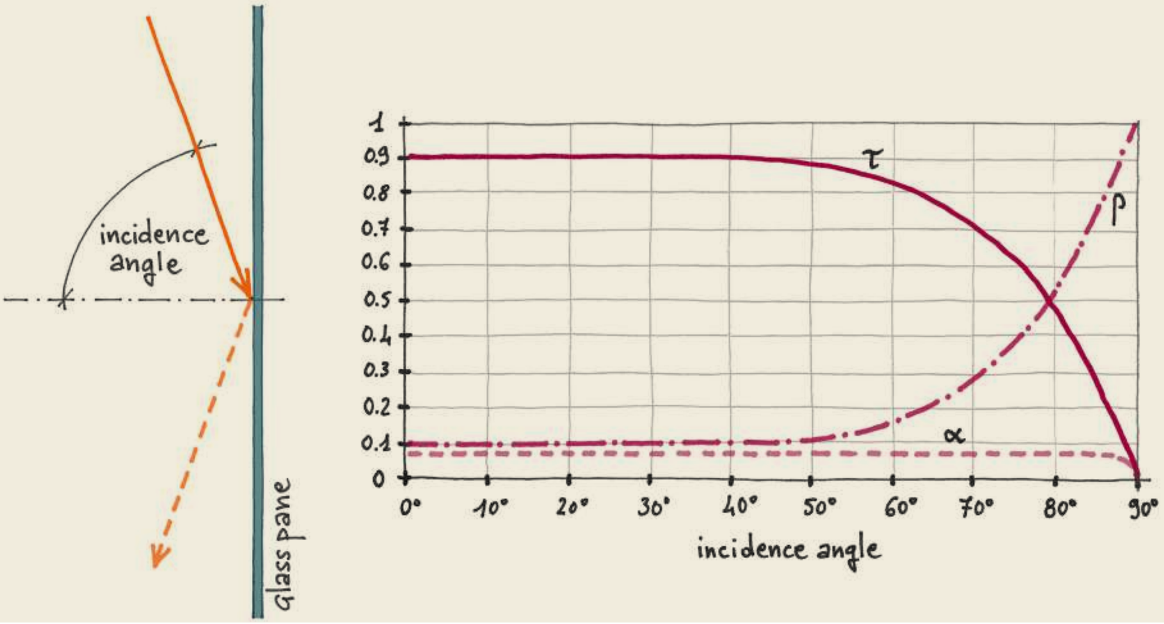
$I_r = \alpha I \cos \theta$ , where I is the incident solar radiation, $\alpha$ is the reflection coefficient (albedo) and $\theta$ is the reflection angle.

FIGURE 2.1.13 **DIFFUSE REFLECTION – LAMBERT COSINE LAW**



Glass, however, when hit by solar radiation with a high angle of incidence (Figure 2.1.14) as in the tropics, reflects almost entirely the solar radiation (specular reflection), which reaches the bottom of the canyon, with the effect that the amount of radiant energy reaching the canyon floor is almost doubled (direct + reflected), and this has obvious dramatic consequences on both thermal comfort and the heat load that buildings derive. This phenomenon, at tropical latitudes, takes place for any canyon orientation and H/W ratio, thus buildings with high WWR (Window to Wall Ratio) should be avoided, as well as any kind of highly reflective surfaces, such as aluminium cladded facades.

FIGURE 2.1.14 **SINGLE GLASS PANE: ABSORPTION (α), TRANSMISSION (τ) AND REFLECTION (ρ) COEFFICIENTS AS FUNCTION OF THE SOLAR RADIATION INCIDENT ANGLE.**



The conclusion we can draw from these findings is that streets in the tropics should be characterised by high H/W (>1) values, and that east-west is the most critical orientation. Such shading strategies, however, should also be evaluated in relation to the drawbacks deriving from the possible reduction in ventilation, air movement being beneficial for both indoor and outdoor thermal comfort.

The physical properties of urban canyon surfaces have a significant effect on the magnitude and the time distribution of the energy fluxes absorbed and emitted, as they depend on the absorption coefficient of the surface of the materials, i.e. their albedo.

The effect of high walls and ground albedo on thermal comfort and energy consumption is similar to that of shading, as in both cases surface temperatures do not rise much and, consequently, neither do the near-surface air temperature or the mean radiant temperature. The mean radiant temperature is a very important parameter, as the effect of a hot pavement on pedestrian comfort is not limited only to the fact that the hot surface heats up the air above it, but comfort is also significantly affected by the long-wave radiation emitted by both the pavement and the canyon walls.

Thus, to prevent or reduce the temperature increase of the surfaces, there are two strategies: a) increase their shading and/or b) increase their albedo.

According to authoritative literature (Erell 2012, Huang 2014), high albedo values may help, but are not a determinant for outdoor comfort (the canyon's aspect ratio is far more important); other benefits may derive from this, such as better natural lighting conditions, which in deep, narrow canyons may be otherwise impaired.

The conductivity and thermal capacity of the materials also count. The thermal mass of the urban canyon gives rise to the same behaviour as the thermal mass of buildings: the amplitude of the temperature variations is a function of the amount of mass capable of storing heat, and peak temperatures are reduced and delayed.

Thus, to minimise the increase in air temperature in the streets during the daytime, the best approach appears to be to design urban canyons with low SVF (high H/W), very light-coloured surfaces and high thermal mass[12]. This would lead to better thermal comfort outdoors and indoors, because of the control of both air temperature and long-wave radiation from the canyon's surfaces (walls and ground).

The optimal thermal mass and H/W value should be carefully evaluated as it may negatively affect night-time comfort: the greater the amount of heat stored by the canyon mass during the day, the greater the amount released during the night, and high H/W restricts the cooling effect due to the long-wave emission towards the sky. This is particularly critical in hot arid and Savannah climates because of the relatively low temperature and clear sky at night, which may provide comfortable conditions both outdoors and indoors with appropriate canyon design in terms of H/W, orientation and thermal mass.

It can be concluded that SVF and shading, together with wall and ground colours, are the most critical parameters in the radiative exchange balance, affecting outdoor and indoor comfort and the energy consumption of buildings in urban canyons and in other urban settings with different geometries. Thus, in the urban design process it is important to be able to compare both the values of the SVF and the amount of daily shading to identify different possible solutions.

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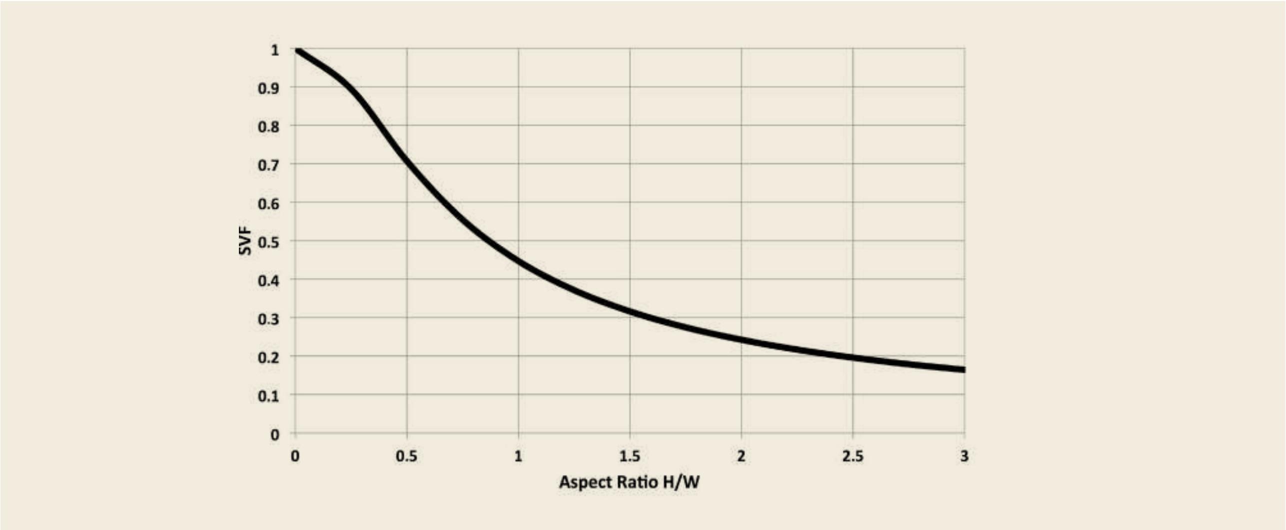
[12] *In some parts of the Mediterranean villages and towns can be found where the typical narrow streets have their heavy-weight buildings whitewashed, to reduce the surface temperature and for improving natural lighting.*

FIGURE 2.1.15 **SVF AS A FUNCTION OF H/W IN THE CENTRE OF THE FLOOR OF A SYMMETRICAL SEMI-INFINITE URBAN CANYON**



## BOX 2.2 SVF EVALUATION

There is a set of cases in which the calculation of SVF is quite simple, in case of semi-infinite, walls or valleys (Figure 2.1.16), and at the centre of a courtyard (Figures 2.17), where (Erell 2011):

$SVF \approx \cos \beta_W \times \cos \beta_L$

whith $\beta_W = \tan^{-1}(2H/W)$ and $\beta_L = \tan^{-1}(2H/L)$.

FIGURE 2.1.16 **SVF AS A FUNCTION OF ANGLE β AND H/W FOR SOME COMMONLY OCCURRING ARRANGEMENTS (PIJPERS-VAN ESCH 2015)**

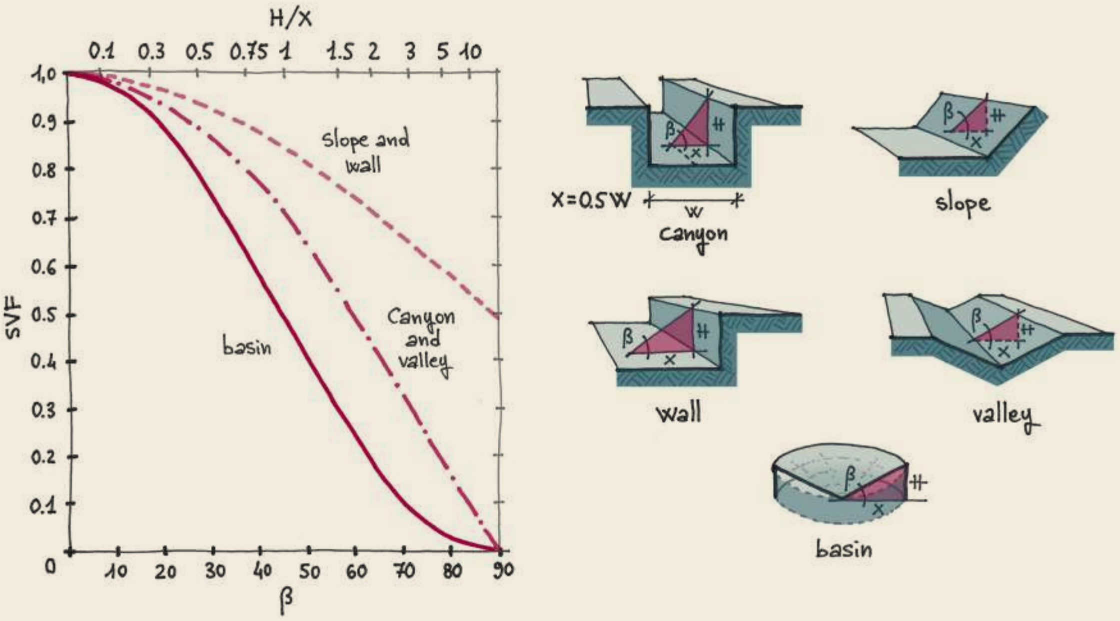
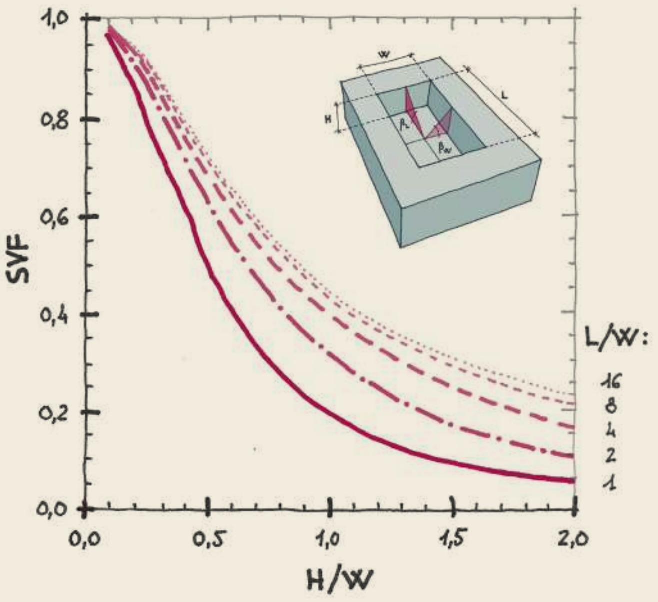


FIGURE 2.1.17 **COURTYARD. APPROXIMATED SVFS AS A FUNCTION OF BOTH H/W AND L/W**



In real urban settings, generally the geometries are complex and irregular, and precise calculations may be long and laborious. In these cases, there are two alternatives. The first is to use specific software tools, often integrated into solid modelling software, and from which the SVF value can be evaluated.

The second alternative does not require any specific software. It is a simple straightforward approach based on two steps.

The second alternative does not require any specific software. It is a simple straightforward approach based on two steps.

Step 1. Plot on a polar chart the obstruction profiles seen from a selected point (Figure 2.1.18), with the method described in Appendix 3.

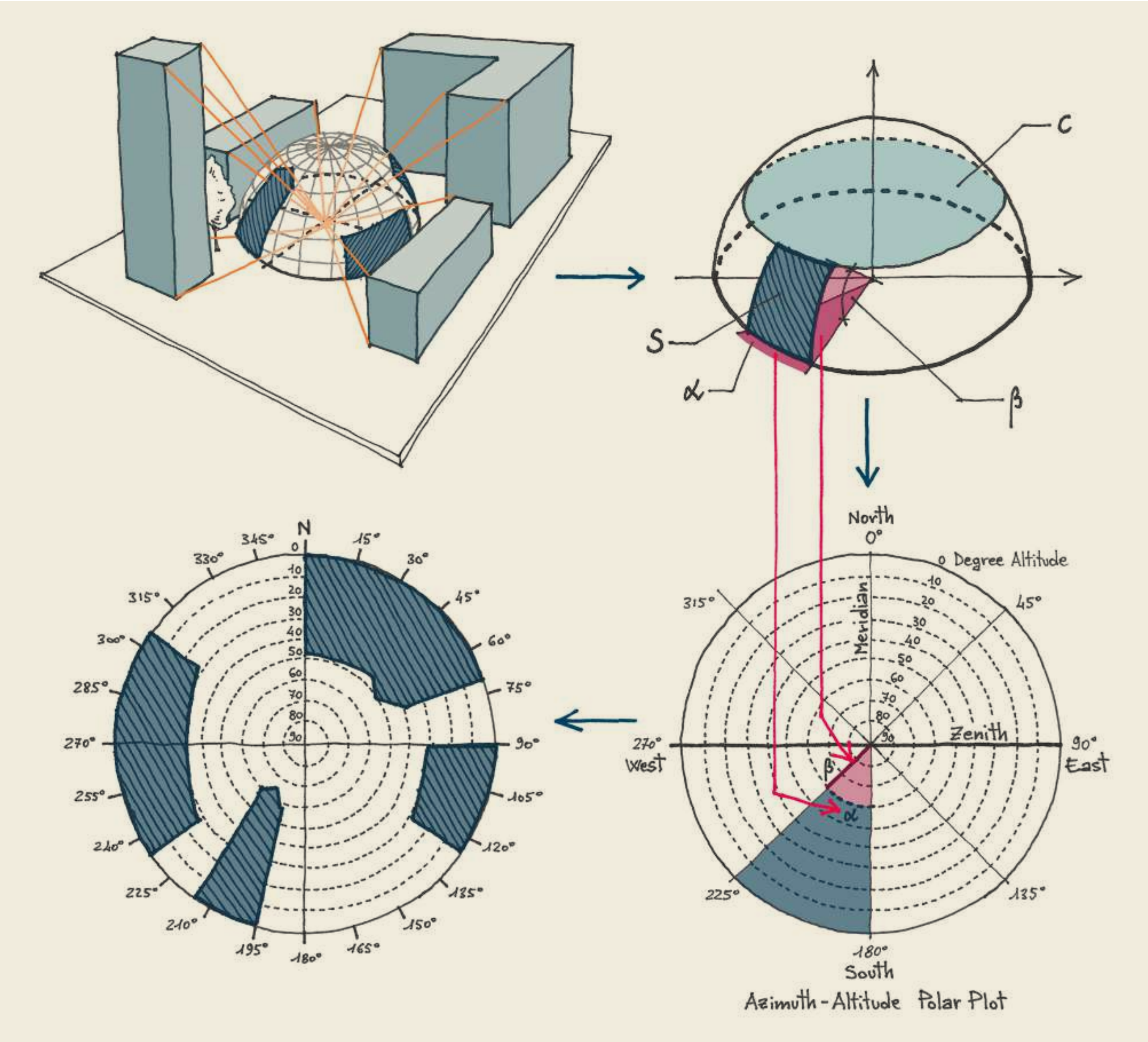
Step 2. Calculate the approximated value of SVF as:

$$SVF \approx (A_{PC} - A_{OP})/A_{PC} = 1 - A_{OP}/A_{PC}$$

where $A_{PC} = \pi r^2$ is the area of the polar chart, r is the radius of the outmost circle (0 degree altitude) of the polar chart used, and $A_{OP}$ is the total area of the obstruction profiles.

In all tropical climates, with the exception of a High Upland climate, it is important to design streets and buildings in such a way as to provide maximum shade in pedestrian sidewalks and in general in public spaces in order to improve their thermal quality, as in tropical climates a large part of people's time is usually spent outdoors, for both productive and leisure activities. Since the sun is high in the tropics, pedestrian streets should avoid an east – west orientation, while a north – south orientation, which provides shade in the morning and in the afternoon on at least one side of the street, will be beneficial. Such shading strategies should be mindful

FIGURE 2.1.18 **CONSTRUCTION OF THE OBSTRUCTION PROFILES ON THE POLAR CHART**



of the need to promote ventilation at building and neighbourhood scales, as shown in section 2.1.3.

Thus, tools for easily controlling shade patterns in urban canyons or in any other urban configuration are crucial at the design stage.

Computer models are available for calculating shading at any hour of any day at a given location (Figure 2.1.19), and for providing information on incident solar radiation and/or the amount of daylighting (Figure 2.1.20). Computer modelling, however, often does not return a global view of the shading of the site, unless a large number of images is produced, for each hour of each month (Figure 2.1.21).

Less detailed but more immediate comprehensive information is given by sun charts coupled with the obstruction profiles of buildings (Figure 2.1.22), as described in Appendix 4.

FIGURE 2.1.19 **PROJECTED SHADOWS PROVIDED BY 3D MODELLING**

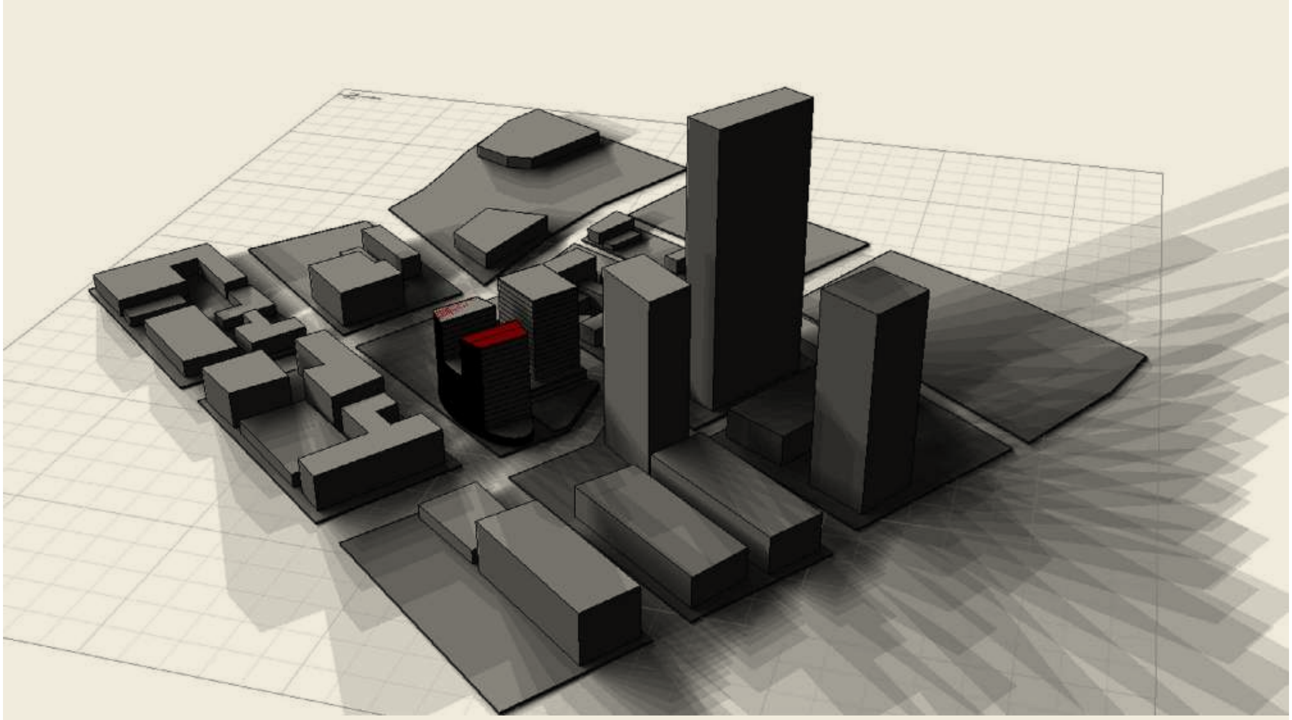


FIGURE 2.1.20 **SOLAR RADIATION INCIDENT ON SURFACES (LEFT) AND DAYLIGHTING (RIGHT)**

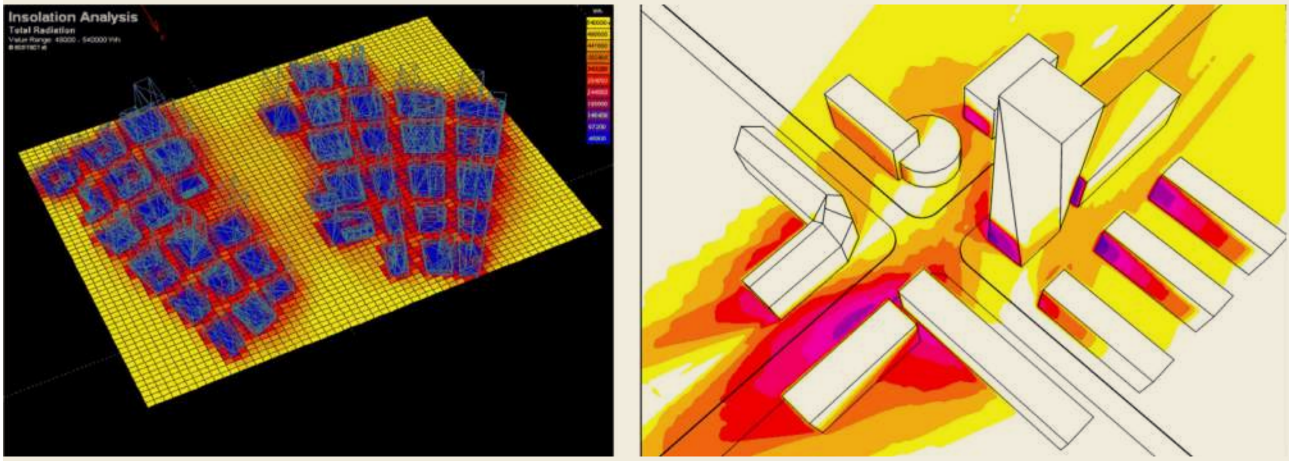


FIGURE 2.1.21 **EXAMPLE OF SHADOW ANALYSIS BY MEANS OF COMPUTER SCREENSHOTS FOR THE NORTH-SOUTH CANYON SKETCHED IN FIGURE A3.4, AT 7S LATITUDE**

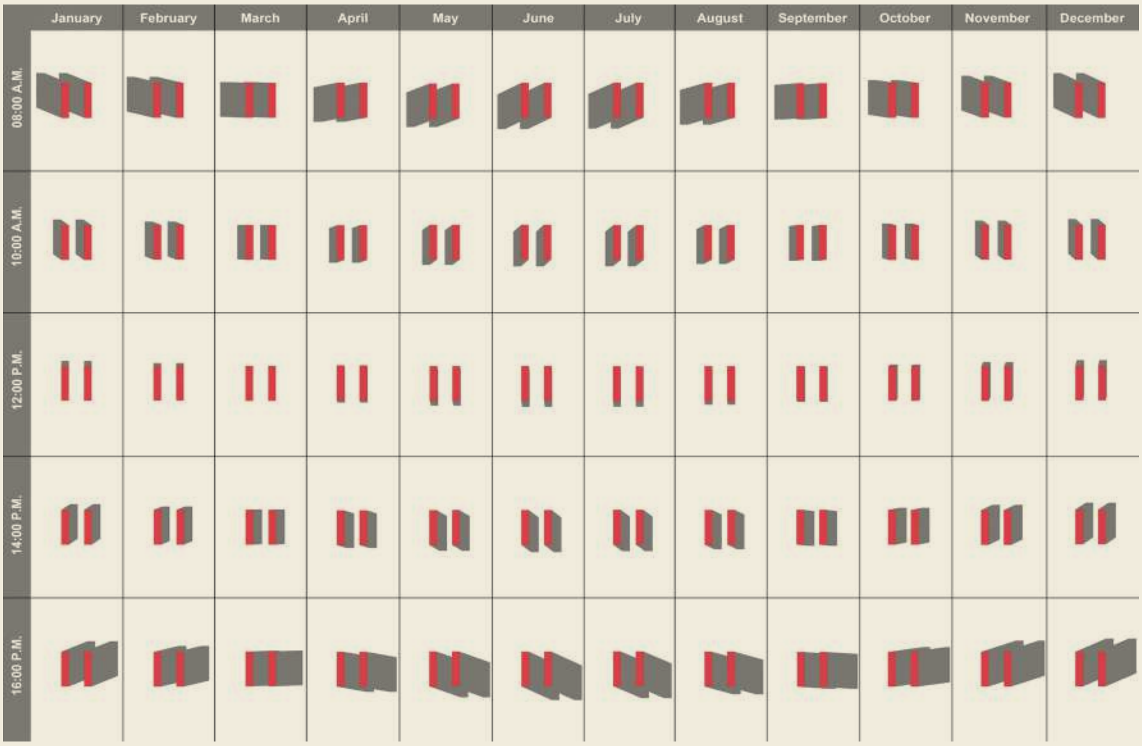
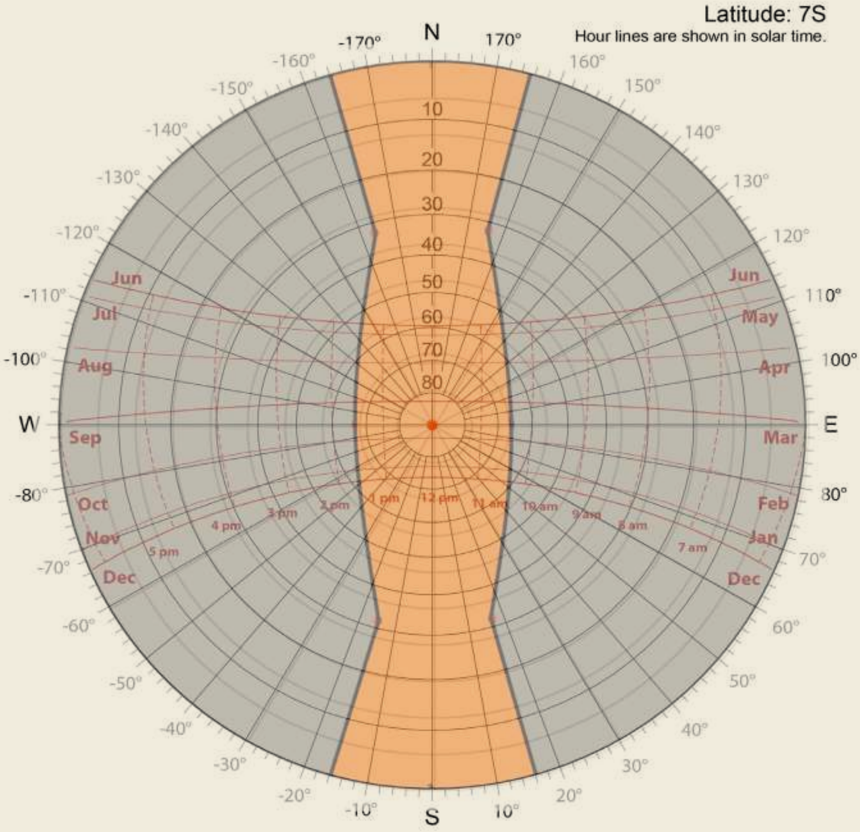


FIGURE 2.1.22 **SUNSHINE AND SHADOW HOURS AT A POINT AT GROUND LEVEL, IN THE MIDDLE OF THE NORTH-SOUTH CANYON SKETCHED IN FIGURE A3.4, AT 7S LATITUDE**



### 2.1.2.1 SUGGESTIONS FOR EAST AFRICAN COMMUNITY CLIMATES

By making use of the obstruction profiles and sun charts and the examples shown in Appendices 3 and 4, some general rules can be derived for the latitudes within which the East African Community lies, i.e. from about 11 S to 5 N.

- A North-South orientation is the best, as a point at centre canyon, ground level, is subject to direct sunshine for the minimum number of hours in all months, thus better outdoor and indoor comfort is achieved, provided that the windows and walls of the upper storeys are appropriately shaded with movable devices or egg-crate protections.
- With the East-West orientation the floor of the canyon is fully exposed to solar radiation for most of the time, irrespective of the aspect ratio: only in the coolest and in the hottest month of the year will the floor of the canyon be fully shadowed for H/W ≥ 2. East-west canyons hold relatively little potential for enhancing outdoor thermal comfort through geometry alone; indoor comfort, however, can be controlled if shading devices or overhangs protect the canyon walls.
- The number of hours of solar exposure decreases as the aspect ratio increases: the deeper the canyon, the lower the direct and diffuse solar radiation at ground level. This finding calls for densely built areas
- Moving away from the north-south orientation, towards the east-west, the amount of solar radiation reaching the bottom of the canyon increases, but not so much up to 45° offset from south.
- It is advisable, for north-south canyons, not to have an aspect ratio lower than 2.

In conclusion, the optimum street grid for outdoor comfort should be structured in the form of deep, narrow north-south canyons and, if required, larger east-west ones. An offset not exceeding 45° from the exact cardinal orientations is acceptable. Canyon walls and windows, especially those of the upper floors, should be appropriately protected with shading devices.

### 2.1.2.2 CREATING SHADE IN OPEN SPACES

Shade, in tropical climates, makes for liveable outdoor spaces. Sidewalks are the most common and thus critical open spaces in the streets, not only as transit areas, but also for their different potential uses, such as small aggregations, recreation or shopping spaces (Figure 2.1.23). In order to expand the potential uses of sidewalks, shading them is a crucial prerequisite.

Due to the sun paths of the tropical latitudes, it is impossible to have all the points of the ground level of an urban canyon shaded for the whole day or all year round, and around noon only horizontal sun protections can provide shade. There are many examples of movable horizontal protections across the street, as in Sevilla, Spain or in Fez, Morocco (Figure 2.1.24). Mobile horizontal protections are particularly effective if they are removed at sunset and activated again in the early morning, because in this way night cooling is not precluded.

Another possibility for having part of the street completely or almost completely shaded at any time of the day and of the year is given by arcades, which are the only way to shade walkways in wide streets (Figure 2.1.25).

FIGURE 2.1.23 **MULTIPLE USED OF SIDEWALKS**

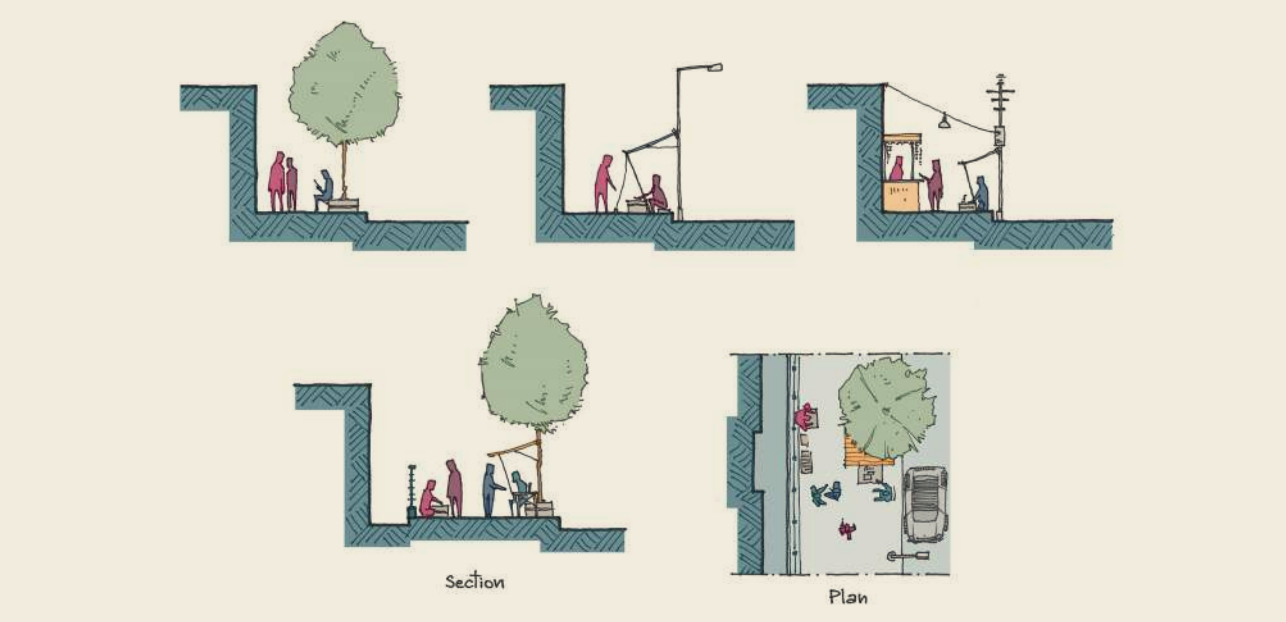
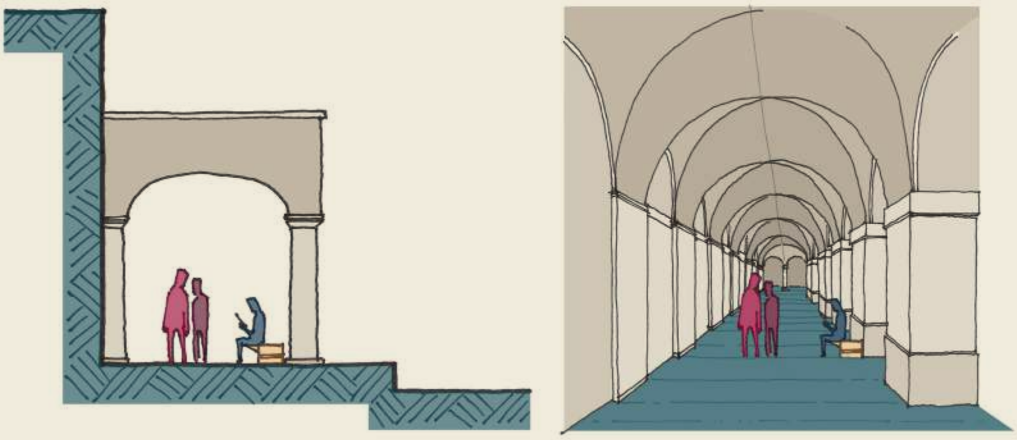


FIGURE 2.1.24 **HORIZONTAL MOBILE STREET SUN PROTECTIONS IN SEVILLE, SPAIN (LEFT) AND IN FEZ, MOROCCO (RIGHT)**

FIGURE 2.1.25 **ARCADES**



### 2.1.2.3 COMBINED ACTIONS

All the above strategies can be appropriately combined to create a comfortable outdoor environment in urban streets. They can be implemented best in a mixed-use neighbourhood, as arcades protect shoppers from sun and rain and are also effective in wide east-west running streets, where recreation areas, like coffee shops, can be enhanced by the appropriate choice and positioning of trees.

A tropical climate makes walking and cycling an unpleasant experience if solar radiation is not sufficiently shielded. Trees that provide shade over the cycle lanes would make this means of mobility far more attractive.

### 2.1.3 AIR MOVEMENT

Air movement not only plays an important role in the energy balance of the urban space, but also greatly affects outdoor and indoor thermal comfort, as well as the energy exchanges of the buildings.

As discussed in Appendix 1, wind behaviour in the built environment is very complex, and precise evaluations can be made only case by case, by means of computational fluid dynamics (CFD) simulations (Figure 2.1.26) or wind tunnel tests.

However, some rules of thumb for urban canyons have been developed, which are guidance for a first approximation to take advantage of air movements or – at least – to avoid design solutions that reduce or inhibit them.

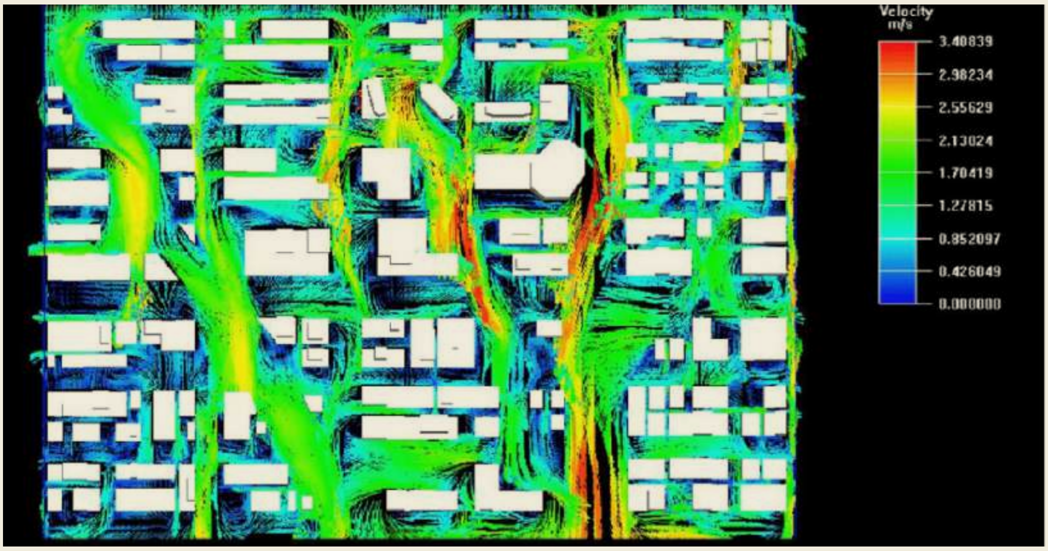
A simple estimate of wind speed $u_c$ near the middle of the street, as a function of the free wind speed $u_r$ blowing above the canyon is given by the empirical linear relationship (Erell. 2011):

$$u_c = u_r P$$

where P is an attenuation factor which depends on the H/W ratio and the wind angle of attack (angle of attack = 0 when wind blows parallel to the canyon axis and = 90° when perpendicular).

Maximum attenuation of wind speed occurs when it blows perpendicular to the canyon axis and the minimum when parallel, progressively reducing from the maximum

FIGURE 2.1.26 **EXAMPLE OF CFD ANALYSIS OF WIND PATTERN IN URBAN CONTEXT**



to the minimum moving from perpendicular to parallel. The attenuation also depends on the canyon's aspect ratio. When the wind direction is near parallel to the canyon's axis, the attenuation factor ranges from P = 0.5 when the canyon's aspect ratio is 0.33, to P = 0.35 for a narrow one (H/W = 2). When flow is near- perpendicular the attenuation approaches P = 0.25 in all cases.

Other values of P, for different conditions can be derived from Figure 2.1.27.

It should be noted that up to an angle of attack of 30° the attenuation factor remains almost constant, i.e. wind velocity in the canyon is insensitive to the canyon's orientation with respect to the prevailing wind within a range of ± 30°. On the other hand, the optimum incidence angle of wind through a window, for indoor ventilation, is between 0° (perpendicular) and 45°. This means that there is a conflict between the optimum canyon orientation for heat removal from the outdoor environment and the optimum canyon orientation for indoor ventilation. A compromise must be found or specific measures, such as wing walls at the windows, should be taken.

Studies on wind behaviour in an urban context show that effective ventilation of urban streets may be promoted by applying the following general guidelines (Erell 2011):

- Avoid uniformity in building height, canyon width and canyon length; uniformity reduces eddies, thus ventilation[13];
- Keep the length of street canyons as short as is practical, to promote flushing at street intersections by corner eddies.

Favouring and enhancing wind penetration in a built area is one of the most critical tasks the urban designer has to face in order to control outdoor and indoor thermal comfort in tropical climates. To that end, a relevant index to keep under control is the permeability P of the built area front:

$$P = S/(S+L)$$

where S is the building separation and L the continuous facade length, as defined in Figure 2.1.28.

It is important, in hot humid climates, to let more wind penetrate through the neighbourhood texture. Breezeways can be in the form of roads, open spaces and low-rise building corridors through which air reaches the inner parts of urbanised areas (Figure 2.29).

Proper orientation and layout of the buildings and adequate gaps between buildings are needed. A staggered arrangement of the blocks allows the blocks behind to receive the wind penetrating through the gaps between the blocks in the front row (Figure 2.1.29).

Studies carried out for Hong Kong (hot humid climate) lead to the following guidelines (School of Architecture (a), School of Architecture (b), DACUHK 2005):

- Permeability equivalent to 20% to 33.3% is a good starting point for neighbourhood design (Figure 2.1.30);
- Building height variation across the neighbourhood and decreasing height towards the prevailing wind direction should be adopted to promote air movements (Figure 2.1.31);
- In canyons, aspect ratio H/W should not exceed the value of 3 (Figure 2.1.32), as excessive building heights reduce air movement;

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[13] *On the other hand, uniformity is beneficial regarding the settlement's albedo, which is higher than in the case of lack of uniformity.*

FIGURE 2.1.27 **CORRELATION BETWEEN WIND SPEED ATTENUATION AND ANGLE OF ATTACK FOR STREET CANYONS OF VARYING ASPECT RATIO (ERELL 2011)**

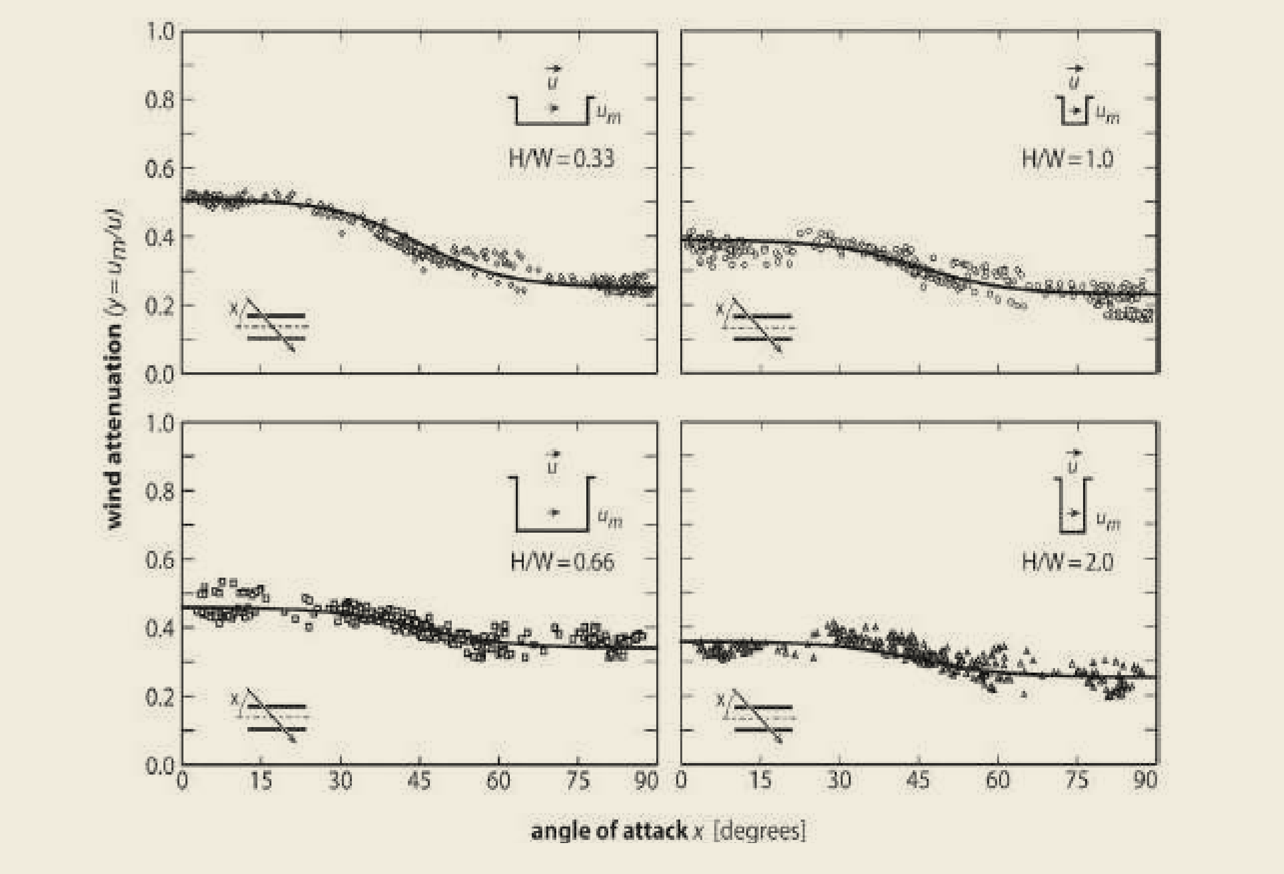


FIGURE 2.1.28 **BUILDINGS PERMEABILITY TO WIND = S/(S+L)**

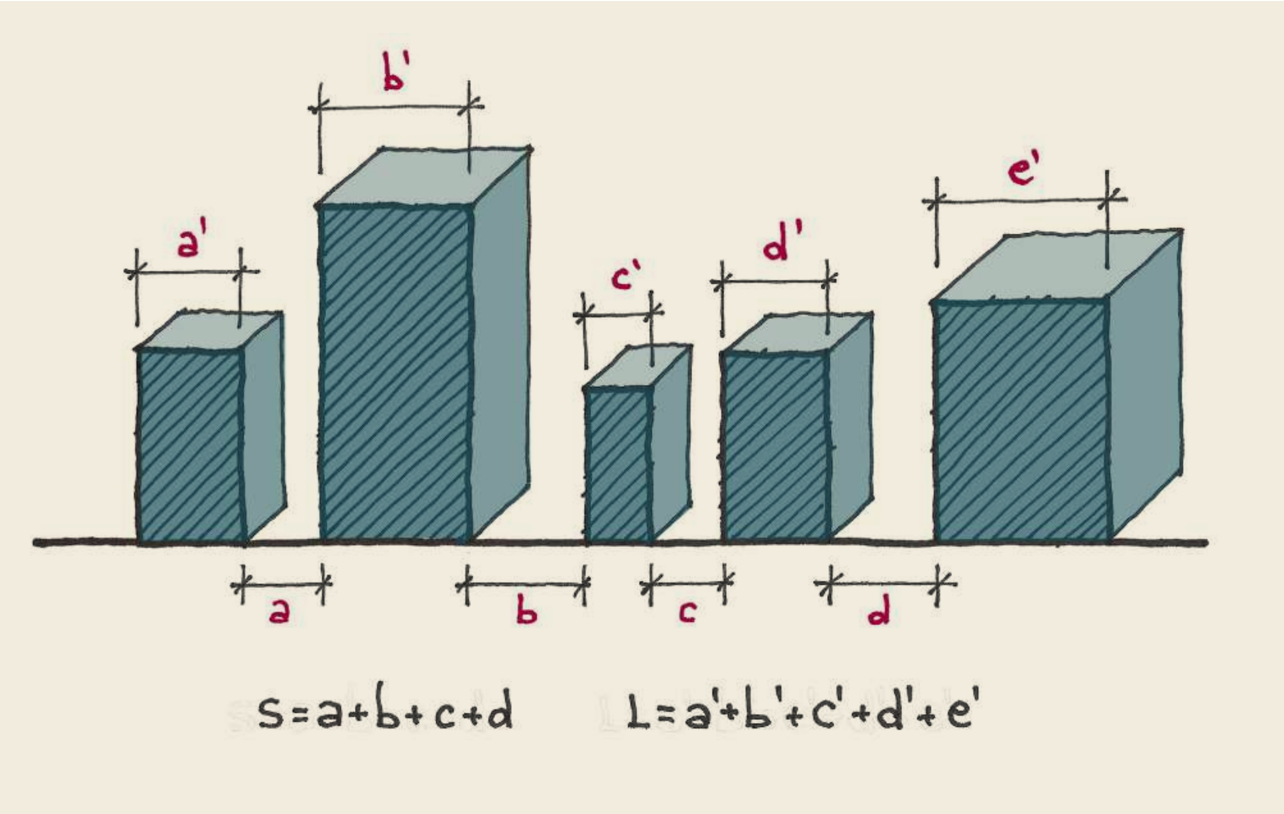


FIGURE 2.1.29 **FAVOURING BREEZEWAYS**

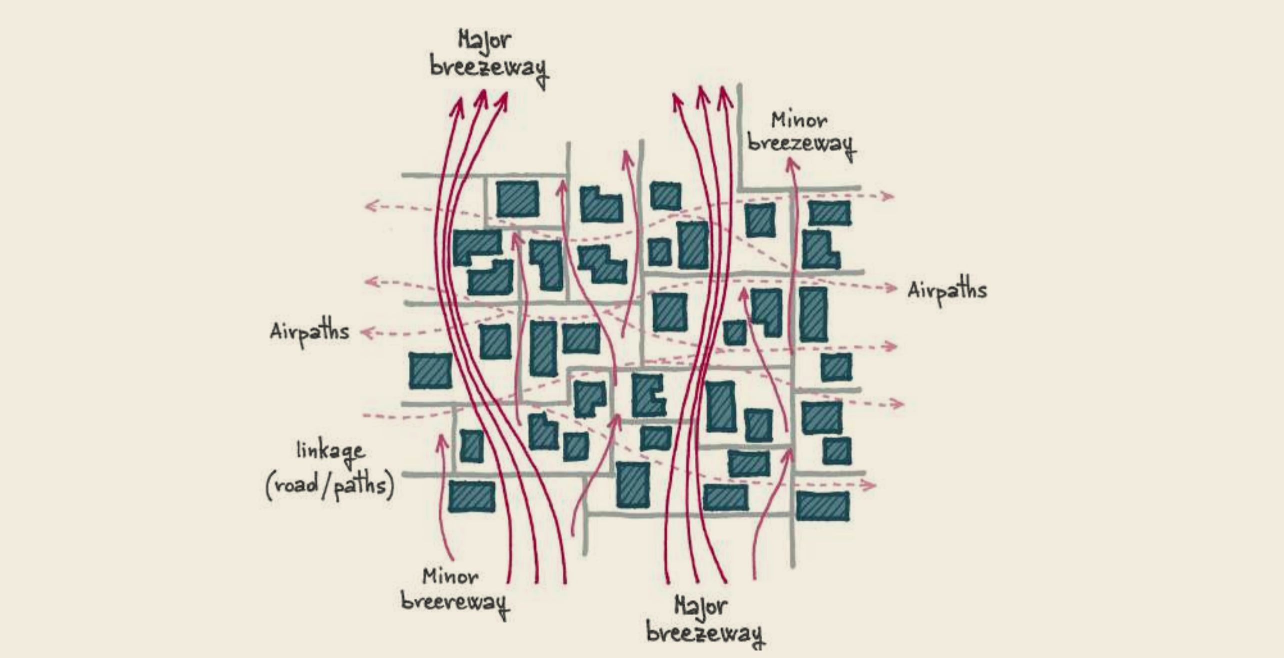


FIGURE 2.1.30 **CLOSELY PACKED BUILDINGS IMPEDE AIR FLOW**

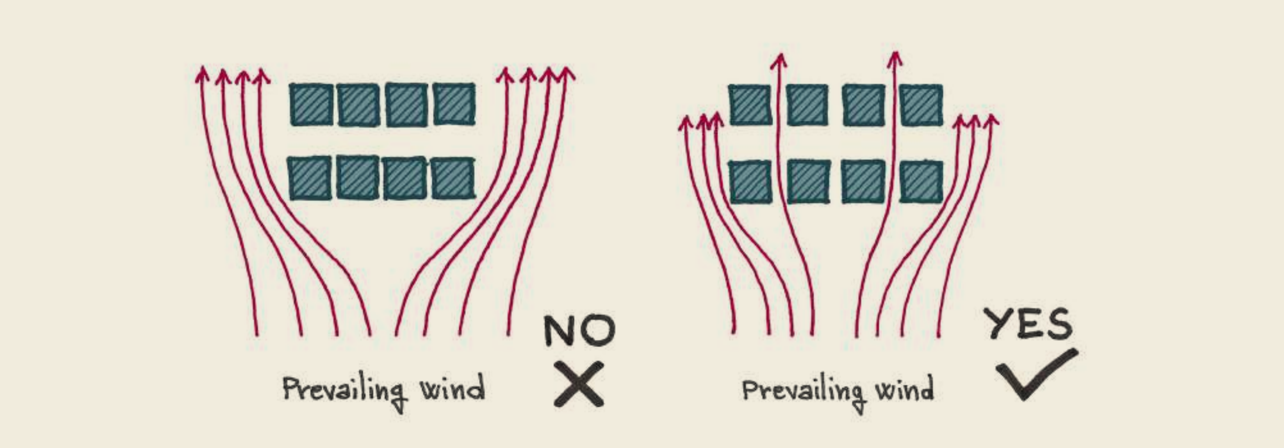
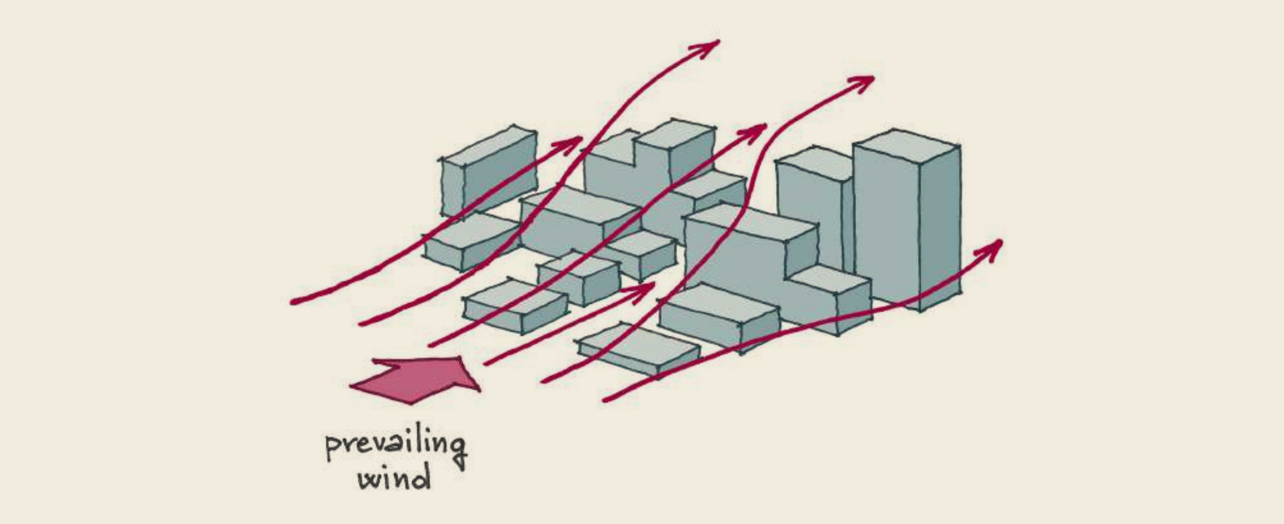
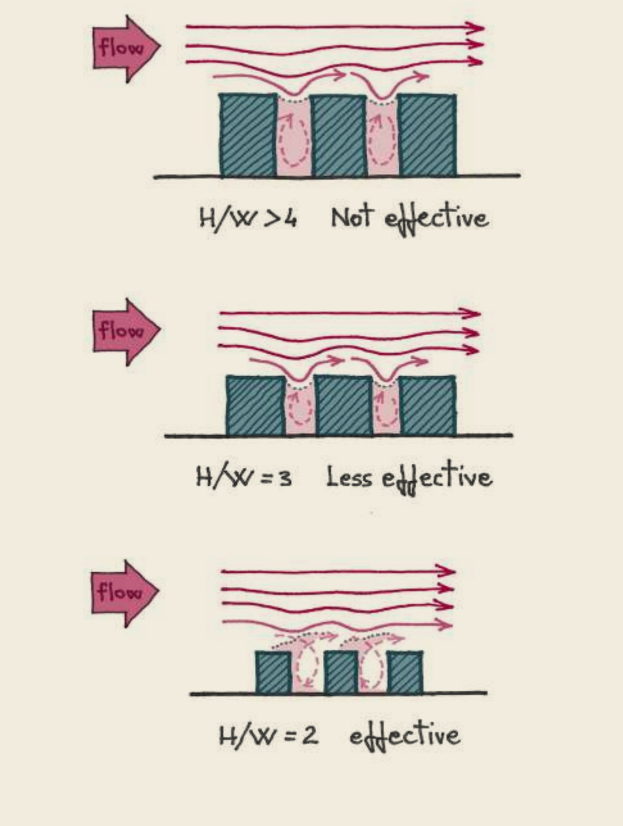


FIGURE 2.1.31 **GRADATION OF BUILDING HEIGHTS HELPS WIND DEFLECTION AND AVOID AIR STAGNATION**



- With high ground coverage[14] it is important to consider measures such as building set back, so that the neighbourhood average ground coverage can be lowered (Figure 2.1.33). Greening at ground level in these areas further improves the urban climate for pedestrian activities. A ground coverage < 70% is recommended;
- When a neighbourhood is by a waterfront, properly orientated air paths connecting to the waterfront or open spaces are effective in bringing air ventilation into it (Figure 2.1.34);
- Open spaces in urban areas allow wind to flow into them and benefit pedestrians with air movement. In general, the dimensions of the open space should be no less than twice the average height of the surrounding buildings. This would create a height to width ratio < 0.5;
- Where possible, open spaces may be linked and aligned in such a way as to form breezeways or ventilation corridors. Structures along breezeways/ventilation corridors should be low-rise (Figure 2.1.35);

FIGURE 2.1.32 **CANYONS THAT ARE TOO NARROW AND DEEP REDUCE THE EFFECTIVENESS OF AIR MOVEMENT**



- A series of main streets/wide avenues should be aligned in parallel, or up to 30 degrees to the prevailing wind direction, in order to maximise the penetration of the prevailing wind through the neighbourhood (Figure 2.1.36). However, the optimum canyon orientation for wind exploitation (parallel to wind direction) should also be carefully considered in relation to these additional conditions:
    - Best canyon orientation from the point of view of solar exposure;
    - Optimum wind direction for effective indoor ventilation.

In the hot humid climates of the EAC the prevailing winds are the monsoons, blowing in a NE-SW direction. From the point of view of the winds alone, the ideal canyon orientation should be the same, but then it would not be ideal from the point of view of sun exposure and indoor ventilation. An offset of about 15-25° from south would optimise all the requirements.

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In hot arid climates openness to wind is not a good strategy, for two reasons:

1. Air temperature during the daytime is very high, and air movements help the heat transfer by convection towards the built mass, contributing to its heating up;
2. Winds often carry sand, from which the built area should be protected.

In savannah climates, where air temperature during the daytime is moderately high, the convective heat transfer to the built mass is not critical, and air movement can be helpful for improving outdoor comfort.

In upland climates, air movement is beneficial during the hot season, but should be minimised during the cool one. This could be obtained by grading the height of the buildings, with the higher ones acting as a protective barrier against the cool winds, taking into account the direction from which they blow.

In the great lakes climate, openness to wind can generally be beneficial all the year round, but it may be very difficult to find a compromise between the street orientation requirements deriving from the need for sun protection and the optimum orientation deriving from the prevailing direction of the wind, since this direction is driven by the breezes, which blow perpendicular to the shoreline; thus, their direction depends on the position of the settlement around the lake.

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[14] *Ground coverage = total built area/total area.*

FIGURE 2.1.33 **REDUCTION OF GROUND COVERAGE BY BUILDING SETBACK**

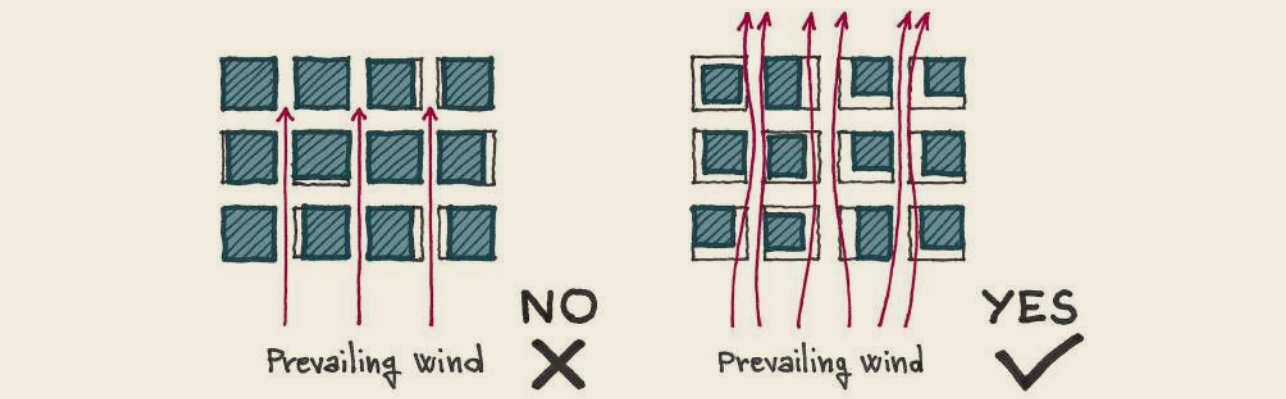


FIGURE 2.1.34 **WAYS OF CREATING BREEZEWAYS AND AIR PATHS IN THE NEIGHBOURHOOD**

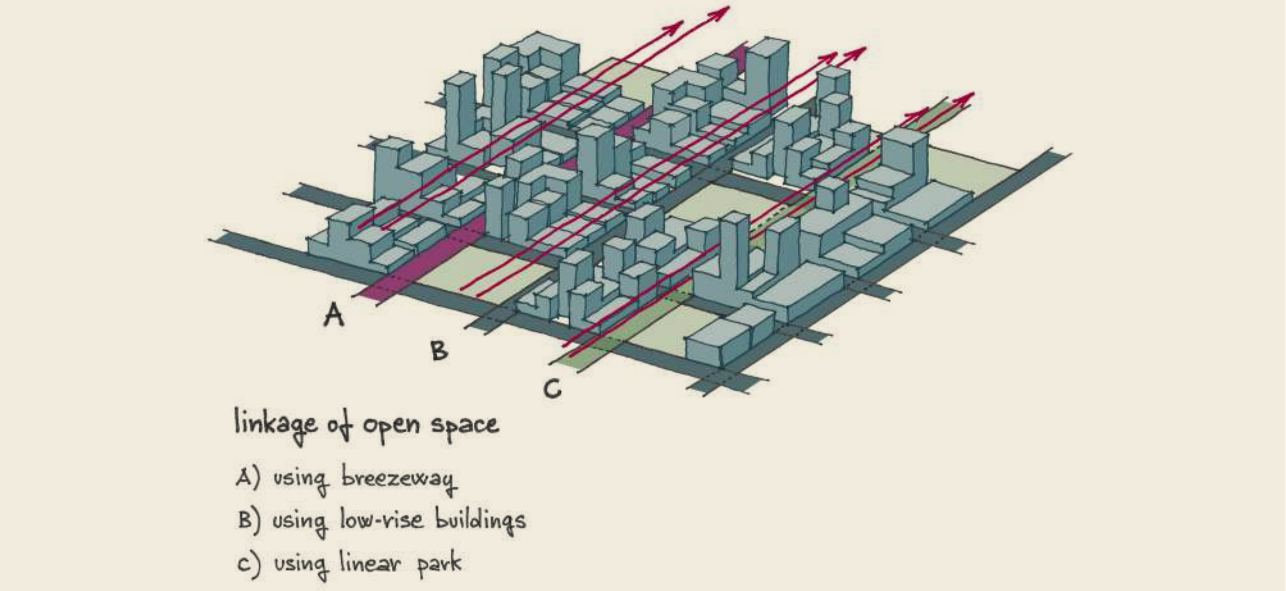


FIGURE 2.1.35 **LINK OPEN SPACES TO FORM VENTILATION CORRIDORS**

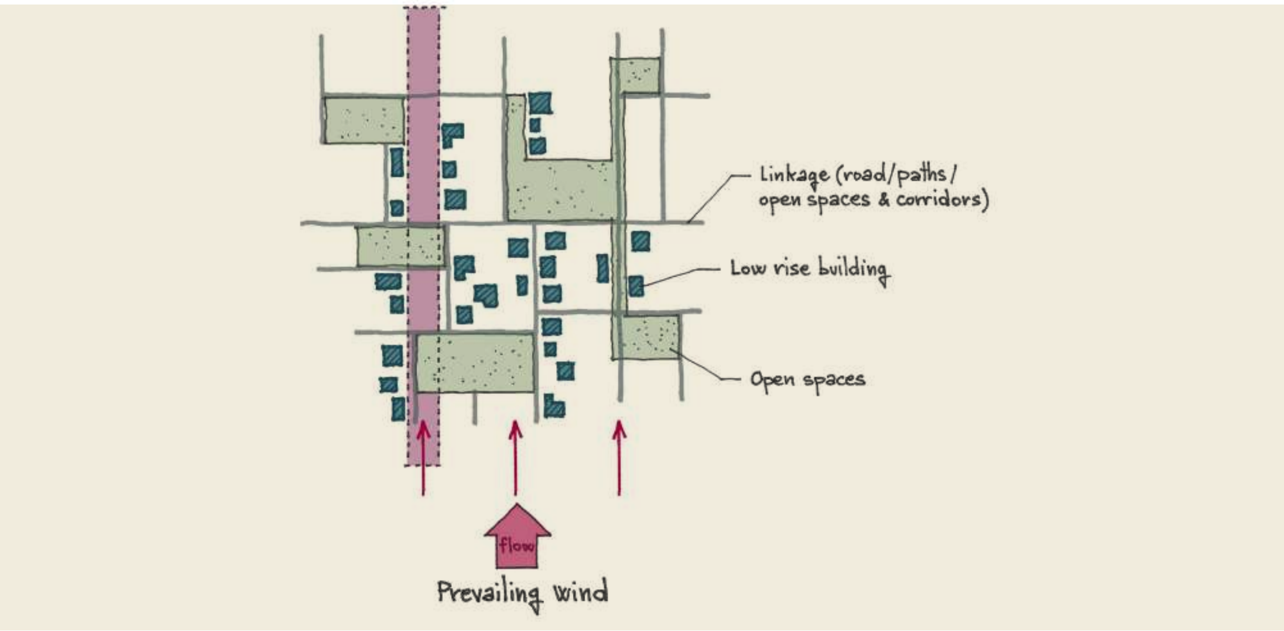
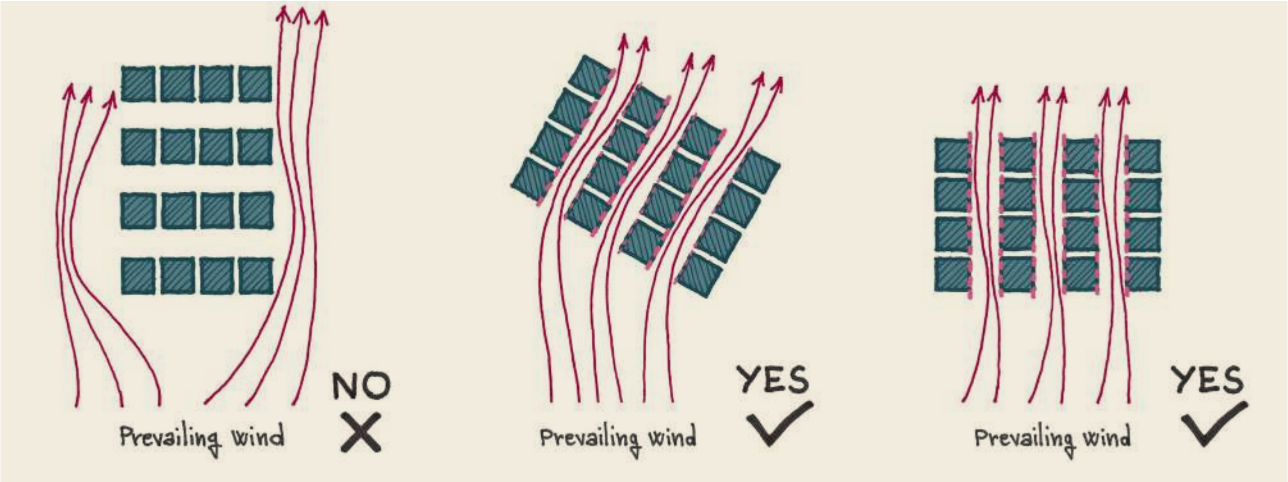


FIGURE 2.1.36 **ORIENTATION OF STREET GRIDS**



## 2.1.4 GREEN SPACES

The albedo of vegetation is often lower than that of solid surfaces such as bare soil or concrete, both because of the dark leaf pigment and because sunlight penetrates the upper surface of the canopy and is then absorbed within the plant following multiple reflections between individual leaves; even grass reflects only 20 to 22% of incident sunlight, while bushes or trees may reflect as little as 12 to 15%, about the same as asphalt pavement (Erell 2011). One would expect that this low albedo would cause the surface, and thus the air, to overheat. Instead, urban greening, i.e. extensive road side tree planting, green patches, urban parks and urban gardens, are very efficient and effective means of improving outdoor and indoor thermal comfort and of reducing energy consumption for cooling buildings. This benefit derives primarily from the heat exchange properties of leaves: intercepted and absorbed solar energy is released by convection, long-wave radiation, and evaporation (Figure 2.1.37). Because of evaporation the leaf temperature does not rise, and thus air around it does not heat up. Moreover leaves, intercepting solar radiation, provide shade, preventing the temperature of the ground underneath from increasing. In this way the low albedo is entirely offset by the thermal properties of greenery.

To sum up, vegetation affects the energy exchanges between buildings and the environment in three ways:

- because of evapotranspiration, plants release less sensible heat to the adjacent air, so that buildings are exposed to cooler ambient temperatures;
- cooler surfaces emit less infrared radiation, thus reducing the radiant load on building surfaces (e.g. a lawn vs. a bare parking lot);
- when vegetation provides shading, the solar heat load on building surfaces is significantly reduced.

Not all the effects induced by vegetation are positive, in relation to the comfort and energy consumption of buildings, as:

- Comfort is not only affected by air temperature, but also by radiation, relative humidity and air velocity; since relative humidity is increased by evapotranspiration, comfort conditions may worsen and energy consumption for air conditioning increase because of the greater amount of latent heat to extract, partially offsetting the benefit of a lower air temperature;
- Shading not only reduces solar gains, but also net long-wave losses at night, as the body and the ground "see" the relatively warm vegetation (at approximately ambient air temperature), instead of the usually much colder sky. Thermal comfort, on a clear, hot night may be worse under a tree canopy than in an open space, with no obstruction between the body and the sky;
- Vegetation reduces wind speed near buildings, restricting the potential for natural ventilation indoors and weakening convective exchanges.

The overall effect of vegetation, however, is always largely positive.

Various studies have measured the following effects of vegetation (EPA 2008):

- Peak air temperatures in tree groves can be 5 °C cooler than over open terrain;
- Suburban areas with mature trees can be 2 to 3 °C cooler than new suburbs without trees;
- Temperatures over grass sports fields can be 1 to 2 °C cooler than over neighbouring areas.

The intra urban temperature differences between parks and built-up areas can be up to 7 °C Eliasson (2000).

Studies carried out in Singapore (School of Architecture (b), NG 2012) (hot humid climate) showed that a 0.8 °C reduction in ambient air temperature is to be expected for a 30% ratio of green to built area (Figure 2.1.38).

FIGURE 2.1.37 **HEAT BALANCE OF A LEAF**

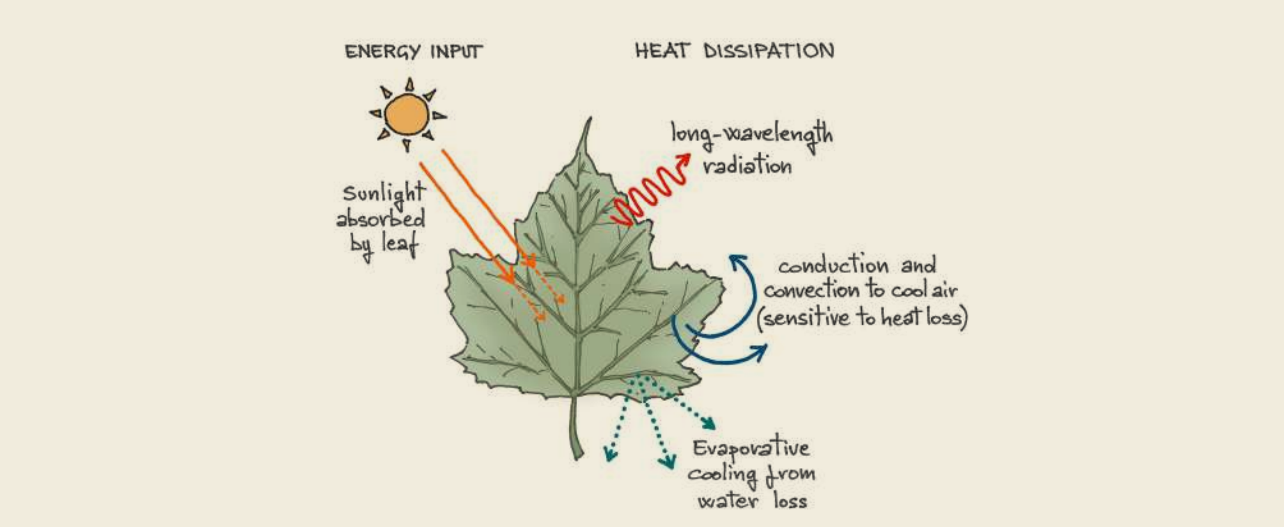
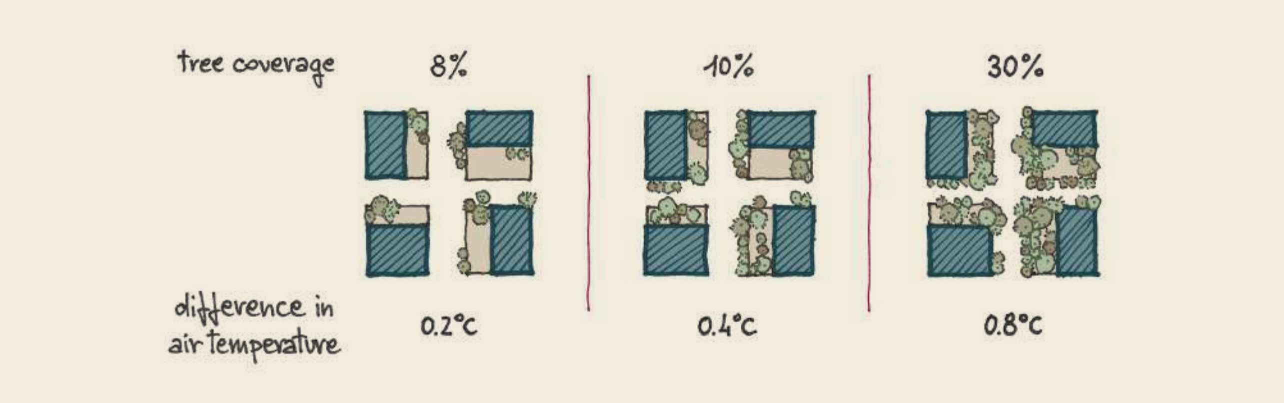


FIGURE 2.1.38 **SIMULATIONS CARRIED OUT FOR HONG KONG (SCHOOL OF ARCHITECTURE (A)**



Urban public and private green areas, to the extent that they can be properly irrigated, are a great benefit especially in a hot dry region, not only because air temperature is reduced and surfaces are shaded, but also because the evaporation from the leaves elevates the air humidity, which is usually very low, improving thermal comfort. Unfortunately, it must be borne in mind that, whereas in hot humid climates greening is generally a relatively easy option because of the availability of water (rain, running water and water bodies), there is a very different situation in hot arid climates, where water is a very scarce resource, and the capability for greening is limited unless local water cycles are activated, as shown in section 2.5.

Providing water for trees, parks, small green areas and/or urban agriculture is thus challenging because of the large amount required and the its cost: the quality of potable water is far higher than that needed for watering plants. This is also the reason why the maintenance of urban greening is often poor, and large amounts of green areas are usually available mainly in the richest and best organised cities.

The issue of urban vegetation, then, intersects with the issue of the urban water cycle: decentralised water management, based on the exploitation of rainwater and on the recycling of wastewater is closely connected with the availability and cost of water for irrigation, and is a prerequisite for a sustainable integration of green areas into the new settlements.

### 2.1.4.1 URBAN PARKS AND GREEN SPOTS

Air and surface temperature in parks may be significantly lower than in the surrounding built-up area, creating what is called a "park cool island".

During daytime, the surface temperature is affected by the presence or absence of shade, by its albedo, by water availability and by the thermal properties of the underlying soil, and this leads to a classification of urban parks according to the type of vegetation and the way it is arranged: grass, grass with tree borders, savannah (grass with isolated trees), garden, forest and multi-use.

A park cool island, in daytime, is the result of the combined effects of soil moisture and shading: grass, when irrigated, is significantly cooler than bare surfaces, and trees shade the surface. The relative coolness of irrigated parks peaks in the afternoon (forest type), or early evening (garden, savannah and multi-use types) (Erell 2011).

The direct temperature reduction due to the presence of a large urban park is about 1-2 °C, but – as trees planted over vegetated areas are able to transpire better than those over asphalt areas – when trees completely cover the sky dome, air temperature reductions of up to 3.3 °C can be expected (Emmanuel 2011).

At night the park cool island may become a "park warm island", as trees block nocturnal long-wave radiative heat losses from the underlying and surrounding surfaces by obstructing part of the sky, and moisture increases the thermal capacity of the soil: the combined effect is a slowing down of surface temperature drop. Urban parks, at night, may be warmer than built-up areas, in relation to the amount and size of trees and to the extent of irrigation.

Cool islands have been measured even in clumps of vegetation less than 200 m across (Erell 2011) and smaller pockets of green oases (~ 70 m x 70 m) of tree planting also provide localised thermal relief to the urban environment (School of Architecture (b)). Even small green areas (60 m x 40 m) show a remarkable cooling effect (it was found that the maximum temperature difference between the small green area and its surroundings was 3 °C) (School of Architecture (b), NG 2012). Computer simulations show that small parks of only tens of metres across may create temperature differentials of 2 °C or more; even in very small courtyards the combined effect of shading and evaporation can create localized temperature differences of the same magnitude, if wind speed is low and mixing of the near-surface air is limited (Erell 2011).

However, the magnitude of the intra-urban temperature difference between parks and their urban surroundings generally increases with park size (Erell 2011).

In consideration of the cooling effect of green areas and of the social value of urban parks and green spots, 15-20% of the neighbourhood land should be allocated to open green spaces (UN-Habitat 2016).

### 2.1.4.2 GREEN ROOFS AND GREEN WALLS

A green roof is a vegetative layer grown on a rooftop. As elsewhere, vegetation on a green roof shades surfaces and removes heat from the air through evapotranspiration. These two mechanisms reduce the temperatures of the roof surface and the surrounding air (Figure 2.1.39).

Green roofs are becoming more and more popular among architects. There are pros and cons in this practice. As reported by Emmanuel (Emmanuel 2010):

- in an experimental study in Japan it was found that a bare concrete roof gave rise to a room temperature of nearly 40 °C, with ivy cover the room temperature dropped to 24-25 °C. However, the night-time cooling experienced by the bare concrete roof was slightly better than the ivy-covered roof;
- in Athens, Greece, indoor temperatures measured with and without a green roof in summer led to an estimate of a cooling load reduction of up to 48% in non-insulated buildings with night ventilation; but in a well-insulated building this reduction became negligible (less than 2% reduction).

These outcomes suggest considering the life-cycle cost of a green roof system when measuring the total benefits, especially if compared to the lifecycle costs of well-insulated buildings.

Green roofs also improve the surrounding air temperature on account of the cooling effect of evapotranspiration, provided that building-height-to-street-width (H/W) ratio is low (<< 1). When the ratio H/W is high (> 1, high density urban development) roof greening is ineffective for human thermal comfort near the ground (NG 2012).

FIGURE 2.1.39 **TEMPERATURE DIFFERENCES BETWEEN A GREEN AND CONVENTIONAL ROOF (EPA 2008)**

In addition to green roofs, another option is the green wall, sometimes referred to as living wall or vertical garden. These walls can involve placing trellises or cables in front of exterior walls and allowing vines to grow up them, or can be more elaborate, with plants actually incorporated into the wall. Green walls van be very effective for improving outdoor and indoor comfort in canyons with low H/W, as they combine the following benefits:

- they have low albedo (thus low reflected solar radiation towards the bottom of the canyon);
- they do not heat up because of evapotranspiration (thus the long-wave radiation emission is low);
- they shade the walls permanently (thus the heat flow through walls is small).

The main drawback with green roofs and walls is the need for effective maintenance and for water, besides the high initial cost.

### 2.1.4.3 TREES

The microclimatic beneficial effect of trees is due to (NG 2012):

- solar heat gains on a building's envelope and on urban surfaces, including human bodies, are lowered because of the shading they provide;
- a building's long-wave exchanges are reduced because of the lower temperature of shaded surfaces;
- the dry-bulb temperatures are lowered because of the evapotranspiration process.

Heat dissipation via transpiration depends on the water balance of the tree. A single large tree can transpire 450 litres of water per day, consuming 1000 MJ of heat energy to drive the evaporation process (Doherty 2009). In the presence of unrestricted water, transpiration will cause substantial cooling. However, if water supply to the root system is restricted, it causes the closure of stomata, reducing the transpiration rate, thus the cooling capacity. This explains why the effectiveness of trees as cooling agents in hot arid climates is usually lower than in hot humid ones, unless the appropriate quantity of water is provided. The use of trees as microclimate modulators in hot arid climates entails a very careful design of the water cycle.

Trees can be particularly effective in improving the microclimate of streets, contributing to better outdoor and indoor comfort and to lower cooling energy consumption; there are some rules to follow for best exploiting their effectiveness (Erell 2011):

- Tree crowns should not occupy large canyon volumes, so as not to suppress the ventilating canyon vortex system and the corner eddies. In particular, sufficient free space between crowns and adjacent walls should be ensured.
- The tree height should not exceed roof level, as this would result in a substantial reduction in entrained above-roof air required to ventilate the street canyon.
- Broad tree spacing creates less of an obstruction, and allows rooftop flow to generate vortices in the street.
- Trees have a smaller effect in shallow canyons (H/W<0.5) than in deeper ones.

As the amount of radiant energy intercepted is crucial, the effectiveness of a tree canopy as a shading element is firstly a function of the density of its leaves, stems and branches (Erell 2011).

Shading provided by trees is far more effective than shading provided by a solid shading component. The reason is that a canopy made of whatever material absorbs solar radiation in the upper surface, heats up, and both upper and lower surfaces emit long-wave radiation, the amount of which depends on the superficial properties (spectral absorption and emissivity) and on the insulation characteristics of the component. In any case, the lower surface will be hotter than air, thus emitting more long-wave radiation than a leaf crown, whose temperature is usually very close to that of ambient air. Consequently, the energy received by a person or a building shadowed by a thick tree crown is lower than that received when shadowed by a surface of any material.

Another quality of trees is their ability to sequester and store carbon in their trunks, leaves, and roots, acting as carbon sinks, so contributing to a reduction in GHG emissions.

Trees provide multiple benefits (Figure 2.1.40).

Trees, however, have drawbacks. The most important, as shown above, are:

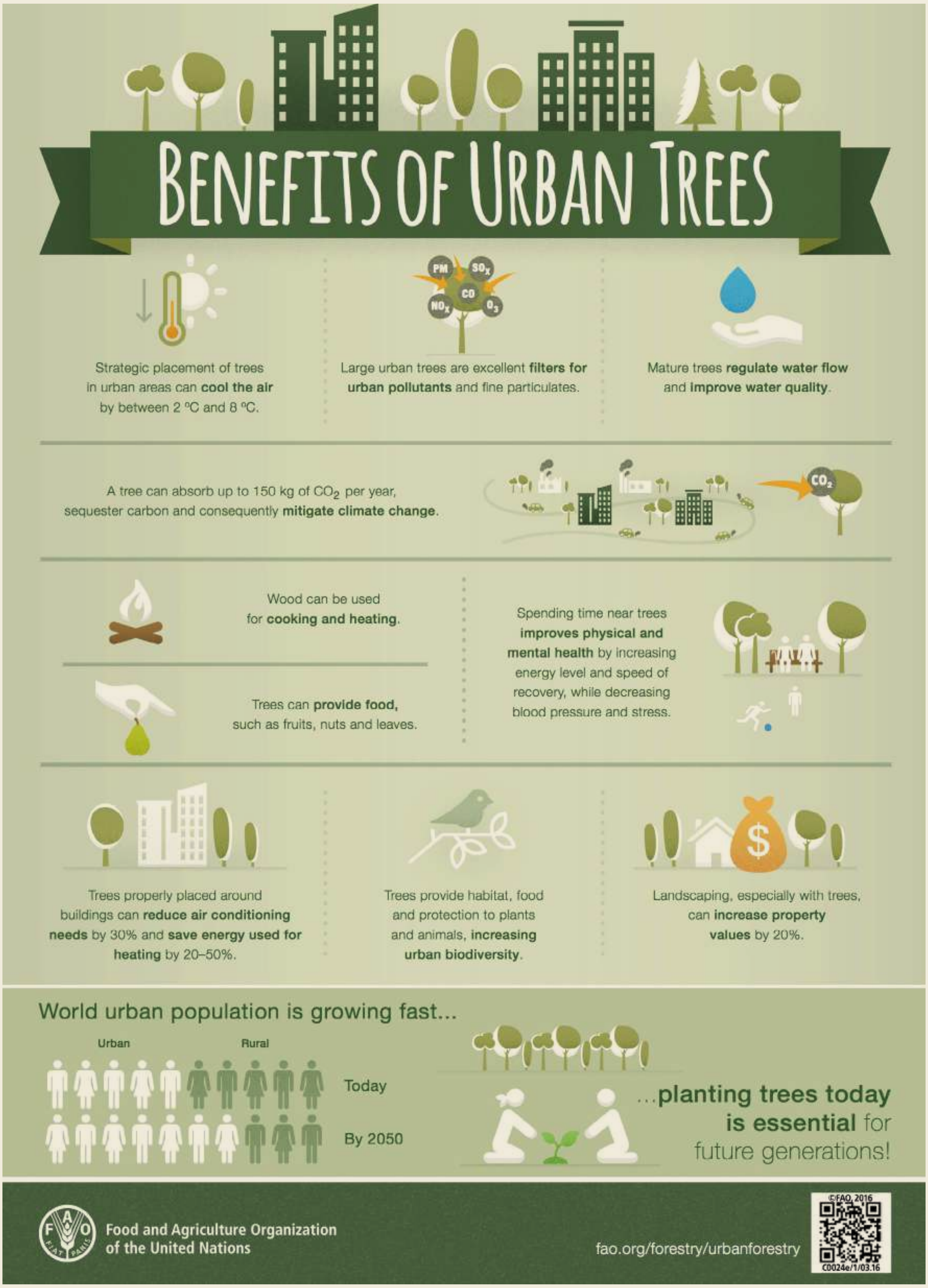
- they may act as obstacles to air movement, so decreasing the convective heat transfer for cooling urban structures;
- they restrict long-wave radiative heat losses of the ground, i.e. nocturnal cooling.

Besides their negative impact on night cooling, trees in the streets give rise to many other problems, such as (Ogunsote 2002):

- **Overgrowth of tree roots** - Probably the greatest problem of growing trees close to houses is the destruction caused to the building by the roots of the trees. When trees are too close to the building, the roots will eventually reach the building causing foundations, floors and walls to crack. Trees grown close to buildings should be carefully selected and replaced after a certain age.
- **Excessive shading** - The rainy season is the period when the highest relative humidity is experienced. This coincides with the period when trees grow most profusely and provide more shade. Some walls of a building may therefore be subjected to high humidity and low temperatures as a result of the shade, leading to condensation. This can lead to the growth of moulds, moss and lichen.

- **Increased Building Height** - The use of trees for shading buildings is most effective for bungalows or two-storey buildings. In the case of multy-storey buildings the effect of trees can usually only be felt on the ground and first floors. On the other hand, higher floors have better ventilation.

FIGURE 2.1.40 **MULTIPLE BENEFITS OF URBAN TREES**



BENEFITS OF URBAN TREES

Strategic placement of trees in urban areas can **cool the air** by between 2 °C and 8 °C.

Large urban trees are excellent **filters for urban pollutants** and fine particulates.

Mature trees **regulate water flow** and **improve water quality**.

A tree can absorb up to 150 kg of $CO_2$ per year, sequester carbon and consequently **mitigate climate change**.

Wood can be used for **cooking and heating**.

Trees can **provide food,** such as fruits, nuts and leaves.

Spending time near trees **improves physical and mental health** by increasing energy level and speed of recovery, while decreasing blood pressure and stress.

Trees properly placed around buildings can **reduce air conditioning needs** by 30% and **save energy used for heating** by 20–50%.

Trees provide habitat, food and protection to plants and animals, **increasing urban biodiversity**.

Landscaping, especially with trees, can **increase property values** by 20%.

World urban population is growing fast...

...**planting trees today is essential** for future generations!

Food and Agriculture Organization of the United Nations

fao.org/forestry/urbanforestry

*Source FAO – http://www.fao.org/resources/infographicsinfographics-details/en/c/411348/*

### 2.1.5 URBAN AGRICULTURE

Urban and peri-urban agriculture can be defined as the growing of plants and the raising of animals within and around cities. It is a "local food" system that provides urban populations with a wide range of horticultural crops – mainly fruit and vegetables, but also herbs, roots, tubers, ornamental plants and mushrooms – that are grown within the city or in its surrounding areas.

Plots of urban land used for agriculture are a special kind of urban greening. Even if less effective than trees with large canopies or lawns for cooling, they may still make a significant contribution to the mitigation of the UHI, and can be included among the greening strategies, with a triple dividend. The first is environmental:

- reduction of GHG emissions due to reduced energy consumption for air conditioning, because of their cooling effect;
- reduction of GHG emissions as they reduce the need to transport products into cities from distant rural areas, generating fuel savings, fewer carbon dioxide emissions and less air pollution[15];
- recycling of organic waste to be used as compost, instead of chemical fertilisers[16];
- recycling of appropriately treated wastewater, to be used for irrigation[17];
- replenishment of water tables, as rainwater can percolate through them;
- flooding mitigation.

The second dividend is socio-economic, deriving from the employment created, directly (farming; estimated at one job for every 110 $m^2$ of cultivated land (FAO 2012)) and indirectly (sales, organic waste collection and treatment for compost production)[18], plus the increase in food security.

The third dividend of urban agriculture relates to health: it provides foods that are rich sources of vitamins, minerals and phyto-chemicals – essential for good health (FAO 2010).

Recycling of organic waste and compost production entails a significant commitment from the community, and can be more easily implemented at neighbourhood scale, if there is direct connection with the benefits achieved. d.

BOX 2.3 **URBAN AGRICULTURE IN DEVELOPING COUNTRIES**

Urban agriculture was quite common all over the world in past centuries, but in developed countries, its importance in the urban economy slowly decreased until the present day. However, it has been making a comeback in the last few years. In developing countries, on the other hand, it is estimated that 130 million urban residents in Africa and 230 million in Latin America are engaged in urban agriculture (FAO 2010).

The size of an urban agricultural plot, in SSA, ranges from 500 $m^2$ in Dakar to up to 5,000 $m^2$ in Zambia (FAO 2010). The city of Kigali, Rwanda is pioneering institutional promotion of urban agriculture. Its master development plan leaves 15,000 ha for agriculture and for safeguarding its wetlands. In Tanzania urban farming has been regulated since 1992, setting a limit of 1.2 ha of land per urban farmer (FAO 2010).

Overall, the most effective and successful modern plan for implementing urban agriculture has been experienced in Cuba, since the dissolution of the USSR (1991), to cope with the sudden blockage of food imports.

Urban agriculture that uses wastewater for irrigation can pose health risks if poorly managed, i.e. if wastewater is not appropriately treated. Wastewater recycling for irrigation needs to be incorporated in urban design and planning, together with the sizing and positioning of urban agricultural plots.

### 2.1.6 PAVEMENTS

A large proportion of the ground surface of a city is covered with pavements, which are usually made of asphalt or concrete; because of the low albedo of such materials (0.5-0.35, respectively, see Table A1.1 in Appendix 1), on clear days, during the hours in which the sun is high in the sky, their surface can reach peak temperatures of up to 60-70 °C, as they absorb 95 to 65% of the solar radiation reaching them.

In many cities pavements may represent the largest percentage of a community's land cover, compared with roof and vegetated surfaces (in US cities paved areas account for nearly 30 to 45% of land cover (EPA 2008)), thus the first, most effective way to reduce their heating effect is to reduce the need to pave. There are various options to reduce the amount of paved surface areas, such as reducing parking space requirements, connecting parking and mass transit services and allowing for narrower streets.

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[15] *The current food system in many industrialized countries uses more than four times the energy to transport food from the farm to the plate than is used in the farming practice itself (Baeumler 2012).*

[16] *In North America, cities routinely recycle organic waste and offer it to citizens as compost for home gardens. In Addis Ababa, a private company collects each day some 3.5 tonnes of organic waste and converts it into almost two tonnes of high-quality fertilizer. Cuba's national programme for UPH prohibits chemical fertilizer in cities and encourages instead organic composting. Source: FAO 2010.*

[17] *In Chile, treated wastewater from Santiago provides 70% of the irrigation water for peri-urban vegetables (FAO 2012).*

[18] *Depending on productivity, urban agriculture and associated services may create employment for 1 in every 50 to 100 city residents. Source: (UNDG 2014).*

The second approach is the most obvious: try to increase the pavements albedo. The albedo of asphalt pavements can be raised by mixing the binder with light coloured aggregates; concrete albedo can be raised up to 70% by using white instead of grey cement. It must be remembered, however, that albedo values change with time: asphalt albedo increases while concrete albedo decreases.

The third approach to mitigating the heat island effect deriving from paved surfaces originates from reproducing in the urban context the mechanism taking place in rural conditions, with the use of permeable, or porous, paving (Figure 2.1.41). Although originally designed for storm water control, permeable pavements are an effective choice for control of urban energy balance. Permeable pavement technologies include porous asphalt applications, pervious concrete applications, permeable pavers, and grid pavements and are designed to allow air, water, and water vapour into the voids of their surface. When wet, the water passes through the voids into the soil or supporting materials below. Moisture evaporates slowly as the surface heats, thus drawing heat out of the pavement, and keeping it cooler by evaporative cooling. Some permeable pavement systems contain grass or low-lying vegetation.

## 2.1.7 COOL ROOFS

Traditional roofing materials have low solar reflectance (or albedo) of 5 to 15%, i.e. they absorb 85 to 95% of the energy reaching them, and become hot. Even white coloured roofs cannot have a solar reflectance exceeding 50%, as they reflect only the visible part of the solar spectrum, which accounts for less than 50% of the energy incident on it (see Figure A1.1), and the rest (UV and IR) is almost entirely absorbed.

But it is not only because of low albedo that traditional roofing heats up, there is another property of the material's surface that determines the temperature reached: its thermal emittance, i.e. the capability of radiating more or less energy at a given temperature, that is, how readily a surface gives up heat. Hence, when exposed to sunlight, a surface with high emittance will reach thermal equilibrium at a lower temperature than a surface with low emittance, because the high-emittance surface gives off its heat more readily.

The combination of solar reflectance and thermal emittance have significant effects on surface temperature, as shown in the example of Figure 2.1.42 for three different roof types.

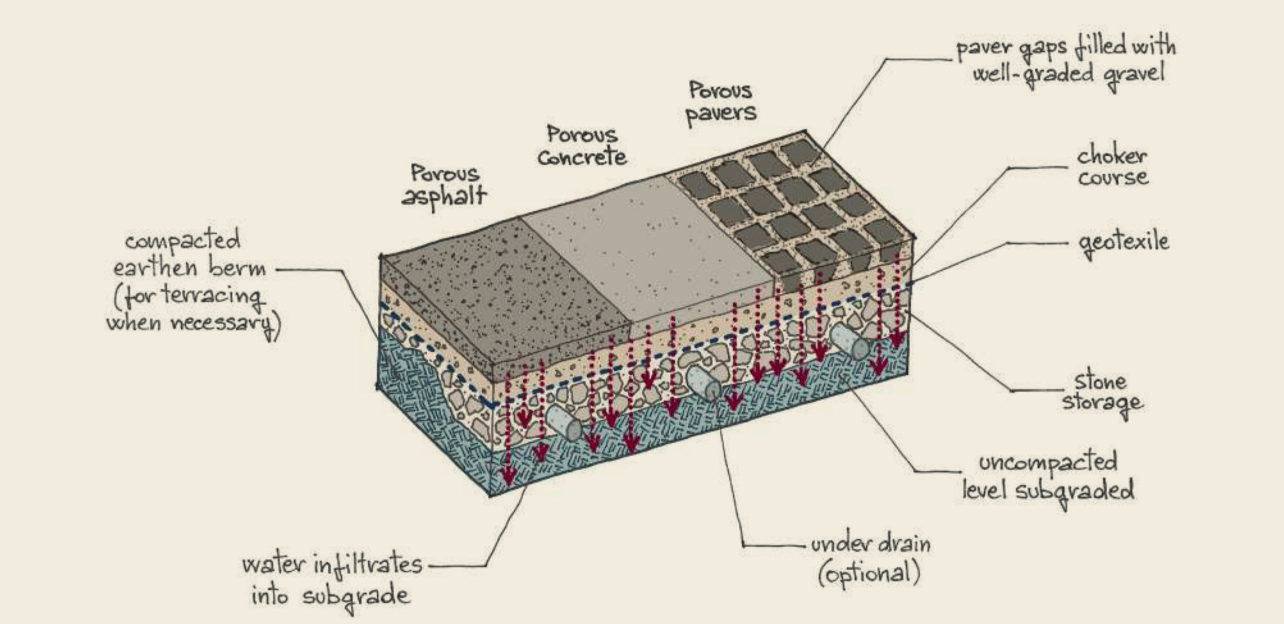
"Cool roofing" refers to the use of highly reflective and emissive materials. They are capable of reflecting not only in the visible spectrum, but also in the near infrared, and their emissivity is high at all the wavelengths of the solar spectrum.

## 2.1.8 WATER BODIES

Water bodies have several potential advantages for cooling the urban environment due to their thermal and optical properties:

- The evaporation process of water requires a high amount of energy, which is extracted from the air, thus lowering its temperature;
- The high specific heat of water delays and buffers the maximum temperature;
- The low reflectivity of water at great incidence angle causes a low solar reflection to other surfaces in the surroundings, in this way preventing them from warming up.

FIGURE 2.1.41 **TYPES OF POROUS PAVEMENTS**



Combining these effects, the temperature of a water body can be around 2 - 6 °C lower than the surrounding urban environment (Manteghi 2015).

Thus, in urban areas, water bodies could have a positive effect upon the microclimate of the surroundings; in addition, if situated among parks and residential areas, they may play a crucial role in the urban ecosystem.

It has been found that (Mirrahimi 2015):

- The microclimatic effects of urban water bodies are affected by their geometry, shape, and depth, in a complex way.
- What counts is the total area of the water body, thus if it is divided into several small water bodies, the benefits and positive effects will still remain the same or are even improved.
- Water bodies strategically placed to take advantage of air movement patterns at a local scale and more trees planted around water bodies highly enhance the potential for cooling the environment.

The positioning of urban water bodies is important in relation to their effectiveness for cooling effect; to maximise the effect water bodies should be located in every neighbourhood at the northern/southern corner (Emmanuel 2005).

Constructed wetlands (see section 2.5) can be included among the water bodies as well as stormwater catchment basins.

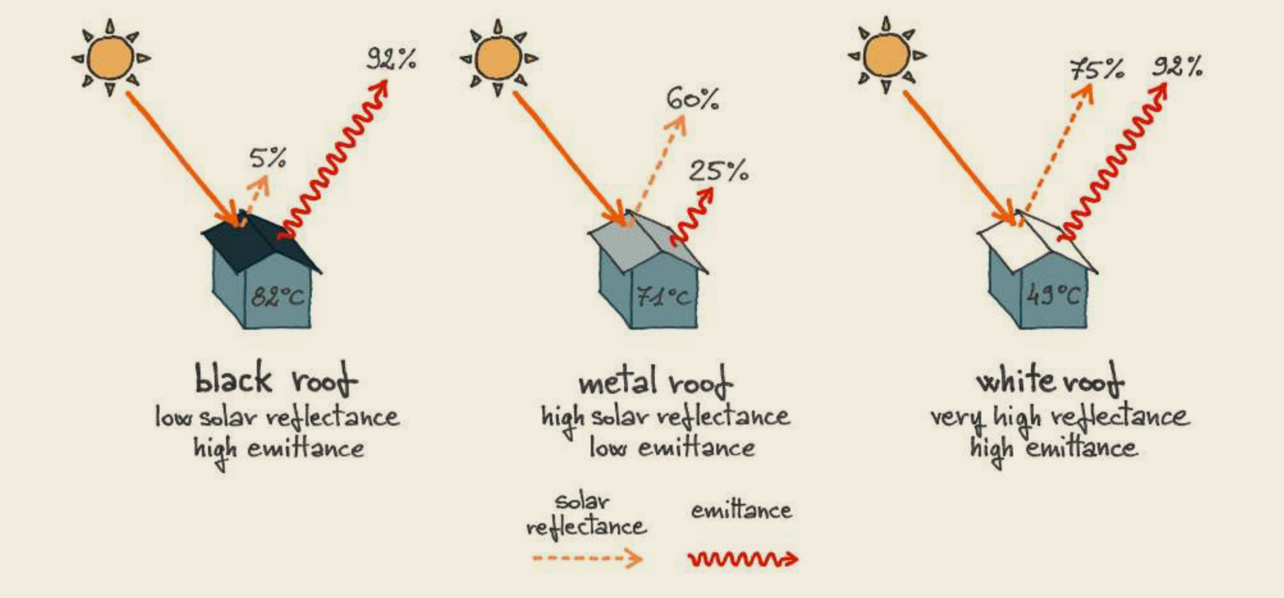
The positive effect of urban water bodies on urban comfort is not universally recognised. Studies have shown that:

- An urban water body has a negative effect on the immediate surroundings as opposed to a vegetated area of similar magnitude (Perera 2014);
- Water bodies increase rather than decrease the maximum temperature. The high heat capacity of water suppresses the diurnal and annual cycle over water, and water temperatures remain relatively high after evening and seasonal transitions (Steeneveld 2014);
- Evaporation from open water bodies may lower the temperature, but on the other hand also increases the humidity, which dampens the positive effect on thermal comfort. In addition, when the water is warmer than the air temperature (during autumn or night), the water body has an adverse effect on thermal comfort (Theeuwes 2013).

Finally, the potential function of urban water bodies as breeding grounds for mosquitoes should be considered.

Thus, the use of water bodies for improving outdoor comfort in tropical climate is rather controversial, and the urban designer should analyse the pros and cons very carefully, in consultation with urban climatology experts.

FIGURE 2.1.42 **ON A HOT, SUNNY, SUMMER DAY, A BLACK ROOF THAT REFLECTS 5% OF THE SUN'S ENERGY AND EMITS AS LONG-WAVE RADIATION MORE THAN 90% OF THE HEAT IT ABSORBS, CAN REACH 82°C. A METAL ROOF WILL REFLECT THE MAJORITY OF THE SUN'S ENERGY WHILE RELEASING AS LONG-WAVE RADIATION ABOUT A FOURTH OF THE HEAT THAT IT ABSORBS AND CAN WARM TO 71°C. A COOL ROOF WILL REFLECT AND EMIT THE MAJORITY OF THE SUN'S ENERGY AND REACH A PEAK TEMPERATURE OF 49°C (SOURCE: EPA 2008).**



## 2.1.9 TAILORING GENERAL RULES TO EAC CLIMATES

A set of simulations was carried out, with the software Envi-met[19], for four climates in the EAC: Mombasa, Lodwar, Dodoma and Nairobi. These climates almost completely encompass the climates that can be found in the EAC. Mombasa represents the hot humid climate, Lodwar the hot dry, Dodoma the savannah and Nairobi the climate of the uplands.

The climate data sets of these locations were used for simulating a medium density urban area made up of a group of buildings as shown in Figure 2.1.43.

The simulations were aiming to find out the optimum H/W ratio and orientation in order to achieve, in the canyons at 1m height from the ground, the maximum possible outdoor comfort in the hottest hour of the hottest day (mean monthly) of the year.

To obtain an acceptable resolution with reasonable computer running time, only a part of the group of buildings was simulated, comprising eight buildings arranged in two rows of four, with a floor area ratio (F.A.R.) of about 0.7 m2/m$^2$, as average density index.

Different orientations and aspect ratios H/W were simulated, as shown in Figure 2.1.44 for the climate of Mombasa.

It can be seen that comfort in canyons improves (colour code: comfort improving from red to green)) with the aspect ratio H/W and that the best orientation, for H/W > 1 is the North-South.

For aspect ratio < 1 the canyon's orientation has little or no effect on outdoor comfort conditions, and thus on the indoor. This means that in the case of shallow canyons the established rule according to which buildings should be elongated along the East-West axis still holds, because with this orientation solar energy incident on the south and north façades is the minimum (the incidence angle of the sun's rays is low all day long) and façades are easy to shade. It is only with deep canyons that the rule is offset.

Simulations carried out for the hot arid climate of Lodwar (Kenya) and the savannah climate of Dodoma (Tanzania) confirmed the above findings.

The effect of greening was also simulated, adding rows of trees in the canyons first and then also adding a green area between the two groups of buildings, as shown in Figure 2.1.45 for the worst orientation, East-West. It can be noted the significant improvement of the comfort achieved with trees and especially with the green area.

Also significant is the effect of vegetation in Lodwar, where the cooling effect of green areas and trees, combined with the high air velocity and the low relative humidity, leads to PMV values lower than the ones achieved in Mombasa, in spite of the fact that the air temperature is about 4 °C higher (Figure 2.1.46).

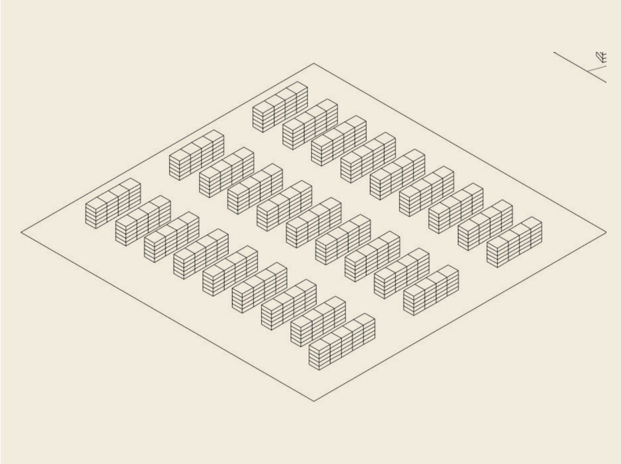
Simulations for Nairobi with trees and green areas (Figure 2.1.47) show that in the hottest hour comfort conditions are nearly achieved in many areas around the buildings (more with H/W = 2), both with the North-South and the East-West orientations. It should be noted that in the cooler period of the year in Nairobi some heating would be much appreciated, thus the East-West orientation (or one close to it) could allow buildings to benefit from solar radiation for passive heating.

## 2.1.10 COMPLEXITY OF URBAN DESIGN

Urban design requires tackling a variety of geometries, materials and environmental conditions in order to accommodate social practices and a wide set of functions within a vibrant urban setting. A degree of knowledge of sustainable building design is also required for managing the possible inconsistencies between optimum canyons orientation, aspect ratio, shading, thermal mass, albedo, etc., and sustainable design of the buildings delimiting the canyon[20].

A deep understanding of optimal design parameters and conditions is a prerequisite for benchmarking design options, but the ability and sensitivity of the urban designer also has to be found in the way he/she handles the combination of permanent urban materials (street and building orientation and geometry, urban materials) and temporary urban furniture (shading devices and vegetation conditions), aiming at improving environmental quality, energy efficiency and human comfort even in unfavourable contexts.

FIGURE 2.1.43 **SKETCH OF THE SIMULATED LAYOUT**



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[19] *ENVI-met is a three-dimensional microclimate model designed to simulate the surface-plant-air interactions in the urban environment, based on the fundamental laws of fluid dynamics and thermodynamics. The model includes the simulation of: flow around and between buildings, exchange processes at the ground surface and at building walls, impact of vegetation of the local microclimate and bioclimatology.*

[20] *For a deeper insight into the subject of sustainable building design in tropical climates, see ref. UN-Habitat (2014).*

FIGURE 2.1.44 **COMFORT DISTRIBUTION IN THE CANYONS AND OUTSIDE, EXPRESSED AS PMV, CHANGING ORIENTATION AND ASPECT RATIO. COLOUR CODE: TOWARDS GREEN, MORE COMFORTABLE; TOWARDS MAGENTA, LESS COMFORTABLE.**

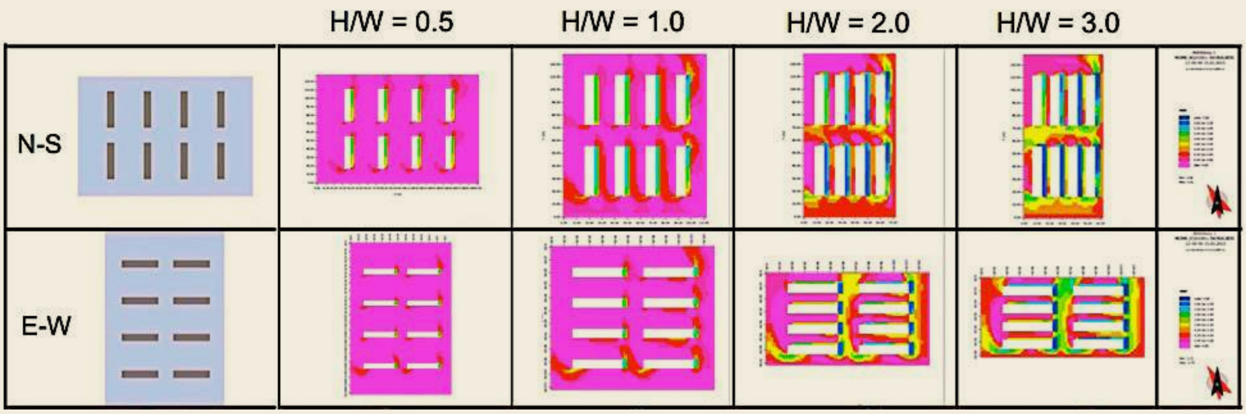


FIGURE 2.1.45 **MOMBASA - EFFECT OF VEGETATION ON COMFORT CONDITIONS. TOP: NO VEGETATION; MIDDLE: TREES AROUND THE BUILDINGS; BOTTOM: TREES + A GREEN AREA BETWEEN THE GROUPS OF BUILDINGS.**

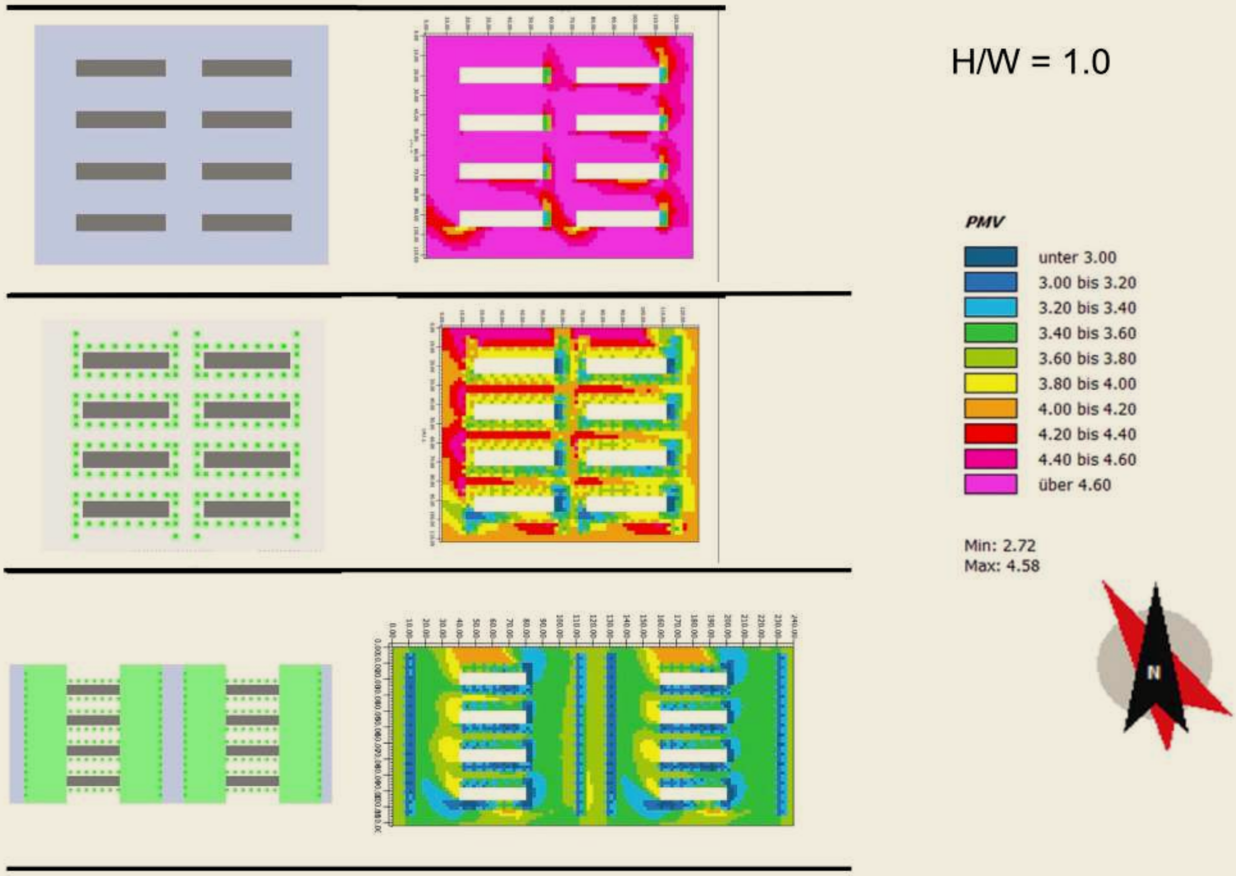


FIGURE 2.1.46 **LODWAR – EFFECT OF VEGETATION ON COMFORT CONDITIONS. TOP: NO VEGETATION; MIDDLE: TREES AROUND BUILDINGS; BOTTOM: TREES AND GREEN AREA BETWEEN GROUPS OF BUILDINGS.**

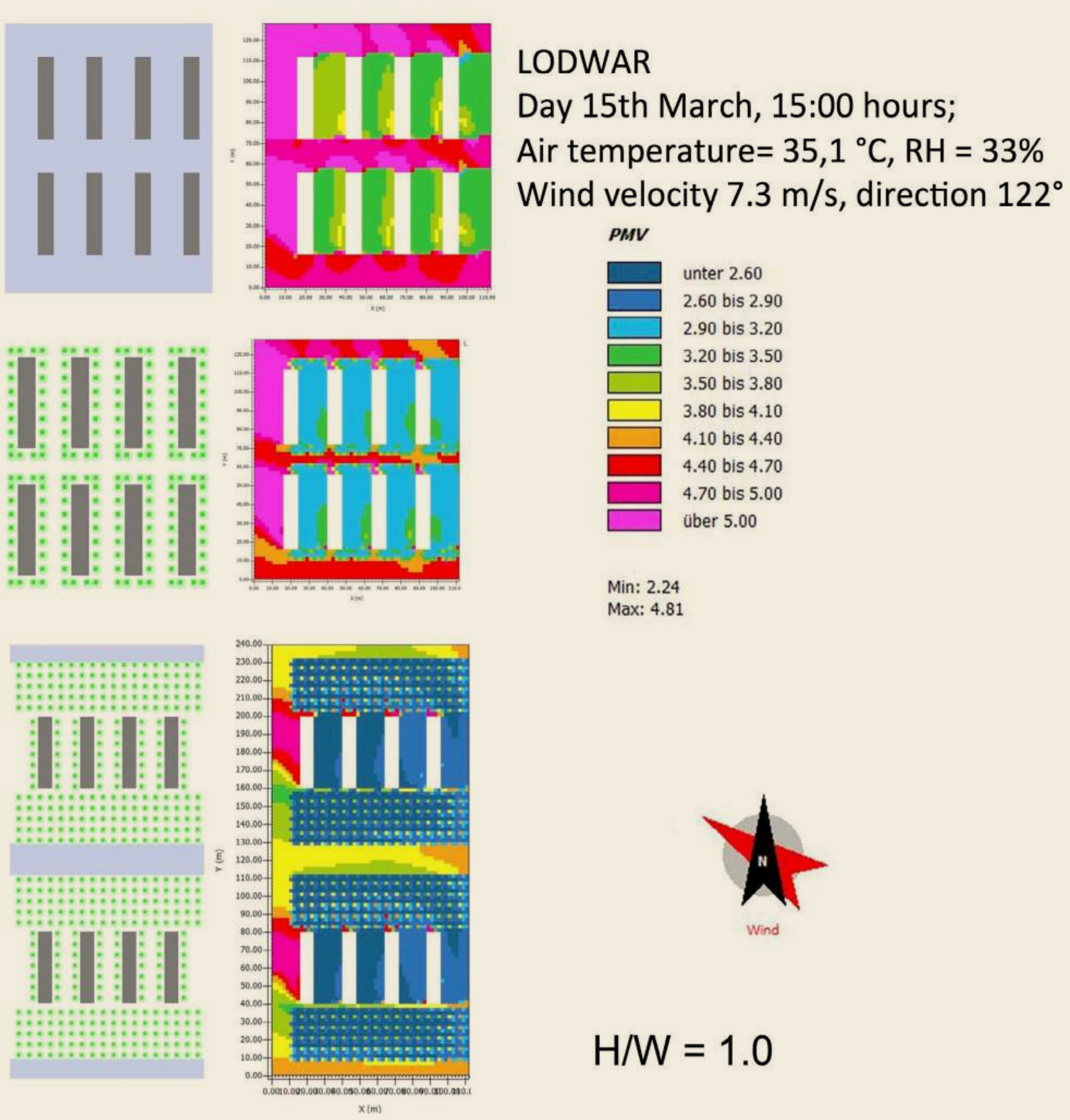
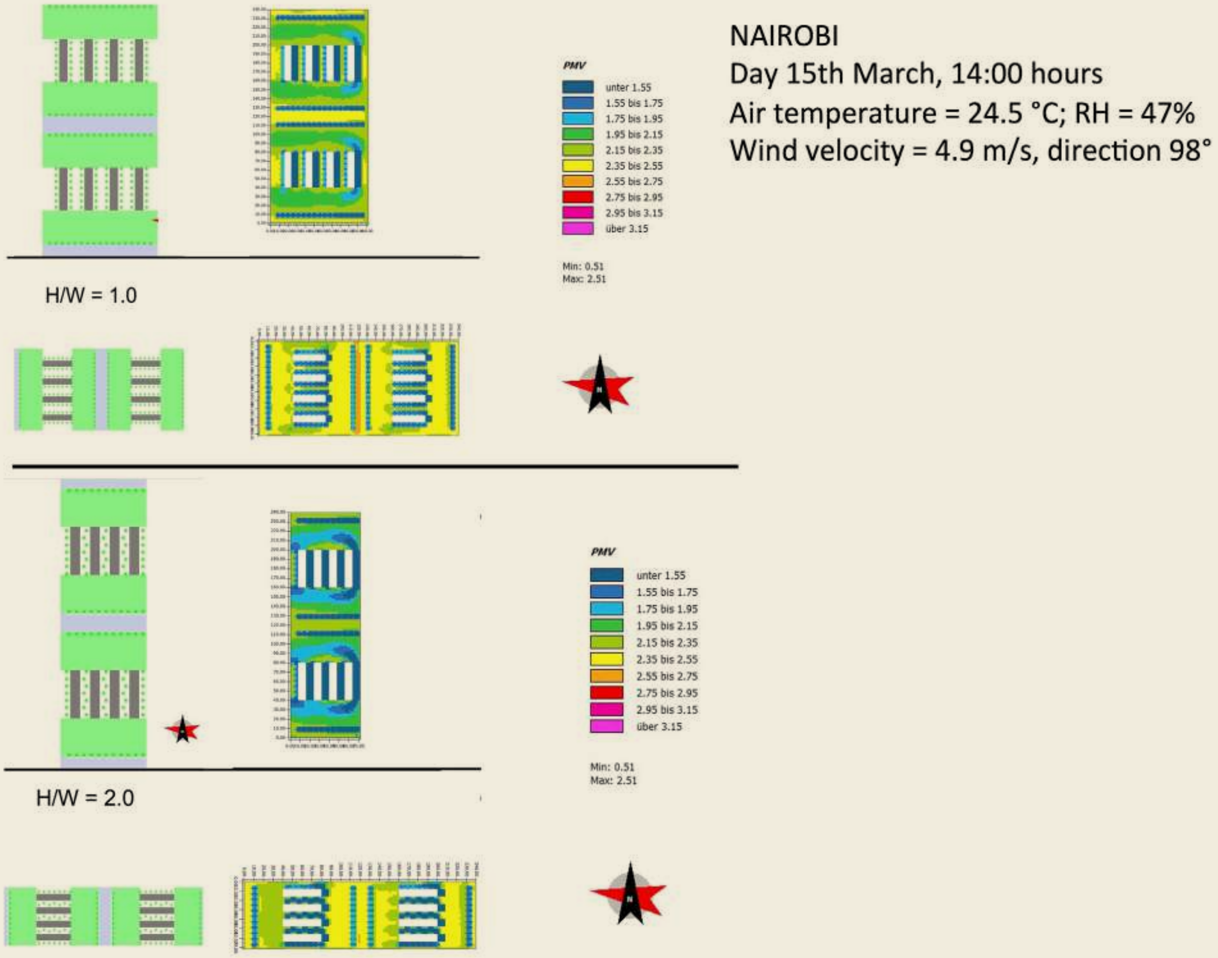


FIGURE 2.1.47 **NAIROBI. SIMULATIONS FOR THE CASE TREES + GREEN AREA FOR H/W = 1.0 (TOP) AND H/W = 2.0 (BOTTOM).**



NAIROBI
Day 15th March, 14:00 hours
Air temperature = 24.5 °C; RH = 47%
Wind velocity = 4.9 m/s, direction 98°

## REFERENCES

Baeumler et al. A. (eds.) (2012), Sustainable Low-Carbon City Development in China, The World Bank - http://siteresources.worldbank.org/EXTNEWSCHINESE/

DACUHK (2005), Department of Architecture CUHK, Feasibility Study for Establishment of Air Ventilation Assessment System - http://www.pland.gov.hk/pland_en/p_study/comp_s/avas/papers&reports/executive_summary_english.pdf

Doherty M., Nakanishi H., Bai X. and Meyers J., Relationships between form, morphology, density and energy in urban environments, https://www.academia.edu/4916721/Relationships_between_form_morphology_density_and_energy_in_urban_environments_GEA_Background_Paper_prepared_by

Eliasson I. (2000), The use of climate knowledge in urban planning, Landscape and Urban Planning 48, 31-44

Emmanuel M. R. (2005), An Urban Approach to Climate-Sensitive Design, Spon Press,

Emmanuel R. (2010), Linking the 'in' and 'out:' new comfort goals for the rapidly urbanising equatorial tropical megacities in a changing climate, Proceedings of Conference: Adapting to Change: New Thinkingon Comfort Cumberland Lodge, Windsor

Emmanuel R., Rosenlund H. and Johansson E. (2007), Urban shading – a design option for the tropics? A study in Colombo, Sri Lanka, International Journal of Climatology Int. J. Climatol. 27: 1995–2004

EPA (2008), Reducing Urban Heat Islands: Compendium of Strategies – Urban Heat Island basics, http://www2.epa.gov/heat-islands/heat-island-compendium

Erell E., Pearlmutter D. (2011), T Williamson - Urban Microclimate, Earthscan

Erell E., Pearlmutter D., Boneh D. (2012), Effect of high-albedo materials on pedestrian thermal comfort in urban canyons, ICUC8 – 8th International Conference on Urban Climates, 6th-10th, UCD, Dublin Ireland

FAO (2010), Growing Greener Cities - http://www.fao.org/ag/agp/greenercities/pdf/ggc-en.pdf

FAO (2012), Growing greener cities in Africa - http://www.fao.org/docrep/016/i3002e/i3002e.pdf

Huang J., Cedeño-Laurent J. G., Spengler J. D. (2014), CityComfort+: A simulation-based method for predicting mean radiant temperature in dense urban areas, Building and Environment Volume 80

IPCC (2014), Climate Change 2014, Mitigation of Climate Change, Chapter 12: Human Settlements, Infrastructure and Spatial Planning, Cambridge University Press

Manteghi G. et al. (2015), Water Bodies an Urban Microclimate: A Review, Modern Applied Science; Vol. 9, No. 6;

Mirrahimi S. et al. (2015), Developing a Sustainable City in a Tropical Area to Create a Balance between Vegetation and Water Bodies, IACSIT International Journal of Engineering and Technology, Vol. 7, No. 1, February 2015

Mochida A. et al. (2007) Management, control and design of urban climate based on the heat balance analysis of outdoor space, Paper presented at the ISWE School, Tokyo, Japan

Ng E., Chen L., Wang Y., Chao Yuan (2012), A study on the cooling effects of greening in a high-density city: An experience from Hong Kong, BUILDING AND ENVIRONMENT 47(1):256–271

OECD (2010), Cities and climate change - http://www.oecd.org/gov/citiesandclimatechange.htm

Ogunsote Olu Ola and Prucnal-Ogunsote Bogda (2002), Control of Tropical Microclimates through Landscape Design: Concepts and Methods, National Workshop on Landscape Design for the Federal Capital Development Authority, Abuja https://www.academia.edu/2951278/Control_of_Tropical_Microclimates_through_Landscape_Design_Concepts_and_Methods

Oke T.R. (1973), City size and the urban heat island. Atmospheric Environment 7: 769-779

Oke, T.R. (1978) Boundary Layer Climates, Methuen & Co, London

Perera N G R and Liyanapathirana A (2014), Influence of urban water bodies on microclimate and thermal comfort: Case study of Beira Lake, Colombo, FARU Journal 2014, Vol. 06, Issue 01 - https://www.academia.edu/19851187/Influence_of_urban_water_bodies_on_microclimate_and_thermal_comfort_Case_study_of_Beira_Lake_Colombo.

Perera N G R, Weerasekara W M S B (2014) The Effect of Street Canyon Geometry on Outdoor Thermal Comfort in Colombo, in R. Dayaratne and J. Wijesundara (eds.), Second International Urban Design Conference on Cities, People and Places, ICCPP- 2014 Colombo, Sri Lanka, Department of Architecture University of Moratuwa, Sri Lanka, 2014.

Pijpers-van Esch M. (2015), Designing the Urban Microclimate, Delft University of Technology, Faculty of Architecture and the Built Environment.

Santamouris, M. (2016), Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change, Solar Energy, Volume 128.

School of Architecture (a), Chinese University of Hong Kong , Urban Climatic Map and Standards for Wind Environment - Feasibility Study – Executive summary - http://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/ucmap_project/content/reports/executive_summary.pdf.

School of Architecture (b), Chinese University of Hong Kong , Urban Climatic Map and Standards for Wind Environment - Feasibility Study – Final report- http://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/ucmap_project/content/reports/final_report.pdf.

Steeneveld G.J. et al. (2014), Refreshing the role of open water surfaces on mitigating the maximum urban heat island effect, Landscape and Urban Planning 121 (2014) 92–96.

Theeuwes N. E. et al. (2013), Modeling the influence of open water surfaces on the summertime temperature and thermal comfort in the city, JOURNAL OF GEOPHYSICAL RESEARCH: ATMOSPHERES, VOL. 118, 8881–8896, doi:10.1002/jgrd.50704, 2013

UN-Habitat (2014), Sustainable Building Design for Tropical Climates - http://unhabitat.org/books/sustainable-building-design-for-tropical-climates/.

UNDG (2014), United Nations Development Group – Asia and the Pacific, INTEGRATING URBANIZATION INTO THE CCA AND UNDAF
A GUIDE FOR UNITED NATIONS COUNTRY TEAMS, Working Draft Version 7 (15.12.2014) For UNCTs Roll Out.

## 2.2 MINIMISE ENERGY DEMAND FOR TRANSPORT THROUGH URBAN DESIGN

The urban transport sector accounts for a large proportion of urban $CO_2$ emissions. The world transport sector in 2010 was responsible for approximately 23% of total energy-related $CO_2$ emissions (IPCC 2014), 40% of which were due to urban mobility (EU 2016). Urban transport energy consumption is expected to double by 2050, despite on-going improvements in vehicle technology and fuel-economy; 90% of this growth in urban transport emissions is expected to come from private motorised travel and will largely take place in developing countries (IEA 2013).

Urban design has a great impact on mobility, as the layout of the urban form greatly affects the way we move in the space. The arrangement of spaces and functions can influence the choice of different transport modes, and this choice affects energy consumption because of their different intrinsic efficiency (see section 2.3). Moreover, energy demand for transport is significantly influenced by the urban, district and neighbourhood design, and it is possible to minimise it with appropriate density and mixed land use (work, home and services close to each other) or even by extending the contiguity of the functions at the individual building scale. Provision at neighbourhood scale for facilitating cycling and collective and individual high efficiency transport, for example, are also key to reducing energy demand and consumption.

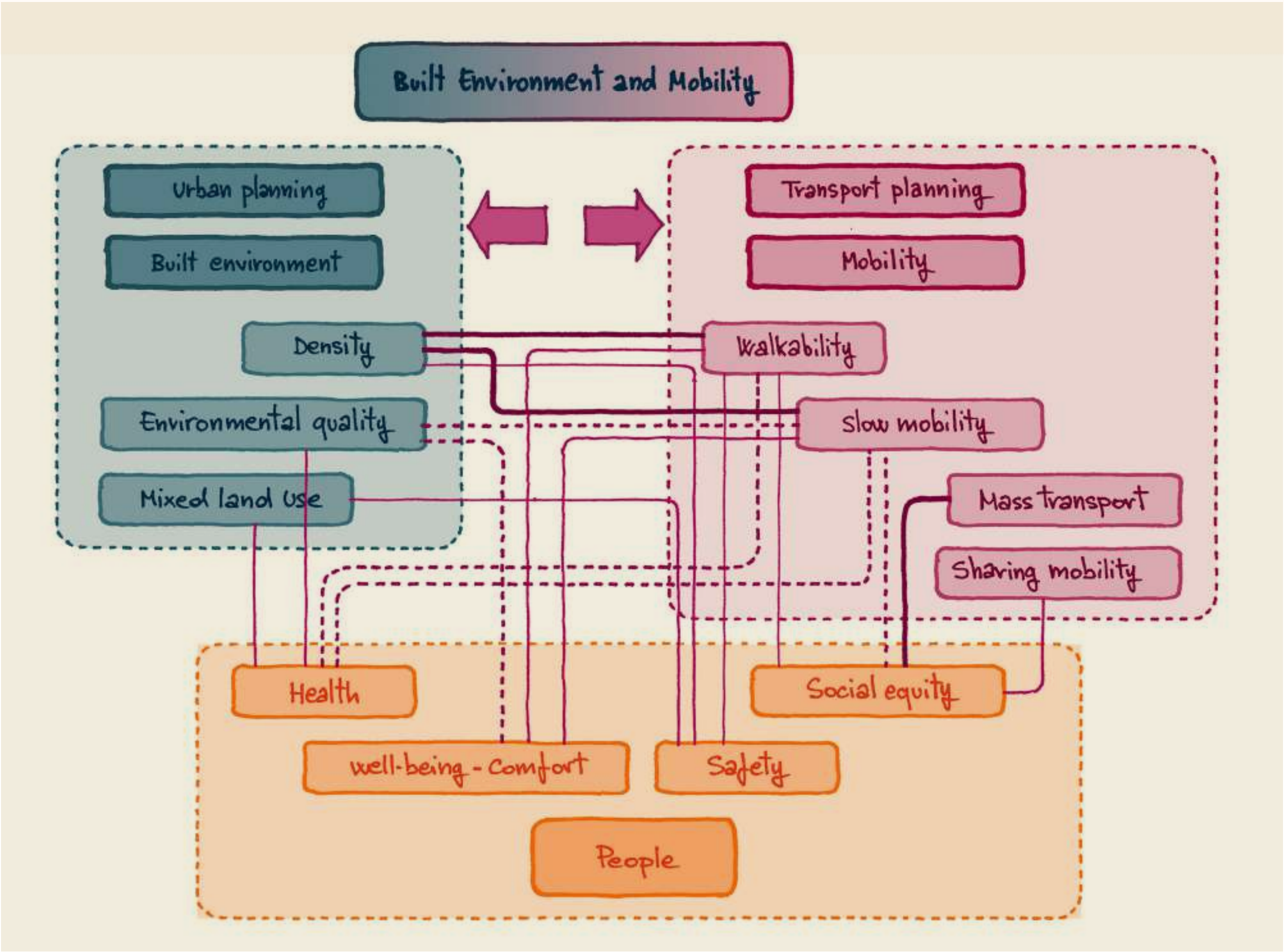
A holistic vision of urban development is required, whereby a genuine integration of transport planning with arrangements of space and function at neighbourhood scale should always be implemented. In fact, transport planning decisions are not a technical matter of engineering choices only, but highly affect the usability of the public realm and urban planning decisions have evident and direct consequences on accessibility and mobility. These decisions are finally implemented in the neighbourhood design, since walking, cycling, public transport and sustainable communities have to be intended "as a single network, and one which replaces the transport idea of providing mobility with a community goal of providing accessibility" (Dittmar 2008).

Indirectly, a walkable environment that encourages slow mobility solutions is also a healthy place (Brown 2009). Today, energy dense food, sedentary lifestyles and motorized mobility all together inevitably have a significant impact on health (see section 2.9). People in walkable cities have more occasions to conduct healthy lifestyle choices and move more. Studies reveal that denser urban environments have less obesity rates than suburbs (Li 2009). Furthermore, mixed-use planning and the presence of a variety of destinations not only promotes walking but also increases the sense of community or social capital through the facilitation of interaction between residents on the streets (Heart Foundation 2017).

Hence, walkable neighbourhoods can have a positive impact on social costs for the care of the person, on people's happiness and on a number of social aspects.

In the following, the interplay between the design of the physical space and mobility is highlighted (Figure 2.2.1), with the focus on new neighbourhoods. "When there is significant new development, then it will be important for transport and land use to be developed together" (Department for Transport, UK 2007).

FIGURE 2.2.1 **INTERPLAY BETWEEN BUILT ENVIRONMENT, MOBILITY AND PEOPLE: SIGNIFICANT THEMES AND RELATIONSHIPS**



## 2.2.1 SITE LAYOUT, MIXED LAND USE AND MOBILITY PATTERNS

New neighbourhoods should become vibrant urban spaces where people enjoy spending their time: the public realm should represent a strong attractor, where people feel safe and develop a true sense of belonging, and where everyone can find a number of services to satisfy their daily needs. A mix of uses and services is the key for a successful urban strategy, and is closely connected to mobility patterns. For instance, if a neighbourhood offers attractive spaces and services, demand for travel can be reduced.

Commuting, traveling from home to work, can be partly affected by the design of new districts, if we take into account the fact that some people will choose to settle close to work if the environment is attractive and the cost affordable. Nevertheless, as demonstrated in literature, an increase of mixité does not always correspond to a reduction in travel demand: be that as it may, it can help and offers an additional choice to people who want to live close to their jobs.

In addition, secondary travel for daily shopping and leisure can be reduced by appropriate neighbourhood design: if services are concentrated in a small portion of the territory, these can be easily accessed by sustainable means of transport or on foot.

It should be considered that urban design has a big influence on people's behaviour in a space, because living in different environments enables different uses of space and different mobility patterns. Hence, designers can approach mobility design with the idea of also providing an environment where people are naturally – almost unconsciously – encouraged to behave in a certain way. In this case, the spatial setting of a neighbourhood is a facilitator for a series of actions whose aim is to support modal shift and reduce people's need to travel.

In general, two main, interconnected design principles are crucial if we are to respond to the multiple dimensions of sustainability: diversity of both land use and types of environment and sufficiently dense places.

Taking into account these two principles, district-wide energy and environmental performance as well as mobility performance, can be satisfied. Moreover, dense and diverse places create a strong identity, thus a greater sense of belonging and use of space.

### BOX 2.2.1 **DENSITY**

Density is inversely correlated with the energy consumption of the transport sector: the higher the density, the lower the energy consumption (Kenworthy 2008; Lefèvre 2009; UN-Habitat 2013a). Density is also related to soil consumption: the lower the density, the higher the amount of land converted from green to build, thus the higher the contribution to global warming because of the reduction of the amount of CO2 absorbed by vegetation,

Positive effects of high density are also (UN-Habitat 2013b):

- Reduced public service costs. High density neighbourhoods tend to decrease the costs of public services such as police and emergency response, school transport, roads, water and sewage, etc.;
- Support for better community service;
- Provision of social equity;
- Support for better public open space;
- Increased energy efficiency and decreased pollution.

High density is a feature of cities at different development levels and contexts. A target value of a minimum of 150 p/ha is recommended by UN-Habitat (UN-Habitat 2013b), suggesting however that cities that are land rich may set a lower target and work progressively towards increased density.

Another principle is self-sufficiency. Transportation is one of the sectors (one of the most crucial, especially in developing countries) where entropy is generated and that should be tackled and minimised, aiming at the double dividend of the minimisation of both the entropy production of the settlement and the resources input, without impairing (indeed improving) its functions.

It should be noted that the principle of diversity should not be applied only at the scale and scope of the urban functions (dwellings, shops, offices, etc.) but also within each function and extended to the economic and social aspects, with many positive side-effects (SCRG 2017):

- A mix of housing densities, price level, and building type - interspersing affordable housing with higher priced housing - will help to attract a diverse population making the community culturally and socially diverse;
- Community diversity will help to create a 'sense of place' that will make the community memorable. A memorable community will be viewed as a desirable place to live;
- The introduction of a variety of housing building types will aid in the inclusion of affordable housing creating a socio-economic mix. A variety of housing types also helps to fulfil the needs of a variety of family types.

Consistent with the need for diversity, to build a sustainable neighbourhood, UN-Habitat (UN-Habitat 2013b) suggests:

- *Mixed land use* - Distribution of the total floor area: 40-60% for economic use, 30-50% for residential use and 10% for public services
- *Limited land use specialisation* – Single function blocks should cover less than 10% of any neighbourhood
- *Social mix* – 20-50% of the residential floor area should be for low cost housing, and each tenure type should be not more than 50% of total.

## 2.2.2 WALKABILITY: THE FIVE-MINUTE-WALK SHED

Walkability is for all. The same levels and opportunities for accessing urban places and services assure the principle of equity within a neighbourhood. The fundamental rule of thumb in designing a new neighbourhood is that the main services and transit nodes have to be reached in a five – maximum ten - minutes' walk (400-800 m, Figures 2.2.3 and 2.2.4); the application of this simple rule alone already supports urban walkability and generates the so-called cities of short distances; or, better, is the conditio sine qua non other more expensive measures are meaningless. In other words, designers can integrate most of the actions presented later in this chapter, but if the core services are not easily accessible and close to households, none of the actions introduced later can be really effective or applicable.

The five-minute-walk shed, the so-called pedestrian shed or simply ped-shed, was the natural growing pattern of human settlements before the era of cars. In the past, people had a limited travel budget time and were not available to spend more time (and money) for covering long distances. In reality, the travel budget time itself did not change so much over time: in fact, the willingness of people to travel is still more or less the same, but the distance we can cover today has radically changed. For instance, if commuters traditionally – yesterday and today – are willing to spend a maximum of two hours for a daily home-work round-trip, the distance that can be covered today has dramatically increased thanks to modern means of transport. The car revolution has completely subverted the natural tight relationship between urban and transport planning: after the 50ies limitations due to travel budget time was revolutionized by the "miracle" of the car.

### BOX 2.2.2 DIVERSITY AND REDUNDANCY

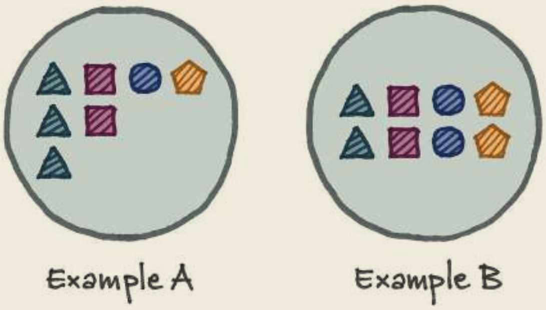
The concept of diversity was first introduced in ecology, where a relationship between diversity and an ecological system's resilience was found. Biological diversity can be quantified in many different ways. The two main factors taken into account when measuring diversity are richness and evenness. Richness is a measure of the number of different kinds of organisms present in a particular area. The more species present in a sample, the 'richer' the sample. Evenness is a measure of the relative abundance of the different species making up the richness of an area.

Species richness as a measure on its own takes no account of the number of individuals of each species present. It gives as much weight to those species which have very few individuals as it does to those which have many individuals. Evenness, on the other hand, takes into account the relative weight of each individual species. As species richness and evenness increase, so diversity increases. A community dominated by one or two species is considered to be less diverse than one in which several different species have a similar abundance. The same approach can be used to evaluate the "mixité", or multi-functionality, of the neighbourhood, where diversity is defined as the number of different types or classes of land use activities that exist in a specified area, taking into account both the richness (the total number of classes of activities that exist in the neighbourhood) and the evenness (the relative contribution of each class to the total number of activities), see Figure 2.2.2. Several diversity indexes have been developed in ecology (Odum 1993), and some of them have been transferred to urban planning; among them the most common are the Shannon-Wiener Index and the Simpson's Index (D). The Shannon-Wiener (or entropy) diversity index H is a widely accepted and commonly used index for representing the land-use mix (Kajtazi 2010). It is derived from the information theory and is expressed as:

$$H = -\sum_{i=1}^{i=k} p_i \ln(p_i)$$

where $p_i = n/N$ is the proportion of activities found in the ith class of activity, n is the number of the activities in the ith class, N is the total number of the activities in all classes and i = 1, 2, 3....k, being k the total number of the different classes of activity; ln is natural logarithm. The value of H can range from 0 to $H_{max} = -\ln(1/k)$, which is the value of H when the activities are evenly distributed thus all pis are equal).

FIGURE 2.2.2 **THE DIFFERENCE BETWEEN RICHNESS AND EVENNESS. ON THE LEFT-HAND IS EXAMPLE "A" WITH FOUR DIFFERENT CLASSES OF ACTIVITIES, EACH HAS DIFFERENT NUMBER OF ACTIVITIES. ON THE RIGHT-HAND IS EXAMPLE "B" WITH FOUR DIFFERENT CLASSES, EACH HAS SAME NUMBER OF ACTIVITIES. THE RICHNESS IS THE SAME IN BOTH EXAMPLES; EVENNESS IN EXAMPLE "A" IS LOWER THAN ON EXAMPLE "B" (KAJTAZI 2007).**



It was found that in ecological systems the value of the Shannon-Wiener index ranges from 1.5 to 3.5 (MacDonald 2003) rarely surpassing 4 (Margalef 1972). Being the ecosystems present on Earth, the result of an evolutionary process reaching a final optimum configuration, we may use this range of values as a first approximation guide for the mixed land use in neighbourhood design.

Simpson index of diversity D is expressed as: $D = 1 - \sum_{i=1}^{i=k} p_i^2$

Where $p_i$, i, n, N and k have the same meanings as in the previous formulas. D ranges between 0 (no diversity) and 1 (maximum diversity). It should not be lower than 0.5 (USGBC 2016) . The system's redundancy R is calculated as (Pierce 1980):

$$R = 1 - \frac{H}{H_{max}}$$

Redundancy ranges between 1 and 0: the lower the diversity the higher the redundancy. In ecological systems, and we may infer likewise in urban systems, redundancy protects against destabilisation caused by unpredictable perturbations; it makes the system more resilient. Redundancy has a cost: the more redundant the system, the less efficient, but also the more resilient.

FIGURE 2.2.3 **REASONABLE DISTANCE BETWEEN HOME AND SERVICES**

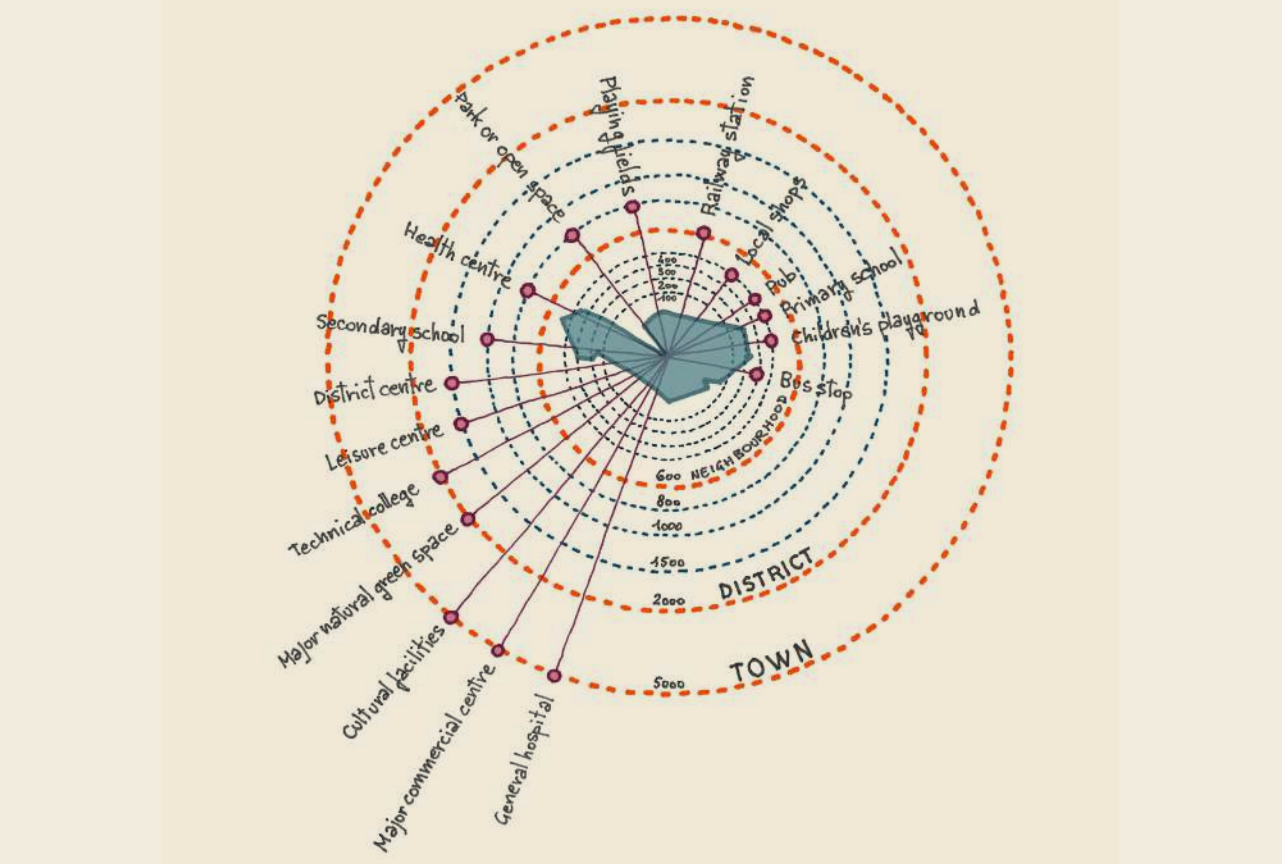


FIGURE 2.2.4 **CATCHMENT AREAS FOR SEVERAL TRANSPORT FORMS (UN-HABITAT 2013B)**

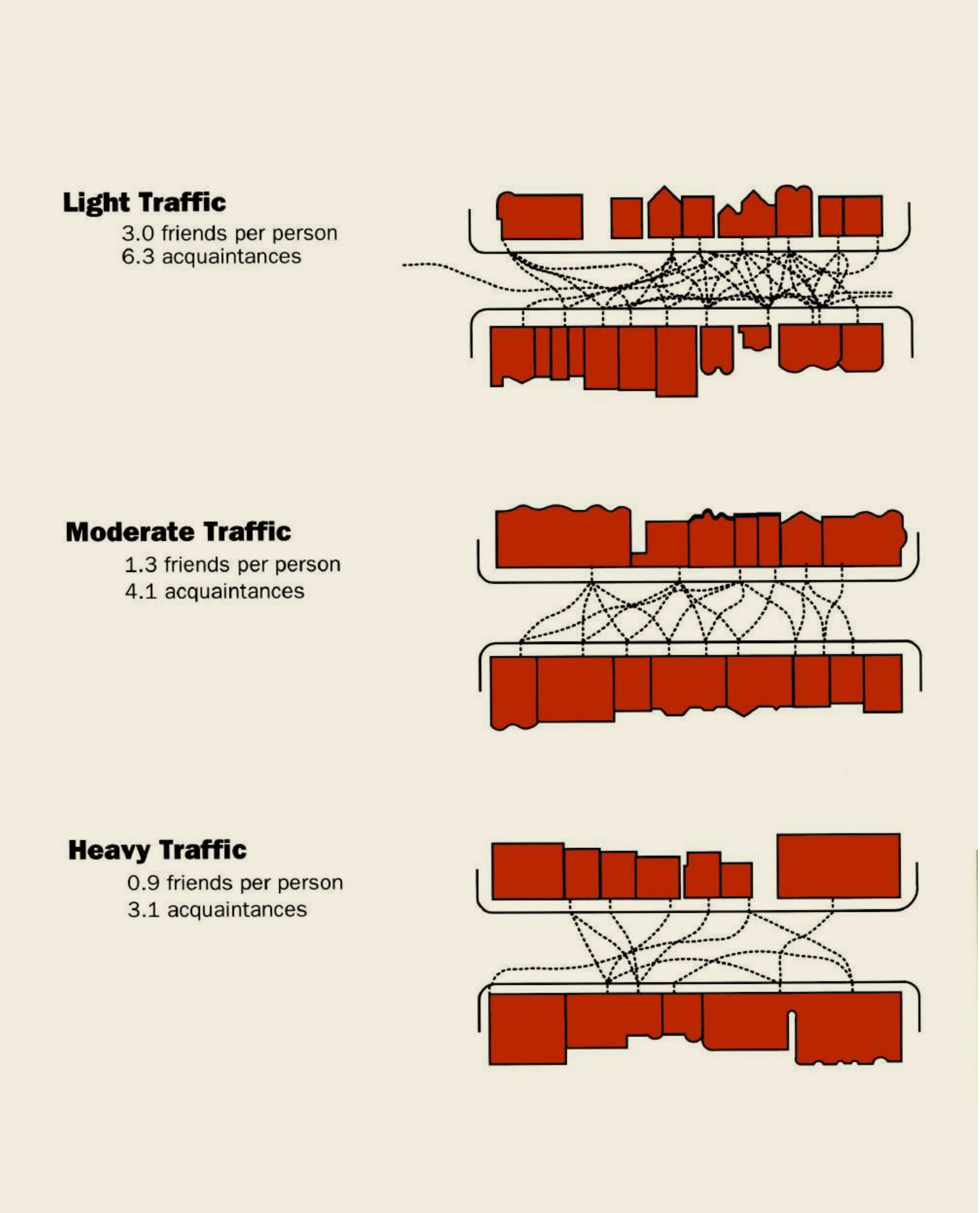
| | INTERVAL (M) | CORRIDOR WIDTH AREA SERVED | CATCHMENT PER STOP |
|---|---|---|---|
| Minibus | 200 | 800 | 320 - 640 |
| Bus | 200 | 800 | 480 - 1,760 |
| Guided Bus | 300 | 800 | 1,680 - 3,120 |
| Light Rail | 600 | 1,000 | 4,800 - 9,000 |
| Rail | 1,000+ | 2,000+ | 24,0000+ |

A parallel dynamic happened with the introduction of mechanical ventilation in buildings: the invention of artificial cooling and the availability of easy and low-cost heating completely replaced site-specific attention to the weather and climate conditions of places, and as a consequence, modern architecture could overcome limitations dictated by nature. In both cases, i.e. transport and architecture, forgetting about the nature of places and people was never a wise solution: in fact, with the increase in the costs of energy (and gasoline) and with the recent awareness of climate change and of the proper use of limited resources in a limited world, parsimony has become a paradigm of sustainable design. In fact, the same targets can be achieved using less energy without reducing peoples' quality of life. On the contrary, designing walkable communities increases the chance of getting healthier citizens and enhances relationships (Figure 2.2.5).

Mixed land use is a necessary but not by itself sufficient condition to promote a neighbourhood's walkability. Two more design strategies can lead to successful walkable neighbourhoods, i.e. places that are accessible and attractive for people:

1. ***Accessible, safe, high-quality and comfortable environments*** - The first strategy refers to the design of physical places that guarantee an urban setting with sufficient standards of quality to convince people to spend more time in the public realm. Accessible, safe, high-quality and comfortable environments are the main identified qualities that walkable neighbourhoods should give. Accessible environments have to be designed for all, including people with disabilities or reduced mobility: 'Universal design' principles have to be guaranteed. Reduced speed as foreseen by traffic calming measures will deliver safe

FIGURE 2.2.5 **WALKABLE NEIGHBOURHOODS REDUCE THE DEPENDENCE ON CARS FOR MOBILITY, THUS THE CAR TRAFFIC, WITH A BENEFICIAL EFFECT ON HUMAN RELATIONSHIPS. RESEARCH IN SAN FRANCISCO CONFIRMS THAT URBAN TRAFFIC UNDERMINES A STREET'S SENSE OF COMMUNITY. IN A SINGLE NEIGHBOURHOOD, THREE STREETS WITH DIFFERENT INTENSITIES OF TRAFFIC ARE COMPARED. AS TRAFFIC INCREASES SO CASUAL VISITS TO NEIGHBOURHOODS DECLINE. (SOURCE: ROGERS 1997)**



places where weaker members of the population can also feel protected. Safety has to be guaranteed when different means of transport interact, mainly through pedestrian crossings and parking lots. High-quality and comfortable environments are the plus factors that make people want to choose to spend their time in local public areas and streets, instead of attending other urban or indoor spaces. If places have all the above-mentioned features and, in addition, they also offer a great sensory experience, there is no doubt that people will be happy to enjoy such a space close to home. High-quality and comfortable spaces (i.e. shaded and ventilated) guarantee well-being, are diverse and capable of satisfying all the specific needs of people, and finally offer a perceptually pleasant urban scene.

2. ***Attractive paths with active frontages*** - Besides the design of a pleasant and accessible urban layout, decisions concerning land use are crucial. Which functions and services and where and how to distribute them are the big questions. Diversity in terms of social experiences and human interactions is a way to invite people to experience places. Hence, the control of ground levels is the main device for providing a vibrant urban scene. For instance, close to the centre of the neighbourhood and on main roads, the concentration of retail activities and urban services is convenient and creates a continuous and dense sense of urbanity. The street landscape, everywhere in the neighbourhood, has to offer frontages with an osmotic permeability between private and public spaces and should be able to guarantee natural surveillance, with grocery shops, repair workshops and cafes serving the inhabitants of the surrounding area.
3. ***Design or configuration of the centre*** – Big-box, car-park dominated retail shopping centres with large parking areas and all the shops facing inside, increase car reliance whilst simultaneously constraining pedestrian activity through a failure to provide a pleasant or easy walking or cycling environment. This increases motivation to drive to the centre, even if people live within a close and comfortable walking distance. Instead, street-fronting mixed-use buildings with small setbacks and 'active' ground floor uses extending onto the street (i.e., café seating areas, external shop displays) encourage walking and cycling access.
4. ***Appropriate employment to housing ratio*** – The employment to housing ratio indicates whether an area has enough housing for employees to live near employment centres and sufficient jobs in residential areas; an imbalance in jobs and housing creates longer commute times, more single driver commutes, loss of job opportunities for workers without vehicles, traffic congestion, and poor air quality; an employment to housing ratio in the range of 0.75 to 1.5 is considered beneficial for reducing vehicle kilometres travelled (UN-Habitat 2017).

To sum up, the walkable neighbourhood is the first and the most important principle to take into account while designing a new neighbourhood. All the daily urban services, including retail and access to transit, have to be provided within five to ten minutes' walk from home in order to reduce car travel. In a walkable neighbourhood all local services should always be accessible within short distances. In fact, people adapt their travel budget according to the type of service (see Figure 2.2.3): for instance, for their daily needs people are able to cover short distances, whereas for special services or city-scale functions (hospital, theatres) that are rarely used, travel budget time can be higher.

### 2.2.2.1 THE WALKABILITY INDEX

Walkability is a measure of the conditions of an area that promote walking, and the ped-shed, even if most important, cannot give a complete picture. Several indexes have been developed for measuring the walkability of a neighbourhood in a comprehensive way. One of them is particularly suitable for new neighbourhood design (Frank 2010), and is based on four sub-indexes, namely:

- Residential density; an indicator of the density of the neighbourhood.
- Commercial density; an indicator of the amount of businesses, restaurants, retail shops and other commercial uses that are located in the area.
- Intersection density; the connectivity of the street network, an indicator of the density of connections in path or road networks and the directness of links.
- Land use mix, or entropy score; the degree to which a diversity of land use types are present in a block group.

The residential density is measured as the ratio of residential units to the land area devoted to residential use.

The commercial density is measured by the Retail Floor Area Ratio, the ratio of the total, or gross, area designated for commercial use within a neighbourhood to the total area of the lot on which the buildings hosting the commercial activities stand.

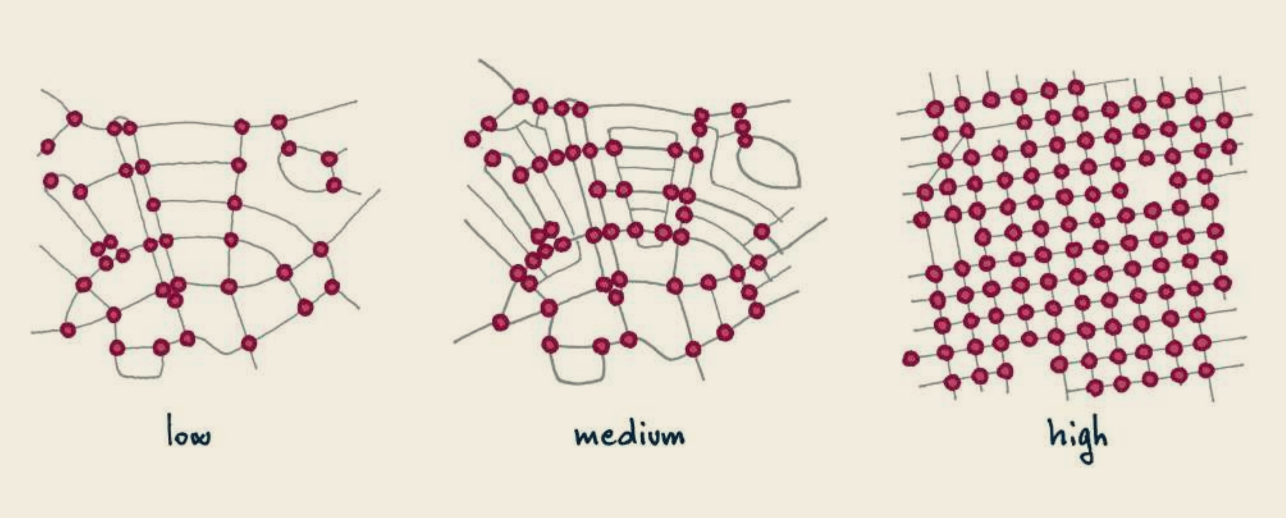
The intersection density, or connectivity index is measured by the ratio of the number of true intersections (3 or more legs) to the land area of the neighbourhood (Figure 2.2.6).

The land use mix is measured by the Shannon-Wiener diversity index H (see Box 2.2.2) applied to the land use types present in the neighbourhood.

Calculating the four values and normalizing them using a Z-score, the Walkability index WI is given by:

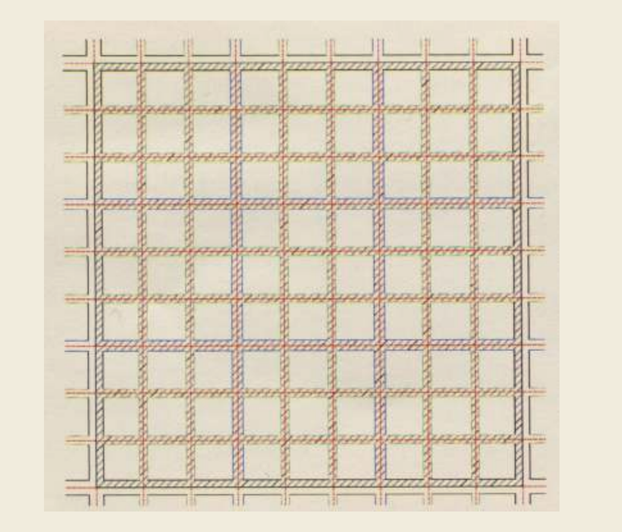
$$WI = [(2 \times z\text{-intersection density}) + (z\text{-net residential density}) + (z\text{-retail floor area ratio}) + (z\text{-land use mix})]$$

FIGURE 2.2.6 **FROM LEFT TO RIGHT: INCREASING CONNECTIVITY INDEX. A WELL-CONNECTED ROAD OR PATH NETWORK HAS MANY SHORT LINKS, NUMEROUS INTERSECTIONS, AND MINIMAL DEAD-ENDS. AS CONNECTIVITY INCREASES, TRAVEL DISTANCES DECREASE AND ROUTE OPTIONS INCREASE, ALLOWING MORE DIRECT TRAVEL BETWEEN DESTINATIONS.**



For encouraging walkability, UN-Habitat (UN-Habitat 2013b, UN-Habitat 2017) suggests 100 intersections/km$^2$ and a street grid where (Figure 2.2.7), in a one square kilometre area, the distance between two adjacent collector roads is 111 m, the distance between local streets is 55 m, and the total street length is 18 km, encompassing at least 30% of the land. Figure 2.2.4 suggests also that the distance between two adjacent arterial roads should be between 800 and 1,000 m.

FIGURE 2.2.7 **STREET NETWORK MODEL DESIGN (SOURCE: UN-HABITAT 2013b)**



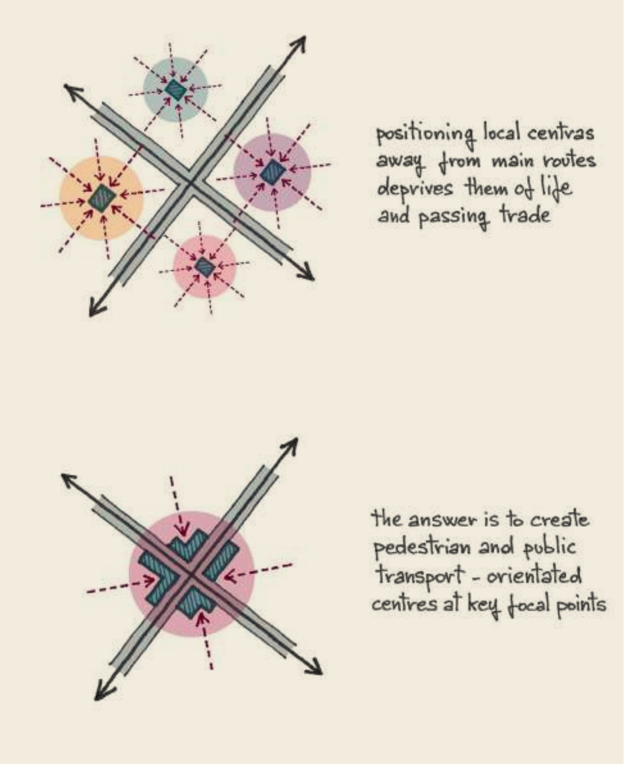
## 2.2.3 TRANSIT ORIENTED DEVELOPMENTS

A neighbourhood cannot fulfil all the needs of its inhabitants, thus must be connected with the surrounding neighbourhoods and the city centre. To reduce car use and enhance walkability but not compromise the connections with the world outside the neighbourhood, the concept of the so-called Transit Oriented Development (TOD) was developed. A TOD typically includes a central transit stop (such as a train station, or light rail or bus stop) surrounded by a high-density mixed-use area.

In the past, after the invention of the train, the rise of polycentric cities with regional polarities organized around local train stations represented the natural evolution of urbanization. This is what the urban design discipline today aims to recreate, in particular guiding the urban growth by infilling with new urban volumes around major transit nodes and reducing the car-dependent sprawl that completely deleted the principle of developing of cities around corridors of rail transport (Figure 2.2.8). Hence, sustainable neighbourhoods should be placed on major arteries where most of the movements happen to be.

Associated with the TOD concept is the urban gradient principle. A controlled rhythm of building density and distribution of services (mixed use) within an urban district reinforces the local centrality making it visible and readable to people. Again, it is a matter of creating environmental diversity so as to increase the tendency to walk inside the community: a homogenous urban tissue causes lack of way finding and points of reference. Usually, in these cases people do not identify a central place, do not know where to go, hence lose the sense of belonging to places and suddenly give up the idea of walking.

FIGURE 2.2.8 **URBAN SERVICES AND CENTRALITY OF CONNECTORS SHOULD MATCH IN A IN A TRANSIT ORIENTED DEVELOPMENT(ADAPTED FROM: EPHC 2000)**



## 2.2.4 INTERCHANGE MODALITIES

A transit node is not only a centre of reference for commuting. It also requires a number of very important services in order to engage people to adopt more sustainable mobility practices. We can distinguish two main types of services: services that are directly related to mobility, and others that support the vitality and urbanity of places. The latter are obviously indirectly related to mobility and refer to the provision of urban functions like retail and other forms of daily use services (pharmacies, education, utilities and so on) that increase the attractiveness of local transit nodes. In short, transit nodes should possibly correspond to local urban centralities.

Services directly related to mobility, on the contrary, are the following:

- Bike stations, i.e. safe and controlled parking lots for private bikes used by citizens for home to transit node trips (local residents), or from transit nodes to work trips (city users, workers). If properly designed, this service is crucial to facilitate the paradigm shift towards sustainable mobility. Stations have to offer a pleasant and safe experience, reduce time for commuting and the change in the means of mobility, be cheap and easily accessible;
- Shared mobility services, like bikes and cars, also equipped with nearby stations to improve the usage of the service;
- Smart parking solutions.

These services require dedicated areas that the urban designer must quantify and position carefully.

## 2.2.5 REVISED CAR ACCESSIBILITY

In the near future, new districts will experience a radical change in mobility patterns. The use of the private car will be drastically reduced (or avoided in cases where car ownership is still not dominant) thanks to three main reasons, namely: the emergence of sharing society principles, the increased availability of public transport and sustainable mobility, and the improved overall urban environmental quality. In such a changing picture, the physical layout of the urban environment cannot remain the same. A revision of current urban design standards has to be tackled and is now possible. If car accessibility will be reduced in the near future, two main solutions should be addressed, i.e. the reduction of car parking lots and the introduction of serious traffic calming solutions. Both measures can be undertaken incrementally, but the current design scheme should already foresee flexible conversion solutions over time according to adaptation principles.

### 2.2.5.1 CAR PARKING

Significantly reducing the number of car parking lots and privately-owned garages in new neighbourhoods represents the first measure of sustainable neighbourhood planning. Attractive short-distance cities are not flanked by cars parked on streets and garage doors. Moreover, the provision of on street parking lots dilates the size of the public space and consumes precious soil. Walkable streets, on the contrary, advocate for denser forms of urbanization and narrower streets, which are also a prerequisite for outdoor comfort control (see section 2.1).

Reducing car parking and garage doors facing streets can happen from scratch in new master plans, or incrementally over time. The second way may be the only solution in cases where the local urban design code stipulates the provision of a specific number of parking lots per capita (or per dwelling unit) as many urban standards ask for. In many cases, this is the biggest limitation to the development of sustainable streets.

Nevertheless, these standards are not the expression of current trends in slow mobility, and future urban scenarios have to seriously reconsider them.

The new trends in urban mobility, characterised by the shared use of different means of transport, combined with advanced ICT solutions (see BOX 4.2.1), lead to a significant reduction in the number of circulating vehicles and, thus, a significant reduction in the parking areas. Besides, car sharing (or even more importantly the not yet available nowadays but, according to many analysts, just around the corner driverless car) will call for a large number of small area parking spots.

If the provision of surface parking lots in public spaces is mandatory because the urban regulations have not been updated to sustainable urban development, surface parking as a transition solution could be used, so that it can be easily re-integrated into the urban masterplan and converted to other uses. The size of large parking lots should hence be compatible and comparable to the size of surrounding blocks, in order to provide sites for new buildings in the future.

Besides reducing parking lots, another strategy is to remove parking lots from streets and increase the density of those in concentrated places, either underground or multi-storey parking buildings (Figure 2.2.9).

Multi-storey parking areas should firstly provide a different use of the ground level, for example with shops facing onto the street, hence not interrupting walkable sidewalks with blind walls with no function or visual permeability; secondly, particular care should be taken over the treatment of the façade and this is often possible thanks to the limited restrictions and requirements of car parking. In fact, only natural ventilation and light have to be provided (there is no need for thermal insulation), hence attractive building skins can be easily developed with the use of light grid solutions, vegetation, and so on. This suggestion is not just a matter of aesthetics, with evident benefits for reduced impact on the urban streetscape and indirect consequences on the pleasantness and walkability of the local communities which are to be turned into car-free zones; it is also another way to restrict car use, limiting its proximity to homes. In this case, people can still own private vehicles, and access private buildings by car, but these are put together in specific places, functioning as the real gates of the neighbourhood.

However, multi-storey parking buildings should be thought through and designed as transition volumes, i.e. buildings that are used temporarily for parking but can be easily converted to other uses in the future, when car driving will be reduced. Conversion to retail units or apartments and lofts could be a profitable strategy and can only happen if the sizing of the block and the dimensions of the entire structure fit with urban uses.

### 2.2.5.2 TRAFFIC CALMING SOLUTIONS

The accessibility of neighbourhoods to cars must always be provided for safety reasons and for moving goods and people on special occasions. The principle should be that cars are temporary guests in the public space, where pedestrians are the masters. Numerous examples of traffic calming solutions flourish in urban design handbooks, and it is not necessary to exhaustively report those in detail (see the main types of solutions in Figure 2.2.10). In any case, the principal strategies are aimed at addressing the reduction of speed through the following actions:

- hindering the linear track for cars, making paths less easy (see the woonerf model as in Figure 2.2.11) for cars and introducing artificial curves and road bumps;
- change the materials of pavements, in order to visually reduce the size of roadways (different materials on the margins of the travel lane) and offering a different tactile experience (for instance, stones create vibration to reduce car speed).

FIGURE 2.2.9 **LIMIT THE ANTI-URBAN EFFECT OF CAR PARKING BUILDINGS: WRAP THOSE BIG BOXES WITH SMALLER UNITS TO CREATE ACTIVE FRONTAGES (LEFT). ALTERNATIVELY, PLACE CAR PARKING UNDERGROUND (RIGHT). (ADAPTED FROM: EPHC 2000)**

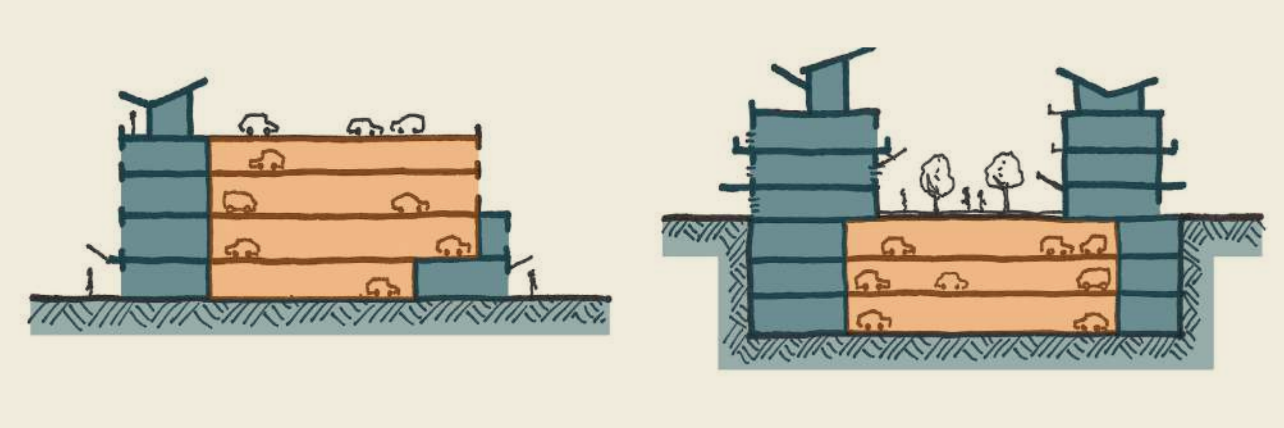


FIGURE 2.2.10 **A CATALOGUE OF TRAFFIC CALMING SOLUTIONS (SOURCE: USDT 2006)**

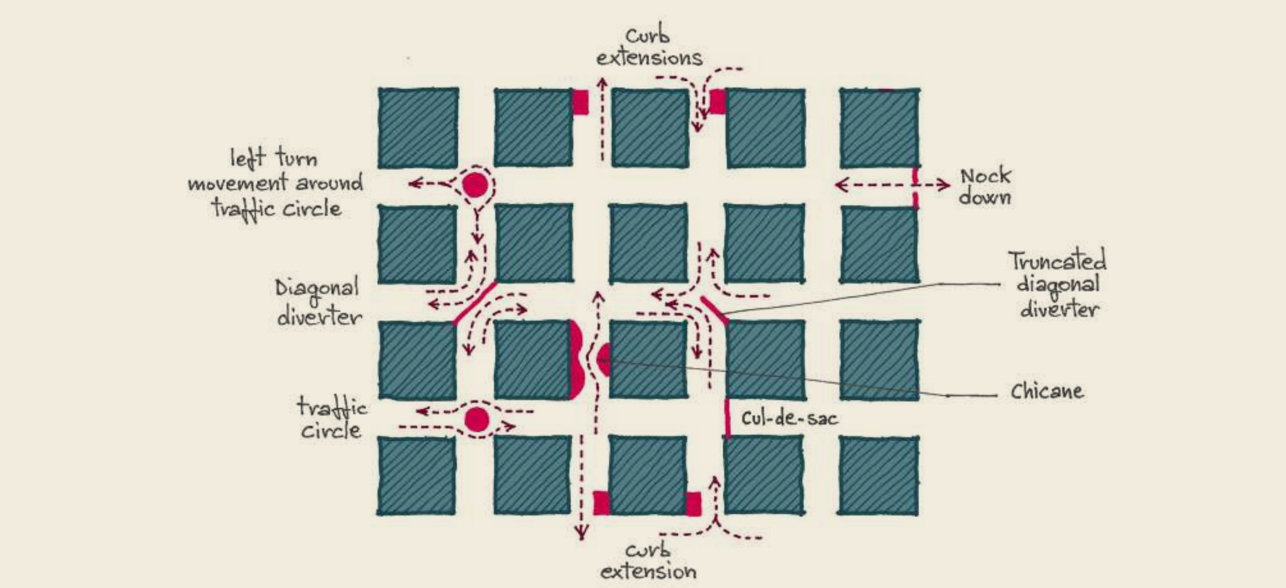


FIGURE 2.2.11 **THE WOONERF SCHEME AND ITS FEATURES (ADAPTED FROM: USDT 2006)**

### BOX 2.2.3 SMART MOBILITY SOLUTIONS

Innovative solutions for mobility rely mainly on two aspects of smartness: the diffused location-based technologies embedded in our smartphones and the infrastructure network embedded in the urban environment. The first category of smartness enables the sharing of services (optimization of resources use), whereas the second one represents the equipment of the city for enabling the smart use of services. In short, smart mobility and sharing society concepts are tightly bounded and the latter can hardly exist without the first one.

Many scholars agree that demand-led shared transport will be the big challenge in the near future. Sharing mobility is already a diffused reality in numerous world cities. Shared transport requires a convenient sizing of the system, and this is currently possible in large cities where the scaling up of the services allows for a safe return of investment. Big cities represent lighthouses where to diffuse new lifestyles to be exported later to other realities. Maybe in the next future also citizens of smaller cities will change mobility behaviours and allow sharing mobility to successful enter the market.

Bike- and e-Bike sharing is the first type of sharing mobility that was implemented as an urban service. Today, it is a mature and successful measure that creates an efficient urban service, saves carbon emissions and generates revenues to the operators that usually sell advertisement spaces diffused in the urban environmental and in the proximity of the bike stations. Not all the cities are suitable for this system, some of the major obstacles that limit the introduction of bike sharing being:

- Topography of the terrain: cities rich of slopes and hills represent incompatible places for bike-sharing. In fact, the management of the system requires to continuously relocate bikes from the stations in the valleys up to the top of the hills, or to make use of electric bikes;
- Very low urban density that does not make the system profitable: the distance between the stations is dictated by reasonable ride times and the installation of too many stations serving only few people is not convenient.

Car- and e-Car sharing is the next level of sharing mobility. Especially electric sharing could represent a promising solution for cities. Shared electric vehicles are the ideal mean of transport for covering short distances and with a diffused infrastructure of recharging points.

## 2.2.6 STREET GEOMETRY: DESIGN FOR NEW NEIGHBOURHOODS

As shown in section 2.1, for minimising a building's energy consumption and maximising outdoor comfort in tropical climates, urban streets should be tree lined and characterised by an aspect ratio H/W between 2 and 3. This implies rather deep urban canyons, i.e. narrow streets unless very tall buildings delimit them. The latter is an option that needs to be very carefully evaluated because, as shown in Chapter 3 it may conflict with the possibility of having zero energy buildings, which should be the prerequisite of a sustainable neighbourhood. On the other hand, "to maintain the human scale, residential buildings should be no more than four storeys in height; from this height, people can still walk comfortably to street level, and still feel part of the activity of the street (Alexander 1977).

The requirement deriving from climatic considerations, i.e. narrow streets, is consistent with a walkable neighbourhood, where the car circulation is limited, and thus wide streets are not required.

It is evident that in a holistic understanding, streets are not only a functional space for mobility, but are a social space as well, as they were in the past. Streets should be designed as places, not just as a channel for movement. They should encourage social interactions and create distinct and inviting spaces that people choose to experience: "streets should be places where people walk, shop, play, relax, sit and talk. Hence, the definition of the urban space comes first, and vehicular mobility follows" (Heart Foundation 2017).

The advice presented above on the physical setting of mobility solutions, leads to a reconsideration of current standards for street design. Numerous compendiums for street design offer (almost) universally valid solutions (EPHC 2007). In new, sustainable, neighbourhoods in a tropical climate, new street typologies should be explored, starting from the assumption that, except for the transit routes, streets are for pedestrians and cyclists first, with only sparse and slow motorised traffic.

### 2.2.6.1 ZONES IN THE PEDESTRIAN REALM

The pedestrian realm is characterised by four zones: frontage, through zone, furnishings, and edge. (Figure 2.2.12): Because interaction occurs between these zones, development of a cohesive design for the pedestrian realm is important. Design must consider the unique conditions associated with each zone as well as how the pedestrian realm interacts with other elements of the street, such as bicycle and transit facilities and junctions. The through zone represents the place where pedestrian flows take place, i.e. the main function of a sidewalk. The other parts can be additional but define the real quality of the street. Frontage, for example, could host outdoor commercial activities (cafes, restaurants, street vendors), and be merged with the furnishing zone, leaving the through zone outside. The provision of trees and grassed swales wherever possible contributes to both thermal comfort and the aesthetics of the pedestrian realm.

### 2.2.6.2 STREET TYPES

Considering the size of a sustainable neighbourhood, which derives from its 400 to 800 metre walkability, and the significantly reduced reliance on cars, the number of street types is rather limited in a sustainable neighbourhood and, in principle, could be reduced to three: transit, access and local streets. It should be clear, however, that, in contrast to what presently happens, street design should not be dictated only by the requirements of cars, and thus be the same design everywhere, but should also take into account other functions and the climatic, socio-cultural and economic context.

This approach is well expressed in the Street Design Manual for Abu Dhabi (ADUPC 2015), proposing – consistent with traditional Arabian architecture and urban form which, in turn, is significantly influenced by climatic factors - narrow streets (Mushtaraks) and pedestrian passageways (sikkas) shaded by buildings (Figure 2.2.13).

Hence, the hierarchy level of each street type should express the urban character of the hosted functions. Considering the local character of a neighbourhood, we mainly refer to local streets with a high access ratio (Figure 2.2.14a), residential access roads (Figure 2.2.14b) and transit roads (Figure 2.2.14c, d), connecting the neighbourhood with other neighbourhoods and the city centre.

### 2.2.6.3 STREET FURNITURE

Alongside vegetation and water, benches, bus stops, and bike parking are the main items of artificial furniture to be placed along streets in the public realm. This furniture needs to respond to the needs of human comfort especially in tropical climates, in order to make sure that people use public spaces and slow mobility solutions. For instance, sheltered, rain-protected seat furniture should be provided. When placing these features, designers should use a simulation of the solar path in order to optimise the provision of shading devices (see section 2.1 for solar geometry and design tools).

## 2.2.7 SERVICE COMPONENTS OF NEIGHBOURHOODS

Providing mixed services is the crucial strategy to enable environmental diversity and to minimise the emissions due to motorised traffic, thus some basic rules should be followed:

- Schools and public open spaces should be placed within five minutes' walking distance and intercept the local transit node;
- Buildings should host multiple functions under the same roof: for instance, retail on the ground floor, tertiary uses on the first floor and housing on the upper levels;
- Variety of uses and services can also be generated by offering short frontages and shop windows on the street.

## 2.2.8 ICTs AND SMART LOGISTICS

In the near future we expect to have smart neighbourhoods with buildings being net producers of renewable energy, connected and optimized transport systems, and electric cars charged with electricity produced from renewable energy sources.

Innovative ICT can enable applications providing more optimized and efficient travel. Moreover, reshaped city spaces designed according to the principles of mixed use and the use of improved virtual interactions can limit the need for travel. Consequently, neighbourhoods will not have to include as much space for vehicle parking and driving, hence freeing space for other functions. ICTs

FIGURE 2.2.12 **THE FUNCTIONS OF THE PEDESTRIAN REALM ZONES (ADAPTED FROM: ADUBC 2014)**

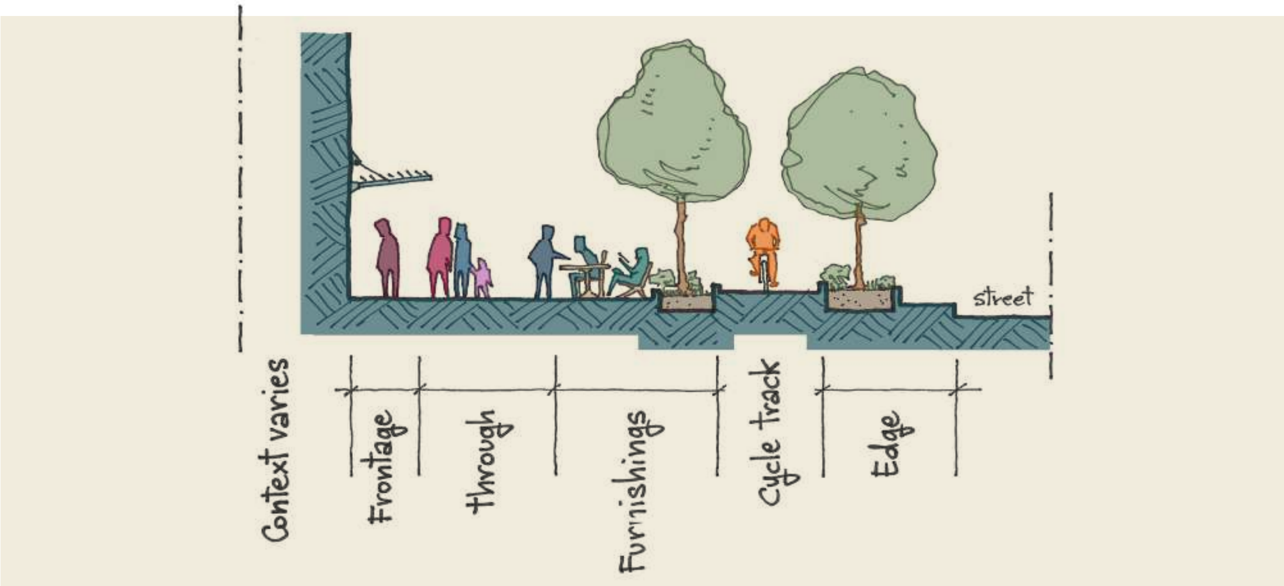
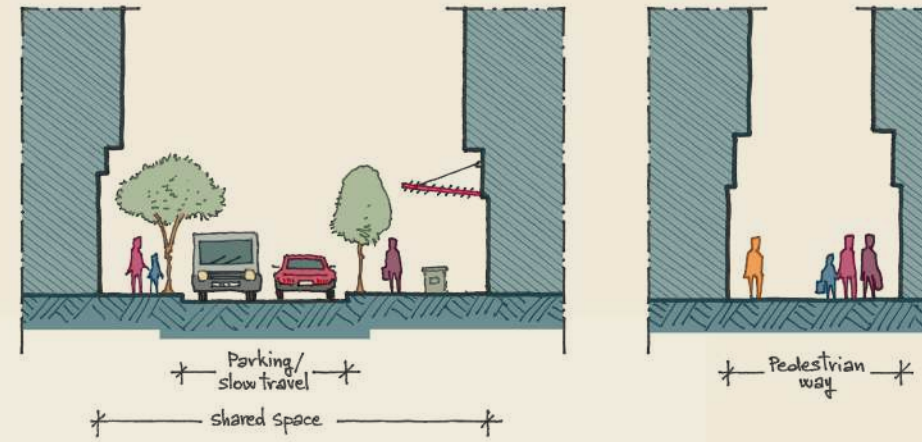
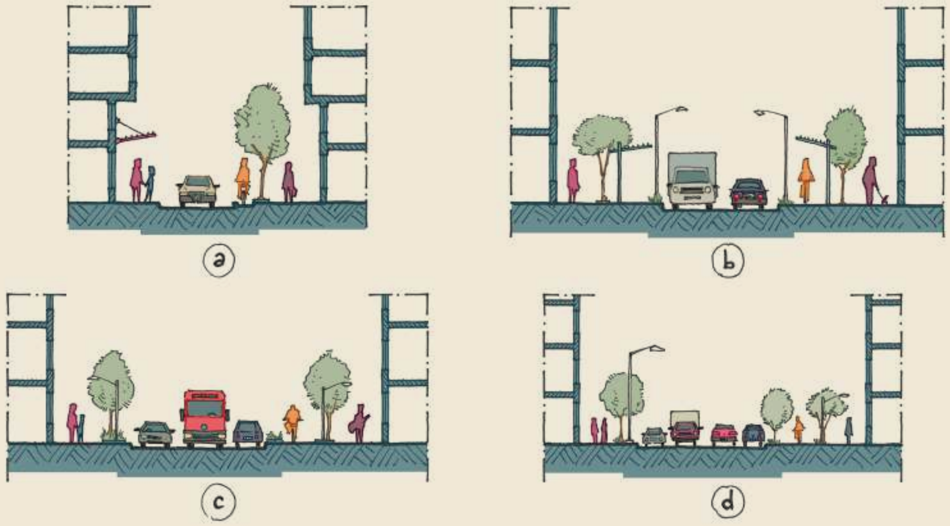


FIGURE 2.2.13 **A MUSHRATAK (LEFT) AND A SIKKA (RIGHT).**



Mushtarak is the Arabic word for a space that is shared by multiple modes: these streets are typically narrower and intended primarily for pedestrian use, but they can accommodate motor vehicles at very low speeds. A Sikka is a pedestrian passageway between properties and is common throughout the Emirate in old and new neighbourhoods; no motor vehicles are accommodated in a Sikka, however cyclists may share this space. The narrow width of the Sikka (typically 2.5 - 5.0 m) increases the amount of shading for pedestrians. (Adapted from: ADUPC 2014)

FIGURE 2.2.14 **EXAMPLES OF STREET DESIGN: a) LOCAL STREET; b) ACCESS STREET; c) AND d) TRANSIT ROADS**



are necessary for the development of the smart grids, for including renewable energy in the electricity grid as well as making existing grids more efficient, reducing losses and increasing speed. ICT can also help make buildings more energy-efficient through smart building control.

Often, planners and designers focus on people only, but the transport of goods is also crucial, especially in dense urban environments. Moreover, the whole retail system and the delivery of goods is rapidly changing because of the shift from physical retail to e-commerce. This revolution cannot be ignored by planners and urban designers, because it will completely redesign the physical space and logistics of our cities in the coming decades, and this urgently requires fresh solutions.

More and more, e-commerce is jeopardizing the distribution of goods inside the city, and this does not necessarily generate a reduction of carbon emissions. On the contrary, if not well organized, trips for the collection and delivery of goods can be even worse than the traditional delivery of goods. Of course, this new approach to goods delivery requires a physical infrastructure that differs from traditional retail spaces. Big, diffused lockers are a way of collecting several deliveries at the micro-urban scale. These storage spaces must be widely distributed, possibly in agreement with a business that is already diffused throughout the territory: for instance, interchange stations of transit or gasoline stations could be convenient places to intercept flows of people without creating extra demand for new trips. Typically, commuters could pick up goods at interchange stations on the way home, thus combining work travel and shopping and optimizing time. The localization of these storage spaces should not reduce the environmental quality and urban nature of the street landscape, hence special attention has to be guaranteed and limitations have to be imposed by local codes.

Even if not directly related to transport at all, a serious side effect of e-commerce and smart door-to-door delivery is the production of wasted packaging, which generates demand for transport for garbage collection. The increase of cardboard in waste collection is noticeable. Strategies to reduce this environmental impact are necessary and could be implemented at the community level, by putting in place new forms of reuse. The establishment of local waste collection islands could be a solution, as mentioned in section 2.7.

### 2.2.9 REMARKS

Some of the guidelines and design tips presented in this section might be evaluated as distant from the East African context. In fact, talking about smart mobility solutions and mass transport programmes is certainly ambitious, considering the limited resources, lack of government support and the lack of an organized and widespread infrastructure. Nevertheless, urban designers, developers and public officers should take into account best practices and make sure that, through careful planning and design, future opportunities will not be inhibited. For instance, providing space for specific mobility features, and perceiving some of the unsustainable car-dependent solutions as temporary, are some of the best ways to adapt urban spaces in the future. Otherwise, if the new district layout will not be able to adapt to future improvements in mobility, the whole energy and environmental strategy of the proposed masterplans will fail. Think about the design of modern cities in the fifties of the last century, when street design completely matched driveway design and the aim was to facilitate car driving. When they did this, cities lost the social aspect of urban streets, which became purely functional spaces for transport. Today, regenerating and readapting this car-dependent road design into urban spaces is a big challenge because of their size, the segregation of flows, and the complex connections to the network. In short, we are suffering the consequences of a planning mistake which originated in a car-dependent era. We should guarantee that the urban layout of new neighbourhoods is firstly for people, and is able to enhance social encounters and to adapt to future uses and mobility solutions.

Transportation, indeed, plays a major role in the overall carbon emissions of African cities, and special efforts have to be made at all levels

## REFERENCES

ADUPC (2014). Abu Dhabi Urban Street Design Manual. Abu Dhabi Urban Planning Council - http://www.upc.gov.ae/template/upc/pdf/Street%20Design%20Manual%20English%20(small)%20FINAL.pdf)

ADUPC (2015), Abu Dhabi Urban Street Design Manual. Abu Dhabi Urban Planning Council- http://www.upc.gov.ae/guidelines/manuals-and-guidelines.aspx?lang=en-US

Alexander, C., Ishikawa, S. and Silverstein, M. (1977). A Pattern Language. Oxford University Press. New York, quoted in: Parameters of the new urbanism – Residential areas

Brown B. B. et al. (2009), Mixed land use and walkability: Variations in land use measures and relationships with BMI, overweight, and obesity, Health Place. 15(4): 1130–1141. Published online 2009 Jul 4. doi: 10.1016/j.healthplace.2009.06.008

Brown. B. B. et al. (2009). Mixed land use and walkability: Variations in land use measures and relationships with BMI, overweight, and obesity, HealthPlace. 2009 Dec; 15(4): 1130–1141. Published online 2009 Jul 4. doi: 10.1016/j.healthplace.2009.06.008

Department for Transport UK. (2007). Eddington Transport Study Executive Summary - http://webarchive.nationalarchives.gov.uk/20090104005813/http:/www.dft.gov.uk/about/strategy/transportstrategy/eddingtonstudy/

Dittmar, H. (2008). Transport and Neighbourhoods. London: Black Dog Publishing Limited.

DOT (2007). Eddington Transport Study Executive Summary. Department for Transport UK - http://webarchive.nationalarchives.gov.uk/20090104005813/http:/www.dft.gov.uk/about/strategy/transportstrategy/eddingtonstudy/

EPHC (2000). Urban Design Compendium. English Partnerships & The Housing Corporation. Retrieved September 1, 2008 from Urban Design Compendium Web site: www.urbandesigncompendium.co.uk.

EPHC (2007). Delivering Quality Places: Urban Design Compendium 2. English Partnerships & The Housing Corporation. Retrieved September 1, 2008 from Urban Design Compendium Web site: www.urbandesigncompendium.co.uk

EU (2016). European Union, Directorate General for Mobility and Transport – Clean transport, Urban transport - https://ec.europa.eu/transport/themes/urban/urban_mobility_en- Accessed 10 Jan 2016

Frank, L. D. et al. (2010). The Development of a Walkability Index: Application To the Neighborhood Quality of Life Study, Br J Sports Med. 2010 Oct; 44(13):924-33.

Heart Foundation (2017), Healthy Active by Design - http://www.healthyactivebydesign.com.au - Accessed on 30 Jan 2017

http://www.eng.mcmaster.ca/civil/sustain/designparam/dparameters2.htm

IEA (2013). A Tale of Renewed Cities - http://www.iea.org/publications/freepublications/publication/renewed_cities_web.pdf

IPCC (2014). Fifth assessment Report, Chapter 8 – Transport - https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter8.pdf

Kajtazi, B. (2007). MeasuringMultifunctionality of Urban Area - https://www.itc.nl/library/papers_2007/msc/upla/kajtazi.pdf

Kajtazi, B. (2010). Measuring Multifunctionality of Urban Area: Advanced GIS Analysis for MeasuringDistance, Density, Diversity and Time of Urban Services, LAP LAMBERT Academic Publishing.

Li, F., Harmer, P. and Cardinal, B. (2009). Obesity and the built environment: does the density of neighborhood fast-food outlets matter? American Journal of Health Promotion, 23 (3), 203–209.

MacDonald, G. M. (2003). Biogeography: Space, Time, and Life. New York, NY: John Wiley & Sons, Inc., p. 409

Margalef, R. (1972). Homage to Evelyn Hutchinson, or why is there an upper limit to diversity, Transactions of the Connecticut Academy of Arts and Sciences, 44, 211-235.

Odum, E. P. (1983). Basic Ecology, CBS College Publishing.

Pierce, J. R. (1980). An Introduction to Information Theory, Dover Science Books.

Ritchie, A. & Randall, T. (Eds.). (2009). Sustainable Urban Design: An environmental approach (II ed.). London, New York: Taylor and Francis.

Rogers, R. (1997). Cities for a small planet, Faber & Faber, London.

Sallis, J. F., Floyd, M. F., Rodríguez, D. A. and Saelens, B. E. (2012). Role of built environments in physical activity, obesity, and cardiovascular disease. Circulation, 125 (5), 729–737.

SCRG (2017). Parameters of the new urbanism - http://www.eng.mcmaster.ca/civil/sustain/designparam/default.htm. Accessed 30 Jan 2017.

USDT (2006). Federal Highway Administration University Course on Bicycle and Pedestrian Transportation. U.S. Department of Transportation, Turner-Fairbank Highway Research Center, Federal Highway Administration, Georgetown Pike, McLean VA.Georgetown Pike,McLean VA.

## 2.3 MAXIMISE EFFICIENCY OF ENERGY CONVERSION TECHNOLOGIES

Choosing the most efficient energy conversion technologies that are needed for the urban system to work, means optimising energy streams from the exergetic point of view (Vandevyvere 2012). Urban energy consumption is conventionally subdivided into three sectors: buildings (residential and commercial), transport, and industry. In cities in developed countries the building sector usually ranks first, while in cities in developing countries, it is generally the transport sector that ranks first (Figure 2.3.1).

The main reason for this difference derives from the fact that cities in developed countries are – with a few exceptions – located in temperate-cold climates, and heating is the main cause of energy consumption. Space heating is a matter of survival, not just comfort, in cold environments. The issue of cooling in hot environments is less critical, as it is a matter of comfort, rarely of survival.

This evidence, coupled with the difference in the wealth of the average household in developed and developing countries, explains why transport, in the latter, weighs more than the building sector, in terms of energy consumption. Improving the economic conditions of households in developing countries will lead to a growing use of air conditioning which, if not mitigated by proper urban and building design and controlled by means of high efficiency equipment, will cause a sharp increase in energy consumption in the building sector.

Traditionally, heat is obtained by the combustion of fuel, either biomass or fossil, but this way of producing heat is not always the most efficient, in terms of exergy, as in the case, for example, of providing hot water or space heating. According to the Second Law of Thermodynamics, burning fuel in a boiler to obtain an ambient air temperature of 20 °C or water at 40°C for showering is the most inefficient way of attaining the desired result (because we use high grade, i.e. high exergy, heat when we need it at low grade, i.e. low exergy). On the other hand, the production of electricity with a thermal power plant necessarily implies the production of some low temperature heat. Since we need low-grade heat for heating, why not use the low temperature heat produced by the power plant, which is otherwise wasted? In this way the overall efficiency of the system is significantly improved[21]. This technological approach is named cogeneration, or CHP (Combined Heat & Power).

Cogeneration is defined as the sequential generation of two forms of useful energy from a single primary energy source. Typically, the two forms of energy are mechanical (transformed generally into electricity) and thermal energy.

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[21] *Moreover, water consumption – in a world in which water shortage is already an emergency – is greatly reduced. Approximately three quarters of the water consumption in Germany and about 50% in USA is used in the cooling systems of fossil and nuclear power stations for extracting the low-grade heat, wasting it in the atmosphere, in the rivers or in the sea causing the so called thermal pollution (Source: Butera 2008).*

With cogeneration, heat – as a by-product of electricity generation in a small-scale power plant – is captured and used for other purposes instead of being disposed of in the environment. In temperate-cold climates CHP waste heat is distributed to the residential and commercial buildings of an area (district heating).

CHP is widely used in many cities in developed countries, where heating is needed for at least eight months of the year, and hot water all year round. This is not only thermodynamically sound, but also cost-effective.

In tropical climates space heating is not required, and if, at high altitudes, some heat may be welcome, the short heating period means that CHP is not economically viable for this function. But CHP can also play a role in cooling, by means of absorption chillers that use the waste heat for producing chilled water (Figure 2.3.2), which can be distributed to the residential and commercial buildings of an area (district cooling[22], Figure 2.3.3). A neighbourhood or district CHP system can provide both electricity, cooling and Domestic Hot Water (DHW). In this way the electricity produced can be used for purposes other than running air conditioners.

An appropriately sized land area must be provided to accommodate the CHP district cooling, taking into account the need for cooling towers, in addition to the CHP units and the absorption chillers.

The use of waste heat for district cooling entails the use of an additional component besides the network for CHP district heating. This additional component is the absorption chiller, which is expensive and is characterised by a low conversion efficiency; the economics of this solution, thus, need to be very carefully analysed and compared to a district cooling system where chilled water is provided by electricity driven compression chillers[23].

Alternatively, waste heat can be used for purifying treated wastewater via vacuum distillation, for producing potable water. In this case also some dedicated space has to be provided for the distillation plant.

The Second Law of Thermodynamics also states that the most efficient way to produce (or subtract) heat for heating or cooling with high quality sources such as fuel or electricity is by means of an appropriate use of the heat pump. The heat pump is a device that "pumps" a heat flow from a lower to a higher temperature, in the same way as a water pump raises a water flow from a lower to a higher height (Figure 2.3.4).

When it is used for heating, it pumps heat from the outdoor to the indoor environment, heating it; when used for cooling (refrigerators, air conditioners), it pumps heat from the indoor to the outdoor environment; as heat is subtracted from the indoor environment, its temperature decreases or remains constant in spite of the heat flow coming from the outdoor environment. This is the way an air conditioning system works: it cools down indoor air and blows hot air into the outdoor environment, increasing the anthropogenic heat produced by motorised traffic and cooking.

There is a way to make this process more efficient: instead of blowing the heat produced outdoors and wasting it, it is possible to use it for hot water production, with some clever technology. In this way the energy consumed for DHW production is saved. This approach can be used at building, block and neighbourhood scale, the latter if district cooling has been implemented.

DHW can be produced by dedicated heat pump units that subtract heat from the environment and pump it at a higher temperature for water heating. Thermodynamically, this approach is far sounder than the usual one which is based on direct combustion of fuel or, even worse, on electric resistance. Heat pump DHW production systems are available at different scales, and their use at individual, building or block scale should be evaluated.

A combination of cogeneration and heat pump for cooling can be considered for district cooling, as shown in Figure 2.3.5, where chilled water is produced by both an electric (heat pump) and an absorption chiller. The electricity produced by the CHP plant is used for supplying the electric compression chiller, while the waste heat supplies the absorption chiller. The amount of electricity and heat produced is such that their sum is capable of producing the amount of chilled water necessary to satisfy the immediate cooling demand.

A careful economic analysis of the cost-effectiveness of such a technological option should be carried out, as it is very sensitive to the structure of the cooling demand, and a dedicated area for the plant must be provided

District cooling, either provided with a CHP system or with compression chillers, or both, can be entirely fuelled by renewable energy: biomass as fuel for the CHP system and sun and/or wind for providing the electricity for the compression chillers, as shown in the next section.

Space cooling implies the production of heat that is released into the outdoor environment. If space cooling is obtained with individual, apartment or building scale air conditioning systems, the heat produced is diffusely released in the neighbourhood, contributing to the anthropogenic heat flow that enters the energy balance, affecting the local climate. With district cooling, heat is produced and released only at the location of the chilled water production, i.e. where the chiller is located, while in the rest of the neighbourhood no production of heat due to air conditioning occurs (in fact, heat is subtracted from the outdoor environment).

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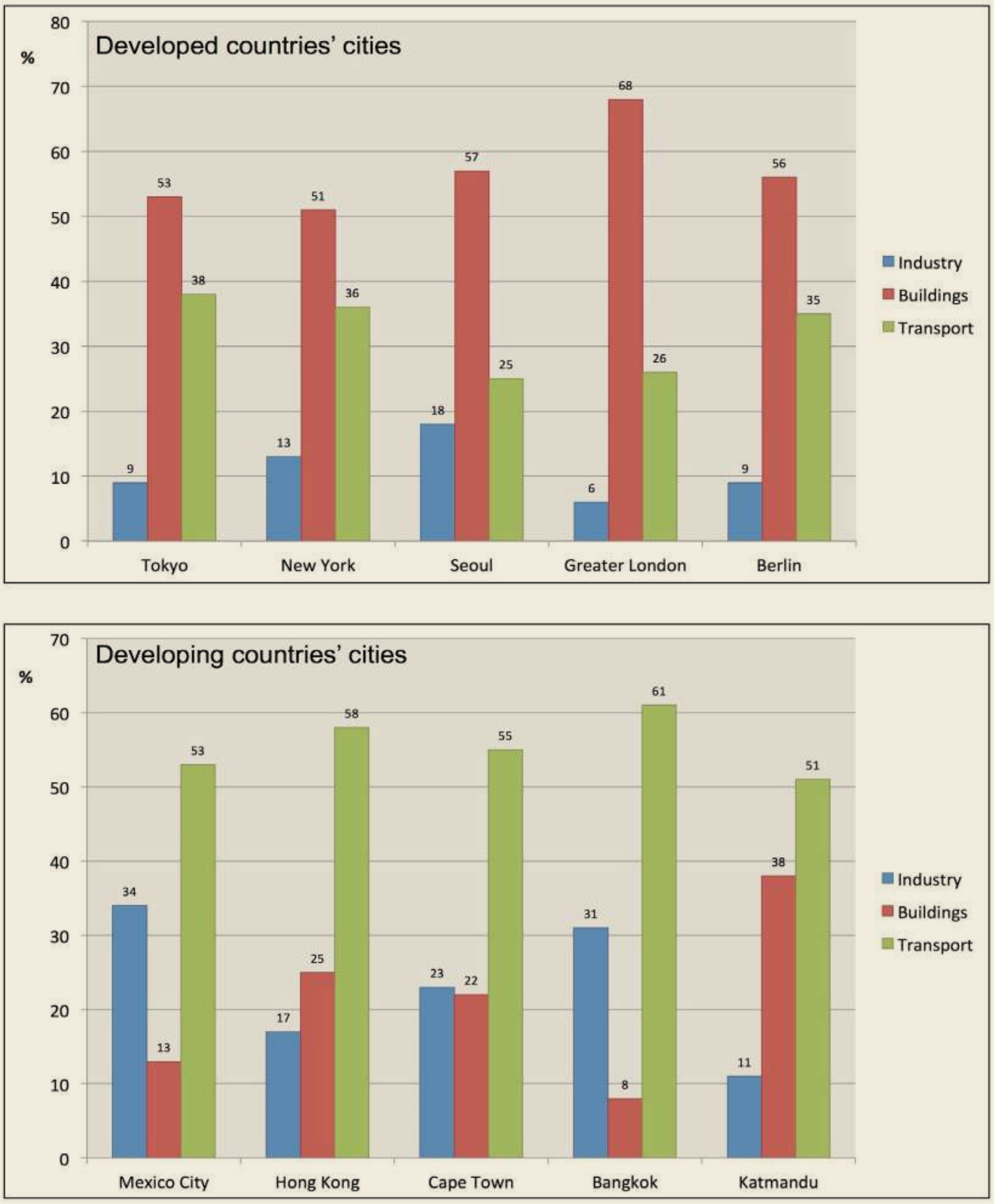
[22] *In a district cooling system, chilled water is produced at a central plant and distributed through an underground network of pipes to the buildings or consumers connected to the system. The chilled water is used primarily for air-conditioning systems. After passing through these systems, the temperature of the water has increased and the water is returned to the central plant where the water is cooled and re-circulated through the closed loop system.*

[23] *The advantage of such a district cooling system is that it is possible to use less energy and emit less $CO_2$ compared to traditional individual systems operated by electrically driven chillers. By aggregating the need for cooling, it is possible to employ more efficient cooling technologies. The disadvantage is the investment cost and the losses in the piping network.*

FIGURE 2.3.1 **ENERGY CONSUMPTION BY SECTOR IN SELECTED CITIES – DATA 1999-2005. (SOURCE: UN-HABITAT 2008)**



Thus, a carefully studied, appropriate positioning of the cooling plant could reduce the heat released in the neighbourhood streets and squares, with a beneficial effect on the energy balance and, consequently, on the local climate.

As noted above, transport is the second most important origin of $CO_2$ emissions. Maximising the energy efficiency of transport refers to the efficiency of the different means of transport. This means not only that their engines or motors must be efficient, but that they must also be efficient in relation to their function: to move people and goods from one place to another. In other words, energy efficiency does not depend only on an efficient, low emissions engine, it also has to be measured in relation to the number of passengers moved, and how far (Figure 2.3.6). From this it follows that there are some means of transport for which the urban designer should provide the necessary infrastructures: bicycles and collective transport. The present progressive penetration of electric cars adds a new competitor in transport efficiency, provided that the car batteries are charged with electricity produced by a renewable energy system and that a car sharing system is set up. To favour this trend the urban designer should provide diffused parking areas where the cars can be picked up and delivered and where they can be recharged with renewable electricity.

FIGURE 2.3.2 **COGENERATION HEAT USED FOR CHILLED WATER PRODUCTION**

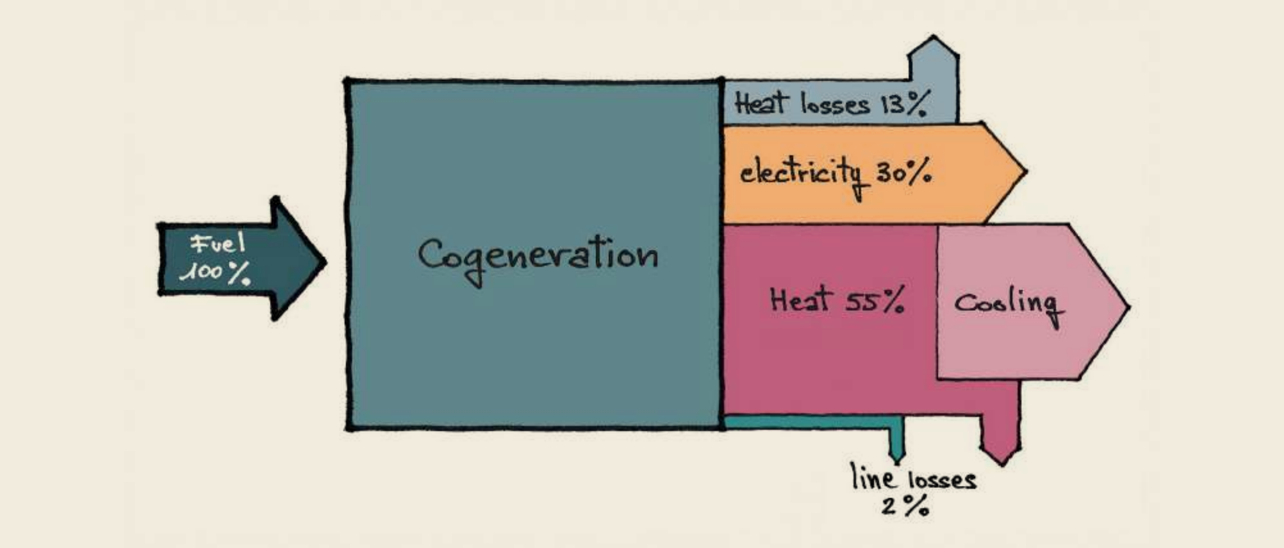


FIGURE 2.3.3 **ILLUSTRATION OF A DISTRICT COOLING SYSTEM**

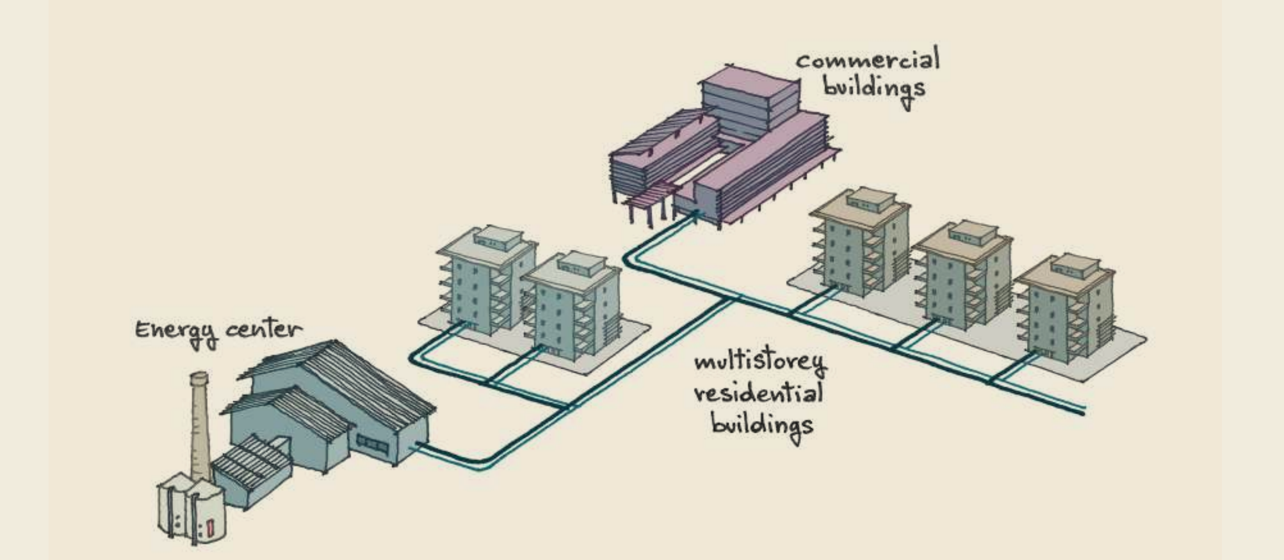


FIGURE 2.3.4 **HEAT PUMP PRINCIPLE**

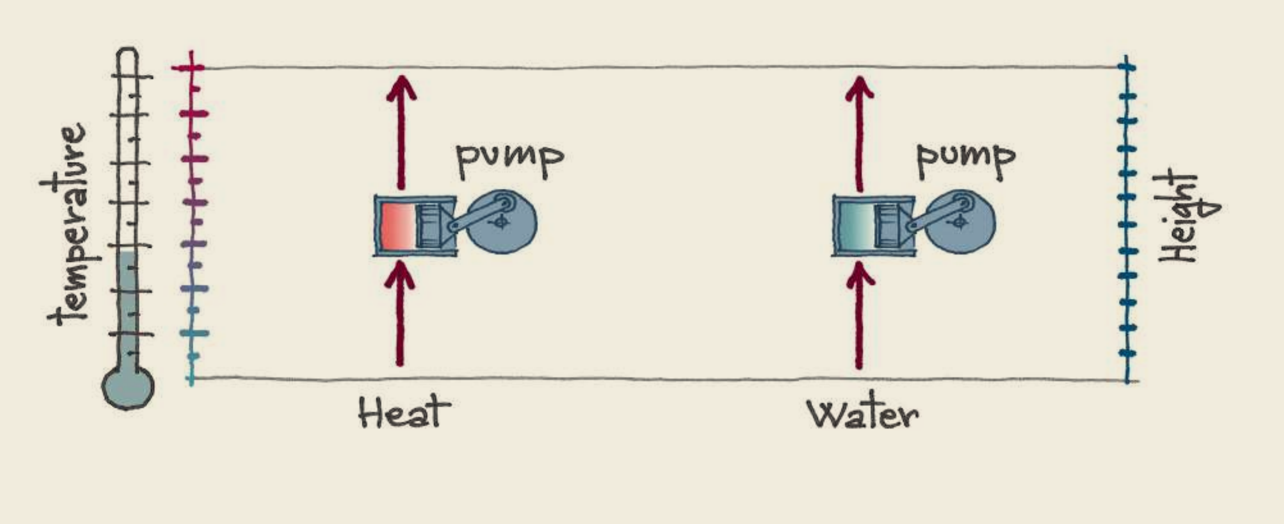


FIGURE 2.3.5 **COMBINED USE OF COMPRESSION AND ABSORPTION CHILLERS DRIVEN BY A CHP UNIT**

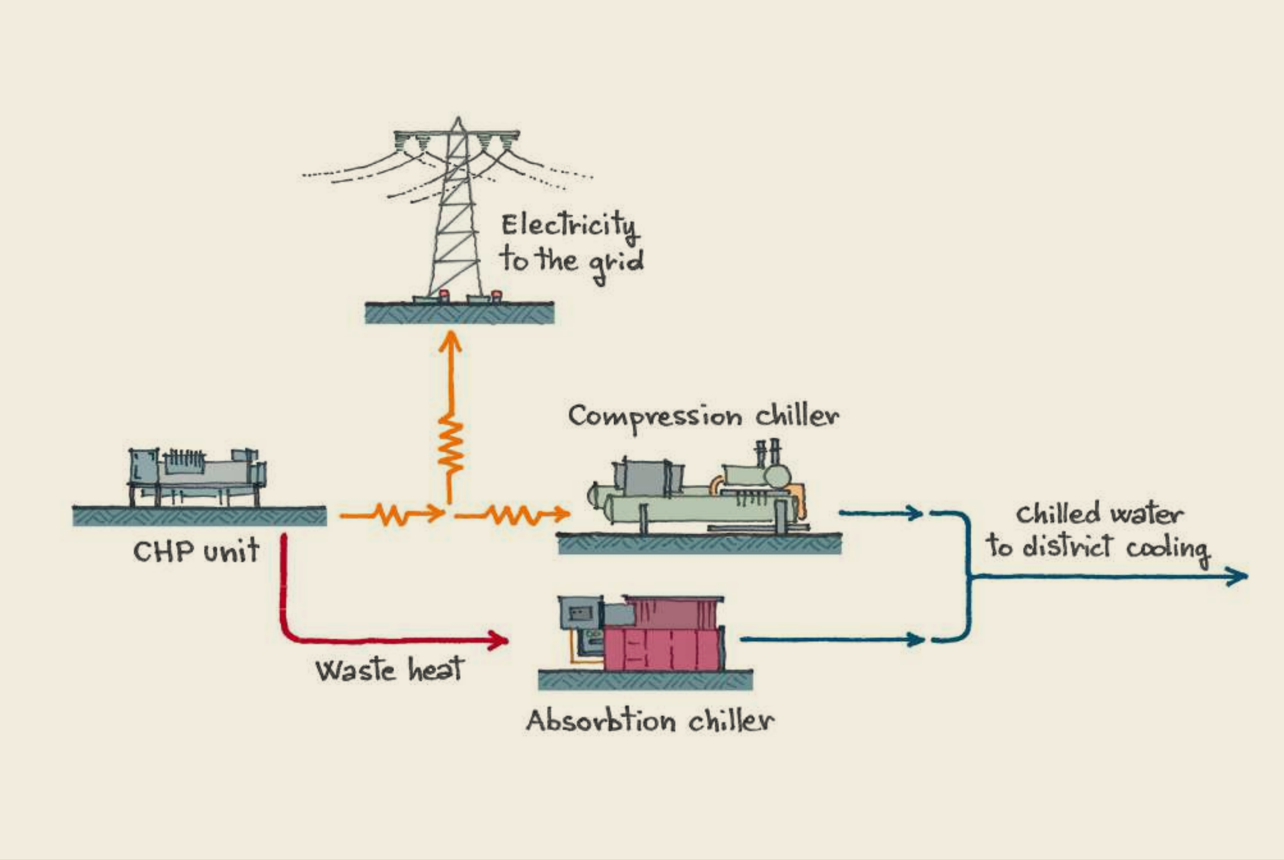
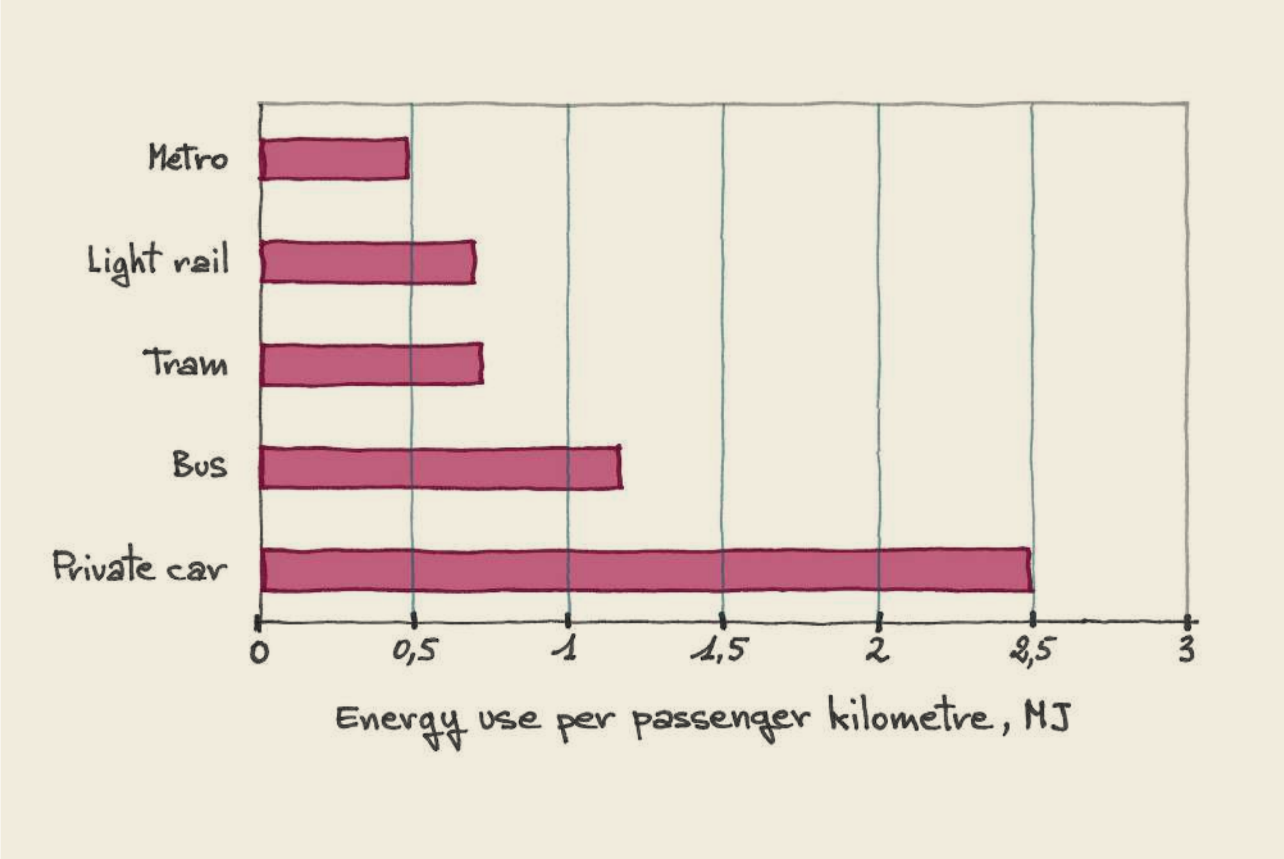


FIGURE 2.3.6 **TRANSPORT ENERGY EFFICIENCY (SOURCE: KENWORTHY 2008)**



In conclusion, for the built environment, low temperature (and thus low exergy) heat sources are of particular importance, for heating, cooling and hot water production. The main aim in designing the energy system should be to avoid using high exergy sources for low exergy uses, and to choose the energy conversion technology accordingly. Therefore, three major constituents of exergy optimization emerge: i) use of direct sourcing of low exergy heat sources (ambient heat, waste heat, etc.); ii) use of high exergy sources only for high exergy uses (electricity, mechanical work); iii) heat exchange and storage. It should be noted that electricity and heat (or cold) are characterized by different transportation and storage possibilities. In basic terms and considering the present situation, this may be summed up as electricity being easy to transport and difficult to store, while the opposite applies to heat and cold.

This leads to a second aspect which illustrates the importance of spatial planning: all the energy related infrastructures must have their place, i.e. a space to accommodate them. Spatial arrangements and distances between energy generation, transfer and storage systems thus become an important issue: many of the most appropriate technologies may require dedicated spaces or infrastructures, especially if the most efficient ones – as often happens – are shown to be the ones centralised at neighbourhood or block scale – such as district cooling or distributed generation units. The urban designer must be able to make provision for responding to such requirements.

## REFERENCES

Butera, F. (2008).Towards the renewable built environment, in: P. Droege (ed.), Urban Energy Transition, Elsevier.

Kenworthy, J. R. (2008). Energy Use and $CO_2$ Production in the Urban Passenger Transport System of 84 International Cities: Findings and Policy Implications, in P. Droege (ed.), Urban Energy Transition, Elsevier.

UN- Habitat (2008). State of the World's Cities 2008/2009 - Harmonious Cities, Earthscan.

Vandevyvere, H. and Stremke S. (2012). Urban Planning for a Renewable Energy Future: Methodological Challenges and Opportunities from a Design Perspective, Sustainability 2012, 4, 1309-1328 - http://www.mdpi.com/2071-1050/4/6/1309

## 2.4 FULFIL THE REMAINING ENERGY CONSUMPTION WITH RENEWABLE ENERGY SOURCES

The potential for renewable energy sources at neighbourhood scale depends on the climate and on the neighbourhood design. The potential for solar and wind energy depends on climate, i.e. on the availability of solar radiation and wind, but also on the number of suitable surfaces that can be covered with solar panels and on the texture of the settlement, as this affects wind velocity. Biomass potential depends on the neighbourhood design, as it includes wood and leaves from the pruning of trees and bushes in the parks, green spots, tree-lined streets, etc. It also depends on the type of wastewater treatment system and on the existence and size of plots dedicated to urban agriculture.

The use of renewable energy technologies is very challenging for the urban designer, as it imposes significant constraints on urban design. PV systems, for example, affect the albedo and size of roofs, the latter if the aim is to have zero energy buildings. PV systems could be used for supplying electricity to fleets of electric cars, and the ideal would be to park these cars in dedicated outdoor parking plots equipped with PV canopies; in this case the challenge is to optimise the size and the position of the parking lots in relation to the number of cars and of the PV area needed to charge them.

Biogas production from liquid organic waste requires appropriate design of the sewerage and provision for the necessary space to accommodate the anaerobic digestion plant or, alternatively, individual digesters for each building (see section 2.5).

Syngas production requires space to be allocated not only for the gasifier, but also for wood storage and pre-processing. In windy areas, wind turbines up to 20 kW are consistent with the urban context and may make a contribution to the energy system. They can be positioned in open spaces such as service areas. Some additional information about renewable energy technologies and their possible applications at neighbourhood scale is provided in Appendix 5.

### 2.4.1 MINI GRIDS

Electricity production from solar and wind energy is not programmable, as PV systems cannot produce at night and both PV and wind systems produce more or less electricity according to the meteorological conditions; thus, it is very unlikely that demand and power supply match. The easiest solution is to be connected to the main grid, which provides power when the renewable production is insufficient and absorbs power when production exceeds demand.

If a connection to the main grid is not available or the power supply is unreliable, there are two options, which are often used in combination. The first option is the storage of electricity by means of batteries, or other storage technology. The second is to have backup provided by a generator supplied with programmable energy sources, such as fossil fuels and biomass. A control system is necessary for the management of both the storage option and the generator, to regulate their output so that instantaneous power demand is met by the corresponding instantaneous power production.

Mini-grids, or micro-grids derive from this approach, and they are defined as local energy systems of distributed energy resources, distributed consumers and, optionally, storage (Siemens 2011).

Distributed generation located close to demand delivers electricity with minimal losses. This power may therefore have a higher value than power coming from large, central conventional generators through the traditional utility transmission and distribution infrastructure, especially when – as is common in Africa – transmission losses are very high (Figure 2.4.1): besides the economic loss $CO_2$ emissions not balanced by any benefit should be taken into consideration.

A microgrid maximizes the benefits of distributed generators and solves the above-mentioned disadvantage (energy transport losses will be less than 1% under normal circumstances, Siemens 2011), distributed generation can also be utilised during utility power system outages.

A microgrid designed for a sustainable neighbourhood includes programmable and non-programmable renewable generation, energy storage facilities and/or optional fossil fuelled generation and load control (Figure 2.4.2). This new system will be scalable, which means that growing loads may require the installation of additional generators without any negative effect on the stable and reliable operation of the existing microgrid. Typical distributed energy resources for microgrids are wind and solar-powered generators, and biomass powered systems.

A crucial component of mini-grids based on non-programmable generation is the storage system. A number of energy storage technologies have been developed or are under development for electric power applications, including:

- Pumped hydropower
- Compressed air energy storage (CAES)
- Batteries
- Flywheels
- Superconducting magnetic energy storage (SMES)
- Supercapacitors

Each of these technologies is characterised by maturity level and by power range and discharge time (Figure 2.4.3).

Among the above-mentioned storage technologies, the most suitable for integration into a neighbourhood mini-grid are, presently, batteries, even though they are rather expensive. A combination of batteries and programmable electricity generators (fossil or biomass fuelled) is the most economical option. The cost of batteries is steadily decreasing and their use is expanding to the automotive sector.

Diversity of building functions (mixed land use) and socio-economic diversity make a positive, very important, contribution to the development of cost-efficient mini and micro grids and to their resilience. The increased cost-efficiency is due to the fact that such diversity allows smoothing the daily electricity load patterns thus reducing the size of the storage needed, as the load moves from productive uses (offices, shops, etc.) to residential uses, when people go home from work. Socio-economic diversity also helps, as it means there is a variety of behaviours.

The increased resilience of the local energy system derives from the variety of the renewable energy sources and technologies used, which increases the system's redundancy (see Box 2.2.1). For this reason, reliance on a single renewable energy source is not a wise option, and a neighbourhood's energy system should be based on as many sources and technologies as possible, and the provision of some excess installed power is recommended.

A possibility offered by mini-grids is that they could be owned by the neighbourhood community, which operates and manages the system and provides all services for the benefit of its members. Mini-grids, or microgrids, are popping up all over the world, from systems that can connect or disconnect from larger 'main' grid systems, to tiny, informally wired connections between very few users.

In new urban developments, especially in developing countries, where most part of the infrastructure for electricity production, transmission and distribution has yet to be built, the mini-grids (or smart grids, as mini-grids are often named because of a "smart" control system managing them) are an almost obligatory technical option. Indeed, it would be very odd to develop new settlements with the kind of obsolete centralised system that developed countries are correcting or abandoning as it is not consistent with an energy system based on renewable energy sources.

The urban planner has a role in this transition, as the distributed energy system requires some land area to construct the programmable energy generation and the storage units, and may require height limits to buildings.

## REFERENCES

Howes, R. and Mtingwa, R. (2009). Issues in the Storage of Electric Power, American Physical Society - Forum on Physics & Society - https://www.aps.org/units/fps/newsletters/200901/howes.cfm)

Siemens (2011). Microgrids - www.siemens.com/download?DLA17_8

World Bank (2013). http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS

FIGURE 2.4.1 **ELECTRIC POWER TRANSMISSION AND DISTRIBUTION LOSSES (% OF OUTPUT). 2013. (DATA SOURCE: WORLD BANK 2013)**

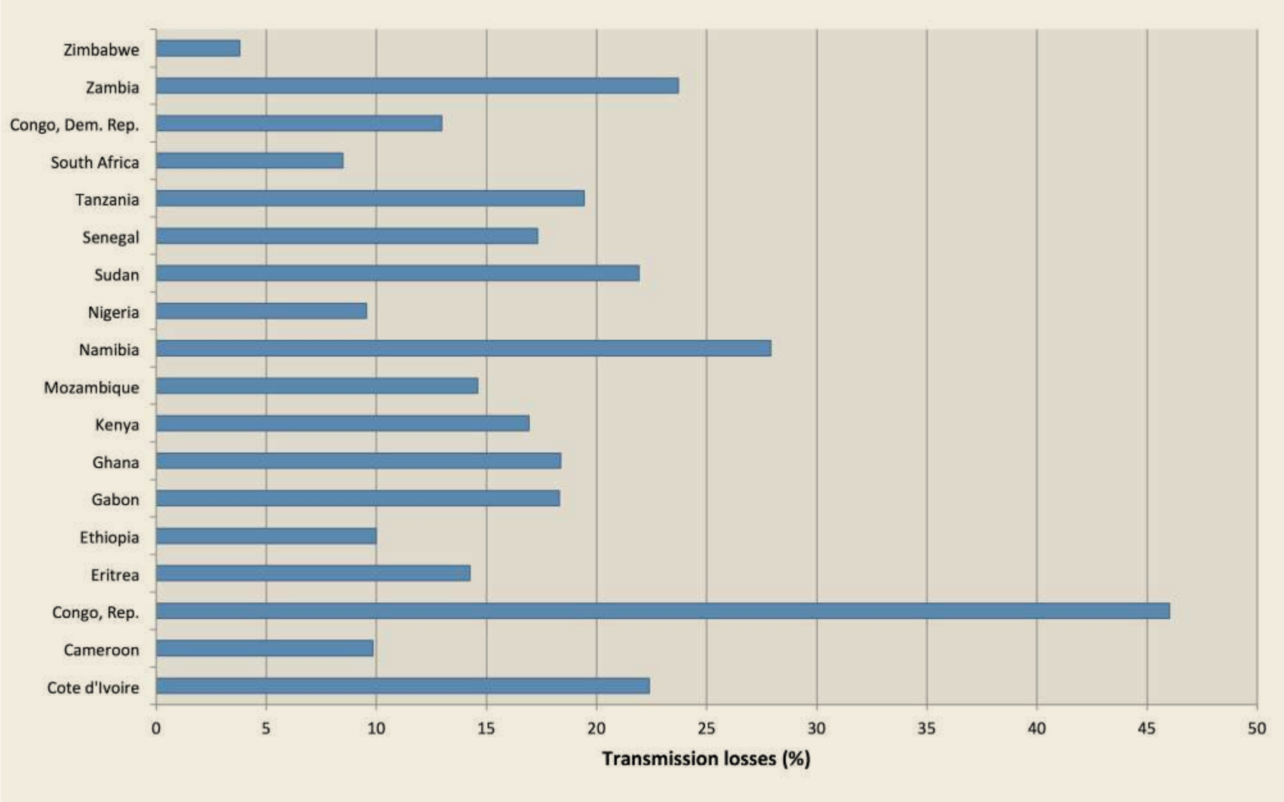


FIGURE 2.4.2 **CONCEPT OF A MINI-GRID**

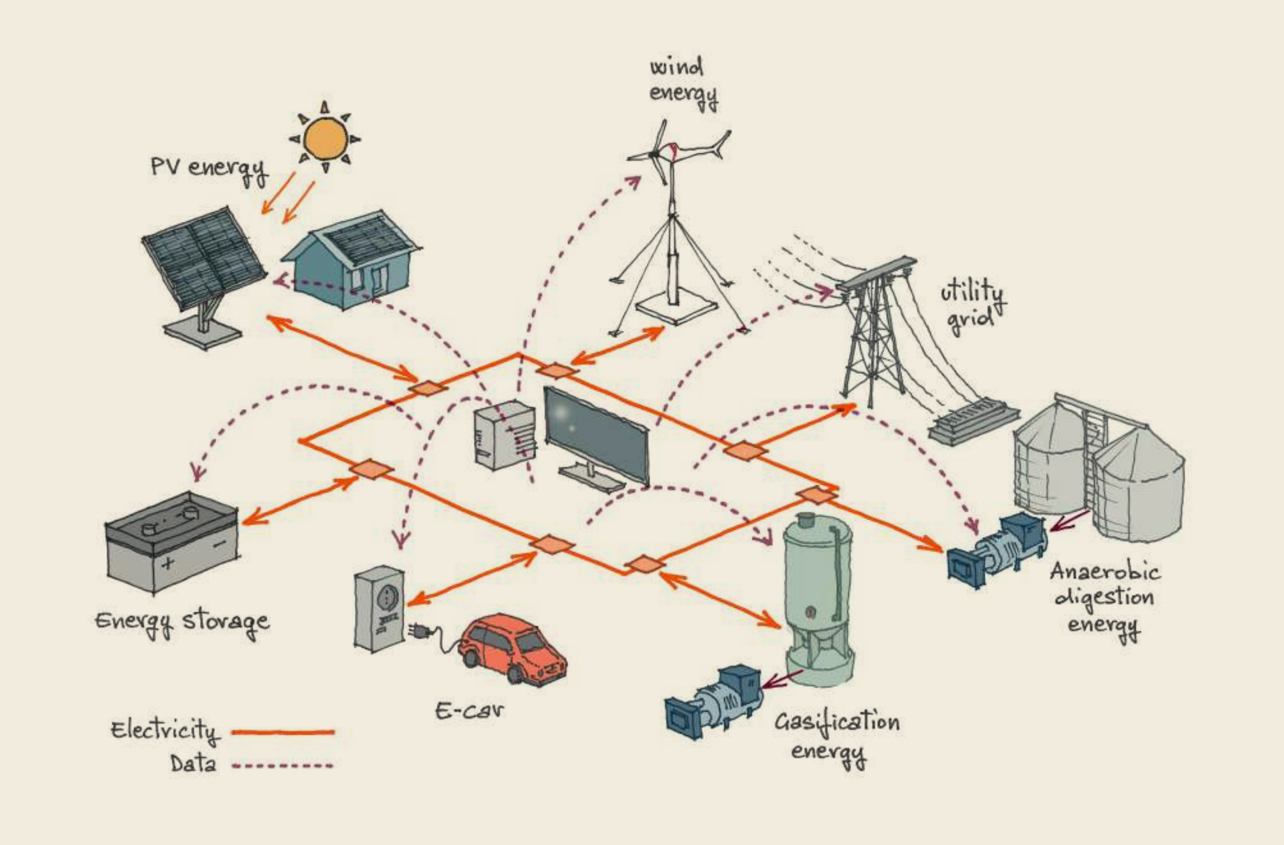
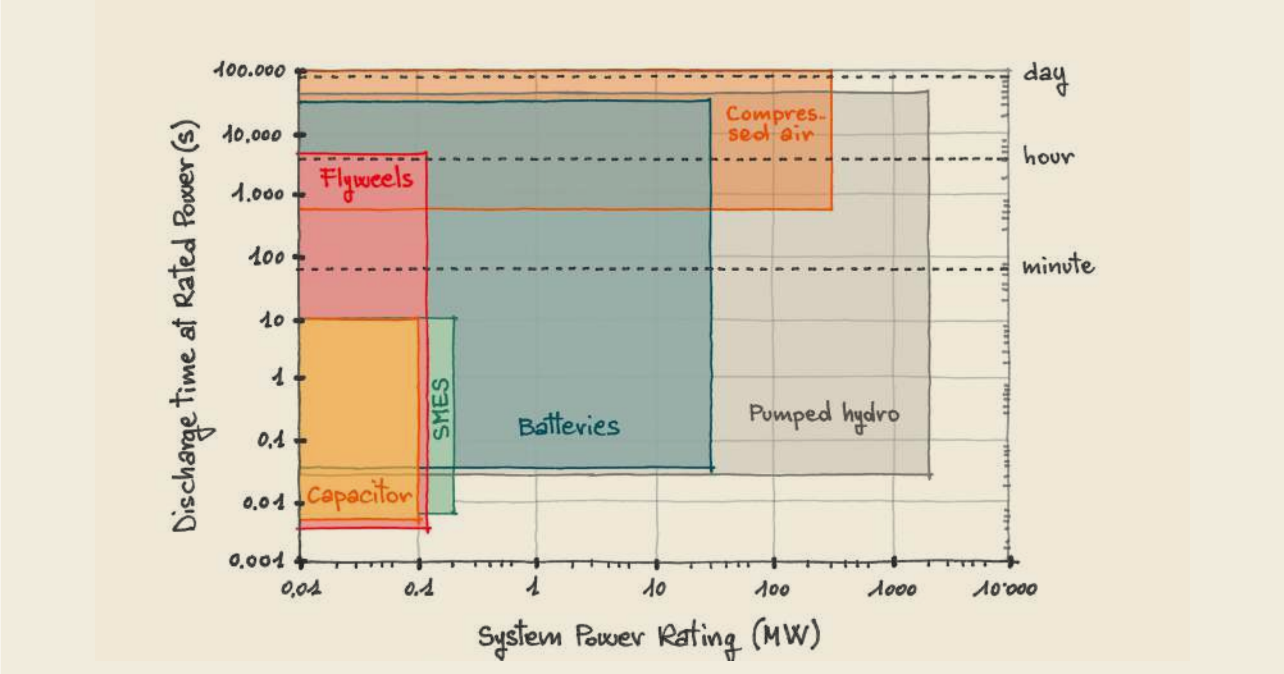


FIGURE 2.4.3 **ENERGY STORAGE COMPARISON OF DISCHARGE TIME AND POWER RATING (ADAPTED FROM: HOWES AND MTINGWA 2009)**



## 2.5 OPTIMISE THE WATER CYCLE

Urban demand for water, especially in developing and emerging economies, will grow significantly in the coming decades - driven mainly by the increasing standard of living of households.

At the same time, observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and will be greatly affected by climate change (IPCC 2008). Already, groundwater supplies are diminishing, with an estimated 20% of the world's aquifers being over-exploited (UNESCO 2015); Globally, the rate of groundwater abstraction is increasing by 1% to 2% per year (UN 2014).

The problem of water is particularly critical in many parts of SSA countries, which face severe challenges in securing sustainable and sufficient access to quality water to meet the increasing demands of a growing population and socio-economic development, while preserving the essential ecosystems on which water resources depend (GWP 2015).

Access to drinking water and sanitation services had been improving over time, but, as the demand for fresh water for domestic use has also been rapidly increasing, access has started to decline recently as a consequence of rapid urbanisation and environmental degradation: "the percentage of people who enjoy piped water on their premises ... has decreased from 42% to 34%" (UNESCO 2015).

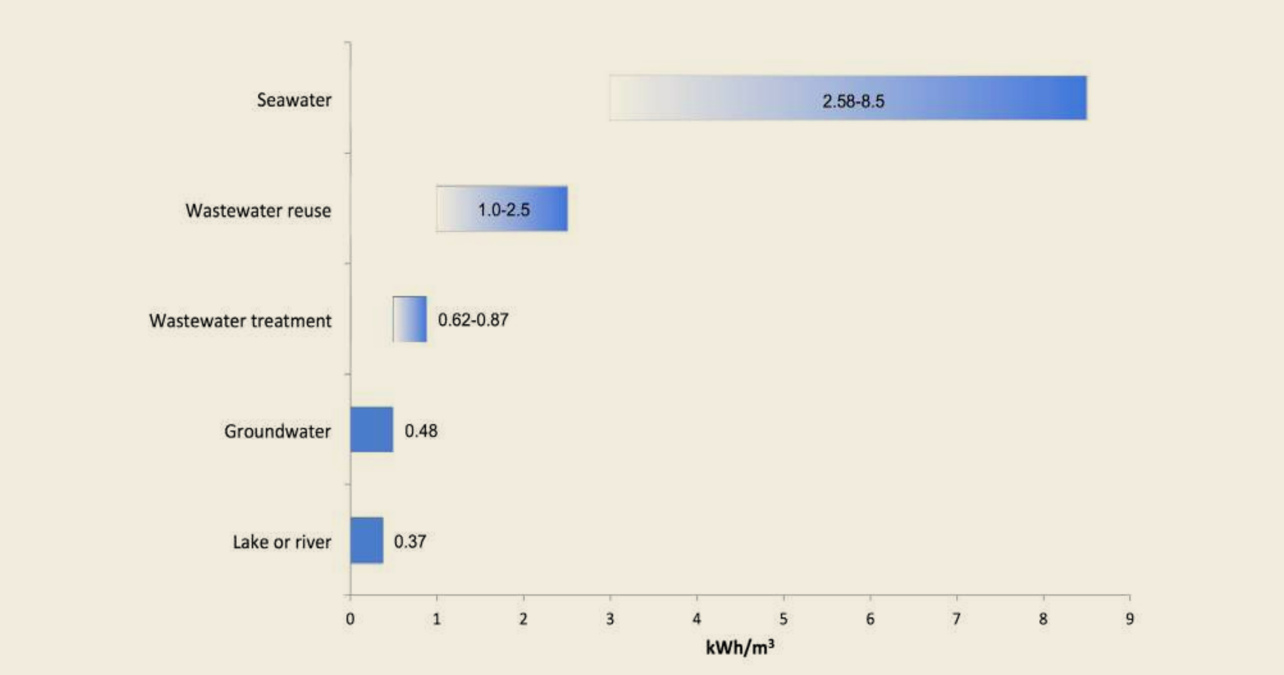
Water and energy are related. Water is used in the production of energy and energy is used in water supply, to pump, treat and distribute water (Figure 2.5.1). With a growing population, the demand for water has been rising simultaneously, requiring more and more energy. Water and energy are specially interrelated in tropical climates since vegetation improves outdoor and indoor comfort, reducing the need for mechanical cooling, and vegetation requires water.

Urban water cycle and energy systems are not only interdependent, but also show amazing similarities in both their historical development and their desirable future.

As pointed out in section 1.3, in the present urban metabolism high quality energy (fossil fuels, electricity) enters the city, is used, and low quality, degraded (thermal) energy is disposed of in the surrounding environment; similarly, high quality water (pure, clean, potable) enters the system, is used, and low quality (impure, more or less dirty, non-potable) is conveyed to a nearby large water body (sea, lake, river). It is the same process: a negentropy flow enters the city, the neighbourhood, the individual buildings, and is degraded into an entropy flow and disposed of into the environment. The water system mimics the energy system: centralised production ➔ distribution ➔ use ➔ waste (wastewater here, $CO_2$ there).

The urban water cycle, as it is nowadays, is the result of an historical transformation. Since the beginning of human urbanisation, the sources of water were rainwater collected in cisterns, nearby springs or streams and wells. The water was used and wastewater disposed of nearby. The urban water cycle was integrated into the natural one (some basic information on the natural water cycle is given in Appendix 6).

FIGURE 2.5.1 **AMOUNT OF ENERGY REQUIRED TO PROVIDE 1M$^3$ WATER SAFE FOR HUMAN CONSUMPTION FROM VARIOUS WATER SOURCES (DATA FROM UN 2014).** *Note: The diagram does not incorporate critical elements such as the distance the water is transported or the level of efficiency, which vary greatly from site to site.*



Then water distribution systems came, with aqueducts bringing clean water from a more or less far away source, and fountains, through which it was distributed to citizens; this was the ancient Romans' approach. In ancient Roman cities, underground or protected sewage and storm water collection systems were also well established (at least in the richest parts of them).

In the middle ages in Europe, there was a sort of regression, as the capability to maintain and/or improve the often grand aqueducts and the sewerage systems was lost, and the main sources were rainwater, collected in cisterns, and underground water raised from shallow wells dug in the town. Human and animal excreta were disposed of in dedicated containers, when the municipality was well managed, or (more often) in the streets.

It is worth noting that, generally speaking, the collection of human excreta was practiced in all settlements, because they had an economic value, being used to fertilise the fields around and inside the settlement. Human excreta were put back into the cycle.

It was only in the 16th century that the first urban water distribution system was set up, in London. Slowly, other European cities followed.

The time came, in the 19th century, when the level of contamination of the available water in the cities was so high that there was a continuous succession of epidemics. To prevent them, the practice of purifying and sterilising drinking water in a centralised treatment plant took place. But it was not enough. The population increase, the increased availability of water and the use of the water closet, led to a progressively unacceptable level of pollution in the rivers, the lakes and the streams into which wastewater was discharged, and from which water was taken to be distributed. It was the time in which sewage treatment plants started to be developed, in the second half of 19th century.

"At the beginning of the centralised wastewater treatment practice, the system was also conceived as a means to help farmers capture the nutrients in the sewage pouring out of rapidly growing cities; but by the end of the century the widespread availability of inexpensive synthetic fertilizers had taken away the economic incentives for sewage farming. Without a market for the nutrients, it was hard to justify doing anything other than discharging sewage directly to surface waters" (Sedlack 2014).

The present situation is still the same, a linear process: catchment of water, transport to the city, treatment to make it potable, capillary distribution to each apartment via a network, disposal of waste water through individual collection systems connected to the urban sewerage network, conveyance to a centralised wastewater treatment plant, from which two products derive: water clean enough to be acceptable for discharge into the sea, a lake or a river, and a sludge that, dehydrated, can be disposed of in a landfill or burned in an incinerator[24].

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[24] *In recent years, some municipalities use wastewater for biogas production; in some other cases water from the wastewater treatment plant is further treated to remove all the pathogen and make it suitable for irrigation.*

Conventional drainage methods usually involve transporting water as fast as possible to a drainage point, either by storm-water drainage or a sewer. If drainage is tackled with a more sustainable attitude, it is possible to benefit from on-site infiltrations. The best strategy should be to slow down the drainage and then clean it by a natural system, before discharging it to a watercourse or, better, reusing it, aiming to manage the water so that the areas' natural water balance is the same after development as it was before.

The linear approach is not only unsustainable, but also makes cities vulnerable.

When a city depends on a remote water resource, and there is a long period without rainfall in the upstream dam sites, its ability to function effectively is seriously compromised.

Global warming is going to make reduced or excessive rainfall more and more likely, with consequences not only on water availability but also on flooding, which cities will be more prone to because of their drainage systems.

Water loss, that is the total amount of water lost through leakage in distribution networks, is another problem which is exacerbated by the centralised system. A conservative estimate for this has been placed at around 35 per cent of the total water supplied. For some low-income countries this loss may be as high as 80 per cent (IPCC 2008).

Thus, the linear model being economically, environmentally and often socially unsustainable, we must instead view water as part of a circular economy, where it retains full value after each use and eventually returns to the system: a system in which water circulates in closed loops, allowing repeated use.

Most communities are struggling to handle low-quality sludge and streams of organic waste. At the same time, new sources for nutrients are being explored, as mineral fertilizer availability depends on finite resources, and, in most cases, they are environmentally harmful in the long term. If we aggregated local organic waste flows, we would help communities deal with their problem while also creating local markets for fertilizer components.

Since wastewater is the largest untapped waste category—as big as all solid-waste categories taken together—it is the natural starting point for the circular revolution (McKinsey 2015).

Like energy, water consumption in cities can be reduced if appropriate choices are made in the early stages of settlement design, through:

1. High density, mixed land use settlements, which significantly reduce water and energy consumption compared to low density land use settlements, as the latter require large amounts of water for irrigation of outdoor landscaping (and energy for transporting water and sewage over long distances);
2. The provision of infrastructure for decentralised urban water management, such as conservation of water sources, use of multiple water sources – including rainwater harvesting, storm water management and wastewater reuse – treatment of water according to end-use, rather than treatment of all water to a potable standard, and exploitation of the energy and nutrient potential of wastewater.

The new goals for the design and operation of wastewater treatment plants should: (a) achieve public health and environmental goals, (b) maximize energy and water recovery from wastewater, and (c) preserve or recover nutrients for reuse.

## 2.5.1 RAINWATER HARVESTING

Rain is the primary source of water; rivers, lakes and ground water are all secondary sources. In present times, we depend entirely on such secondary sources: it is generally forgotten that rain is the ultimate source that feeds all these secondary sources and that rainwater can be harvested.

Rainwater is a free source of nearly pure water; rainwater harvesting is the process of intercepting stormwater runoff from a surface (e.g. roof, parking area, land surface), and putting it to beneficial use (Phillips 2005). The benefits are several (UN-Habitat 2005):

- Capturing and using stormwater runoff reduces site discharge and erosion, and the potential transport of stormwater pollutants;
- Collecting and storing water within an accessible distance of its place of use greatly enhances the accessibility and convenience of water supplies;
- Raising the water levels in wells and bore holes that are drying up;
- Solving water problems in areas that have inadequate water resources;
- Reducing soil erosion as the surface runoff is reduced;
- Decreasing the blocking of storm water drains and flooding of roads;
- Saving the energy used for raising ground water.

Rainwater can be harvested from:

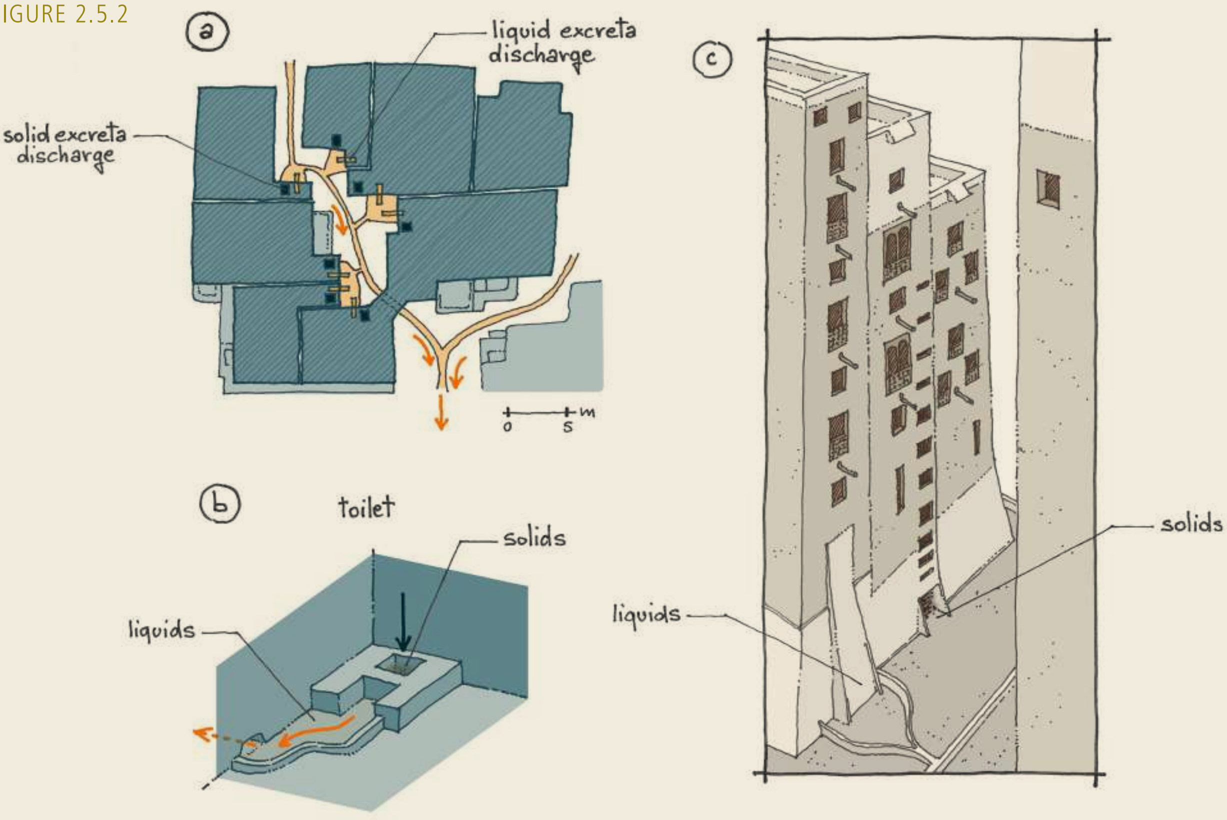
- Rooftops;
- Paved and unpaved areas, i.e. storm water drains, roads and pavements and other open areas;
- Storm water drains; if properly designed and maintained they offer a simple, cost effective means of rainwater harvesting.

Typically, a rainwater harvesting system consists of three basic elements: the collection system, the conveyance system, and the storage system; it can be both individual and community/utility operated and managed.

BOX 2.5.1 **SHIBAM**

In the ancient city of Shibam (Yemen, V°-IV° century BC) each house had lavatories which discharged waste material externally differentiating the urine from the faeces – the latter descended the outside of the house by external pipes, were collected in baskets where they quickly dried in the hot dry climate and were put to use in the fields as fertiliser. The initial division between the liquids and solids could take place thanks to the double structure of the lavatory, the front part designed to accommodate the liquids and the back part the solids. The service walls, behind which were the lavatories, all gave on to secondary or perimeter roads (Butera 2014).

FIGURE 2.5.2



### 2.5.1.1 ROOFTOP HARVESTING

The large cumulative area of roofs in a neighbourhood means that a very significant amount of rainwater can be harvested. Rainwater harvesting is an important water source at the building level, and in many cases, could provide anywhere from half to over 200% of the water needs of a building, or a city (Elmer 2011). The wide range depends on the local rainfall and on the total roof area available; this implies that there is a limit to the maximum building height, deriving from the balance between water demand and water collection[25].

Collected and stored rainwater can supplement other water sources when they become scarce or are of low quality, like brackish groundwater or polluted surface water in the rainy season. It also provides a good alternative and replacement in times of drought or when the water table falls and wells go dry.

The main components of a simple roof water collection system are the collection surface, the gutters, the pipes from the cistern and the cistern itself, plus some additional components, such as the first flush device[26], water treatment devices, a pump, etc., and filtration device in cases where the collected water is used for well or groundwater recharge, as shown in Figure 2.5.3.

Water treatment usually includes filters to remove solids and organic material, and additives to settle, filter, and disinfect.

It is generally believed that rainwater can provide clean, safe and reliable water that can be consumed without pre-treatment. This may be true in areas that are relatively unpolluted. Rainwater collected in many locations, however, contains impurities. Once rain comes into contact with a roof or collection surface, it can wash many types of bacteria and other contaminants into the cistern or storage tank. If rainwater is for potable use, it needs to be treated (Figure 2.5.4).

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[25] *High-rise residential buildings provide a small roof area/water demand ratio, so that the amount harvested is insufficient to meet the demand. The same happens with solar energy, whose annual availability per square metre depends on local climate: if all the electricity needs of the building have to be fulfilled by a PV system in the roof, there is a height limit (see Appendix 5).*

[26] *The first flush device is a first rain separator to divert and discard and manage the first 2.5 mm of rain, to prevent contaminants and debris reaching the cistern.*

FIGURE 2.5.3 **ROOFTOP RAINWATER HARVESTING SYSTEM**

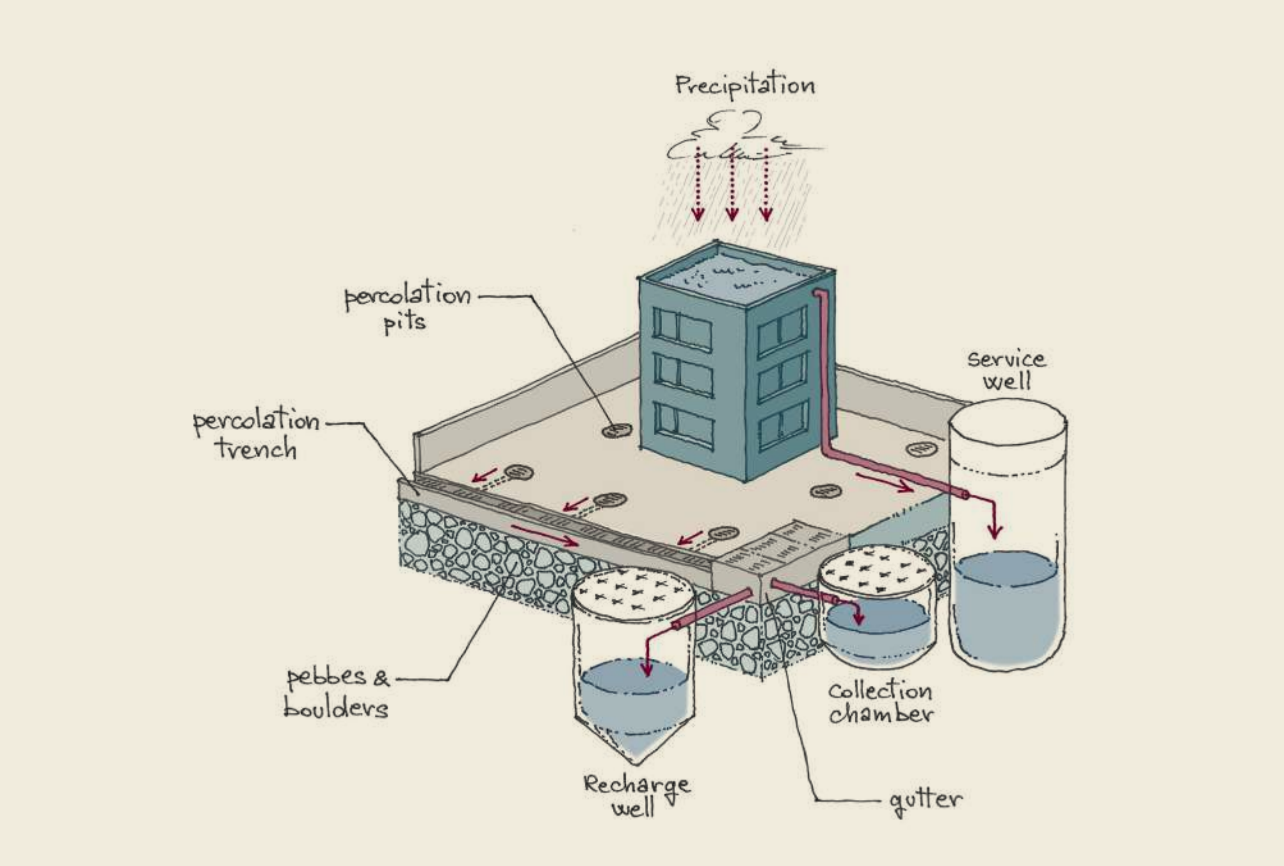
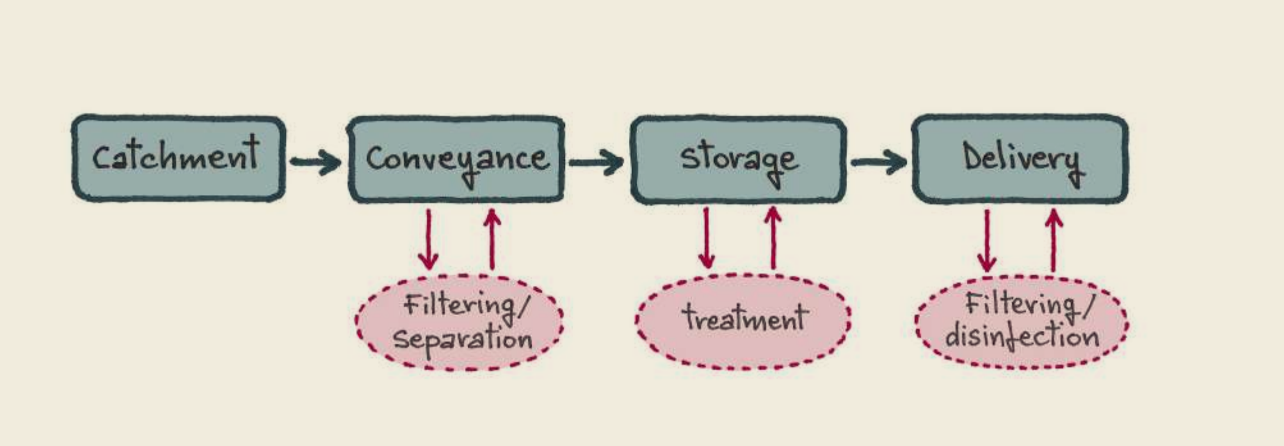


FIGURE 2.5.4 **RAINWATER HARVESTING: PROCESS DIAGRAM FOR DRINKING WATER**



There are many well established techniques and devices for making rainwater potable, both at individual household and neighbourhood scale.

At neighbourhood scale a rooftop rainwater collection system with a single large common storage tank should be considered by the urban designer, as it should be part of the neighbourhood infrastructure, as well as a filtering/ disinfection system for making rainwater potable. The advantages could be in the lower cost of storage and maintenance and in the possibility of obtaining safer water quality, as skilled operators can manage the water treatment system. Of course, the space necessary and the location of the large volume storage tank has to be integrated into the neighbourhood design.

Three options can be followed:

1. Rainwater collected is stored for direct use; excess water, if any, is diverted from the storage tank and is lost;
2. Rainwater collected is stored for direct use; excess water, if any, is diverted to a recharge system to improve the quality of ground water and raise the water levels in wells and bore wells;
3. Rainwater collected is all used for underground water recharge.

Options b) and c) are especially important if the water system of the neighbourhood is decentralised, and relies heavily on groundwater rather than on a municipal potable water network. The aquifer, in this way, becomes large additional storage.

The decision whether to store or recharge (or both) water depends on the local rainfall patterns and on the characteristics of the underground water system.

The possibility of supplying new developments only with potable water obtained by the appropriate treatment of collected and stored rainfall and of underground water should be always considered, and the cost, reliability and resilience of such a decentralised system should be carefully compared with that of a conventional connection to the main potable water network.

It should be also considered that the advantage of collecting and using rainwater during the rainy season is not only to save water from conventional sources, but also to save the energy expended on transportation and distribution of water at the doorstep.

In any case, even if the comparison leads to the designer choosing connection to the main urban water network, rainwater should be considered for non-potable uses, so reducing the flow of potable water that needs to be provided to the settlement, with the consequent economic benefits deriving from smaller piping, and the fact that, for non-potable uses, treatment requirements can be less stringent or not required at all.

### 2.5.1.2 SCALE OF WATER HARVESTING

Most of the methods above described are applicable to a single building, a group of buildings or a neighbourhood, as illustrated in Figure 2.5.5, where – as a possible design choice - the runoff from individual houses is dealt with at the building-level itself, while remaining runoff from the storm water drain (which drains water from roads and open areas) is harvested at neighbourhood level.

The current, linear, urban water supply catchments are typically far from the urban area they serve, but with this approach the city itself can be seen as a catchment for its water requirements. Rooftops, paved areas and unpaved areas and the entire city itself is, therefore, to be managed as an area of water provision.

### 2.5.1.3 OTHER CATCHMENT SURFACES (STORM WATER)

Runoff is that component of rainwater which flows over a surface and out of the catchment area: it is generated when the intensity of the rainfall reaching the ground exceeds the infiltration rate of a soil, and after surface puddles, ditches and other depressions have been filled (Hatibu and Mahoo 2000).

Runoff in rural areas or in parks is a very limited part of the rainfall, as the infiltration rate is high; the opposite occurs in urbanised contexts, due to the large extent of impervious surfaces (Figure 2.5.6).

FIGURE 2.5.5 **EXAMPLE OF RAINWATER HARVESTING**

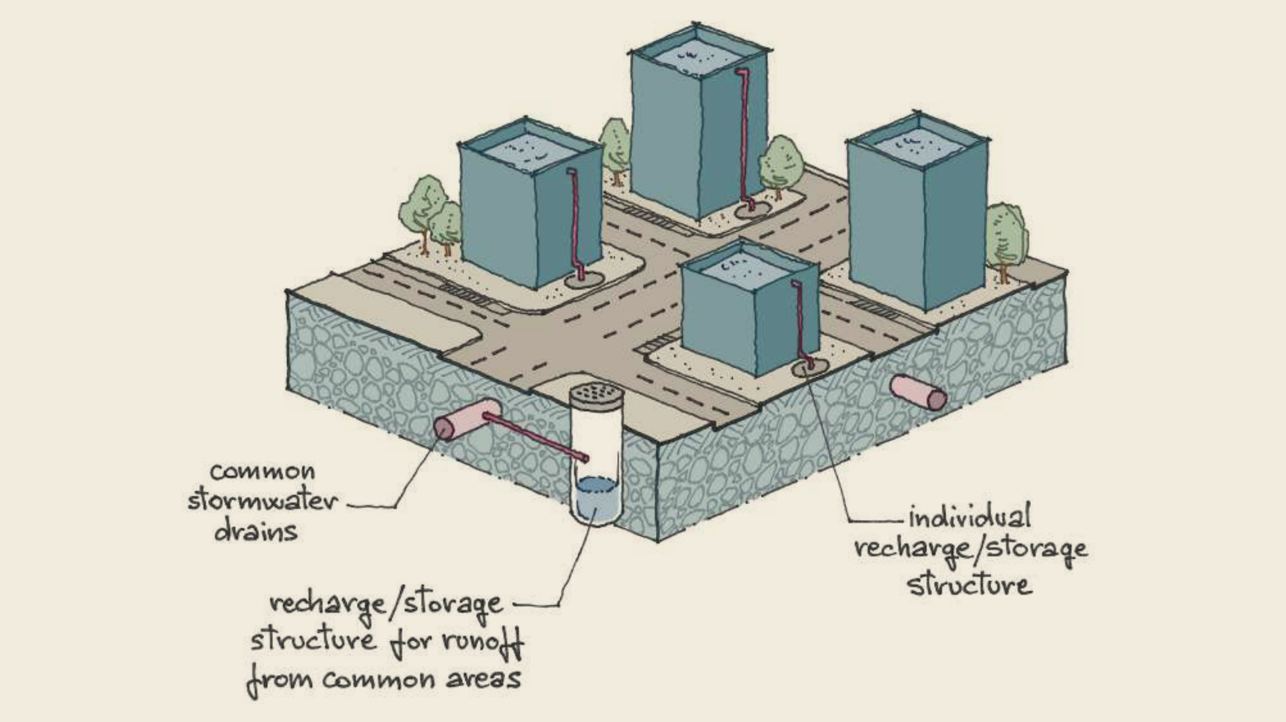


FIGURE 2.5.6 **RUNOFF PERCENTAGE IN RURAL (LEFT) AND URBAN (RIGHT) CONTEXT. THE VALUES ARE INDICATIVE AND REPRESENT THE OPPOSITE EXTREMES.**

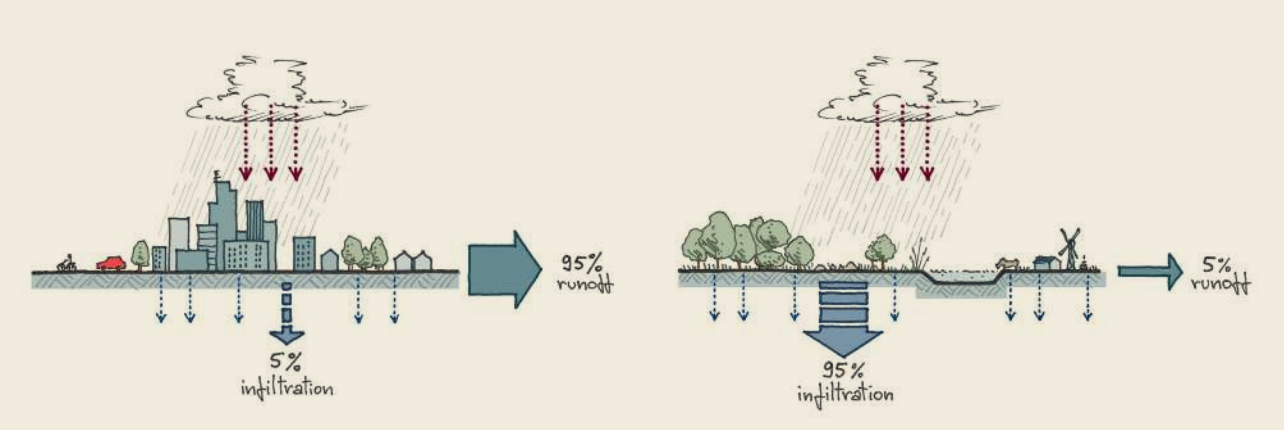
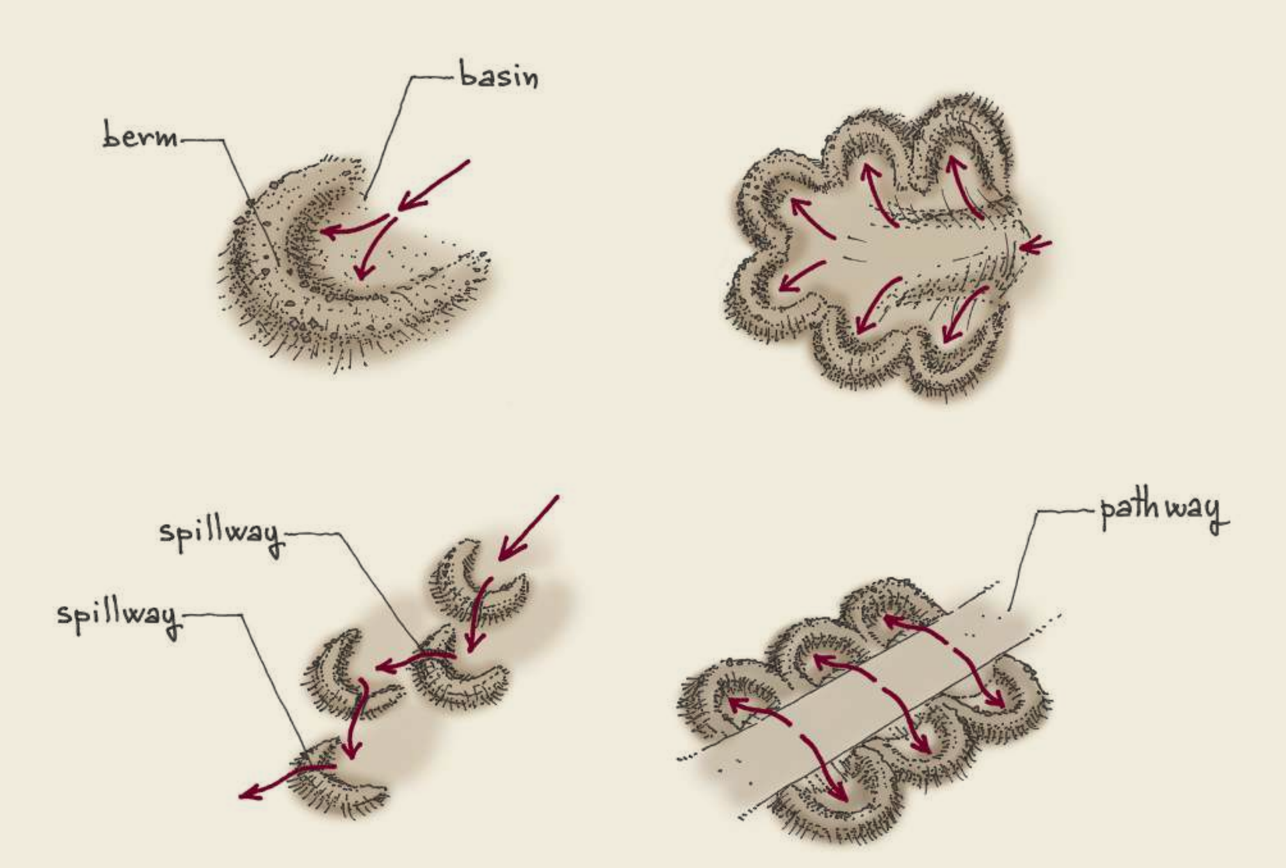


FIGURE 2.5.7 **SKETCH OF A MICROBASIN AND ITS VARIATIONS**



Usually, stormwater conveyance systems are designed to convey the rainwater that falls in the catchment areas to the nearest storm water drain or to the sewerage system. In order to reuse this water later on and to avoid overloading the sewerage system, collected rainwater should instead be directed to a recharge structure, to restore aquifer extraction potential.

Rainwater harvested from catchment surfaces along the ground[27], if stored in cisterns instead of being used for recharging the aquifer, should be directly used only for non-potable uses, because of the risk of bacteriological and chemical contamination.

Cisterns holding water harvested from adjacent public sites could be incorporated into streetscape design, as could earth-formed stormwater basins and catchment techniques.

Intercepted stormwater can be collected, slowed down, and retained or routed through the site's landscape using micro basins, swales and other water harvesting structures.

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[27] *They can be paved areas like streets, pavements, terraces or courtyards, or an unpaved area like a lawn or open ground.*

FIGURE 2.5.8 **SWALES ON-CONTOUR AND VARIATIONS**

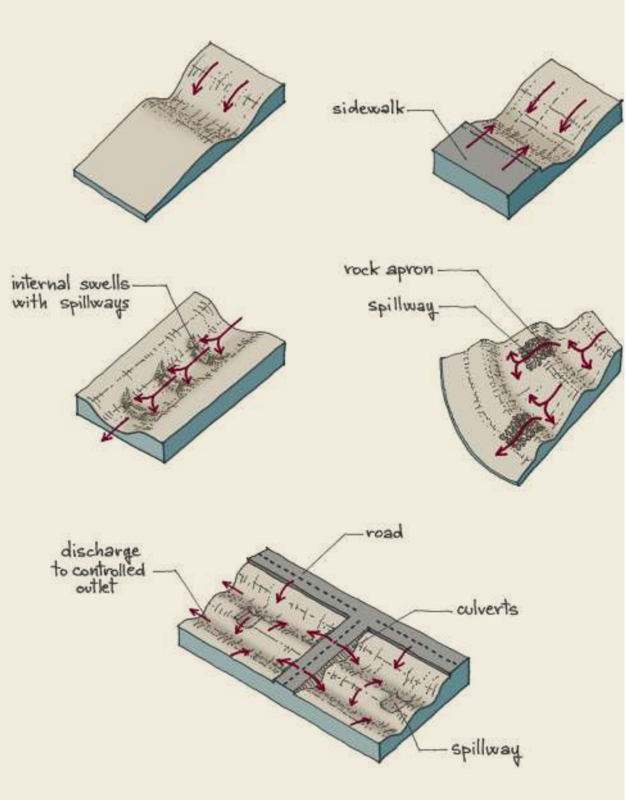
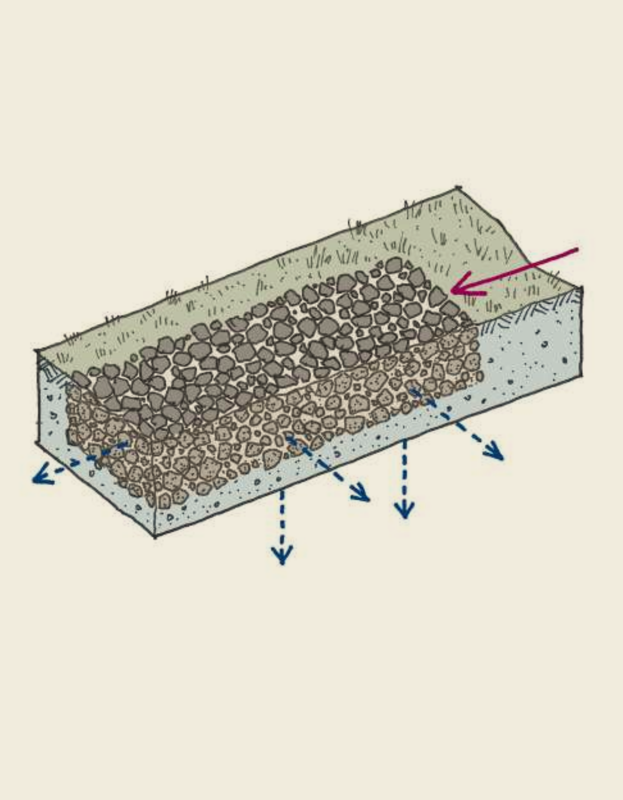


FIGURE 2.5.9 **FRENCH DRAINS**



Capturing and using stormwater runoff also reduces site discharge and erosion.

There are many ways to intercept and control rainwater runoff, according to the City of Tucson Water Harvesting Guidance Manual (Phillips 2005):

1. ***Create multiple small watersheds***[28] by dividing the site into small watersheds based on existing topography, or reshaping as necessary, to maximize stormwater harvesting; as more stormwater infiltrates into the soil, less stormwater has to be managed as surface runoff.
2. ***Prepare for overflow.*** Water harvesting structures need to allow excess stormwater to overflow safely to other locations where it will be used beneficially. Overflow devices (tank overflow pipes, spillways, etc.) should be sized to safely handle large rainfall events. Several types of watersheds can be used: micro basins (Figure 2.5.7), swales (Figure 2.5.8), French drains (Figure 2.5.9), in many variations.
3. ***Mulch to reduce evaporation.*** Mulching soil by adding a thick layer of organic or inorganic material reduces evaporation of water from, and retains moisture in, the soil to support plants. All water harvesting swales and basins should be mulched to substantially reduce water loss through evaporation, especially in hot arid and semi-arid climates.
4. ***Put harvested water to beneficial use. Harvested*** stormwater is much lower in salts and higher in nitrogen than groundwater, which benefits plants. Stormwater stored in well-mulched soil supports plants during and after the rainy season; stormwater stored in tanks is typically available beyond the rainy season.

## 2.5.1.4 SPONGE CITIES

A Sponge City refers to a city whose urban underground water system operates like a sponge to absorb, store, leak and purify rainwater, and then releases it for reuse and/or for recharging precious groundwater for human consumption and food production (Figure 2.5.10).

A sponge city, or a sponge neighbourhood, is designed in such a way as to make sustainable urban drainage systems possible. The aim of sustainable urban drainage systems is to relieve the load on the sewer system, reuse/recycle stormwater water as a contribution to the closure of the urban water cycle, with the added advantage of reducing the risk of floods and water damage. Sustainable urban drainage systems include:

- systems for the collection of stormwater from roofs;
- green roofs that can delay stormwater reaching the sewer;

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*[28] The term watershed is commonly used to describe an area within which all stormwater drains towards a common collection point.*

- porous paving systems (Figure 2.5.11) that can accommodate average vehicular and pedestrian traffic while allowing water to percolate and recharge the groundwater; and green spaces that contribute to stormwater infiltration, instead of its being conducted to the sewer system;
- swales – ditches filled with native plants that naturally collect and filter rainwater along each sidewalk or within roadways to detain run-off (Figure 2.5.12); water can then either be allowed to seep into the soil to replenish the groundwater or be collected in underground cisterns;
- soils adjacent to roads and sidewalks used to cleanse and reduce the volume of stormwater entering the roadway and storm drains (Figure 2.5.13);
- roadway intersection geometrics changing traditionally large impervious paved areas to pervious green spaces that soak up water like a sponge;
- runoff catchment basins.

The principles of sustainable urban drainage systems are included in the Copenhagen climate adaptation plan (Copenhagen 2011) and in the "Sponge City" construction guidelines of the Chinese government (CCTV 2015). The concept of a sponge city is quite similar to the United States' Low Impact Development (LID) (USEPA n.d.), the United Kingdom's Sustainable Drainage Systems (SuDS) (NetRegs n.d) and Australia's Water Sensitive Urban Design (WSUD) (WSUD n.d.).

## 2.5.2 RECHARGING GROUND WATER AQUIFERS

Aquifer recharging plays an important role in a neighbourhood's water security and increases a neighbourhood's resilience. Aquifers, in fact, act as large water storage systems that, in the case of dry periods or in the case of failure or unreliability of the municipal network, can provide water. In normal conditions a well-managed aquifer can permanently supplement the harvested rainwater flow.

Three important components, which need to be evaluated when designing the rainwater recharging structure, are:

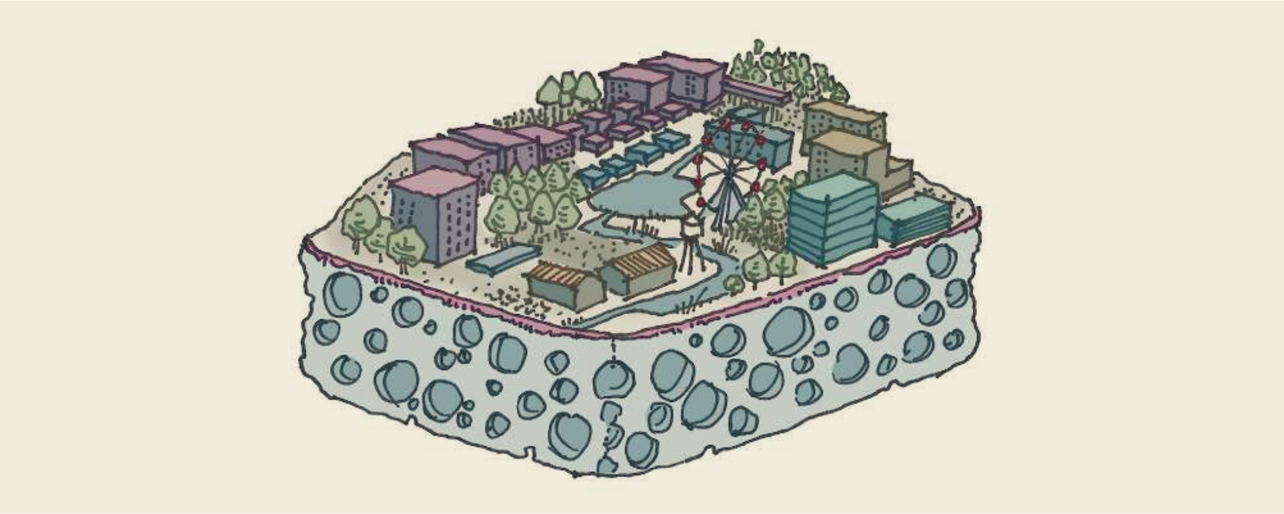
- Hydrogeology of the area including nature and extent of aquifer, depth to water levels and chemical quality of ground water;
- Area contributing to runoff, i.e. the size of the area, the land use patterns, whether industrial, residential or green belt, and water retention capability of the catchments;
- Hydrometeorological characteristics, i.e. duration, general pattern and intensity of rainfall.

Commonly used recharging methods are:

- Recharging of bore and dug wells;
- Recharge pits;
- Recharge trenches.

Recharging through recharge trenches and recharge pits is simpler than recharging through wells. Fewer precautions have to be taken to maintain the quality of the rainfall runoff. For these types of structures, there is no restriction on the type of catchment from which water is to be harvested, i.e., both paved and unpaved catchments can be tapped.

FIGURE 2.5.10 **CONCEPT OF SPONGE CITY**



### 2.5.2.1 BORE WELLS AND DUG WELLS

Rainwater collected in the catchment should not be heavily polluted (as would happen in some industrial areas) and, in any case, needs to be pre-treated in some way before it is allowed to reach the aquifer. The best rainwater to use is collected from roofs, as rainwater collected from ground level paved surfaces may be too polluted.

Figure 2.5.14 shows typical systems of recharging wells directly with rooftop runoff. Rainwater is collected from the rooftop of the building and diverted by drainpipes to a settlement or filtration tank, from which it flows into the recharge well (bore well or dug well).

### 2.5.2.2 PERCOLATION PITS

Percolation pits are designed to let rainwater enter in the aquifer directly (Figure 2.5.15); they are generally not more than 60 x 60 x 60 cm, designed on the basis of expected runoff. They are filled with pebbles or brick jelly and river sand and are covered with perforated concrete slabs wherever necessary.

### RECHARGE TRENCHES

A recharge trench is a trench excavated in the ground and refilled with a porous medium such as pebbles, boulders or brickbats (Figure 2.5.16). It is usually designed to harvest the surface runoff. Bore wells can also be provided inside the trench as recharge shafts to enhance percolation. This method is suitable for playgrounds, parks and roadside drains.

The trench may be 0.5 to 1 m. wide, 1 to 1.5 m. deep and 10 to 20 m. long depending upon the amount of runoff expected.

FIGURE 2.5.11 **POROUS PAVING SYSTEMS**

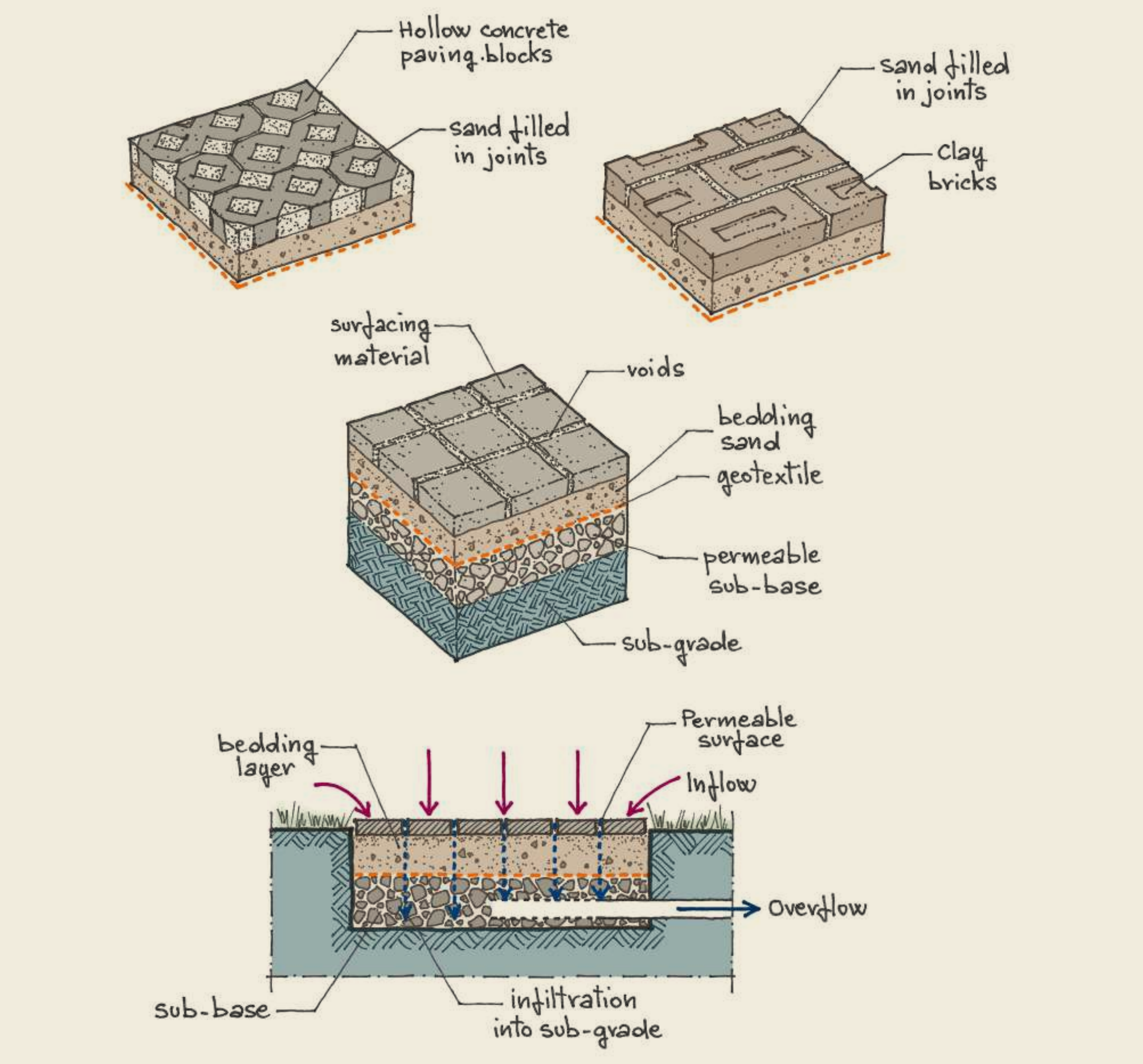


FIGURE 2.5.12 **SWALES. THEY ALSO ACT TO TEMPORARILY STORE AND INFILTRATE THE RUN-OFF INTO THE GROUND. SEDIMENTS ARE REMOVED FROM THE WATER, AND VEGETATION CAN TAKE UP ANY NUTRIENTS IN THE WATER.**

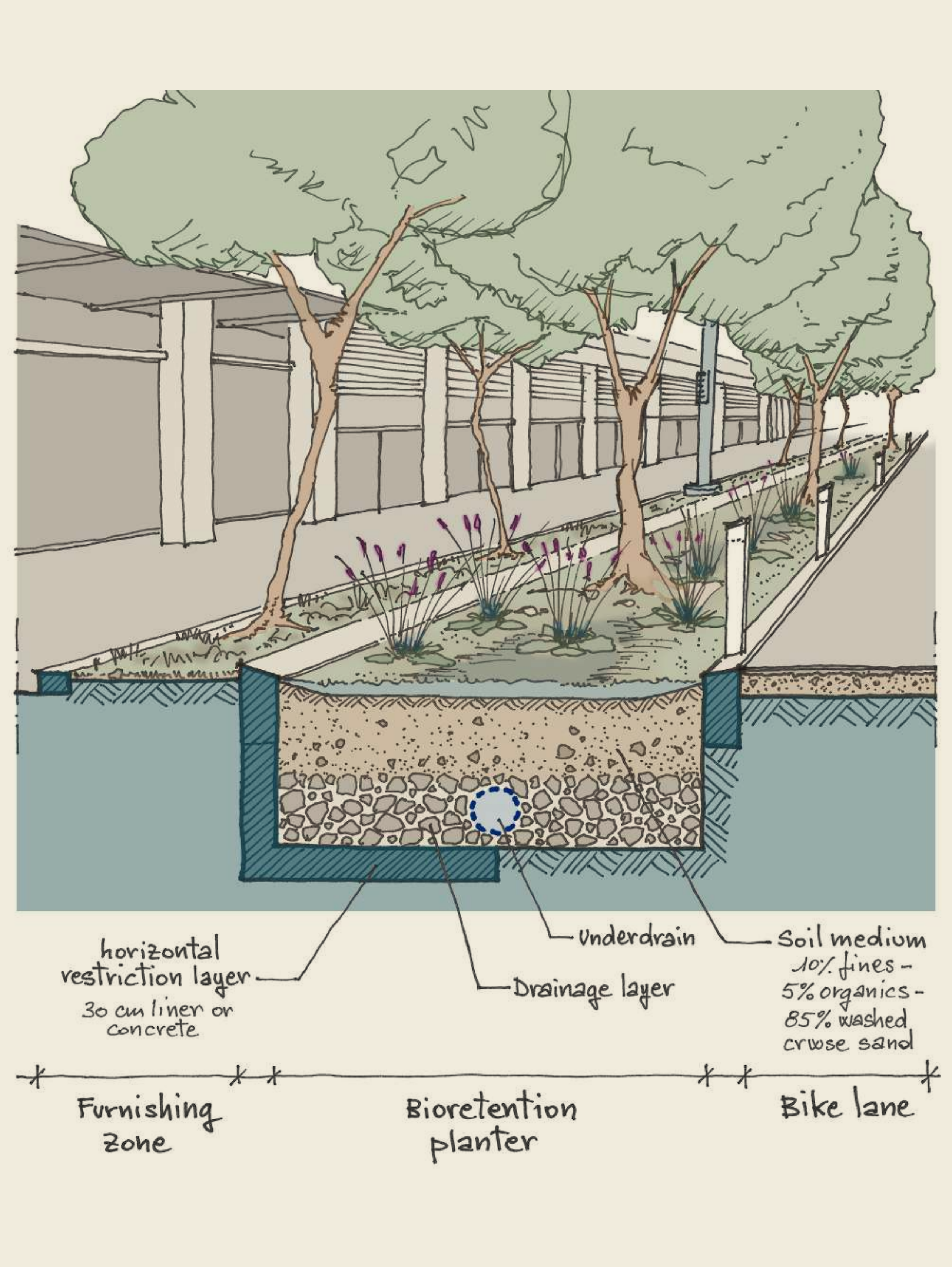


FIGURE 2.5.13 **SOILS ADJACENT TO THE ROADS (ADAPTED FROM: PHILLIPS 2005)**

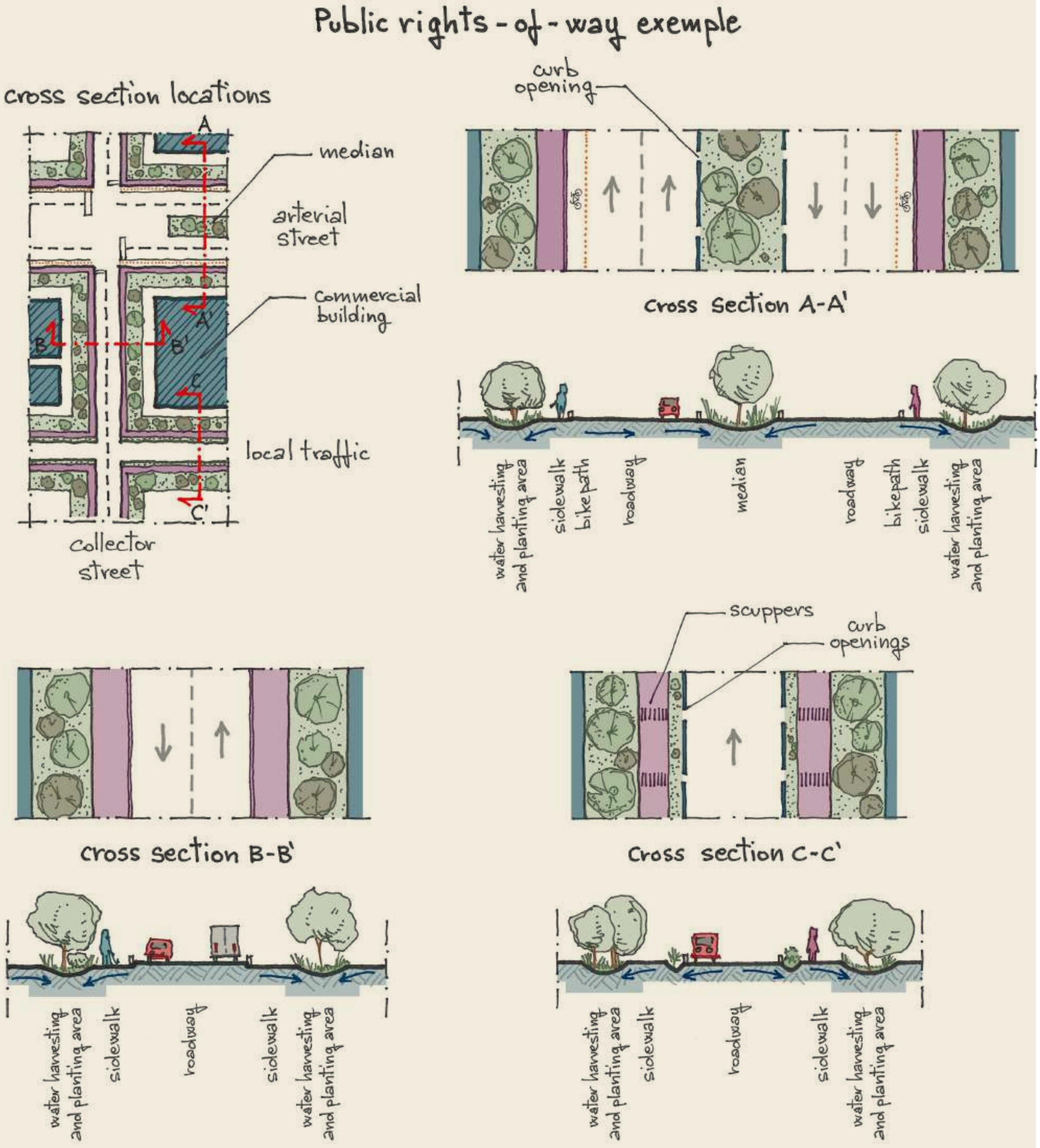


FIGURE 2.5.14 **BORE WELL AND DUG WELL RECHARGE WITH ROOFTOP RUNOFF**

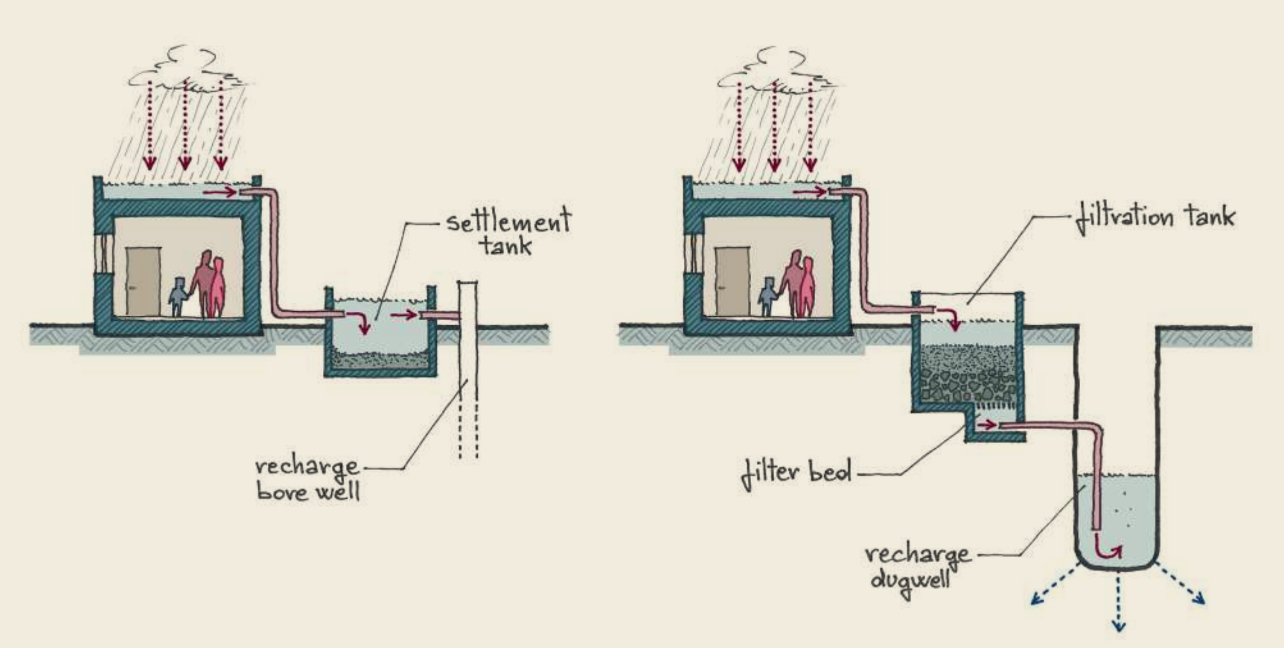


FIGURE 2.5.15 **SKETCH OF A RECHARGE PIT**

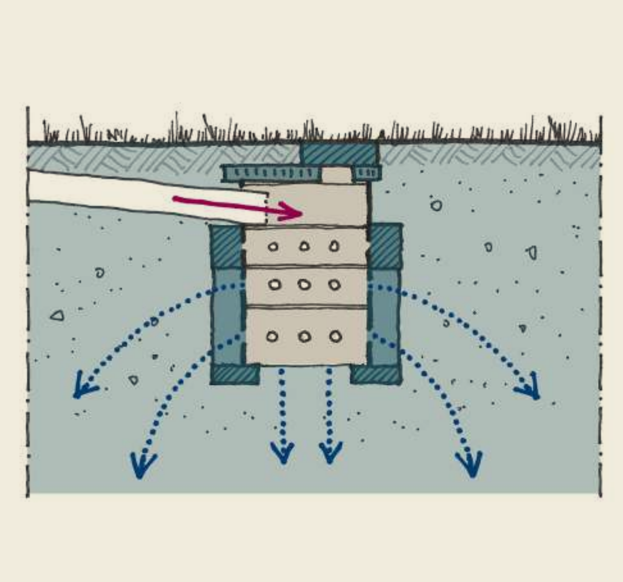
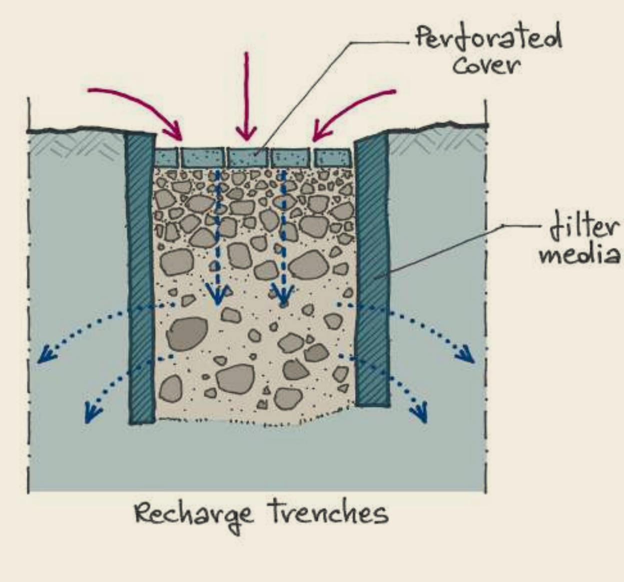


FIGURE 2.5.16 **SECTION OF A RECHARGE TRENCH**



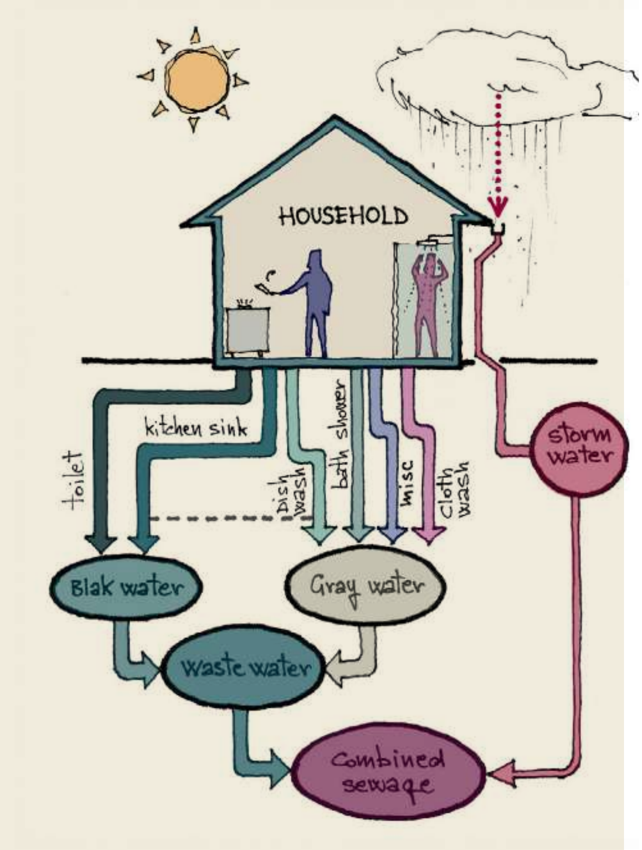
## 2.5.3 DECENTRALISED WASTEWATER MANAGEMENT

Wastewater produced by households is usually subdivided into black water, grey water and storm water (Figure 2.5.17). Black water is the wastewater from the toilet and the kitchen sink; grey-water consists of the wastewater from washing/bathing and the washing of clothes.

Grey water is of far higher quality than black water because of its low level of contamination and higher potential for reuse. When grey water is reused, either on-site or nearby, it has the potential to reduce the demand for new water supply, reduce the energy and carbon footprint of water services, and meet a wide range of social and economic needs. In particular, the reuse of grey water can help reduce demand for more costly high-quality potable water.

In spite of its potential usefulness, because of the way the sewerage systems were - and still usually are - designed, all the wastewater produced by households, commercial buildings, industrial buildings (if water is not contaminated and does not need a special treatment) and generally also the rainwater runoff, is collected and conveyed to a single large treatment plant. This implies an extensive network converging all the flow into a necessarily large and off-site plant, to keep it far from the inhabited areas.

FIGURE 2.5.17 **SOURCES OF HOUSEHOLD WASTEWATER**



Wastewater treatment plants are based on a biological process. The treatment can be carried out either in the presence of oxygen (aerobic system) or in its absence (anaerobic system). At the end of the process we have a flow of clean water and a flow of sludge plus, in the case of the anaerobic system, a flow of biogas (see section 2.4 and Appendix 5).

In a conventional large-scale aerobic system, wastewater is pre-treated (screening and settling), passes to the activated sludge chamber, is then post-settled in a secondary clarifier, and finally disinfected if required; treated wastewater is either conveyed to a water body, or used for agriculture, industrial or domestic (non-potable) reuse; the sludge can be treated in different ways, according to its final use (Figure 2.5.18). The process is highly mechanised and thus mainly adapted for centralised systems where energy, mechanical spare parts and skilled labour are available. In some plants the sludge, before further treatment, is sent to an anaerobic digester where biogas is produced.

The benefits of anaerobic digestion of sewage sludge are widely recognised and the technology is well established in many countries. Today, a high proportion of biogas produced in biogas plants is from those on municipal wastewater treatment sites (see Table 4.5.1).

### 2.5.3.1 DEWATS

DEWATS (Decentralised Wastewater Treatment System) is a modular system approach to ensure efficient performance in wastewater treatment. It is a different, decentralised approach, suitable at neighbourhood scale, that allows the on-site closure of the water cycle. In addition, it is an approach that does not necessarily have highly skilled manpower and maintenance requirements (but has high quality standards in planning and construction) and its energy demand is far less than conventional treatment systems. It provides treatment for wastewater flows from 1 m$^3$ to 1000 m$^3$ per day and unit (WEDC 2010).

DEWATS is not just a technical hardware package, but an approach, as besides technical and engineering aspects it also takes into consideration the specific local economic and social situation, and it can be seen as complementary to other centralised and decentralised wastewater-treatment options.

Typical DEWATS applications suitable for wastewater treatment at neighbourhood scale are based on three basic technical treatment modules, which are combined according to demand (Figure 2.5.19):

- primary treatment in septic tanks, Imhoff tanks, or bio-digesters;
- secondary anaerobic treatment in baffled reactors (baffled septic tanks) and fixed-bed filters;
- tertiary aerobic treatment in sub-surface flow filters constructed wetlands (horizontal gravel filters).

A post-treatment in aerobic polishing ponds may be considered according to the final conditions of effluents and their intended use.

Some more detailed information about the components of a DEWATS system is provided in Appendix 6.

Depending on the total volume and the nature of the wastewater and its temperature, the values given in Table 4.5.2 may indicate permanent area requirements for setting up a treatment plant (WEDC 2010):

For decentralised wastewater treatment in a new neighbourhood two basic options can be considered:

1. primary, secondary and tertiary filtration and disinfection treatments take place in decentralised plants, to which untreated wastewater from households is conveyed, via a sewer line. The advantage of such a system is the relatively low cost (only the sewerage system). The disadvantage is that piping must be large enough to prevent clogging, to which the system is prone anyway;
2. primary treatment takes place in on-site, septic tanks, fully mixed digesters or Imhoff tanks, servicing an individual building or group of buildings; wastewater is then discharged into a sewer leading to a common plant for the secondary and tertiary filtration and

disinfection treatment. The advantage of such a system is that diameter of piping can be smaller without clogging problems, as the wastewater does not carry solids, being already settled in the tank. The disadvantage is the higher cost.

The selection of appropriate technical configuration of a DEWATS depends on the:

- volume of wastewater;
- quality of wastewater;
- local temperature;
- underground conditions;
- land availability;
- costs;
- legal effluent requirements;
- cultural acceptance and social conditions;
- final handling of the effluent (discharge or reuse).

The urban designer should make allowance for the land area requirements and the position of components in the neighbourhood, working closely with wastewater treatment experts, who can also advise on different, conventional or technologically advanced systems for decentralised wastewater treatment. They are available, but are more expensive than DEWATS, require more skilled manpower for running them, and consume energy. Among these, some advanced and sustainable systems have been developed, such as the Advanced Ecologically Engineered System (AEES), also known as the Living Machine.

FIG. 2.5.18 **SCHEMATIC DIAGRAM OF AN ACTIVATED SLUDGE WASTEWATER TREATMENT PROCESS (ADAPTED FROM ANBP 2016)**

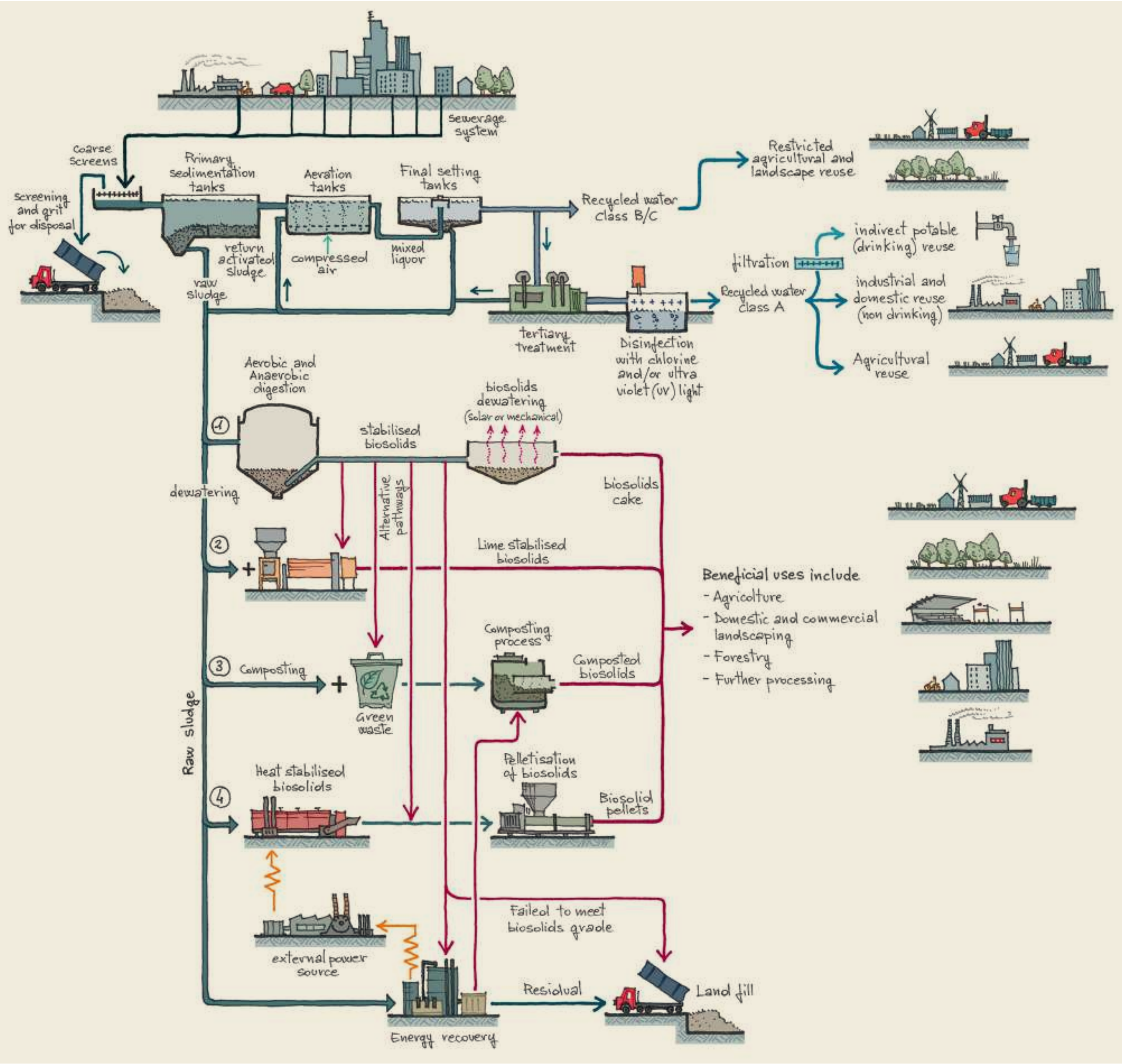


TABLE 4.5.1 **BIOGAS PRODUCTION FROM SEWAGE SLUDGE IN SOME OECD COUNTRIES (BACHMANN 2005)**

| Country | Year | Biogas production (GWh/y) |
|---|---|---|
| Brazil | 2014 | 42[3] |
| Denmark | 2012 | 250[1] |
| Finland | 2013 | 126[2] |
| France | 2012 | 97[3] |
| Germany | 2014 | 3,050[2] |
| Norway | 2010 | 164[1] |
| South Korea | 2013 | 969[1] |
| Sweden | 2013 | 672[1] |
| Switzerland | 2012 | 550[1] |
| Netherlands | 2013 | 711[1] |
| United Kingdom | 2013 | 761[1] |

[1] Energy generated as gross gas production

[2] Energy generated as electricity, heat, vehicle fuel or flared (excluding efficiency losses)

[3] Electricity generation only (excluding efficiency losses)

TABLE 4.5.2 **PERMANENT AREA REQUIREMENTS FOR SETTING UP A TREATMENT PLANT**

| | |
|---|---|
| Septic tank, Imhoff tank | 0.5 $m^2/m^3$ daily flow |
| Anaerobic baffled reactor, anaerobic filter | 1.0 $m^2/m^3$ daily flow |
| Subsurface Horizontal Flow Constructed Wetland | 30 $m^2/m^3$ daily flow |
| Polishing pond | 25 $m^2/m^3$ daily flow |

### 2.5.3.2. ADVANCED ECOLOGICALLY ENGINEERED SYSTEM (AEES), OR LIVING MACHINE®

The Living Machine® is an emerging wastewater treatment technology that utilizes a series of tanks which support vegetation and a variety of other organisms.

A typical AEES comprises six principle treatment components, after influent screening. In process order (see Figure 2.5.21), these are an anaerobic reactor, an anoxic tank, a closed aerobic reactor, open aerobic reactors, a clarifier, and ecological fluidized beds, or constructed wetlands. While the open aerobic reactors and constructed wetlands are found in almost all AEESs, the other components are not always utilized in the treatment process. The specific components used are selected by the designers depending upon the characteristics of the wastewater to be treated and the treatment objectives. Sometimes additional process components may be added if considered necessary by the designers.

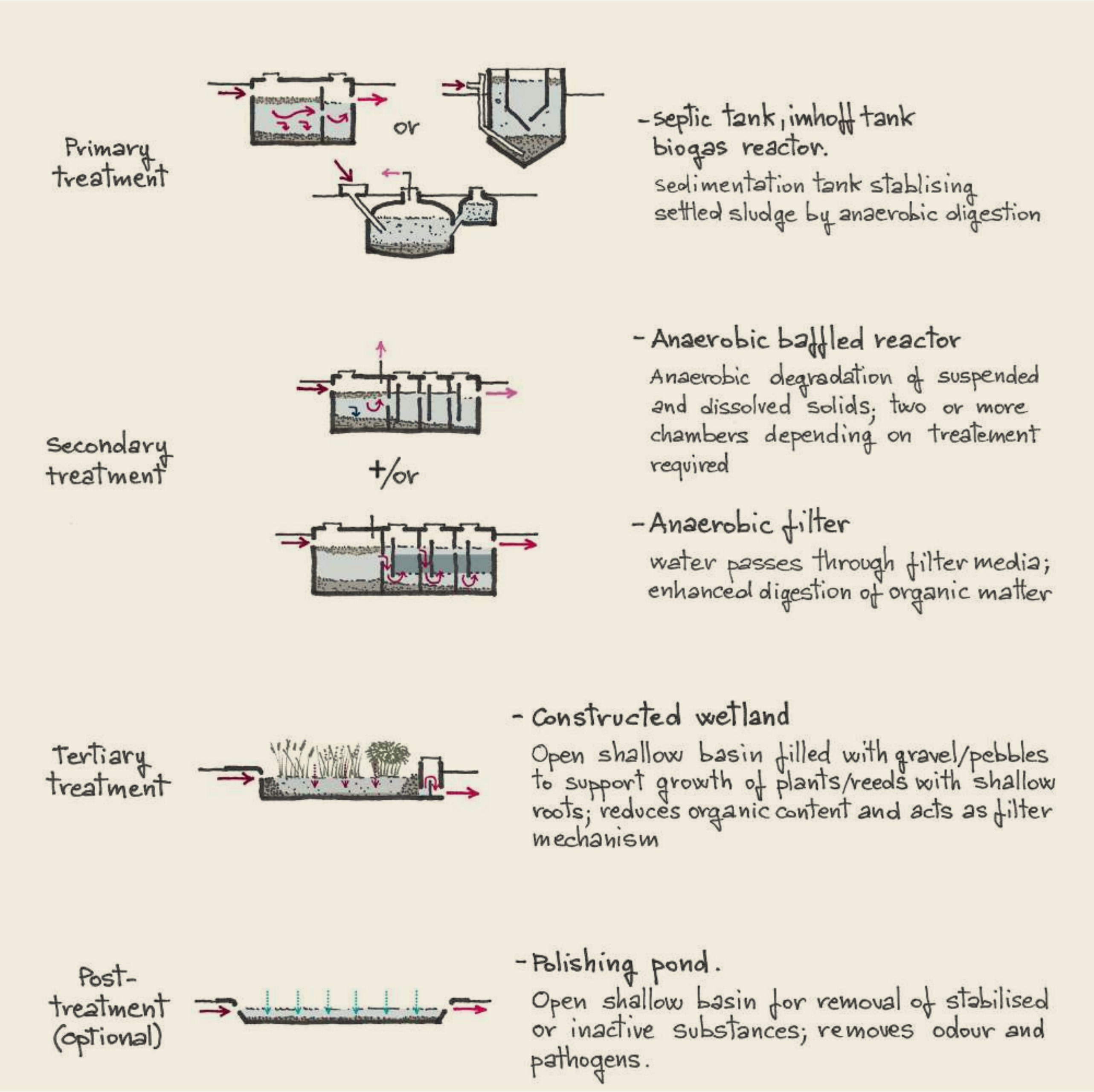
AEES is a wastewater treatment system that (EPA 2002):

- Is capable of achieving tertiary treatment;
- Costs less as investment cost and to operate than conventional systems when used to achieve a tertiary level of treatment; and
- Does not typically require chemicals that are harmful to the environment" as a part of its treatment process;
- It has an aesthetically pleasing appearance

The system, according to the company producing and installing it (Living Machines 2017), requires some energy to be used for pumping (not much, and less than any other conventional system, about 0.8 kWh per cubic meter of water treated) and its footprint (about 3.5 $m^2$ per cubic meter of treated water) is limited, and is lower than that of a DEWATS system.

The routine operation and maintenance requirements for this system are similar to those of DEWATS (cleaning the inlet/outlet structure; cleaning the tank; removing and

FIGURE 2.5.19 **DEWATS CONFIGURATION SCHEME SUITABLE FOR SMALL-SCALE DECENTRALISED WASTEWATER TREATMENT (ADAPTED FROM: WEDC 2010)**



- septic tank, imhoff tank biogas reactor.
sedimentation tank stablising settled sludge by anaerobic digestion

- Anaerobic baffled reactor
Anaerobic degradation of suspended and dissolved solids; two or more chambers depending on treatement required

- Anaerobic filter
water passes through filter media; enhanced digestion of organic matter

- Constructed wetland
Open shallow basin filled with gravel/pebbles to support growth of plants/reeds with shallow roots; reduces organic content and acts as filter mechanism

- Polishing pond.
Open shallow basin for removal of stabilised or inactive substances; removes odour and pathogens.

disposing of sludge; maintaining and repairing machinery, vegetation management, including routine harvesting to promote plant growth, and removal of accumulated plant litter) plus the requirements for a conventional wastewater treatment plant. This implies that both systems require a certain amount of manpower, at various levels of skill, favouring both employment and social inclusion.

## 2.5.4 USE OF TREATED WASTEWATER AND SLUDGE

Sludge derived from wastewater treatment is rich in nutrients and can be used as fertiliser either in the form of a solid product, after it has been dewatered and dried on sand beds, or as a liquid spread directly, provided that compatibility between the pathogen content and the kind of agricultural products being fertilised can be guaranteed, i.e. that no health hazard derives from this practice.

Alternatively, sludge can be mixed with organic material such as food waste and composted (co-composting). A neighbourhood's treated wastewater can be used for

### BOX 2.5.2 DEWATS MAIN FEATURES (WEDC 2010)

DEWATS make use of the natural biological and physical treatment processes to reduce and remove pollutants from wastewater. External energy supply, dosing of chemicals and movable parts are avoided to minimise both possible flaws in operation and maintenance. With DEWATS primary, secondary and tertiary treatment of wastewaters from domestic or industrial sources can be provided, and biogas that can be used locally for cooking or power generation. DEWATS can reduce pollution load to fit legal requirements. Like all other wastewater treatment systems, generated solid waste (sludge) must be handled, treated and disposed of in accordance with hygiene and environmental standards.

### BOX 2.5.3 RRC

In most fast-growing urban areas, the existing infrastructure is challenged by the high demand for drinking water and energy as well as rapidly increasing amounts of wastewater and solid waste. One possible approach to address these challenges is the so-called "semi-centralised" supply and treatment system. This innovative approach was developed by the Technical University of Darmstadt, Germany, for applications in fast-growing urban areas, such as those in China. It focuses on the integrative assessment of the different material and energy flows, in particular water, wastewater, and waste. The treatment of waste, graywater, and blackwater takes place in a semi-centralised Resource Recovery Centre (RRC) within or close to the residential area, and the water is reused for non-potable uses. Depending on site-specific conditions, 30-100% of wastewater can be reused, resulting in a significantly lower amount of wastewater to be discharged into water bodies. The other main advantage is internal energy recovery enabled by the increased biogas production through co-digesting biowaste with waste-activated sludge.

The first RRC opened in April 2014 in Qingdao Shiyuan, China, serving a total of 12,000 population equivalents. Its service area consists of residential areas, a large administration center with guest houses, and two hotel complexes. Graywater from showers, hand washbasins, and washing machines is collected and transported separately from the blackwater to the RRC (Figure 2.5.21). Graywater treatment consists of mechanical pre-treatment, biological treatment (elimination of organic carbon compounds), and disinfection. To meet the strict quality standards for service water and irrigation water, a membrane bioreactor (MBR) with subsequent disinfection is employed. The RRC will provide service water for toilet flushing via a separate distribution system. In addition, service water is used for street cleaning. Blackwater from kitchens and toilets is also conveyed to the RRC and treated separately from graywater (Figure 2.5.21).

The third important material flow within the RRC in Qingdao is food waste from restaurants and canteens. Following pre-treatment, the food waste is mixed with waste-activated sludge and thermophilically co-digested. The digestate is used as biosolids in landscaping, utilizing phosphorus from the wastewater as a fertilizer. The biogas derived from anaerobic treatment and a combined heat and power unit generates electricity and heat, resulting in a self-sufficient operation of the RRC.

FIGURE 2.5.20 **FLOW SCHEMATIC OF THE SEMI-CENTRALISED RESOURCE RECOVERY CENTRE IN QINGDAO, CHINA. SOURCE: NAP 2016**

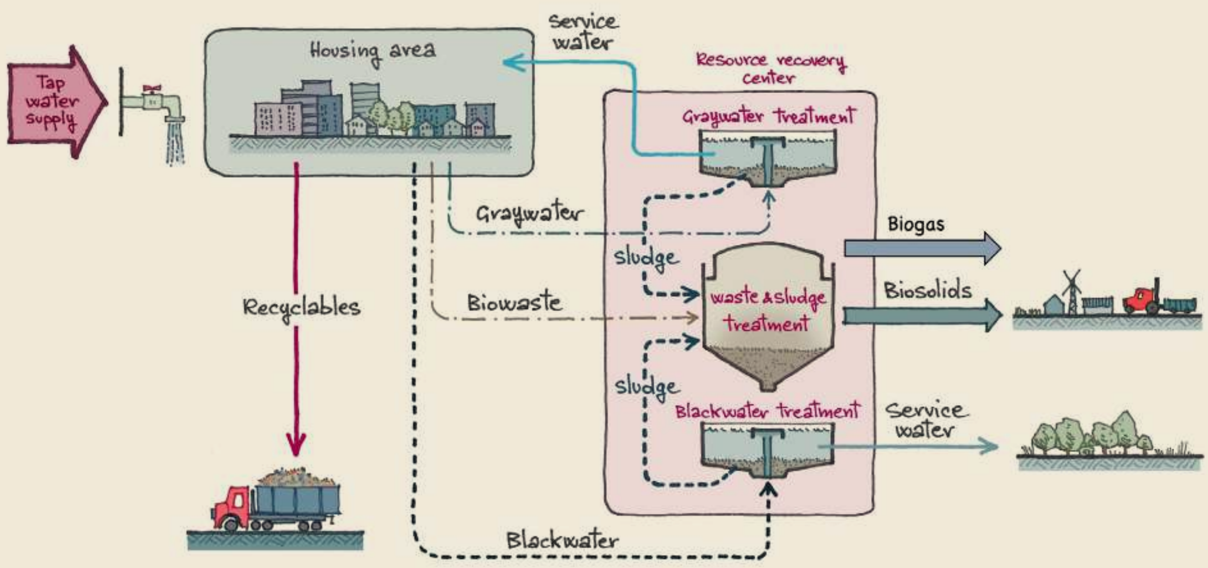
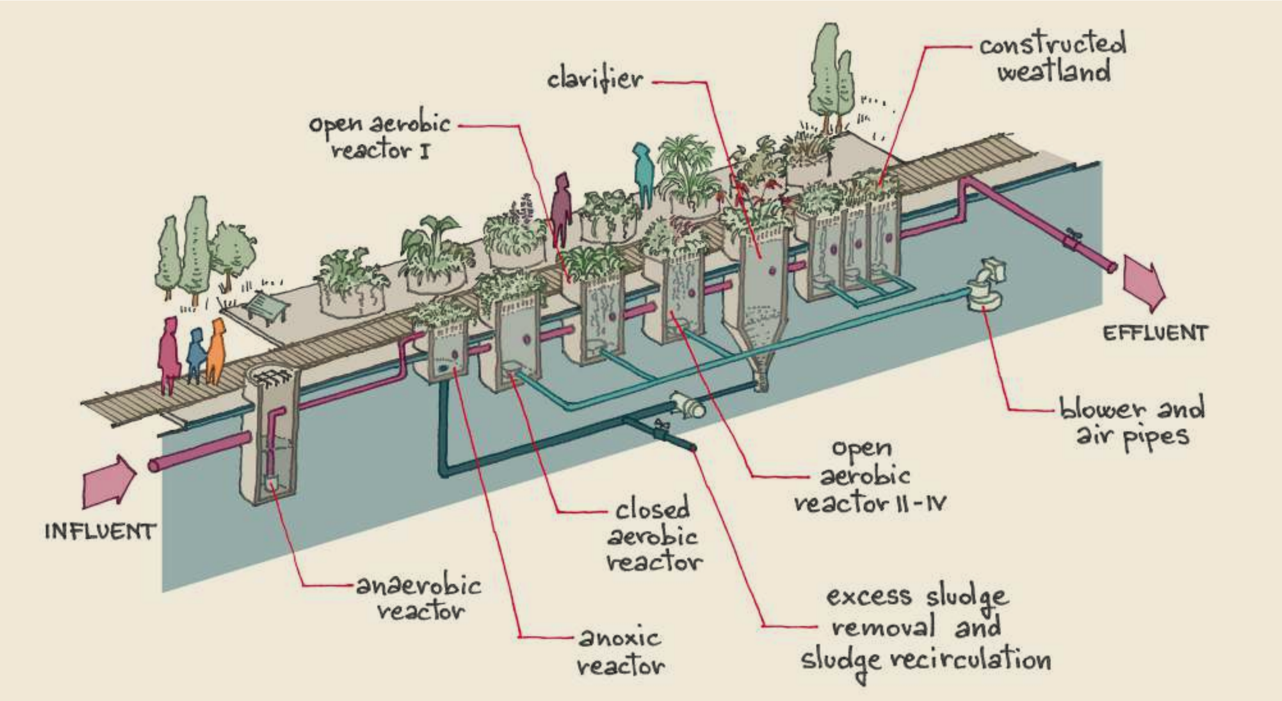


FIGURE 2.5.21 **A SCHEMATIC DIAGRAM OF THE ADVANCED ECOLOGICALLY ENGINEERED SYSTEM (ADAPTED FROM: LAYLIN 2010)**



irrigation or for groundwater recharge; it should not be used directly as process water in industries or as flushing water in toilets. Treated domestic or mixed community wastewater is ideal for irrigating parks and flower gardens[29].

To reduce dependence on freshwater and maintain a constant source of water for irrigation throughout the year, wastewater of varying quality can be used for urban and peri-urban agriculture. The concept of agricultural irrigation combined with nutrient fertilization, either by adding fertilizer to the irrigation water or by applying (partly) treated wastewaters of varying quality is called fertigation. While plants take up the fertigation water and some of it infiltrates into the soils, most nutrients and biological oxygen demands are removed and pathogens die off.

Moreover, irrigation water percolates through the soil, contributing to aquifer replenishment.

Recharge of groundwater is probably the best way to reuse wastewater particularly since the groundwater table tends to be lowered almost everywhere. Wastewater was once freshwater, and freshwater drawn from wells has been groundwater before. Sustainable development is directly related to the availability of water from the ground. Thus, recharging of this source becomes absolutely vital. The main question is to what extent the wastewater needs treatment before it can be discharged to the ground. Due to the high risk of groundwater pollution, this topic is very delicate and needs to be handled with the greatest precaution.

## 2.5.5 CLEAN WATER AND WASTEWATER NETWORKS

In a sustainable water cycle at neighbourhood scale the following water flows have to be considered and combined:

1. Potable water flow from municipal network, if any;
2. Potable water flow from common neighbourhood wells;
3. Roof rainwater flow to storage;
4. Roof rainwater flow, directly from storage to domestic uses, i.e. WC flushing, washing machines, irrigation;
5. Roof rainwater flow, filtered and disinfected to make it potable, for domestic uses, i.e. kitchen and bathroom taps;
6. Roof rainwater flow diverted for recharging ground water aquifers;
7. Stormwater flow collected from impervious surfaces;
8. Wastewater flow from households to the treatment system (could/should be two separate flows, if black water and grey water are not mixed);
9. Treated wastewater flow to green areas (urban agriculture, parks, street greening, etc.);
10. Treated wastewater flow to recharge wells or recharge basins;
11. Treated wastewater flow to water bodies (alternative to flows 9 and 10).

---

[29] *Irrigation normally takes place in the evening or early morning so that people will not be bothered by the slightly foul smell of anaerobic effluent.*

## BOX 2.5.4 SOIL AQUIFER TREATMENT (SAT)

Soil Aquifer Treatment (SAT) is an artificial groundwater aquifer recharge option (Figure 2.5.22). As the effluent moves through the soil and the aquifer, it can undergo significant quality improvements through physical, chemical and biological processes. The water is stored in the underlying unconfined aquifer generally for subsequent reuse, such as irrigation or even for drinking water purposes (generally after a water purification step). Underground water storage can reduce the evaporation rate (especially in arid and semi-arid regions), the potential breeding places for insect-vector diseases, and risk of contamination and pollution compared to water stored on the surface.

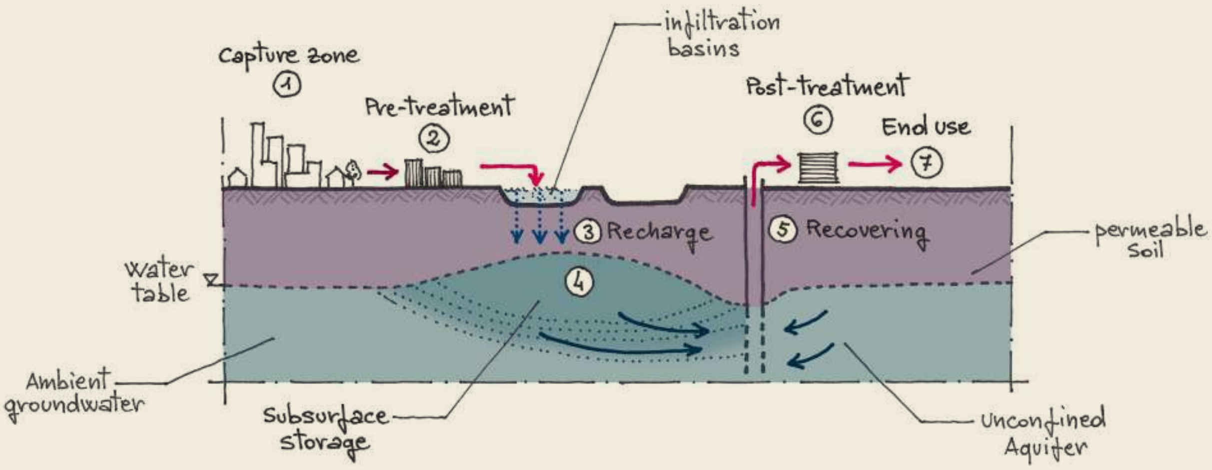
### *Advantages of SAT*

- Low cost and a fitting option for wastewater reclamation
- Increases capacity of existing groundwater resources, to buffer seasonal and weather variations (i.e. facilitating a "drought-proof" water supply)
- Improvement of the quality of the infiltrated water through soil filtration and storage in the aquifer. Reclaimed water can be mixed with groundwater resources, increasing its quality and the acceptance for reuse of reclaimed water
- Groundwater recharge can also preserve water levels in wetlands and mitigate saltwater or contaminant intrusion.

### *Disadvantages of SAT*

- If reclaimed water is used but not sufficiently pre-treated, discharge of nutrients and micro pollutants may affect natural water bodies and/or drinking water.
- Introducing pollutants into groundwater aquifers may have long-term negative impacts
- Can change the soil and groundwater hydrological properties
- Surface soil aquifer treatment requires a big area for the infiltration basin
- It needs to be carefully designed such as to avoid any stagnant water, which would be the ideal habitat for mosquitos.

FIGURE 2.5.22 **SCHEMATIC OF THE TREATED WASTEWATER AQUIFER RECHARGE PROCESS (ADAPTED FROM: SSWM 2017)**



Flows 2, 3, 4 and 5 could be used as a substitute for the conventional potable water network. The extra cost due to the piping to and from the storage and the piping for non-potable water (dual water system), plus the extra cost of filtering/disinfection devices, could be counterbalanced by the savings obtainable by not having the connection to the municipal water network and because of the average smaller piping diameter of the network. Such a distributed, local provision of water would also be far more resilient than the usual, centralised system and would provide local employment, at different levels of skill.

The extra cost of recharging wells to recycle into the aquifer from both the excess roof rainwater and stormwater is counterbalanced by the consequent high reliability of the water system and by the effective defence against flooding.

### BOX 2.5.5 ARTIFICIAL SUBSURFACE GROUNDWATER RECHARGE

Artificial subsurface groundwater recharge refers to recharge techniques (generally recharging wells) that release the water below the ground (SSWM 2017), Figure 2.5.23. Subsurface groundwater recharge, as opposed to surface water recharge does not provide any additional treatment through soil filtration. Therefore polluted wastewater should be treated before subsurface groundwater recharge. The effective and efficient operation of an artificial groundwater recharge system depends on the method of recharge, the characteristics of the aquifer, the residence time (hydrological study), the amount of blending with other waters and the history of the system. Direct subsurface recharge methods can reach aquifers located at greater depth and require less land than direct surface recharge methods, but are more expensive to construct and maintain. Recharge wells, commonly called injection wells, are generally used to replenish groundwater resources when aquifers are located at greater depth and confined by materials of low permeability.

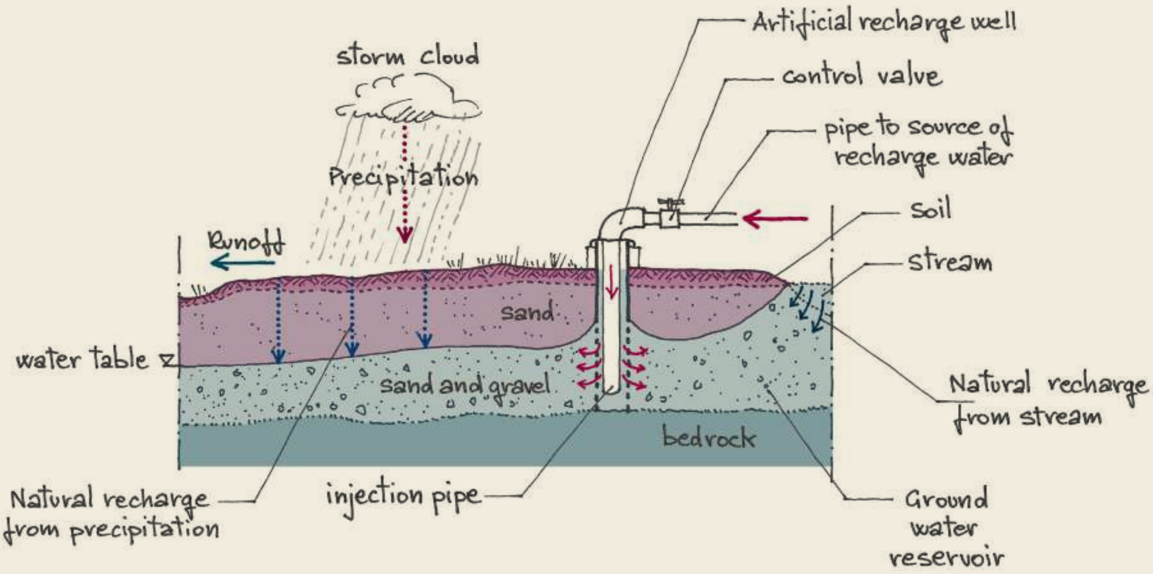
*Advantages*

- May provide a 'drought-proof' water supply (from groundwater)
- Technology is easy to understand and operate
- Groundwater recharge collects water during wet season for use in dry season, when demand is highest

*Disadvantages*

- Discharge of nutrients and micro-pollutants may negatively affect the receiving soil and the aquifer
- Introduction of pollutants may have long-term impacts
- Potential of groundwater contamination from injected surface water runoff, especially from agricultural fields and road surfaces
- Recharge can degrade the aquifer unless quality control of the injected water is adequate
- Unless significant volumes can be injected into an aquifer, groundwater recharge may not be economically feasible
- During the construction of water traps, disturbances of soil and vegetation cover may cause environmental damage to the project area .

FIGURE 2.5.23 **ARTIFICIAL RECHARGE OF GROUNDWATER (USGS 2016)**



When reusing the treated wastewater for irrigation and for ground water recharging, an additional pipe network is necessary, which is never included in conventional water systems. It must be considered, however, that this extra cost is offset by:

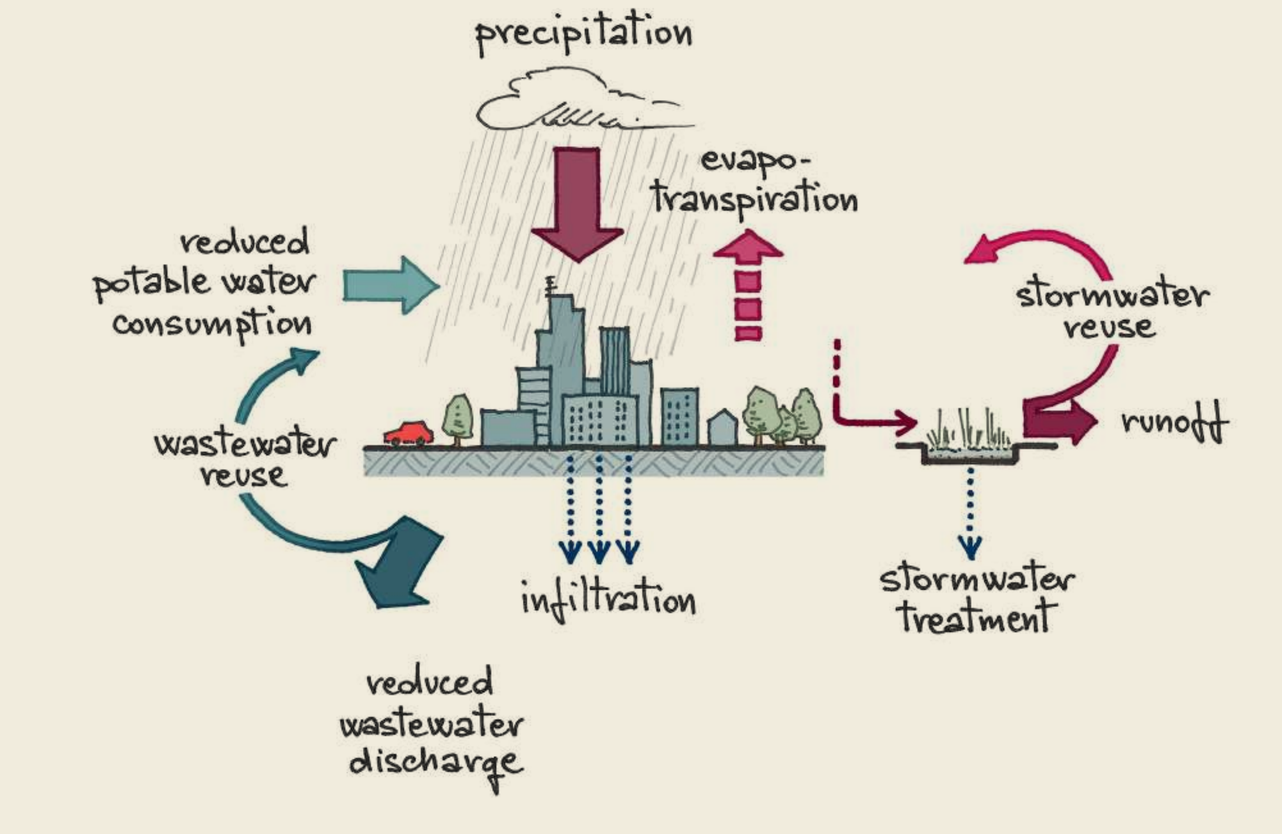
- the improved economics of urban agriculture, as usually the water already contains most of the nutrients needed and, in any case, the fertiliser that should be added would be organic and derived from the local, decentralised, wastewater treatment system;
- the improved capability of ensuring that all the neighbourhood greenery flourishes, with a significant advantage, especially in hot dry climates, in terms of outdoor and indoor comfort – with the consequent energy savings for air conditioning.

## 2.5.6 THE IDEAL WATER CYCLE

Centralized wastewater processing plants in developing countries are often vulnerable because of inadequate upgrading and maintenance as well as frequent power cuts, resulting in the release of pathogenic wastewater. A safe, sustainable and resilient neighbourhood should be able to rely only on rainwater for providing, at different quality levels, all the water necessary to fulfil the communities' needs, based on the cycle depicted in Figure 2.5.24.

In many cases this ideal aim – for technical and/or economic reasons – cannot be reached. However, the urban designer should at least do his/her best to minimise the neighbourhood's reliance on the centralised water supply.

FIGURE 2.5.24 **THE IDEAL URBAN WATER CYCLE**



## REFERENCES

ANBP (n.d). Australian and NewZeland Biosolids Partnership - http://www.biosolids.com.au/what-are-biosolids.php.

Butera, F. M. (2014). Dalla caverna alla casa ecologica – Storia del comfort e dell'energia, Edizioni Ambiente.

CCTV (2015). China-Sponge-like Cities/Guidelines. CCTV News Contents -

http://newscontent.cctv.com/NewJsp/news.jsp?fileId=321687

Copenhagen (2011). Copenhagen climate adaptation plan, 2011 - http://en.klimatilpasning.dk/media/568851/copenhagen_adaption_plan.pdf.

Elmer, V. and Fraker, H. (2011). Water, Neighbourhoods and Urban Design: Micro-Utilities and the Fifth Infrastructure, Working Paper 2011-4, Institute of Urban and Regional Development, University of California, Berkeley.

EPA (2002). Wastewater Technology Fact Sheet – The living Machine, EPA - https://www6epa.gov/npdes/pubs/living_machine.pdf

Hatibu, N. and Mahoo, H. F. (2000). RAINWATER HARVESTING FOR NATURAL RESOURCES MANAGEMENT, RELMA -http://www.samsamwater.com/library/TH22_Rainwater_Harvesting.pdf

IPCC (2008). Climate Change and Water- http://ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf

Laureano, P. (1996). La piramide rovesciata, Bollati Boringhieri.

Laylin, T. (2010). The Living Machine: an ecological approach to poo, Ecologist, 8th June 2010 - http://www.theecologist.org/investigations/waste_and_recycling/503649/the_living_machine_an_ecological_approach_to_poo.html

LivingMachines (n.d.). Living Machine site: Technology comparison - http://livingmachines.com/About-Living-Machine/Tidal-Flow-Wetland-Living-Machine-System/Comparison.aspx

McKinsey (2015). Rethinking the water cycle. McKinsey&Company,May 2015.

http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/rethinking-the-water-cycle

NAP (2016). THE NATIONAL ACADEMIES PRESS, Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits - http://www.nap.edu/21866.

NetRegs (n.d). Sustainable Urban Drainage Systems (SUDS) - http://www.netregs.org.uk/environmental-topics/water/sustainable-urban-drainage-systems-suds/.

Phillips, A. A. (2005) (ed.), CITY OF TUCSON WATER HARVESTING GUIDANCE MANUAL, City of Tucson -https://www.tucsonaz.gov/files/transportation/2006WaterHarvesting.pdf.

UN-Habitat, Blue Drop Series on Rainwater Harvesting and Utilisation – Book 2 - http://unhabitat.org.np/?post_type=publications&p=1485.

Sedlak, D. (2014). Water 4.0, Yale University Press.

SSWM (n.d). Sustainable Sanitation and Water Management Toolbook, Soil Aquifer Treatment - http://www.sswm.info/print/2853?tid=1313

UN (2014). United Nations World Water Assessment Programme, WWDR 2014, Water and energy - http://unesdoc.unesco.org/images/0022/002257/225741e.pdf

UNESCO (2015). Water for a Sustainable World - http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2015-water-for-a-sustainable-world/

UN-Habitat (2005). Blue Drop Series on Rainwater Harvesting and Utilisation – Book 2 - http://unhabitat.org.np/?post_type=publications&p=1485

USEPA (n.d). Low Impact Development (LID), Urban Design Tools Website. US EPA Office of Water 104b(3) Program - http://www.lid-stormwater.net/index.html

USGS (2016). USGS Water Science School – Infiltration. U.S. Geological Survey's - http://water.usgs.gov/edu/watercycleinfiltration.html

WEDC (2010). Decentralised Wastewater Treatment Systems and sanitation in developing countries (DEWATS): a practical guide, Water, Engineering and Development Centre (WEDC), Loughborough University, Leicestershire, UK - https://wedc-knowledge.lboro.ac.uk/details.html?id=10409

WSUD (n.d.). Water Sensitive Urban Design - http://www.ciria.org/Resources/Free_publications/Water_Sensitive_Urban_Design.aspx.

## 2.6 IMPROVE SOLID WASTE REUSE AND RECYCLING

Urban waste is a serious contributor to greenhouse gases and is a cause of climate change. This is mainly due to methane released from the anaerobic decay of wastes in landfills, and nitrous oxide from the uncontrolled combustion of solid waste, as methane has 25 times more global warming potential than carbon dioxide and nitrous oxide has 310 times the global warming potential (ACCRN 2011).

Solid waste collection and disposal is an issue that is generally considered to be related to city governance, not to urban design: only the area occupied by landfill or by the incineration plant involves land use and space planning. But if, instead of being centralised, solid waste collection and disposal is decentralised at neighbourhood scale, the urban designer becomes directly involved.

### 2.6.1 DECENTRALISED SOLID WASTE MANAGEMENT

Decentralised solid waste management has many advantages. Localised collection and processing of wastes avoids the shipping of wastes to far off dumping sites, reducing the energy used and the emissions that arise from the transport, as well as reducing air pollution and road maintenance costs. It also reduces the contamination of ground water through the leakage of leachate in landfills.

The management of solid waste at neighbourhood scale allows the exploitation of waste as a resource to be maximised. Solid waste's resources are the organic part, which can be recycled by transforming it into biogas and fertiliser, and the reusable and recyclable materials. The part that is left goes to landfill or the incinerator.

Segregation at source provides recyclables that have the least degree of contamination, but it requires the cooperation of citizens. This cooperation can be more easily obtained if the benefits of a well-done segregation are clearly visible to the neighbourhood's inhabitants and the stakeholders in the process, from collection to the recycled product, are local, i.e. they live and work in the same neighbourhood.

In an ideal waste management system at neighbourhood scale, sorted solid, non-organic, waste is brought to a transfer station where the recyclable materials are further sorted, and cleaned if necessary, and from there are handed over to the dealers who will buy them. Non-recyclable materials are sent from the transfer station to landfill or to the incinerator.

Organic material is conveyed to the neighbourhood composting plant, which could also be fed with urban agriculture residuals and landscaping waste (urban parks, lawns and street trees residuals). Branches from tree pruning could feed a neighbourhood gasifier, and the compost from the composting plant used as fertiliser in the urban agriculture and the urban green spaces, closing the cycle.

This type of approach has been put into practice by BORDA, a German based non-profit organisation in a number of pilot projects in communities in developing countries. BORDA's, Decentralised Solid Waste Management involves the following activities (Figure 2.6.1, BORDA 2014):

- Segregation of waste at source;
- Primary collection and transport to the Material Recovery Facility (MRF);
- Waste separation into organic, recyclable, and residual waste at the MRF;
- Composting of biodegradable waste;
- Recycling of non-biodegradable waste.

***Segregation of waste at source*** - Households separate the waste at source into biodegradable (wet) waste and non-biodegradable (dry) waste. Each household is provided with two bins in different colours for the wet and the dry waste respectively.

***Collection*** - Door-to-door collection of waste takes place on a daily basis or on alternate days. After the waste has been collected from the households, the waste is transported to the Material Recovery Facility, which combines the Material Separation Facility (MSF) and the Compost Facility (CF).

***Waste separation*** - Waste is separated into organic, recyclable, and residual waste in the MSF.

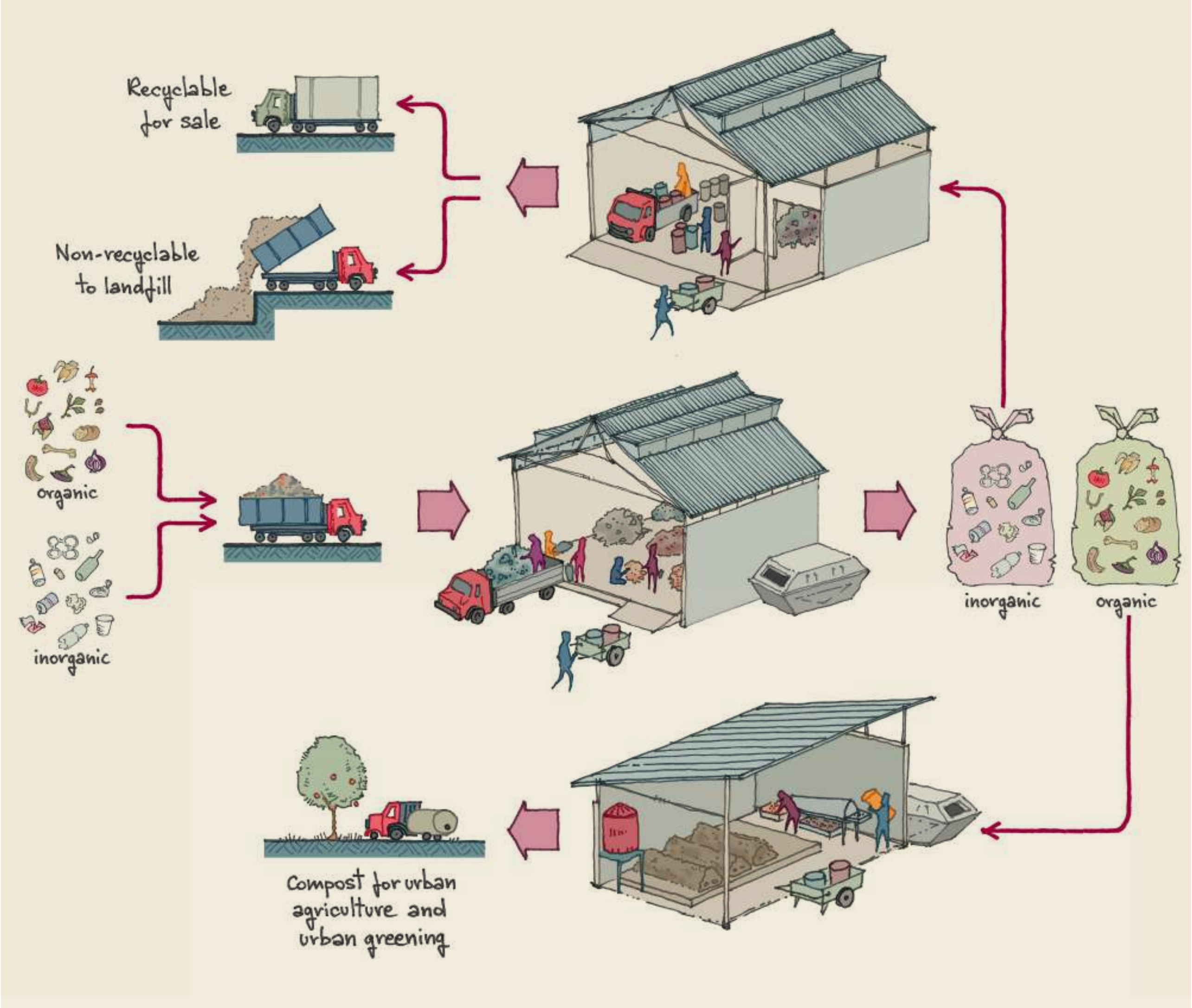
***Composting of biodegradable waste*** - Organic waste is transformed into compost in the CF. Compost can be sold for use as a natural soil additive and fertiliser.

***Recycling of non-biodegradable waste*** - Recyclable waste is sold to the private sector or industry for other uses. Residual waste is transported to the final landfill.

Facilities such as the Material Separation Facility and the Compost Facility, or similar, require space and a suitable location, which has to be planned, as planning and positioning is necessary for the gasifier, if any, with the necessary area for feedstock storage.

The urban planner, with such a solid waste management system, is heavily involved and needs to work very closely with waste management experts.

FIGURE 2.6.1 **DECENTRALISED SOLID WASTE MANAGEMENT**



## 2.6.2 SOCIAL AND ECONOMIC IMPACT OF DECENTRALISED WASTE MANAGEMENT

Micro and small enterprises, such as small community-based cooperatives, may be contracted to provide labour-intensive waste management services. They can provide a good service because of their links to the neighbourhood where they work and their own interest in living in a clean environment.

Waste processing may be a significant employment opportunity for the least skilled manpower living in the neighbourhood, who would be motivated and efficient. Informal waste pickers or formally employed workers living in a different neighbourhood could provide a similar service, but as their interests would not be entirely coincident with the interests of the community, the end result may be unsatisfactory.

The above-described way of managing solid waste is environmentally, socially and economically appropriate, and there is a trend, in the most advanced cities of developed countries, towards this kind of approach, combined with a more or less high level of mechanisation and automation of the process.

## REFERENCES

ACCRN (2011). Decentralized Solid Waste Management through Community Participation, Asian Cities Climate Change Resilience Network - http://www.hamaragorakhpur.com/PDF/decentralised-solid-waste-final-report.pdf

BORDA (2014). Decentralized Solid Waste Management (2014) - http://www.borda-net.org/fileadmin/borda-net/Knowledge/Education/Bildungsbroschuere_B2_DESWAM(en)_web.pdf

## 2.7 CLOSING ENERGY, WATER AND WASTE CYCLES ON SITE

A sustainable neighbourhood rejects the idea of waste, be it of energy, water, food or materials; instead it seeks to transform waste into beneficial uses. In so doing, it seeks to reduce or even cut out inputs of water and energy from afar and to reduce the flow of materials. This concept leads to efforts to decentralize the production of energy and food. It also powers the three "R's" (Reduce, Reuse, Recycle) of decentralised solid waste management.

Energy, water and waste flows are interconnected (Figure 2.7.1). In the conventional, centralised, linear, urban metabolism the connections are one-way: the higher the standard for providing water to households, the higher the water input, and the higher the energy consumption for water purification and for pumping; the higher the standard of sanitation, the higher the energy consumption for wastewater treatment; the better the solid waste collection and disposal system, the higher the energy consumption for transport.

In the circular metabolism, however, energy is linked to water and waste in many other ways:

- the use of rainwater and treated wastewater for replenishing water tables stops them from getting lower and less pumping power is required;
- the use of treated wastewater for vegetated areas means that they can flourish because of fertigation, which is also beneficial for both outdoor and indoor comfort, reducing the need for air conditioning;
- the availability of natural fertilisers and water means that urban agriculture can be promoted and the use of locally produced food also reduces the energy consumed for supplying it from distant locations;
- organic waste and wastewater can produce biogas, which, among other uses, can be used in a cogeneration system whose waste heat can make potable water from treated wastewater via vacuum distillation;
- organic waste from urban agriculture and green maintenance residuals can provide energy, via digesters and/or gasifiers;
- the reduction of the need for private transport deriving from mixed use reduces energy consumption and - because of the reduced traffic - the necessary street width, with a consequent reduction in the impervious areas, in favour of pervious surfaces which allow stormwater to percolate and replenish the water tables.

Thus, in a sustainable neighbourhood, conventional linear processes are substituted by circular ones, reducing the entropy production in each flow; moreover, an appropriate interconnection between flows can lead to a further reduction of the entropy production in the neighbourhood's metabolic process, making it more sustainable and reducing both direct and indirect emissions (Figure 2.7.2).

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FIGURE 2.7.1 **WATER, WASTE AND ENERGY FLOWS**

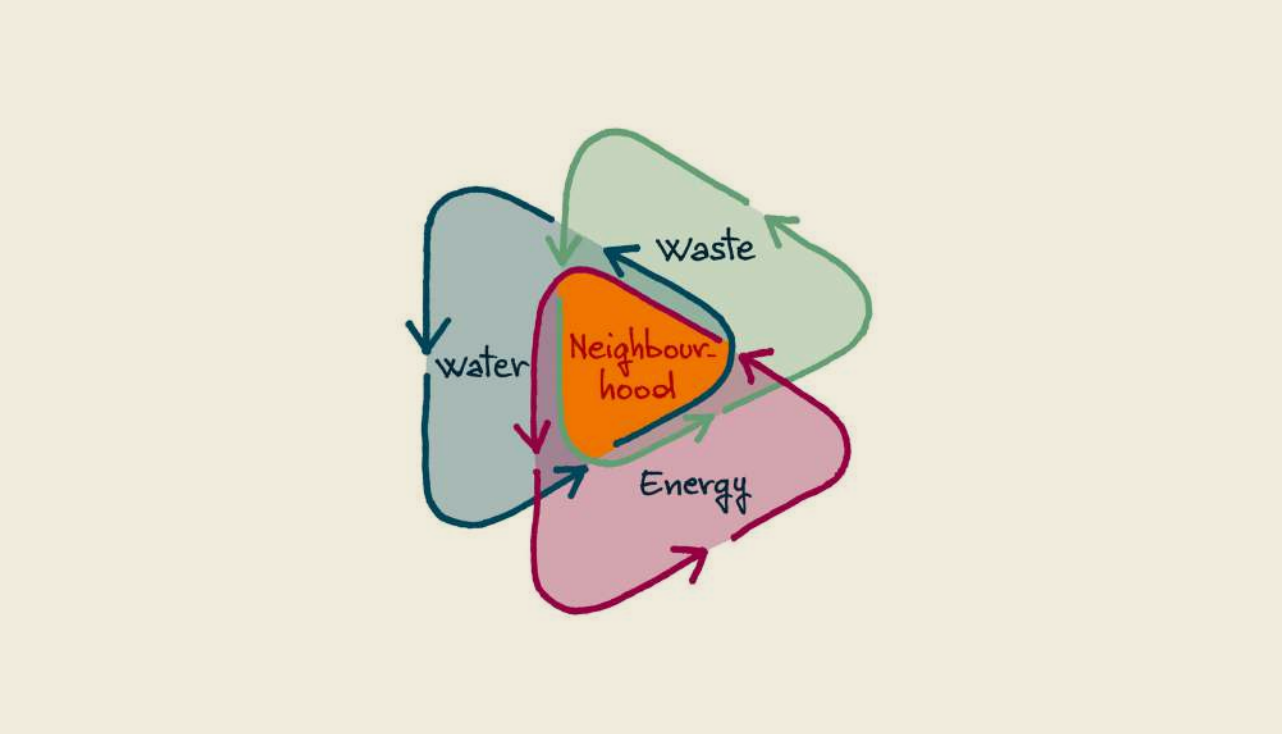
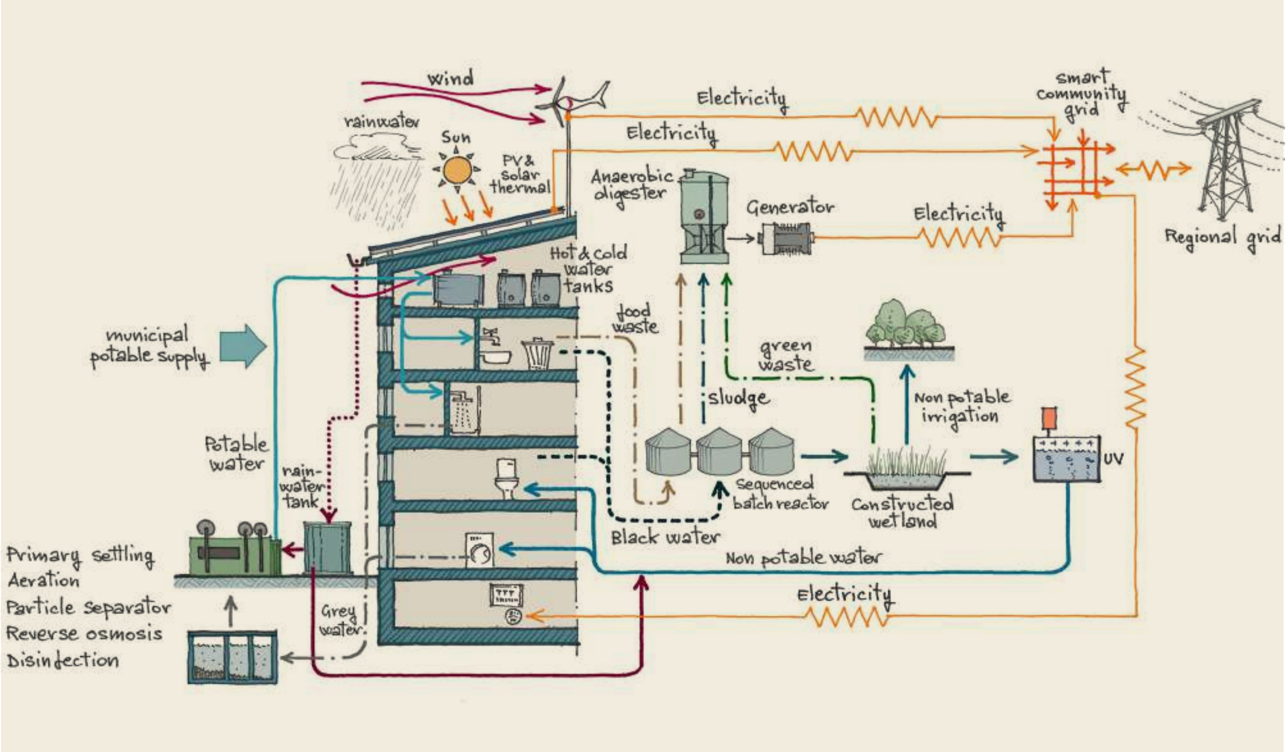


FIGURE 2.7.2 **SCHEMATIC OF INTEGRATED WATER, WASTE AND ENERGY SYSTEMS FOR A SUSTAINABLE NEIGHBOURHOOD. ADAPTED FROM THE QUINDAO ECOBLOCK (SEE CHAPTER 4 FOR MORE INFORMATION))**



The combination of demand management and an efficient supply of energy and water, based on decentralised systems and a closed cycle approach is the only way to drive cities towards their aim of sustainable development. A sustainable neighbourhood needs to begin to approach zero emissions if it is to cope with future challenges.

The interactions between structure (layout, form, land use, materials, greenery), energy, water and waste can be used for minimising the flow of resources (or negentropy) needed for the operation of a neighbourhood and – at the same time – can make the neighbourhood more resilient, thus more capable of coping with the challenges of climate change.

The increased resilience of the neighbourhood derives mainly from the diversity of both the energy supply (sun, biomass and wind, if available, fossil) and of the water supply (rainwater, wastewater, well water plus water from the city's distribution system).

Further resilience is created by the reduced flood danger, which is the result of a more controlled runoff, because of the large percolating areas, i.e.the green spaces.

A sustainable neighbourhood is not only more resilient, but also more secure, as political or economic crises will have less effect on the availability of energy, water and food.

## 2.7.1 INTEGRATED NEIGHBOURHOOD DESIGN

The way a neighbourhood is designed is crucial. Typically, infrastructure systems are designed independently by specialists in the individual areas after the master plan has been designed, ignoring or overlooking the mutual interactions between the infrastructures and the urban form and layout. However, the multifaceted nature of sustainability requires engineers and urban designers to work together, adopting a holistic perspective, including the interactions between the neighbourhood and the greater urban region.

To accomplish this task, the urban designer must actively involve – from the earliest stages of the design process – specialists in many different areas of expertise, i.e. experts in fields such as urban climatology, urban ecology, energy systems, water and wastewater management, agriculture, solid waste management, mobility and economy and they should all work together, synergistically. The usual design process - in which the urban designer takes decisions only on the basis of aesthetic, sociological and economic issues balanced with the political and economic interests of the local stakeholders - should be widened to include all of the abovementioned areas of knowledge, thus putting in place an integrated design process.

The role of the urban designer, then, becomes that of integrating all the information provided by the specialists, treating the neighbourhood as a living organism. To do this in the best possible way it is necessary for the urban designer to have basic knowledge of the principles and the technologies regarding each specialist area. This knowledge will allow the urban designer to share a common language with the specialists, without which effective integration cannot take place. This is the main purpose of the previous sections; whose aim is to provide the urban designer with the basic information regarding the main components of the neighbourhood metabolism.

Integrated design can create the conditions for mitigating the local climate, collecting and distributing rainwater, cleaning stormwater and sewer effluent, providing biomass for energy and growing food; integrated neighbourhood design also influences transportation choices and reduces automobile use.

## 2.8 MINIMISE INDIRECT GHG EMISSIONS

A large proportion of urban GHG emissions is due to those embodied in the material flow entering the city, i.e. the ones associated with the extraction, production, and transportation of products or services entering the city.

The urban designer can control a part of these embodied, or indirect, emissions, as they are affected by his/her design choices.

The largest proportion of embodied emissions consequent to the choices of the urban designer is that required for the production of concrete, steel, glass, and other materials used in civil infrastructure. The production of cement, steel, glass, aluminium and fired bricks, which are the basic building materials for most modern constructions, has very high environmental impact, consumes a significant amount of energy and causes most of the GHG emissions of the construction sector (CIB 2002) because it requires the processing of mined raw materials at very high temperatures. The cement industry is responsible for ~5% of annual worldwide $CO_2$ emissions from fossil fuels (IEA 2009). The production of iron and steel, which is also used in reinforced concrete, is responsible for more than 4% of world total energy use and the corresponding GHG emissions (WRI 2001). The production of glass and aluminium also causes large GHG emissions because their production is energy intensive.

Building materials like stone, timber, bamboo, stabilised compressed bricks, etc., by contrast, have low embodied emissions, and should be favoured. They can also be produced locally, reducing the need for transport energy and reinforcing the local economy.

A significant reduction in the indirect emissions due to building materials can also be obtained by an urban design that aims to minimise the quantity of resources used.

There is an inverse relationship, for example, between urban density and indirect GHG emissions, due to the fact that the lowe the surface to volume (S/V) ratio of buildings, the lower the amount of material required for providing a given useful floor area: a multi-storey building has a lower S/V ratio than a detached house, and it is capable of providing more useful floor area with the same footprint (Figure 2.8.1). The greater the amount of construction material needed, the higher the amount of embodied GHG emissions.

FIGURE 2.8.1 **VARIATION OF SURFACE TO VOLUME RATIO (S/V)) FOR INCREASING VOLUME OF A CUBE.**

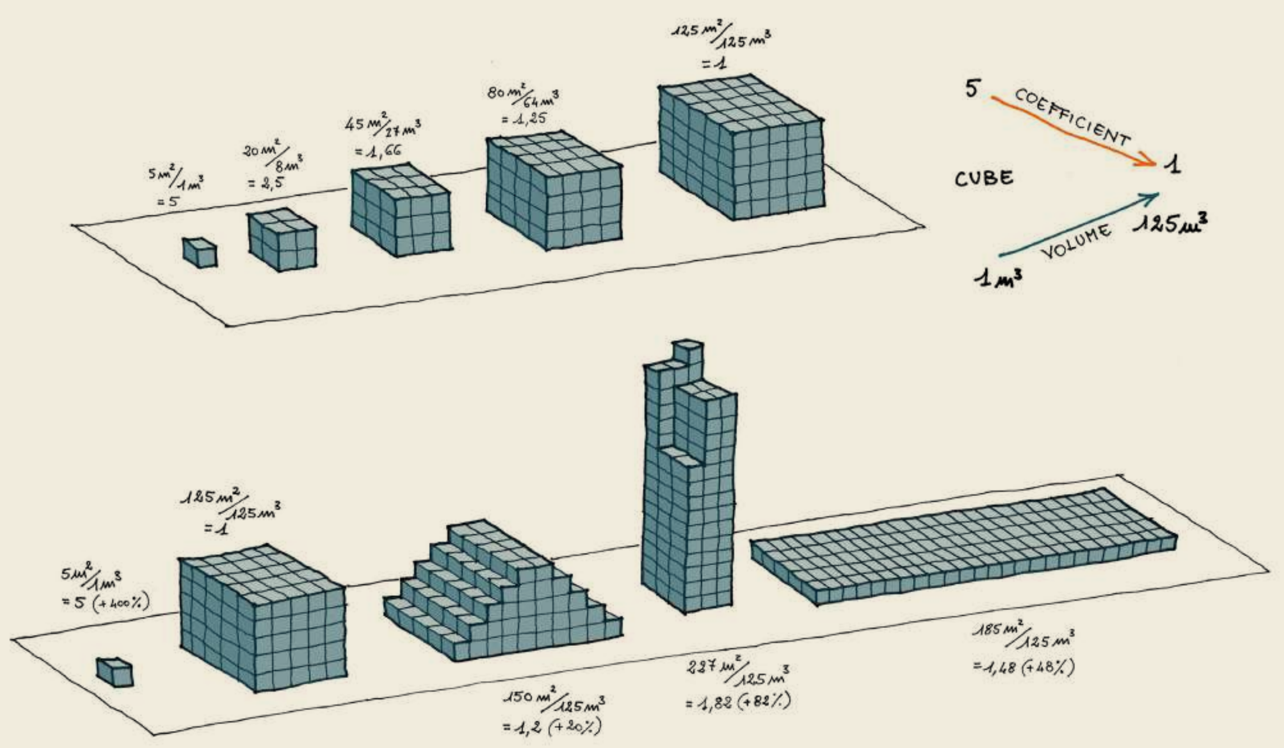
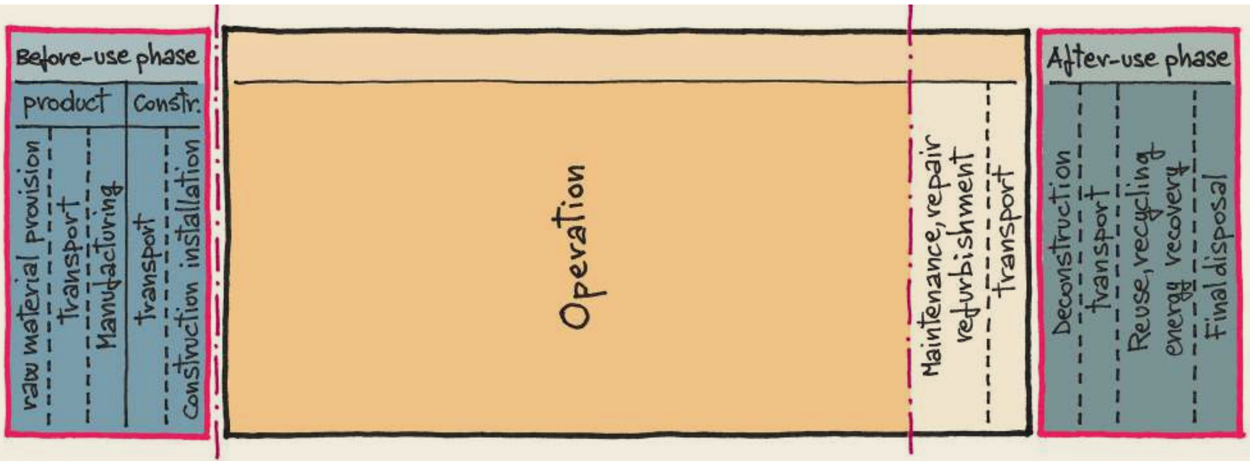


FIGURE 2.8.2 **GHG EMISSIONS OF BUILDINGS ACROSS THEIR LIFE-CYCLE**



*(Adapted from: UNEP, Common Carbon Metric - for measuring Energy Use & reporting Greenhouse Gas Emissions from building operations, http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf)*

The choices regarding building materials should also take into account their durability (the more durable, the lower the amount of GHG embodied emissions spread over the entire life cycle of the building), their reusability and recyclability.

Figure 2.8.2 shows in some detail the components of the overall GHG emissions of a building during its complete life-cycle, from emissions related to the before-use phase of the buildings, e.g. raw material extraction for metals, to transport related activities in vehicles at all stages of the building's life cycle, to after-use activities such as re-use, recycling, thermal recycling, and waste disposal processes.

It should be noted that, as the aim of a sustainable city, or neighborhood, is to reduce to zero, or nearly zero, the amount of fossil energy needed for the operation of the buildings, the amount of emissions due to this phase of the buildings' life-cycle should be converging on zero.

Thus, the main impact of the building stock on global warming would be due to the embodied emissions, and their control becomes of paramount importance, so it is not only the shape of buildings that counts: the choice of the materials is also crucial.

The urban planner's decisions affect neighbourhood mobility; the more limited the use of private vehicles, because of an appropriate mix of functions, the less the need for private cars and thus the lower the overall amount of GHG emissions embodied in the neighbourhood's fleet of cars. Moreover, reduced numbers of cars reduce the road infrastructure needed, with a consequent reduction in the materials used, thus in indirect emissions.

The urban designer's choices also affect indirect GHG emissions in relation to the amount of green spaces planned, as biomass is a CO$_2$ sink and urban agriculture has an impact on the embodied emissions of food (CO$_2$ for irrigation and transport and N$_2$O[30] for fertilisers ), especially if water and nutrients are generated within the neighbourhood through the closure of the water cycle.

## REFERENCES

CIB (2002). Agenda 21 for Sustainable Construction in Developing Countries. CIB, UNEP – IETC, South Africa 2002.

IEA (2009). Cement Technology Roadmap 2009, International Energy Agency - http://www.iea.org/publications/freepublications/publication/Cement.pdf

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change - http://www.climatechange2013.org/report/full-report/

UNEP (2010). Common Carbon Metric - for measuring Energy Use & reporting Greenhouse Gas Emissions from building operations - http://www.unep.org/sbci/pdfs/UNEPSBCICarbonMetric.pdf

WRI (2001). World Resources 2000-2001- http://www.wri.org

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[30] *Nitrous oxide (N2O) Global Warming Potential (GWP) in the 100 years' time horizon is 298, even more powerful than methane. (Source: IPCC 2013).*

## 2.9 IMPACT ON HEALTH AND ON THE SOCIAL AND ECONOMIC ENVIRONMENT

In the previous sections urban design is treated mainly from a technical point of view, aiming to reduce the impact of urban developments on the environment, both at local and on a global scale.

The aim of this section is to highlight the ways in which sustainable neighbourhood design is also beneficial to a neighbourhood's health, and to its social and economic environment.

### 2.9.1 HEALTHIER PEOPLE, HEALTHIER PLANET

Outdoor discomfort is not only a subjective, unpleasant status and a cause of energy consumption for cooling, but it also has serious consequences at individual and social level because of its connection with health.

A direct effect is an increase in temperature-related illnesses and deaths. Prolonged intense heat waves coupled with humidity may increase mortality and morbidity rates, particularly among the urban poor (as they cannot afford air conditioning and live in low quality buildings) and the elderly (OECD 2003). Infants and children are also especially vulnerable to the effects of heat and heat waves.

An increase in mortality due to heat has been reported for in relation to cardiovascular disease, respiratory disease, mental, and nervous system disorders; diabetes; and kidney and urinary system diseases (Basagaña 2011).

Extreme heat can have a deleterious effect on the health of persons who are already sick from other causes, which will then be assigned as the cause of death.

The relationship between extreme heat and mortality is of increasing concern with global warming, which will exacerbate the urban heat island effect.

Local researchers have suggested that an increase of 1 °C daily mean temperature above 28.2 °C is associated with an estimated 1.8% increase in mortality rates (School of Architecture, 2010).

A well designed, sustainable neighbourhood is cooler than a conventionally designed one, not only because of the UHI control but also because of the reduced anthropogenic heat produced by motorised traffic, and reduces the number of illnesses and deaths due to heat.

The reduction of motorised traffic has another positive effect: a reduction in air pollution. Urban air pollution not only contributes to climate change, but also kills hundreds of thousands of people annually (Sallis 2016).

Urban design that creates neighbourhoods with connected and shaded street networks, combined with mixed-use and higher-density development, promotes walking and cycling for transport, as opposed to car-based mobility, with several beneficial consequences on health:

- less heart disease, lung cancer, and a reduction in both chronic and acute respiratory diseases, including asthma (WHO 2016);
- fewer road traffic injuries and deaths;
- less exposure to road traffic noise, which influences physical health issues such as cardiovascular disease and hypertension, and, as chronic noise exposure has implications for physical and mental health through annoyance, sleep disturbance, and chronic stress (Giles-Corti 2016). Emerging evidence suggests that living close to roads where there is heavy traffic might adversely affect cognition (Chen 2017). Exposure to long-term residential road traffic noise has been associated with a higher risk for Myocardial Infarction (Sørensen 2012);
- more physical activity, which decreases the risk of major non-communicable diseases (NCDs), including coronary heart disease, type 2 diabetes, colon cancer, and breast cancer, as well as increasing life expectancy (Giles-Corti 2016). Epidemic levels of physical inactivity contribute to the deaths of millions through effects on multiple NCDs (Sallis 2016).

Sustainable urban design places high value on green areas, which are beneficial not only because they mitigate the Urban Heat Island and $CO_2$ emissions, but also because scientific evidence shows that green spaces and parks are associated with improvements in physical and mental health (Giles-Corti 2016), maintenance of good health and prevention of illness in urban environments (Dekker 2014).

A key component of a sustainable neighbourhood is urban agriculture, because it helps to close the water and waste cycles, to reduce the energy use due to food transport and because it helps to mitigate the Urban Heat Island. These are not the only benefits: urban agriculture creates a greater availability of fresh and healthy food, which is also associated with a lower prevalence of diet-related disease (Active Design Guidelines 2010).

### 2.9.2 SENSE OF COMMUNITY

Evidence suggests that walkable (i.e., denser, mixed-use and more connected) environments and the presence of a variety of destinations and housing types and population sub-groups enhance the sense of community by encouraging and facilitating social ties or community connections through opportunities for residents to meet, interact and engage in their neighbourhood (Heart Foundation 2017).

The quality of parks within the neighbourhood has also been associated with psychosocial outcomes, such as sense of community and sense of place (Heart Foundation 2017).

## 2.9.3 SOCIAL INCLUSION AND EMPLOYMENT

A thermally comfortable outdoor environment in a neighbourhood is primarily beneficial for the poor, as they spend most of their time outdoors (working, cooking, resting), and – when indoors – the discomfort is mitigated. The middle classes spend far less time outdoors, and in most cases, can afford air conditioning.

In mixed-use neighbourhoods the demand for motorised transport is reduced, and alternative modes of mobility (walking and cycling) can be promoted because work and home are close. This is especially beneficial for the urban poor, as usually – in the typically zoned city – their jobs are far from their homes. Consequently, they are forced to take multiple modes of transportation, which may involve spending a significant portion of their income (Dekker 2014) and of their time.

In order to benefit from the mixed-mode neighbourhood design, the poor have to live in it. This is a prerequisite of a sustainable development not only for social reasons, but also for the energy sustainability of the urban development, for four reasons, all linked to the urban metabolism.

The first is directly linked to the energy system of the neighbourhood. In developing countries, and especially in SSA, the distributed energy production model is the only sustainable, reliable and affordable model for dealing with both the depletion of fossil fuel resources and global warming. At neighbourhood scale, a distributed energy system, based on renewable energy sources, needs to include energy storage and to be integrated with the smart grid technology. In such a system, the energy demand pattern throughout the day is a crucial technical and economic issue, impacting on the size of both the production and the storage systems. The more diversified in quality, quantity and time distribution the energy demand, the smaller the physical energy storage required and the larger the "virtual" energy storage that can be controlled with the smart grid. Consequently, a social-economic mix should be planned within the residential area, as a mix of different energy demand patterns would derive from this. This poses one more challenge to the urban designer, as a variety of residential buildings, according to income, would have to be provided.

The second reason for which a sustainable neighbourhood should be characterized by a social mix derives from the optimization of the urban solid waste cycle. In the decentralized vision of urban development, local collection, separation and treatment of solid waste is a viable possibility, which would create employment for the poor among the local residents, and would deal with the issue of waste in a sustainable way.

The third reason derives from the adoption of a decentralised water supply and local wastewater treatment and reuse. As shown in section 3.5, rainwater harvesting and local wastewater management imply the use of a low to medium skilled workforce, who would provide a better service if locally recruited, because they would be directly interested in the appropriate operation and maintenance of the infrastructures. Moreover, the re-use of waste can increase local agricultural productivity, resulting in increased revenue for local producers.

The fourth reason is linked to the employment opportunities offered to less skilled people by the integration of urban agriculture into the development's texture.

The issues of social inclusion and employment are thus closely connected to a circular economy and renewable energy sources in a sustainable neighbourhood, and need to be enhanced by the design. In order to obtain such a social mix, the prerequisite is the availability of affordable housing for the less wealthy members of a neighbourhood's population, as stressed by the UN-Habitat principle (UN-Habitat 2013b), which recommends the allocation of 20-50% of residential floor area to affordable housing, one single tenure not exceeding 50% of residential floor area.

## 2.9.4 THE GENDER ISSUE

Women's multiple responsibilities – e.g. providing food and water, maintaining a household, and caring for children, elders, and sick family members – lead to diverse interactions with the urban environment (UN-Habitat 2012). Since women hold primary responsibility for care and reproductive activities, they are especially affected by limited (or, in some cases, lack of) access to basic services. Limited access to essential infrastructure such as water and sanitation and restricted mobility all contribute to an increase in the burdens related to unpaid carework, and thus exacerbate gender-based disadvantages (Tacoli 2012).

Limited access to a municipal piped water service, or a badly working service, means that women, who are primarily responsible for providing water, have to spend a long time queuing at overcrowded public standpipes and other water sources, as water purchased from private suppliers can be prohibitively expensive, reducing time for education, employment, childcare and rest.

Because women tend to spend more time than men in the home and neighbourhood, they are also more directly exposed to the environmental hazards of poor sanitation (WomenWatch 2009).

Sustainable neighbourhoods may significantly soften this aspect of women's lives, as the provision of better sanitation facilities together with better access to water and energy reduces women's reproductive labour and time burdens (UN-Habitat 2013).

Employment is one of the key dimensions of the economic empowerment of women in cities (UN-Habitat 2013), and implies mobility, especially considering that domestic service is a major category of employment for women in the urban areas of low-and middle-income countries. Moreover, women's mobility is related to a variety of activities, from work to shopping to school trips, unlike men who are more likely to move only between their home and their workplace. Balancing paid work with domestic responsibilities increasingly requires mobility. At the same time, the growing cost of essentially private "public" transport in most cities, as well as the very real threat of sexual harassment and physical violence for women travelling alone on public transport or walking act as powerful restrictions on women's mobility and their right to the city (Tacoli 2013).

A mixed-use, mixed income walkable neighbourhood would significantly minimise the need for long journeys, also reducing the time spent on travelling, as it becomes more likely that a job as a domestic worker is available within the neighbourhood, and all the other activities imply short distances to travel.

The risk of violence is also reduced because of the improved sense of community characterising a sustainable neighbourhood.

Neighbourhoods of mixed uses with short travel distances and close proximity to work, childcare, and schools, plus extensive availability of stores and services, along with safe pedestrian environments and frequent and easily accessible public transportation systems — these constitute some of the main elements of an urban life that fits the needs of women as caregivers (Jaeckel and van Geldermalsen 2006).

## 2.9.5 ECONOMICS

Can a sustainable neighbourhood be cost-effective? It is an often asked but incomplete question. It is incomplete because a crucial detail is missed: cost effective for whom? For the private developer, for the municipality, for the state, or for the neighbourhood's inhabitants?

For each of these players there is a different answer.

Let us consider the developer's point of view. His aim is a productive investment, obtaining a certain amount of profit by selling the buildings. Of course, the sale price of buildings will include a share of the urbanisation costs, i.e., all the infrastructures such as streets, electricity grid, water network, sewerage, their connection to the municipal systems, greening, etc. When a conventional neighbourhood development is compared to a sustainable one, it can be seen that the sustainable development allows some savings deriving from the higher density, especially in the residential buildings (the cost per cubic meter of a multi-storey building is lower than that of a detached or semi-detached house), and from the reduced road and parking areas (in a walkable neighbourhood streets and roads can be narrower and fewer parking areas are needed). Other savings derive from the lower or zero cost for connection to the municipal water and sewage networks, as this connection may not be necessary at all or will require less expensive infrastructure. The capital investment for decentralized wastewater systems is generally less than for centralized systems in peri-urban areas, and they are also likely to be cheaper to construct and operate. By tackling wastewater problems close to source, the large capital investment of trunk sewers and pumping costs associated with centralized systems can be reduced, thus increasing the affordability of wastewater management systems (Parkinson 2003).

Some savings may also derive from the reduced cost of connection to the electricity grid, depending on the degree of self-sufficiency of the neighbourhood.

However, a higher investment cost derives from the renewable energy system and from the water network (rainwater harvesting and storage system and dual piping for drinkable and non-drinkable water), even if part of the cost is compensated for by the lower costs of the connection to the national electricity grid and to the municipal water system.

The extra green areas (parks, agriculture plots) that derive from the need for containing the Urban Heat Island must also be regarded as an indirect cost as they reduce the areas on which buildings could be constructed and sold.

Finally, a further cost is that deriving from all the measures that are to be taken to reduce the amount of runoff and to provide for the recharging of the underground water table.

Considering all these costs and savings, and adding the higher cost of the integrated design process compared to a conventional one, the balance is such that – in order to make some profit – the buildings would have to be sold at a price higher than the average elsewhere, and would not be competitive.

From the point of view of a private developer, then, a sustainable neighbourhood is not cost-effective or is, at least, a very risky investment, even if, according to the economic evaluations carried out for the EcoBlok in Qindao, China (see Chapter 4 – Case studies), the total extra cost would be about 5-10%, compared with a conventional development, and the return time about 10 years (the extra cost could be recovered if the service fees for electricity, water and waste were paid to the developer). There is, however, the financial problem, for the developer, of a larger initial investment, which should be made easier by the municipal or central government, considering that, as shown below, the most important benefits are social and cannot easily be quantified in terms of money.

Let us consider now the point of view of a neighbourhood resident, or a shopkeeper or a company that decided to pay more than the average for their dwelling, premises, or office space, respectively.

The extra cost for PV and other renewable energy systems would be recovered in a short period of time. Moreover, a decentralised energy system integrated into a mini-grid, would significantly reduce or even eliminate the outages and the power surges typical of centralised electricity systems in SSA cities (and in general in cities in developing countries).

The extra cost for greening would be recovered to a certain extent by the savings in electricity consumption for air conditioning. The unrecovered part of the cost would be largely offset by the quality of the urban environment, which is not quantifiable in terms of money, but is a recognised value, for which there is a willingness to pay.

Water costs should be lower than in a conventional neighbourhood, with a further advantage: the reliability of the sustainable neighbourhood's water system is far higher than that of a conventional centralised one, whose unreliability – in most cities in developing countries and especially in SSA – induces additional costs for providing storage tanks and for pumping.

Thus, a decentralised water system relying on rainwater and on recycled wastewater can compete with a conventional one and, taking into account its non-monetary advantages, might be considered more than cost-effective by the neighbourhood's residents (or a shopkeeper or a company).

The extra cost, if any, of the decentralised wastewater treatment system can be offset by the sale of both fertiliser and treated wastewater, and the service could be cheaper than in a conventional system.

It may be concluded that a potential buyer of an apartment, or in general of floor space, in a sustainable neighbourhood, would not spend, for both investment and operation, more than in a conventional neighbourhood, and possibly less in a longer term perspective of ten-twenty years. The balance is different for the municipality, which has to consider and prioritise other, more complex, economic analyses.

The first factor that a public institution has to consider is that, as a new urban development may last for centuries, the usual – short term – economic analysis cannot be applied. Investments whose payback period must be only a few years are not consistent with the construction of urban infrastructures. Their economic viability must be calculated comparing the present initial cost with the long term total economic return. This approach makes viable many investments that are not compatible with a short term economic return.

Moreover, there are investments that may not have a computable economic return, but must be made, as they have a social value. During the 19th Century, European and American cities developed water and sewerage networks. The investment was not made for profit, but for social reasons. Water was – and is – a need and a right, and sewerage was needed for fighting recurrent epidemics, which had a very high social cost. It was a public investment, not aiming for profit, and the municipality managed the two networks directly. At the beginning of 20th Century, European cities started to buy from private companies another service that had become a need for the citizens: gas. The reason for this move was that when there is a need, a social need, different management principles must be used. These are principles that do not match with the short-term profit approach of private companies, which did not provide the services to low-income customers, as they consumed too little to justify the investment in the network and were unable to pay for the connection. So, gas companies become municipal companies to provide the service to those low-income households as well, billing them with social tariffs.

Later on, when electricity became a social need, many municipalities bought the grid and the power stations servicing the city from the private owners, the electricity companies becoming municipal companies, for the same reasons for which they had bought the gas companies. In all cases, the municipal companies' losses caused by charging social tariffs were compensated for through progressive taxation: the richer paid for the poorer.

Then there are investments whose benefits are difficult or impossible to quantify. There are several of these that are related to sustainable neighbourhoods.

The first is health. Improving the citizens' health brings economic benefits, because of both the direct cost of the health service and the lost productivity deriving from the illness. The second is the increase in both productive activities and employment, deriving from the management of electricity, water, wastewater and solid waste and from urban agriculture. The growth of wealth brings higher tax revenues. Moreover, employment reduces the amount of money that is spent for assisting families with low or no income. The third is the reduction of the number and the extent of flooding events, with the consequent avoided cost.

Finally, there are factors than do not belong to the realm of economics, such as quality of life, sense of community, social inclusion, and improved food security.

Municipalities, if involved in a sustainable neighbourhood development, should adopt the life cycle cost evaluation. "Life cycle costing estimates the capital and operating costs of an entire development over a period of time. It can include an assessment of both public and private costs, and can be defined in financial, social, and environmental terms[31]. It can be used to assess development projects at any scale.

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[31] *A life cycle cost assessment can include capital and operating cost estimates for:*

- *hard infrastructure (e.g., roads water, sewers)*
- *municipal services (e.g., transportation, fire, police, waste management)*
- *private costs (e.g., commuting/transportation, home heating)*
- *costs of externalities (e.g., air pollution, motor vehicle accidents).*

A life cycle costing assessment assesses the proposed development holistically. It examines not only the capital cost of certain features, but also the cost over their life span, including maintenance and their potential to be adapted to different uses in the future" (CRP 2011).

From the municipality's standpoint, sustainable neighbourhoods do not have any drawbacks. They are economically viable from a holistic point of view – the one municipalities should have - and aim for both a better local quality of life and the global benefit of the planet, by contributing to control of global warming.

Sustainable neighbourhoods should be seen as social needs, just as water, wastewater, solid waste, gas and electricity were considered to be social needs in the past two centuries. They are the social needs of the 21st Century, and their extra cost must be redistributed over the entire community, according to the citizens' wealth, as is already happening all over the world for the extra cost of energy efficient buildings., They have been made mandatory – and, in the same way, there should be mandatory urban regulations that impose sustainable neighbourhoods on urban development planning.

## REFERENCES

Active Design Guidelines Promoting Physical Activity and Health in Design (2010), City of New York - https://centerforactivedesign.org/dl/guidelines.pdf

Basagaña, X.et al. (2011). Heat Waves and Cause-specific Mortality at all Ages, Epidemiology -Volume 22, Number 6.

Chen, H. et al. (2017). Living near major roads and the incidence of dementia, Parkinson's disease, and multiple sclerosis: a population-based cohort study, The Lancet, Vol.389 Number 10064, 2017 - http://dx.doi.org/10.1016/S0140-6736(16)32399-6

CRP (2011). Greenfield Tool Box, Connectivity index. Calgary Regional Partnership - http://greenfield.calgaryregion.ca/tools/greenfield_process_connectivityIndex.pdf

http://calgaryregion.ca/dam/Website/reports/General/Toolbox/Greenfield/Part-3_-process-tools/Part%203_%20process%20tools.pdf

Dekker, S. (2014). Climate Change, Influencing the Health of Urban Populations, International Center for Climate Governance - http://www.iccgov.org/iccgstudies/climate-change-influencing-the-health-of-urban-populations/

Giles-Corti B. et al. (2016). City planning and population health: a global challenge, www.thelancet.com Vol 388 December 10, 2016.

Heart Foundation (n.d). Healthy Active by Design - http://www.healthyactivebydesign.com.au

Jaeckel, M. and van Geldermalsen, M. (2006). Gender equality and urban development: building better communities for all, Global Urban Development Magazine, Volume 2, Issue 1, March 2006 - http://www.globalurban.org/GUDMag06Vol2Iss1/Jaeckel%20&%20van%20Geldermalsen.htm

OECD (2003). Poverty and Climate Change - http://www.oecd.org/env/cc/2502872.pdf

Sallis J. F. et al. (2016). Use of science to guide city planning policy and practice: how to achieve healthy and sustainable future cities, www.thelancet.com Vol 388 December 10, 2016

School of Architecture, Chinese University of Hong Kong (2010), Urban Climatic Map and Standards for Wind Environment - Feasibility Study – Executive summary - http://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/ucmap_project/content/reports/executive_summary.pdf

Sørensen, M. et al. (2012). Road Traffic Noise and Incident Myocardial Infarction: A Prospective Cohort Study, PLOS ONE, http://dx.doi.org/10.1371/journal.pone.0039283

Tacoli, C. (2012). Urbanization, gender and urban poverty:paid work and unpaid carework in the city, IIED and UNFPA - http://www.unfpa.org/resources/urbanization-gender-and-urban-poverty

Tacoli, C. (2013). The benefits and constraints of urbanization for gender equality, Environment&Urbanization Brief – 27 - http://pubs.iied.org/10629IIED/

UN-Habitat (2012). GENDER ISSUE GUIDE - URBAN PLANNING AND DESIGN - http://unhabitat.org/books/gender-responsive-urban-planning-and-design/

UN-Habitat (2013). STATE OF WOMEN IN CITIES 2012-2013 - http://mirror.unhabitat.org/pmss/listItemDetails.aspx?publicationID=3457

WHO (2016). Ambient (outdoor) air quality and health - http://www.who.int/mediacentre/factsheets/fs313/en/

WomenWatch (2009). Gender Equality and Sustainable Urbanisation - fact sheet (2009) -http://www.un.org/womenwatch/feature/urban/

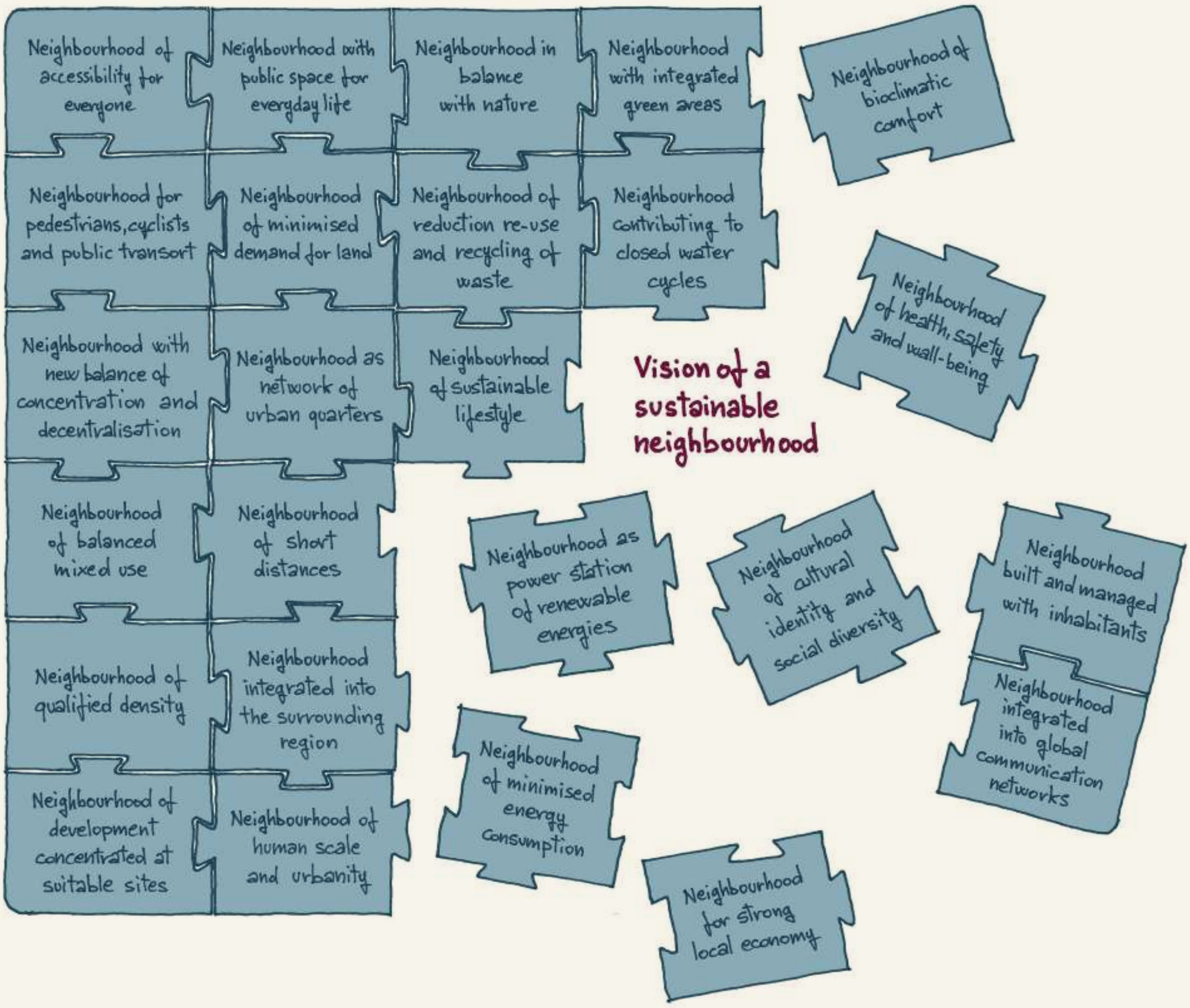
# DEFINING A SUSTAINABLE NEIGHBOURHOOD

In basic terms, a neighbourhood is an area of dwellings, employment, retail, and civic places and their immediate environment that residents and/or employees identify with in terms of social and economic attitudes, lifestyles, and institutions; by itself the neighbourhood is a village, but combined with other neighbourhoods it becomes a town or a city (USGBC 2011).

Size is a defining feature of a sustainable neighbourhood and is typically based on a comfortable distance for walking from dwellings to the more frequently used services. This leads to an area no greater than 30-40 ha, and a population of no more than 4,500-6,000 inhabitants, according to the area, which corresponds to a density of more than 38 dwellings per hectare – assuming 4 people per dwelling.

What characterizes a sustainable neighbourhood is not only its walkability, which minimises dependence on motorised mobility. A sustainable neighbourhood relies mainly on on-site renewable energy sources and closes water, wastewater and solid waste cycles within itself, minimising its environmental impact and maximising its resilience.

A sustainable neighbourhood is also a pleasant place to live in, where social equity, employment and a sense of community are emphasised.



*Adapted from: Schubert 2001*

# 03

# DESIGN TIPS AND CHECKLIST

In this chapter, tips for urban design have been collected and organized to provide a synthetic guide for the design of more environment and energy-aware urban neighbourhoods in tropical climates in general and more specifically in EAC climates.

The growth of cities in developing countries is unavoidable, but it should be good growth. New developments should follow the principles of sustainability and resilience, simply because the way we build today will last for many decades and will affect the lifestyle of the citizens of the future.

The physical design of neighbourhoods demands special attention. The rules, or tips, for urban design given in the following chapter are based on what has been discussed in the previous chapters and incorporate the UN-Habitat Five Principles (UN-Habitat 2013), relevant literature on sustainable urban planning and design (Alexander 1977, ADG 2010, GTB 2011, LNWAG 2009), and suggestions from the Green Building Council's LEED ND rating system (USGBC 2011).

Of course, there are no absolute values or easy rules to apply without serious scientific investigation of each topic; in fact, even scholars do not always agree on some design values or rules. Be that as it may, it is important to tackle all the points mentioned from the very beginning of the design of a new neighbourhood, even at a basic level: the idea, indeed, is to provide a set of themes which should be included in the concept scheme.

Only short descriptions are provided here in order to make the check-list more user-friendly; more in-depth and detailed information is provided in the previous chapters.

Very different aspects are listed here, and some topics can generate conflicting ideas: looking for the compromise among these is the added value of design, whereby the designer has to justify his/her choice on the basis of his/her values and priorities. This is because of the complexity of the aspects that urban design has to take into account.

Figure 3.1 summarizes some of the interrelations occurring between the built environment and other planning aspects.

The planning and design of new neighbourhoods should respond to performance requirements. Performance requirements in the built environment are mainly the following:

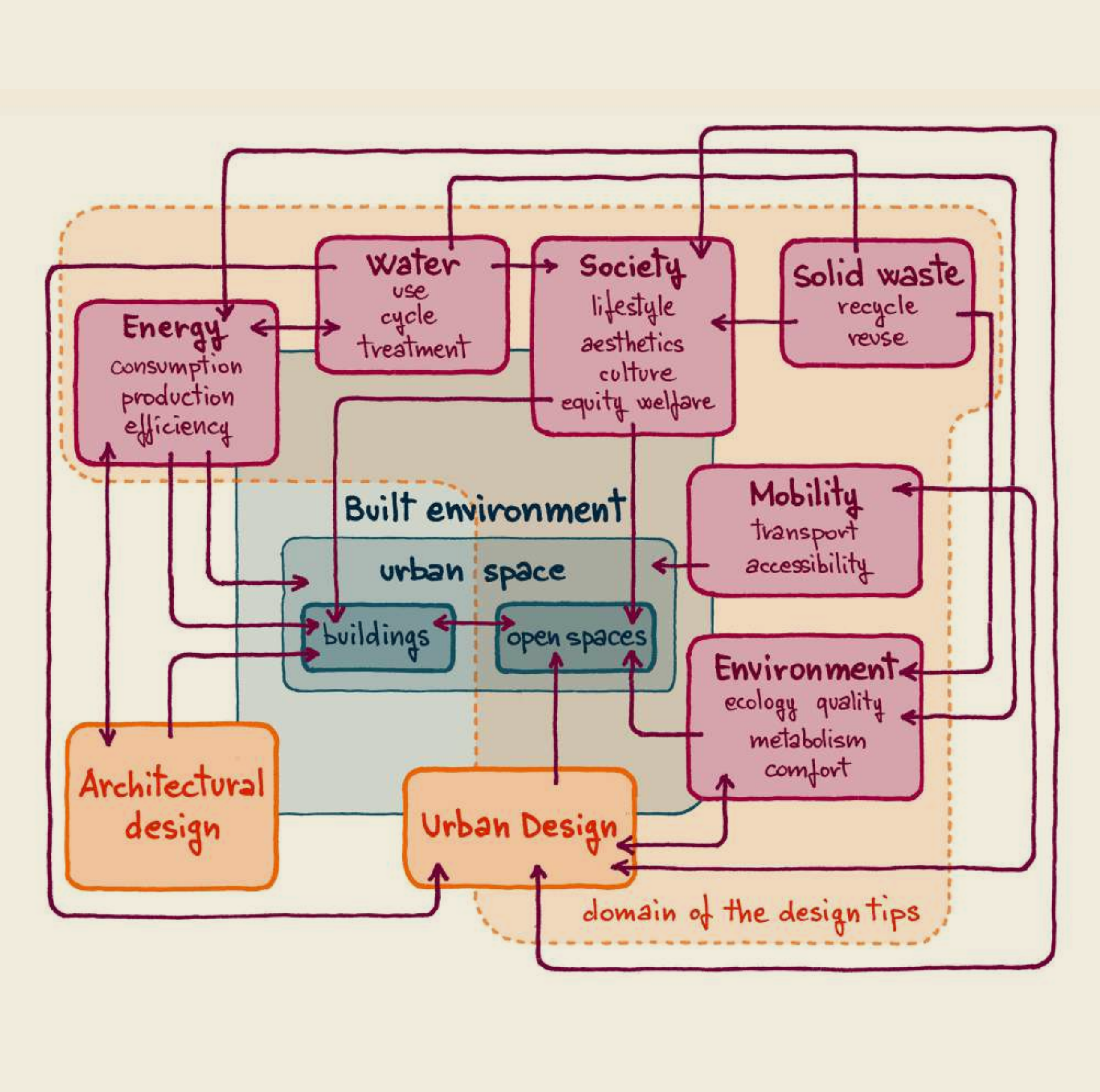
- Well-being, which includes physiological aspects related to human comfort, such as identity, sense of belonging and safety, besides thermal and visual comfort;
- Energy efficiency and clean sources of energy;
- Environmental quality and sustainability, which involves water, sanitation and materials;
- Resilience.

Design has to give a sound response to meet these requirements. The object of the design response and the corresponding effectiveness of a design action can vary in relation to the performance requirement (see Figure 3.2). For instance, different design domains can better respond to performance requirements than others.

The design tips address the following subjects:

- Site layout; location,
- Site layout; planning,
- Climate responsive design,
- Energy supply,
- Urban metabolism and closed cycles,
- Social and economic domains.

FIGURE 3.1 THE SPATIAL DIMENSION OF THE BUILT ENVIRONMENT – AND THE URBAN SPACE IN PARTICULAR – COLLECTS INPUTS FROM DIFFERENT DOMAINS. THE MUTUAL DEPENDENCIES AMONG DISCIPLINES, BUILDINGS AND OPEN SPACES DEFINE THE COMPLEXITY OF THE WORK.



The design tips are presented according to the following template:

Design tip background (why it is important)

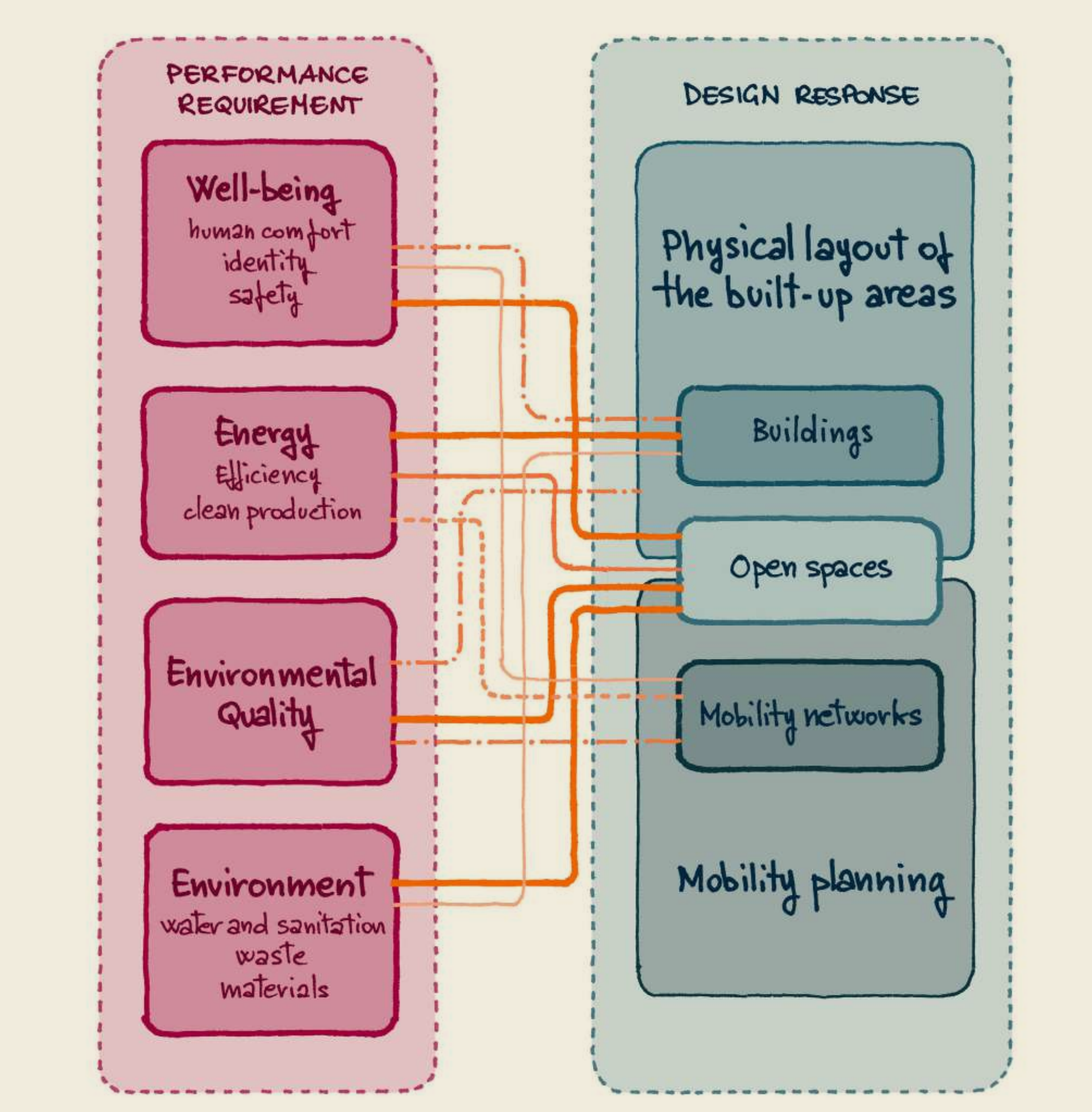
**Design tip**

*Quantitative design values or evaluation methods*

The checklist at the end of the design tips is a simple way to verify if the design schemes for new neighbourhoods have included the wide spectrum of relevant environmental and energy topics that will affect urban sustainability in the long term. The large representation of design measures within the design scheme alone is already a very good message.

The tips and checklist can be read as an independent part of the guidebook. In fact, this chapter summarizes the theoretical and experimental knowledge presented throughout the guidebook.

FIGURE 3.2 **THE INTERPLAY BETWEEN PERFORMANCE REQUIREMENTS AND DESIGN RESPONSE OF DIFFERENT DOMAINS OF THE BUILT ENVIRONMENT.**



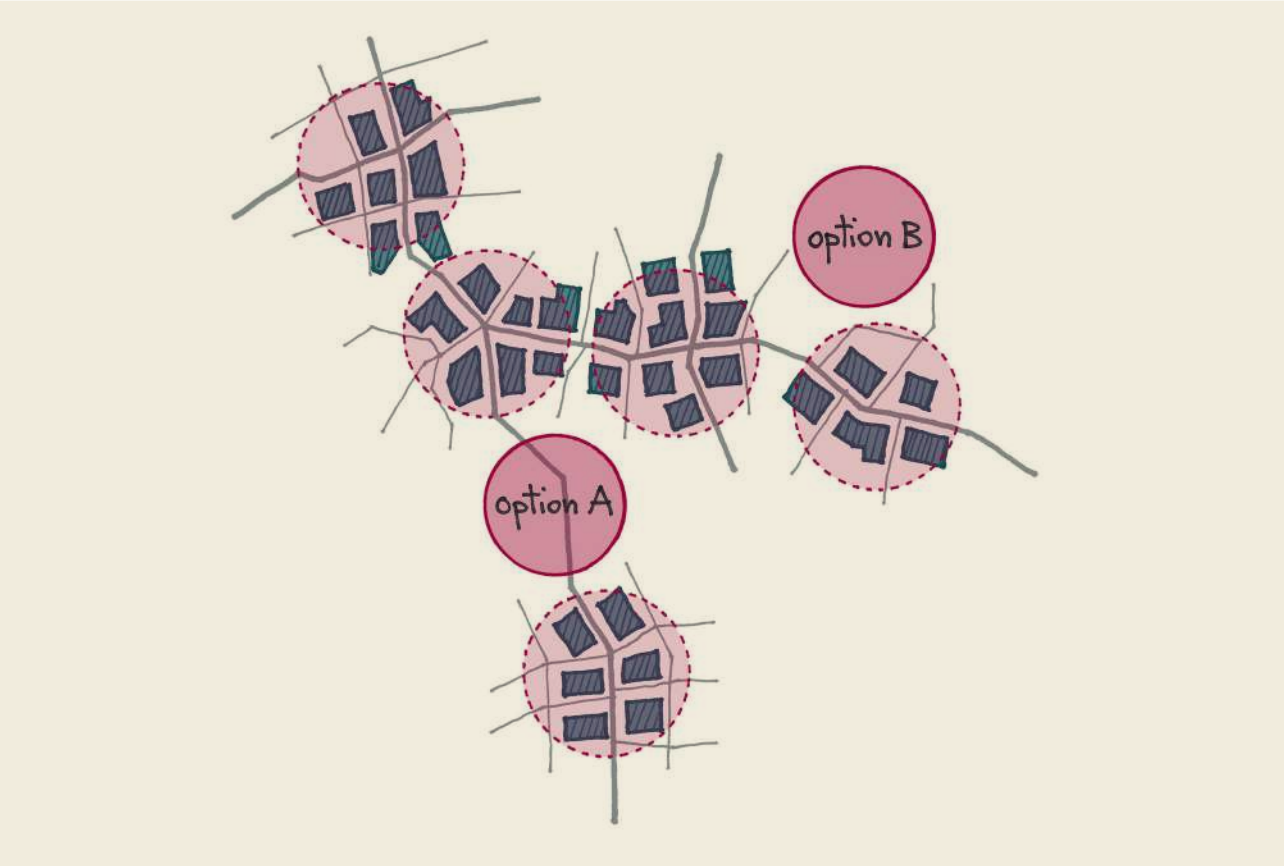
## 3.1 SITE LAYOUT: LOCATION

The very earliest stage of the decision-making process concerns the choice of the location of the neighbourhood, which is crucial for the future environmental quality, energy consumption and lifestyle of the inhabitants. The choice of a smart location for the new settlement that takes into account the significance of the local climate, is represented by essential checks on our list.

### 3.1.1 LINKAGE TO EXISTING URBAN AREAS

Most of the time, the choice of location for the new neighbourhood does not depend on the designer or the developer, but is a given condition. Therefore, the following set of tips should be carefully considered by public authorities. Moreover, the choice of location should be taken into account by everyone working on the plan for a new district, because it gives a measure of the starting point conditions and the potential of the new neighbourhood to improve the overall sustainability of the district.

FIGURE 3.3 A NEW NEIGHBOURHOOD SHOULD BE PLACED ON EXISTING INFRASTRUCTURAL CORRIDORS. OPTION A AND B ILLUSTRATED IN THE SCHEME (WITH BLUE CIRCLES) REPRESENT TWO DIFFERENT LOCATIONS FOR NEW NEIGHBOURHOODS: OPTION A IS PLACED ON A MAIN ROAD AND REPRESENTS AN EXAMPLE FOR AN INFILLING STRATEGY (PREFERRED OPTION), WHEREAS OPTION B IS PLACED ON AN OPEN AREA, WITH NO ROUTING ON THE EXISTING MAIN ROAD NETWORK (TO BE AVOIDED).



**Locate the new neighbourhood on existing infrastructure and priority development axes, in order to increase its access to main urban functions and reduce commuting time. in this case, special attention is devoted to transit oriented developments (TODs). Give preference to infilling areas inside the existing city, avoid construction on un-urbanized land. In particular, make sure the new centrality generated by the neighbourhood is directly interconnected to existing (or available in the near future) local or regional centralities along an urban or regional corridor, typically (or potentially) served by public means of transit. In fact, high-density nodes can sustain the delivery of public services. If the new neighbourhood is not interconnected to any existing transit corridor, it should itself become the occasion for recomposing dispersed urban nuclei and identify the trajectory for a new mainstream DEVELOPMENT (figure 3.3).**

**Limit sprawl and avoid building the next 'cathedral in the desert'. Try to build in continuity with urbanized land.**

*As a measure, you can quantify the percentage of already urbanized land on the boundary of your design area (Figure 3.4), as follows:*

$$\text{percentage of linkage to urban land } [\%] = \frac{\text{urbanized perimeter } [m]}{\text{total design area perimeter } [m]} * 100$$

Try to provide a percentage of linkage to urban land ≥ 50%.

FIGURE 3.4 **THE LEVEL OF URBAN INTEGRATION CALCULATED ON THE PERIMETERS OF A NEW NEIGHBOURHOOD: THE HIGHER THE PERIMETER DIRECTLY IN CONTACT WITH THE URBANIZED AREAS THE STRONGER THE INTEGRATION WITH THE EXISTING NEIGHBOURHOODS.**

## 3.2 SITE LAYOUT: PLANNING

This initial master-planning phase is made up of several steps:

- Identification and analysis of the climatic conditions of the site, which provide natural resources such as sun and wind potential, water availability (rainwater, underground water, water bodies, running water), soil characteristics;
- Identification of important natural constraints (topography, rivers, parks, forests, wetlands, agriculture);
- Identification of environmental and other threats and risk areas;
- Identification of main access points and infrastructure (roads from city to highway);
- Identification of legal restrictions (protected natural areas, heritage sites).

Then, the functional brief with the diverse land uses, the overall density and its distribution over the site and the urban form (which includes street network layout and building typologies design) have to be defined.

Sustainable neighbourhood design should:

- Promote high density urban growth, alleviate urban sprawl and maximize land efficiency;
- Promote sustainable, diversified, socially equal and thriving communities in economically viable ways;
- Encourage walkable neighbourhoods and reduce car dependency;
- Optimise use of land and provide an interconnected network of streets which facilitate safe, efficient and pleasant walking, cycling and driving;
- Foster local employment, local production and local consumption;
- Provide a variety of plot sizes and housing types to cater for the diverse housing needs of the community, at densities which can ultimately support the provision of local services.

*UN-Habitat (2013)*

### 3.2.1 PROVIDING LAND USE AND INCOME DIVERSITY

Mixed land use and urban functions are crucial prerequisites to sustainable neighbourhood design. Avoid single use zoning because this will inevitably lead to car-dependence. Specialized citadels like business parks, shopping malls, and so on, always involve large parking lots and encourage private mobility, promoting energy consumption and air pollution. Moreover, outside office or shopping hours, specialised urban areas are empty, dead spaces.

Mixed income housing is also crucial both for social equity and for supporting the operation of decentralised energy, water, wastewater and solid waste systems. The provision of several building typologies and types of dwelling units enables an effective social mix and the creation of varied places where different environmental qualities can satisfy people's different needs.

**Scatter work places throughout the district, rather than concentrating them in areas that only contain other workplaces. By increasing the proximity of work and home, we also eliminate the need for workers to use motorised vehicles to travel between home and work.**

*At least 40 per cent of floor space should be allocated for economic use in any neighbourhood.*

*Twenty to 50 per cent of the residential floor area should be for low cost housing; and each tenure type should be not more than 50 per cent of the total.*

**Follow land use rules to enhance mixed use in buildings with high density. Putting Housing on the upper floors and retail units and offices on the lower ones is a good strategy to create urban vitality, to make dwellings more comfortable because they will be better ventilated and, indirectly, to reduce travel demand.**

*Single function blocks should cover less than 10 per cent of any neighbourhood.*

**Ensure that a good overall level of mixité is reached by evaluating the diversity and the redundancy of the land uses by analogy with ecological systems.**

*Check that the value of the Shannon-Wiener diversity index ranges from 1.5 to 3.5, or that the Simpson diversity index is greater than 0.6*

*At least 15 different land uses at walkable distance from each dwelling should be provided.*

### 3.2.2 CALIBRATING STRUCTURE AND DENSITY

The density of urban plots has a big impact on street width and building height, thus on solar access, on the size of green areas and on local airflows which, in turn, affect outdoor comfort, the liveability of open spaces and – through the impact on indoor comfort – the amount of energy needed for air conditioning. Density also affects mobility and the possibility of making use of decentralised energy production, of wastewater and solid waste treatment systems, of efficient conversion technologies and of urban agriculture. Furthermore, a compact design with higher density housing units, mixed land use, multi-purpose streets, and appropriate grid layout preserves valuable land resources and municipal services can be provided cost effectively. Given the number of parameters involved and the complexity of the system, the optimum density is the result of a trial and error iterative process which also checks whether the space requirements for energy, water and waste systems are consistent with the chosen density.

**Start the iterative process, bearing in mind that the new neighbourhood should aim to accommodate at least 150 people/ha in the medium-long term.**

**Design the neighbourhood around a 5 or maximum 10-minute walk. As a general check, all the housing should be placed within a five to ten-minute walk of the more frequently used services. Hence, all the residential areas should be covered by the ped-shed calculated on the local centres.**

*Draw the ped-shed, or walkable catchment, from the central spot (where the local civic or service centre should be located). The ped-shed is a map (Figure 3.5) showing the five and ten minute walk accessibility of the neighbourhood, both theoretical and actual. The theoretical five-minute walking distance is a circle with a radius of about 400 m drawn around any particular centre, resulting in a circle with an area of 50 ha. When calculating a ten-minute walking distance, the radius used is about 800 m, resulting in a circle with an area of 200 ha.*

*The actual walking distance area is obtained as follows:*

- *First, draw a circle around the destination with a radius of 400 m. This circle represents the maximum possible walking distance "as the crow flies."*
- *Second, measure the walkable distance (e.g., 400 m.) from a destination along the pedestrian routes. This mapping process identifies the actual walking distance. Note that the 400-metre distance from the destination will probably fall short of the circle mapped in the previous step – this is due to the 400-metre distance being mapped "as the crow flies."*
- *Third, identify the plots, buildings, parks, and other destinations that can be reached within that distance. The area around these features represents the walkable catchment. This is the actual area from which a pedestrian would be able to access the centre along the available streets in a five-minute walk.*

*Ped-shed or walkable catchment calculations are expressed as the actual area within a five-minute walking distance as a percentage of the theoretical area (as the crow flies) within a five-minute walking distance (or ten-minute).*

## BOX 3.1 EXAMPLE - CALCULATION OF THE SHANNON-WIENER DIVERSITY INDEX, OF THE REDUNDANCY AND OF THE SIMPSON DIVERSITY INDEX

With reference to Box 3.2.1, Chapter 3:

1. Calculate the Shannon-Wiener diversity index H for the neighbourhood:

$$H = -\sum_{i=1}^{i=k} p_i \ln{(p_i)}$$

2. Calculate the maximum possible diversity $H_{max:}$

$$H_{max} = -ln\frac{1}{k}$$

3. Calculate the redundancy R:

$$R = 1 - \frac{H}{H_{max}}$$

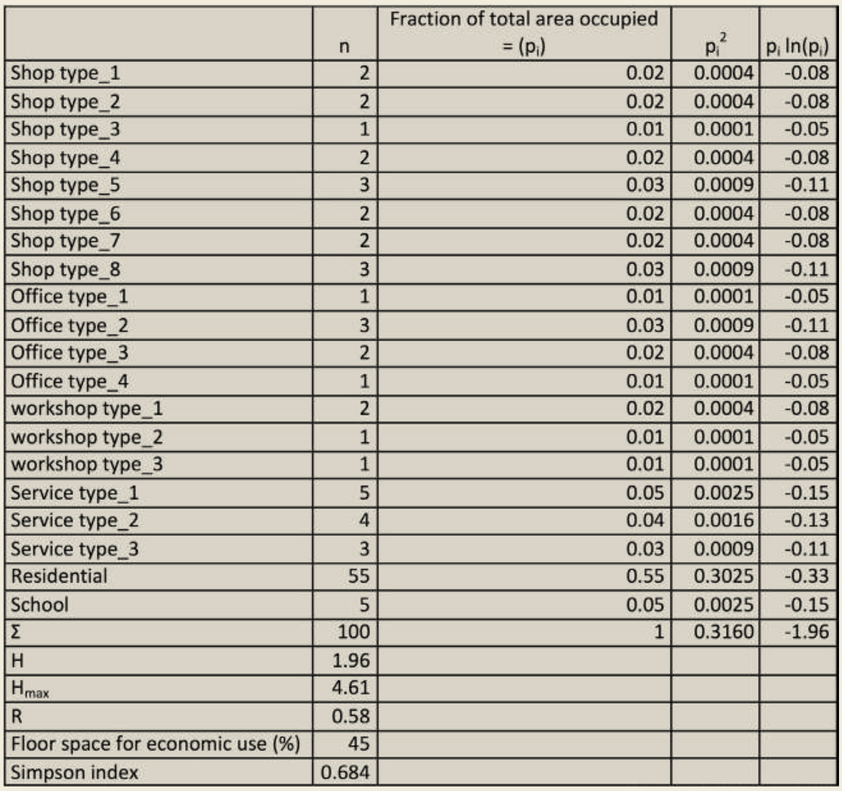
Example:

In a neighbourhood k = 20 different classes of land use functions are present, as listed in column 1 of Table B5.1. Each land use function can be present more than one time, so there are 55 apartments, 1 school, 3 shops type_8, etc., for a total of N, as shown in column 2. In the third column pi = n/N is calculated, i.e. the weight of each land use function. Alternatively, $p_i$ can be used to represent the fraction of the total land allocated to each function if n is expressed as floor area occupied and N is the total floor area of the neighbourhood, as chosen in this example. In the fourth column the values $p_i$.ln ($p_i$) are calculated.

The calculations show that the Shannon-Wiener diversity index is H = 1.96, the redundancy is R = 0.58, and that 45% of floor space is allocated for economic use; the values of both the diversity index and the redundancy are within the limits characterising healthy ecosystems and, by analogy, resilient neighbourhoods. The value of the Simpson index D for the same example is:

$$D = 1 - \sum_{i=1}^{i=k} p_i^2 = 1 - 32 = 0.68$$

TABLE 3.1 **THE EXAMPLE WITH 20 DIFFERENT CLASSES OF LAND USE FUNCTIONS IS USED.**



| | n | Fraction of total area occupied = ($p_i$) | $p_i^2$ | $p_i$ ln($p_i$) |
|---|---|---|---|---|
| Shop type_1 | 2 | 0.02 | 0.0004 | -0.08 |
| Shop type_2 | 2 | 0.02 | 0.0004 | -0.08 |
| Shop type_3 | 1 | 0.01 | 0.0001 | -0.05 |
| Shop type_4 | 2 | 0.02 | 0.0004 | -0.08 |
| Shop type_5 | 3 | 0.03 | 0.0009 | -0.11 |
| Shop type_6 | 2 | 0.02 | 0.0004 | -0.08 |
| Shop type_7 | 2 | 0.02 | 0.0004 | -0.08 |
| Shop type_8 | 3 | 0.03 | 0.0009 | -0.11 |
| Office type_1 | 1 | 0.01 | 0.0001 | -0.05 |
| Office type_2 | 3 | 0.03 | 0.0009 | -0.11 |
| Office type_3 | 2 | 0.02 | 0.0004 | -0.08 |
| Office type_4 | 1 | 0.01 | 0.0001 | -0.05 |
| workshop type_1 | 2 | 0.02 | 0.0004 | -0.08 |
| workshop type_2 | 1 | 0.01 | 0.0001 | -0.05 |
| workshop type_3 | 1 | 0.01 | 0.0001 | -0.05 |
| Service type_1 | 5 | 0.05 | 0.0025 | -0.15 |
| Service type_2 | 4 | 0.04 | 0.0016 | -0.13 |
| Service type_3 | 3 | 0.03 | 0.0009 | -0.11 |
| Residential | 55 | 0.55 | 0.3025 | -0.33 |
| School | 5 | 0.05 | 0.0025 | -0.15 |
| Σ | 100 | 1 | 0.3160 | -1.96 |
| H | 1.96 | | | |
| $H_{max}$ | 4.61 | | | |
| R | 0.58 | | | |
| Floor space for economic use (%) | 45 | | | |
| Simpson index | 0.684 | | | |

FIGURE 3.5 **PED-SHED MAP. ACTUAL REACHABLE AREA WITHIN FIVE MINUTES: 60% OF THE THEORETICAL; WITHIN TEN MINUTES: 40%. ADAPTED FROM LNWAG 2009.**

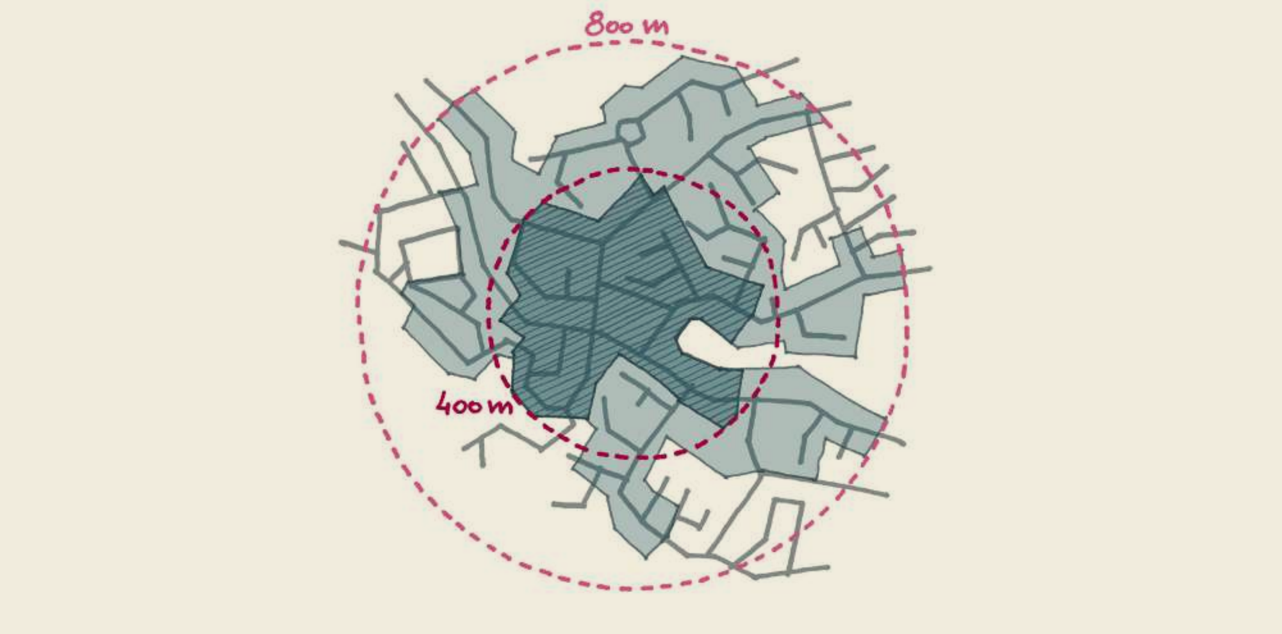


TABLE 3.2 **USES REACHABLE WITHIN 5 MIN WALK**

**Food Retail**
Supermarket
Other food store with produce

**Community-Serving Retail**
Clothing store or department store selling clothes
Convenience store
Farmer's market
Hardware store
Pharmacy
Other retail

**Services**
Bank
Gym, health club, exercise studio
Hair care
Laundry, dry cleaner
Restaurant, café, diner

**Civic and Community Facilities**
Adult or senior care (licensed)
Child care
Community or recreation centre
Cultural arts facility (museum, performing arts)
Educational facility
Family entertainment venue (theatre, sports)
Government office that serves public on-site
Place of worship
Medical clinic or office that treats patients
Police or fire station
Post office
Public library
Public park
Social services centre

*A good target is to have 60 per cent of an area within a five-minute walk, or a ten-minute walk to a transit station.*

*Note that the walkable catchment should always count the area of land used for dwellings but not include the public open spaces contained in the accessible area.*

*Locate and/or design the project such that at least 50 per cent of its dwelling units are within a 400-m walking distance of the number of diverse uses in Table 3.2, including at least one use from each of the four categories (USGBC 2011)*.

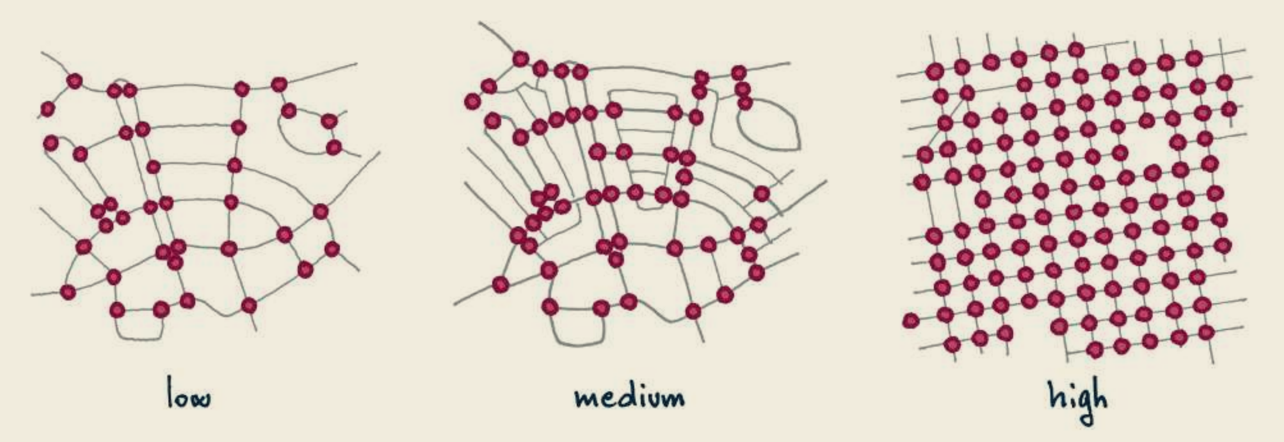
### 3.2.3 WALKABILITY

Walkability is the key to promoting a sustainable city. Building a neighbourhood of short distances where people can reach most of the services to satisfy their daily needs is the most effective way to improve energy efficiency for mobility, i.e. through energy savings from the reduction of travel demand.

Walkability is supported by the connectivity of the street network and by a pleasant and comfortable urban landscape that should be diverse and rich in experience in a sufficiently dense space.

FIGURE 3.6 **NEIGHBOURHOOD'S CORE SERVICES, INCLUDING PUBLIC TRANSPORT, REACHABLE IN FIVE MINUTES' WALK**

FIGURE 3.7 **INTERNAL CONNECTIVITY (COMPUTED AS NUMBER OF NODES IN THE GRID).**



**Place the community's core services at the centre of the neighbourhood, close to other communities and public transport nodes in order to recreate an urban mixed-use setting (Figure 3.6).**

**Ensure that services and retail outlets are located along home-to-work routes, so that it is convenient for commuters to do their shopping and leisure activities as part of their daily routine, and additional, time consuming trips can be saved. Provide comfortable street landscapes**

**Consider the canyon's aspect ratio (see section 3.1.1) to provide shadowed pathways and cycle lanes to make walking and cycling more pleasant.**

**Provide internal connectivity[32] of the street network inside the new neighbourhood (Figure 3.7). to promote walkability, planners should provide a street network which is rich in opportunities for movement.**

*Make sure that at least 100 intersections/km² are provided internally and close to the new neighbourhood (UN-Habitat 2017); the more, the better.*

$$Street\ Connectivity = \frac{Number\ of\ intersections\ [-]}{Area\ of\ reference\ [km^2]}$$

---

[32] *Connectivity is the degree to which the movement networks interconnect. It refers to the directness or ease of moving between origins (e.g., households) and destinations along the movement network.*

### 3.2.4 SUSTAINABLE MOBILITY

Direct strategies to tackle transport refer to solutions for sustainable mobility. These refer primarily to non-motorised mobility solutions, then to the limitation of car usage. Discouraging car mobility, especially the use of private vehicles, is a way to promote different lifestyles, where the ownership of a car is no longer seen as a status symbol. Of course, there is a long way to go, but perhaps sustainable lifestyles will become more attractive, once people understand that these increase the quality of life.

**Increase opportunities for sustainable mobility by creating space for cycle lanes or cycle-friendly streets (that do not provide dedicated lanes, but a safe environment for cycling) and safe, enclosed storage places for bicycles in each building.**

*Count the total linear extension of cycle lanes and cycle-friendly streets and compare it to the total motorised linear extension. They should be at least equal.*

**Car parking should not occupy the ground floors of buildings, especially those spaces facing streets with high urban potential. Two options for car parking are preferable: firstly, diffused parking lots at street level, mainly dedicated to car sharing and electric vehicles (hence with charging stations that make use of on-site solar energy); main roads with shops and services could eventually benefit FROM PARKING spaces along the street, but as a general rule, try to limit car parking at street level. Secondly, mainly for residential use, give preference to concentrated parking areas possibly not directly facing streets, in multi-storey buildings or underground.**

**Present standards for parking lots inside the development are usually not consistent with the principles of sustainable mobility. Today, providing a minimum number of parking spaces per inhabitant or household is mandatory in numerous urban codes. If this is the situation, use the minimum allowable value.**

**Make sure the pedestrian route from home to the parking lot represents a direct, attractive, safe and comfortable experience for people.**

**Provide shaded and rain sheltered pedestrian and cycling paths, including parking lots with trees or urban furniture to promote low energy mobility**

**Consider the possibility of creating car-free residential areas at the borders of which are a number of parking lots**

**Look ahead, make provision for the new trends in urban mobility, based on electric car sharing (conventional or self-driving), which will entail a number of small parking lots distributed within the neighbourhood, at walking distance from residences and SERVICES, PROVIDED with charging stations.**

## 3.3 CLIMATE RESPONSIVE DESIGN

Climate is the main driver of energy consumption for heating or cooling, and the urban form plays a significant role in determining the amount of energy needed. Geometry, size and materials (including vegetation) have a big impact on outdoor and indoor comfort and liveability, and consequently on indoor energy consumption. The design scheme of a neighbourhood impacts both on people's behaviour (mobility habits) and on the performance of buildings (shading, ventilation, vegetation and infrared radiation are the drivers of the energy loads in indoor spaces, Figure 3.8).

Strategies for controlling outdoor comfort (i.e. mitigating the UHI) in a tropical climate are:

- Manipulate the geometry of the neighbourhood, i.e. the three-dimensional volume formed by buildings to minimise radiation trapping and enhance shadowing;
- Manipulate the street layout and building shape to favour wind access;
- Control the thermal properties of urban surfaces, i.e. colour and mass;
- Maximise evapotranspiration loss with vegetation and water bodies.

### 3.3.1 URBAN CANYONS

The primary design strategy is to manipulate urban geometry (height and width of buildings, street orientation and street width) to enhance self-shading of buildings and shading of public spaces, to increase urban albedo and to exploit the cooling potential of wind. This strategy should be combined with - and enhanced by - the shading potential of trees in the streets.

Appropriate design of urban canyons (i.e. their depth and orientation) is the most crucial step, as they dictate the width of the streets and the height of the buildings.

**Consider that orientation of the street network and the aspect ratio of the urban canyons are crucial factors for shadowing and ventilation, AS THEY have a significant effect on outdoor comfort and the liveability of the streets, and the thermal and visual comfort achievable indoors.**

*North-South oriented streets provide the maximum shadowing at pedestrian level, provided that the canyon's aspect ratio, H/W, (building Height/street Width) is between 2 and 3. Lining the streets with trees is recommended, as it provides further shadowing during the central hours of the day.*

*In order to favour both ventilation and shadowing, in lowland EAC climates, other than hot arid, where monsoon winds are active, moving the orientation of these streets from NS to NNE-SSE or even to NE-SW improves the comfort of pedestrians (Figure 3.9).*

FIGURE 3.8 **CLIMATE RESPONSIVE NEIGHBOURHOOD DESIGN**

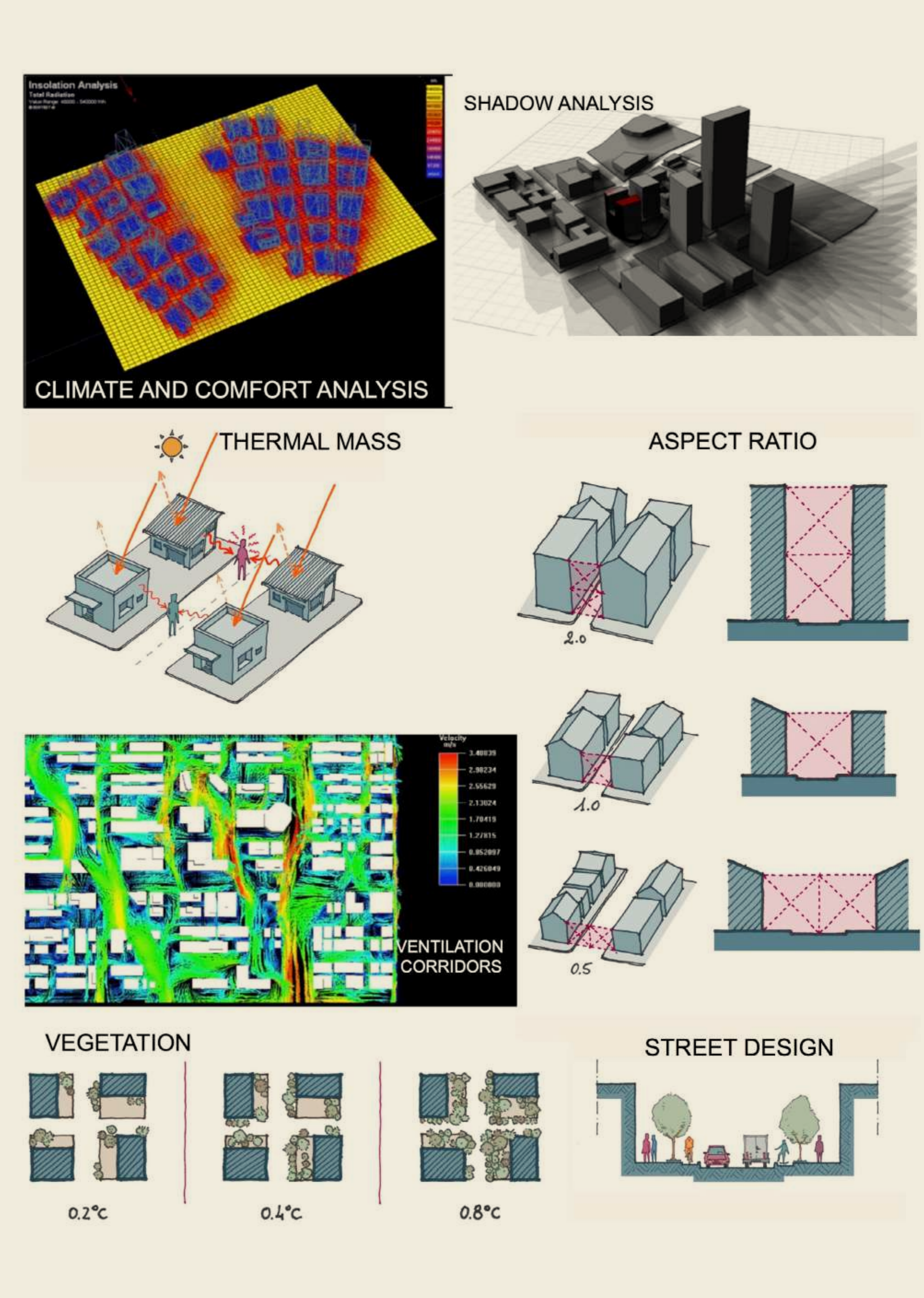
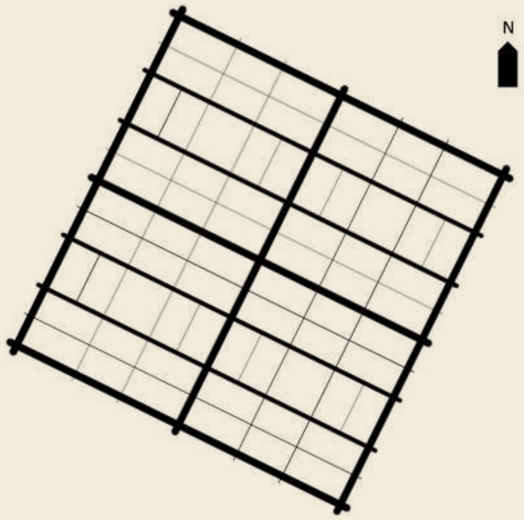


FIGURE 3.9 **OPTIMUM NEIGHBOURHOOD GRID ORIENTATION IN LOWLAND EAC CLIMATES, OTHER THAN HOT ARID, AFFECTED BY MONSOON WINDS.**



*East-West running streets are more critical, and require supplemental choices, such as the planting of trees to line them and high albedo ground and wall surfaces.*

*In highlands climates East-West running streets with aspect ratio H/W ≤ 1 may be beneficial for passive heating during the cool season.*

**Use deep N-S, NE-SW oriented canyons for comfortable pedestrian pathways, shops, coffee houses, small artisan workshops, as the sidewalks will be in shade almost all day if the street is tree lined. In such canyons, sidewalks should be wide enough to allow for outdoor activities (leisure or productive). The upper floors should contain residences, as the height above street level favours ventilation.**

**Use east-west oriented streets mainly for vehicular traffic and leave north-south oriented streets mainly for pedestrians. Consider the possibility of making use of horizontal overhangs appropriately dimensioned and spaced along the height of the walls: they protect canyon walls very effectively from direct exposure to the sun, reduce solar radiation reflected by the walls towards the canyon floor and the heat flux through the walls towards the indoor space (see Appendix 4).**

**Consider that, due to the sun paths characterising the tropical latitudes, it is impossible to have all the points of the ground level of an urban canyon shaded all day or all year, and that around noon only horizontal sun protections can provide shade.**

*Avoid large public squares; when they are too large, they look and feel deserted, and it is not comfortable to cross them on a hot day. Do not make a public square wider than 20 m on its shorter side. In general, the dimensions of the open space should be no less than twice the average height of the surrounding buildings and have a proportion no narrower than 1 unit of width to 4 units of length.*

**Pay attention to the mass and surface colours of materials: both influence comfort in both urban canyons and open spaces. Avoid dark surfaces, especially horizontal ones.**

*Albedo values of opaque surfaces should be higher than 0.4 (see section 2.1 and Appendix 1).*

**Control the mass of walls (heavyweight in a hot dry climate, lightweight in a hot humid climate, medium weight in a highland climate)**

**Be cautious about using glazed or reflective materials for canyon walls: the comfort (thermal and visual) conditions in the street are significantly worsened, unless appropriately designed devices shadow the façade.**

*In order to control the excessive reflection due to glass surfaces, Window to Wall Ratio (WWR) should not exceed the value 0.3, unless the window is fully shadowed all day (Figure 3.10).*

$$Window\ to\ Wall\ Ratio\ WWR\ [0-1] = \frac{area\ of\ windows\ [m^2]}{total\ area\ of\ the\ facade\ [m^2]}$$

**Consider using vegetation on streets, as it significantly improves outdoor comfort and reduces energy consumption indoors.**

**Provide as many green areas as possible, compatible with other design needs. A green area is not only beneficial for the buildings directly around it, but also induces – because of its lower air temperature and thus lower pressure in comparison with the built-up areas – mild air movements that, with appropriate street and building design, can significantly improve outdoor and indoor thermal comfort.**

FIGURE 3.10 **WINDOW TO WALL RATIO (WWR) CALCULATION**

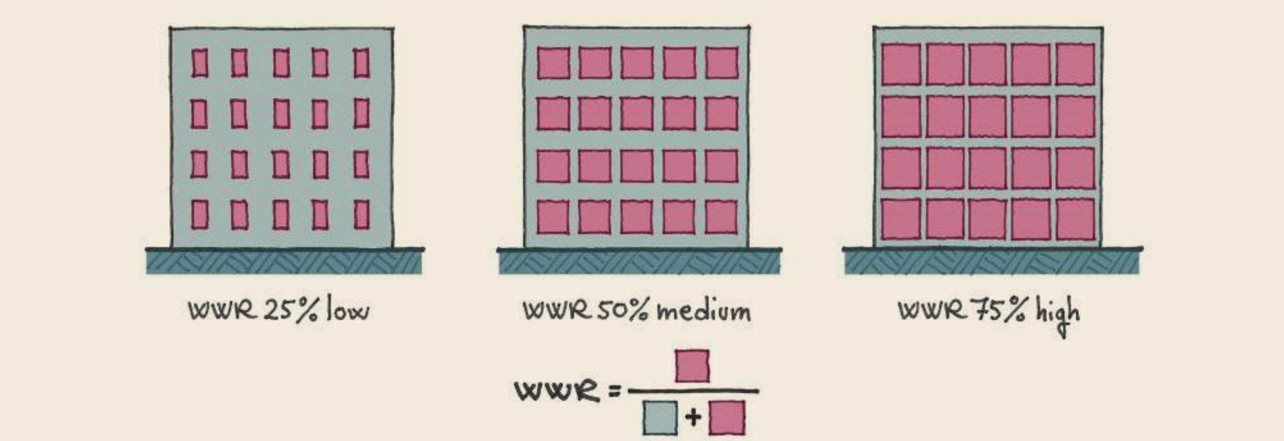
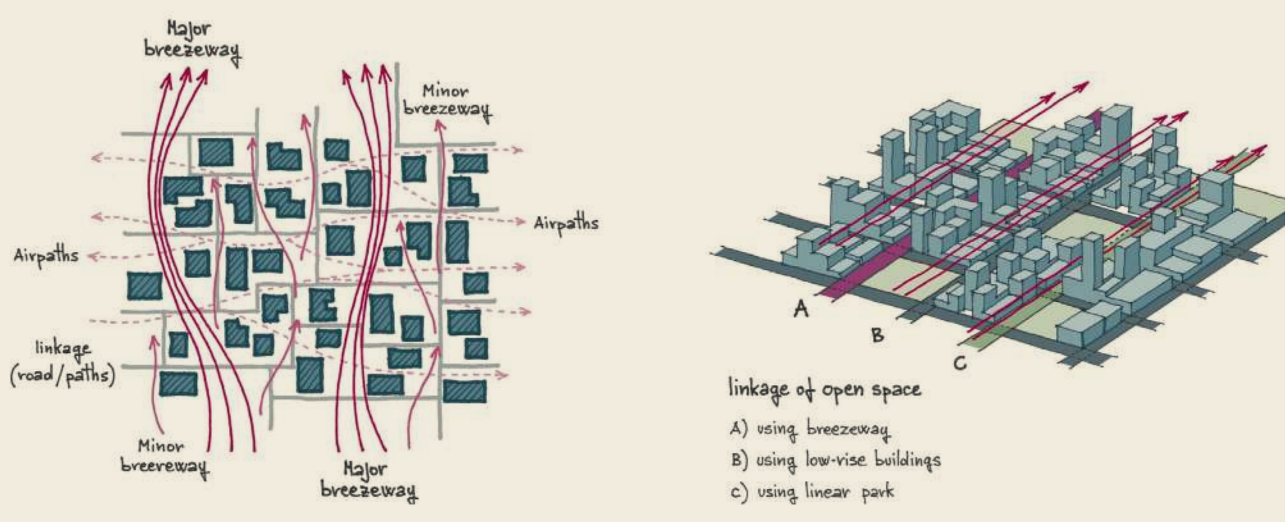


FIGURE 3.11 **BREEZEWAYS**



**Check that the design choices deriving from climatic drivers do not conflict with the choices promoting the reduction of motorised mobility. In the tropics, a large part of the anthropogenic heat production is due to motorised mobility. The reduction of motorised mobility would be indirectly beneficial in further reducing the heat island because of the reduction of pollutants in the atmosphere, which cause an increase in the long-wave radiation from the sky and a decrease in the radiative heat losses towards the sky. there is, of course, also an impact on health.**

**Encourage easy channelling of the prevailing winds. Wind has a multiple positive effect in tropical climates: it improves outdoor thermal comfort, removes the sensible and latent heat and reduces air pollution.**

**Encourage wind penetration (see section 2.1) by creating breezeways. Breezeways can be in the form of roads, open spaces and/or low-rise building corridors through which air reaches the inner parts of urbanised areas (Figure 3.11).**

*Closely packed buildings impede air flow. Building front permeability equivalent to 20% to 30% is a good starting point for neighbourhood design. Permeability to wind P is calculated as (figure 3.12):*

$P = S/(S+L)$

*Widening the setback of buildings setback improves permeability.*

**If streets are aligned to the prevailing wind direction, wing walls in the buildings' façades should be considered to enhance indoor ventilation.**

**Avoid uniformity in building height, canyon width and canyon length; uniformity reduces eddies, thus ventilation. Variation in Building height across the neighbourhood with the height decreasing towards the direction of the prevailing wind should be adopted to promote air movement (Figure 3.13). a Staggered arrangement of the blocks allows the blocks behind to receive the wind penetrating through the gaps between the blocks in the front row.**

FIGURE 3.12 **PERMEABILITY EVALUATION AND IMPROVEMENT**

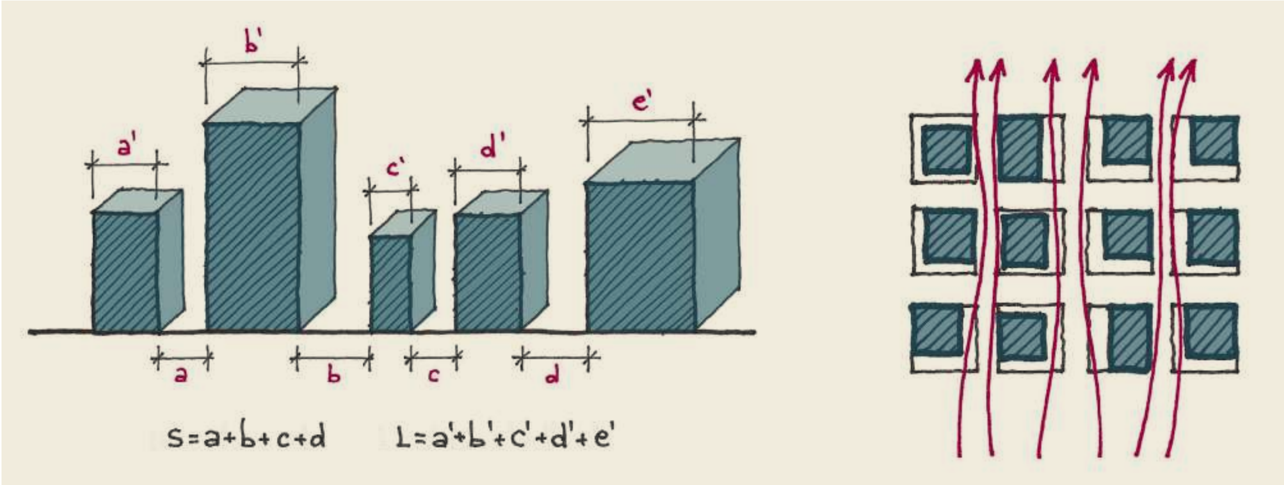
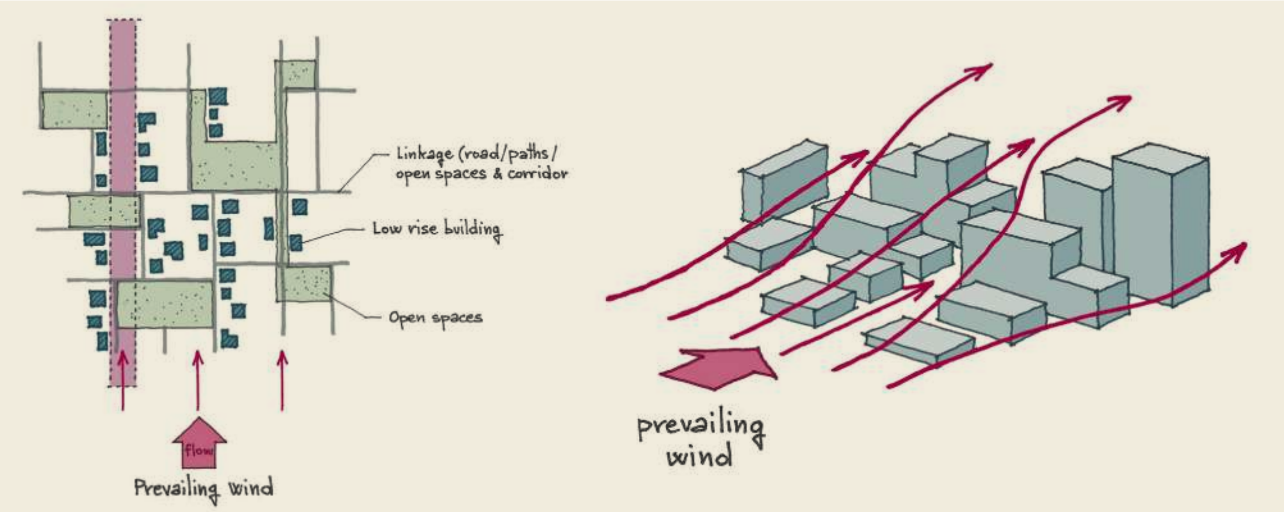


FIGURE 3.13 **VARIATION IN BUILDING HEIGHT**



**Keep the length of street canyons as short as is practical, to promote flushing at street intersections by corner eddies.**

**When a neighbourhood is by a waterfront, properly orientated air paths connecting to the waterfront or open spaces are effective in bringing in air ventilation.**

**Open spaces in the urban area allow the above roof-top wind to flow into them and benefit pedestrian air ventilation.**

## 3.3.2 STREET DESIGN

Street design entails two decisions a) the street grid and b) the street width.

**The orientation of a perpendicular street grid is driven by the need for shadowing and ventilation, but topography should also be carefully considered. Roads should also be perpendicular or parallel to the direction of the slope, so that water can run off the street. In this case, a compromise is necessary.**

*The spacing of streets is first of all determined by their hierarchy.*

*In a simple, square, road grid (Figure 3.14), the spacing recommended by UN-Habitat (UN-Habitat 2016; UN-Habitat 2013), according to the road hierarchy, is:*

- *Major streets – 300 m*
- *Connector streets – 110 m*
- *Access streets – 55 m*

The main decisions about street width are driven, besides the street hierarchy, by the need for solar protection of the pavements, which depends on the orientation, and the aspect ratio H/W. The aspect ratio, in turn – given the height constraints of the buildings deriving from energy and water self-sufficiency (see sections 3.4.2 and 3.5.2) – is constrained by the minimum street width compatible with its function (connector, access, pedestrian only).

FIGURE 3.14 **STREET HIERARCHY AND SPACING (UN-HABITAT 2016)**

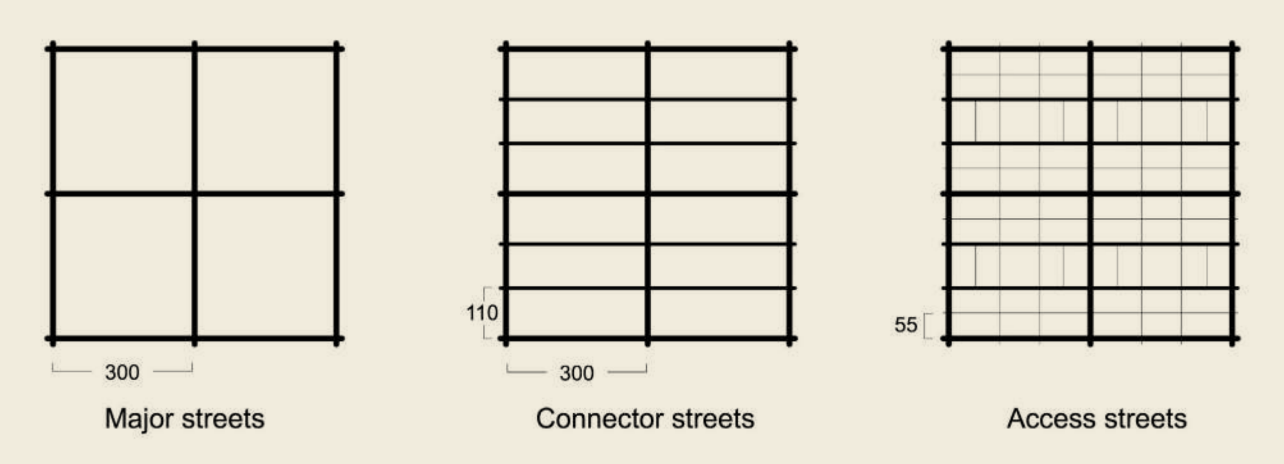


FIGURE 3.15 **PHYSICAL DETERMINANTS FOR STREET WIDTH. ADAPTED FROM LNWAG 2009.**

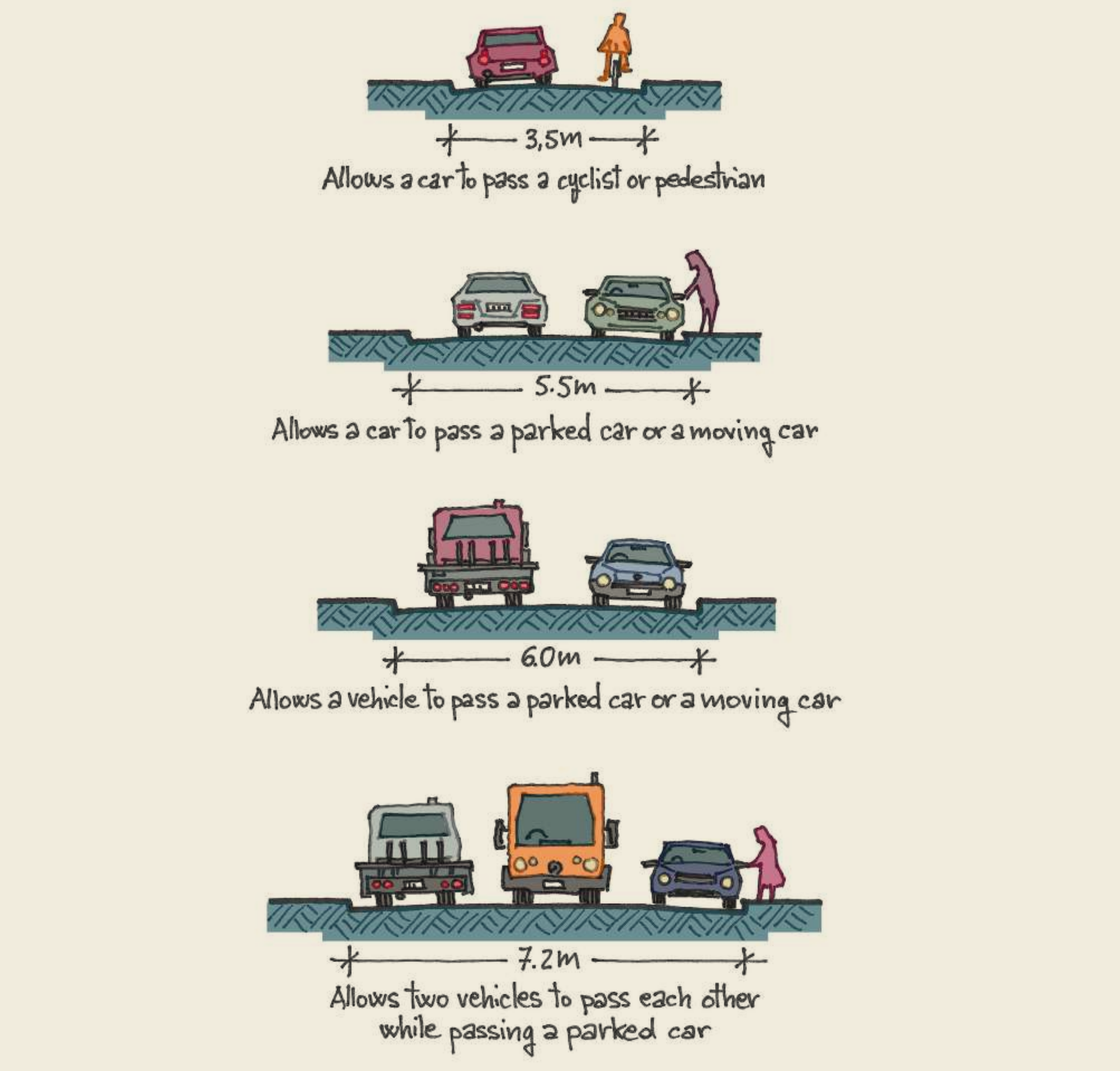
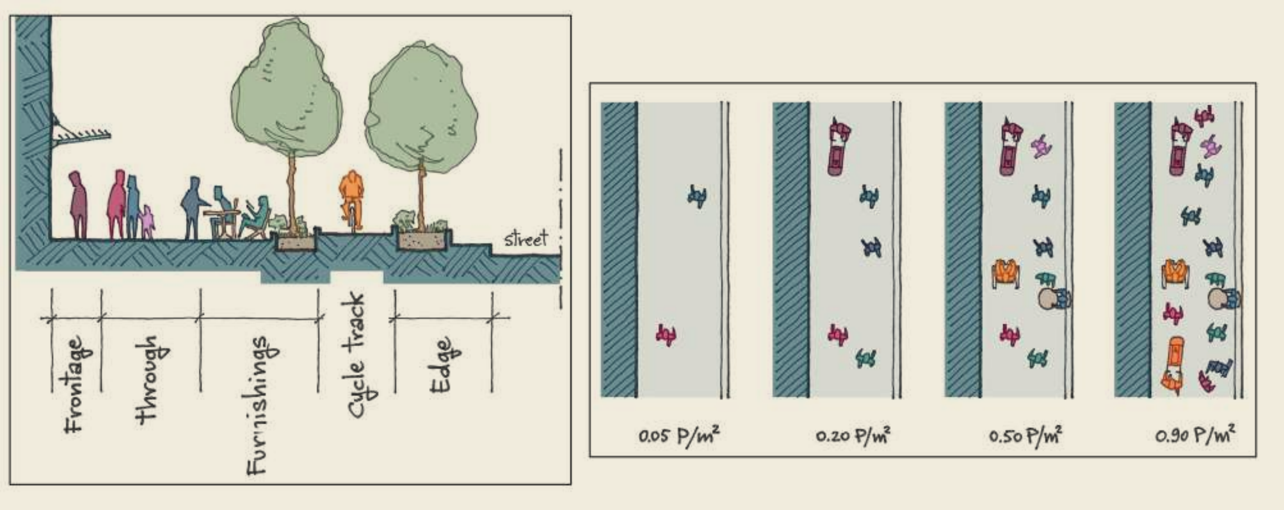


FIGURE 3.16 **MOBILITY PRIORITIES**

FIGURE 3.17 **THE FUNCTIONS OF THE PEDESTRIAN REALM ZONES (LEFT) AND DIFFERENT DENSITIES OF USE FOR SIDEWALKS MEASURED IN NUMBER OF PEDESTRIANS PER SQUARE METER (RIGHT). ADAPTED FROM (ADUPC 2015 AND DTUK 2007).**



**When defining the width of neighbourhood streets, consider that:**

- **the minimum street width compatible with vehicular traffic ranges from 3.5 m to 7.5 m, as shown in Figure 3.15;.**
- **a sustainable neighbourhood street has to accommodate pedestrians and cyclists, and that they should have priority over all the other forms of mobility (Figure 3.16);**
- **in a walkable neighbourhood sidewalk size is of foremost importance. It depends on the human flows expected on particular streets, and is increased by the activities besides walking planned on the sidewalk (Figure 3.17).**

**As a starting point for streets designed according to their function in a sustainable neighbourhood, consider the suggestions deriving from Figure 3.18.**

**Consider that, for shadowing purposes, when the street width is first defined, street orientation and building height are dependent variables.**

*In an EAC lowland climate access streets and footpaths or shared path streets are best located in North/South or North-East/South-West oriented streets, with aspect ratio H/W ≥ 2, as they would be very well protected from direct sun and be well ventilated, providing quite a comfortable outdoor environment. Neighbourhood connectors and access streets, on the other hand, should be East/West oriented, as even with aspect ratio higher than 2, they would not be shadowed.*

*Pedestrian walkways (based on 1.8 m width within the through zone) should be 80% shadowed; cycle lanes and parking 50%; open spaces 65% (ADUPC 2010). Shade calculations must be undertaken on the 21st of the hottest month at 1:00 pm local time. Check the actual shadowing of sidewalks with the graphical method suggested in section 3.1 and Appendices 3 and 4, or with appropriate software. If sidewalks are not sufficiently sheltered from the sun, provide them with arcades or some other sun-sheltering device (Figure 3.19).*

*Sidewalks should be provided along 100% of the street length.*

FIGURE 3.18 **LEFT: NEIGHBOURHOOD CONNECTOR; THESE STREETS SERVICE AND LINK NEIGHBOURHOODS. CENTRE: ACCESS STREET; TO ACCOMMODATE SHARED PEDESTRIAN, BIKE AND VEHICULAR MOVEMENTS. RIGHT: FOOTPATH OR SHARED PATH; PEDESTRIAN AND CYCLIST STREET ALLOWING TEMPORARY ACCESS TO VEHICLES. ADAPTED FROM LNWAG 2009.**

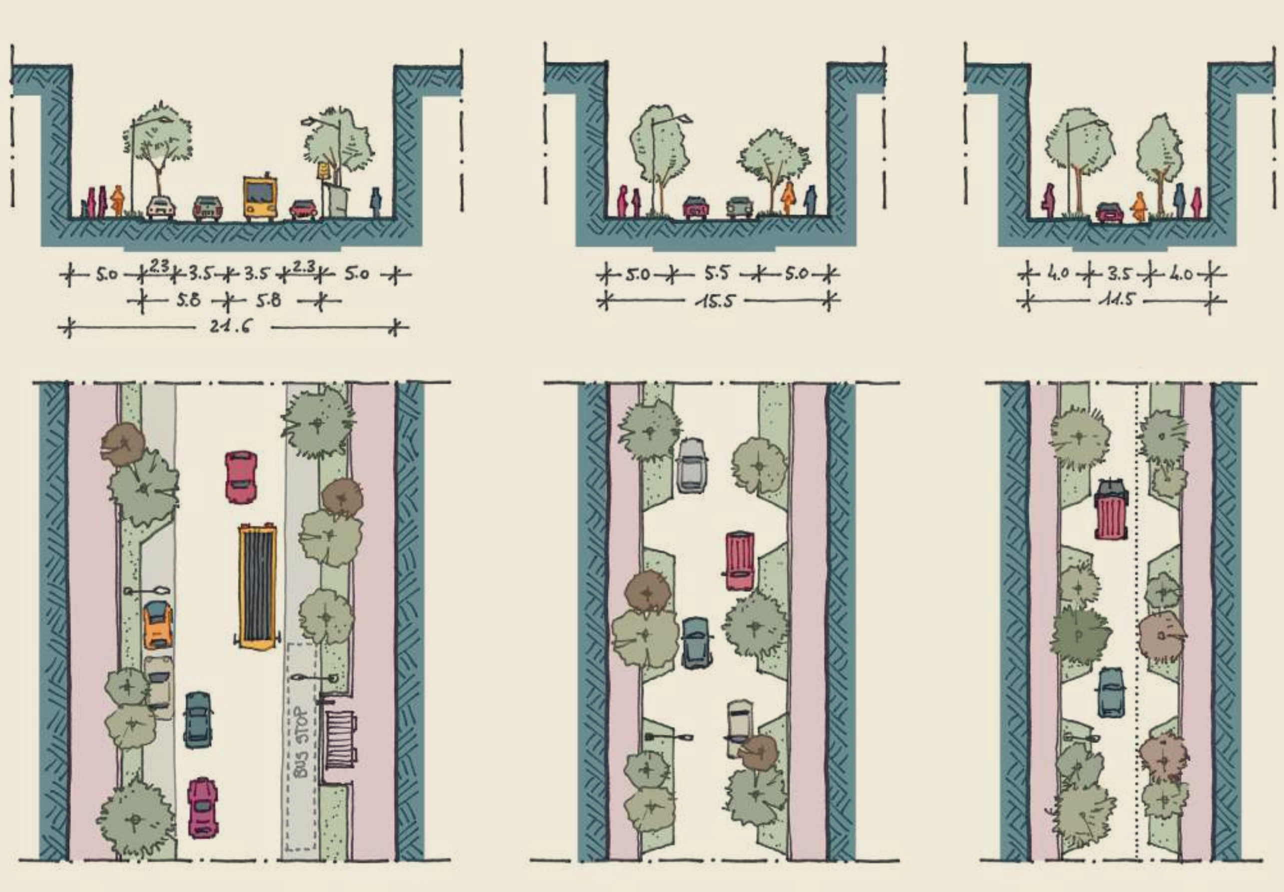
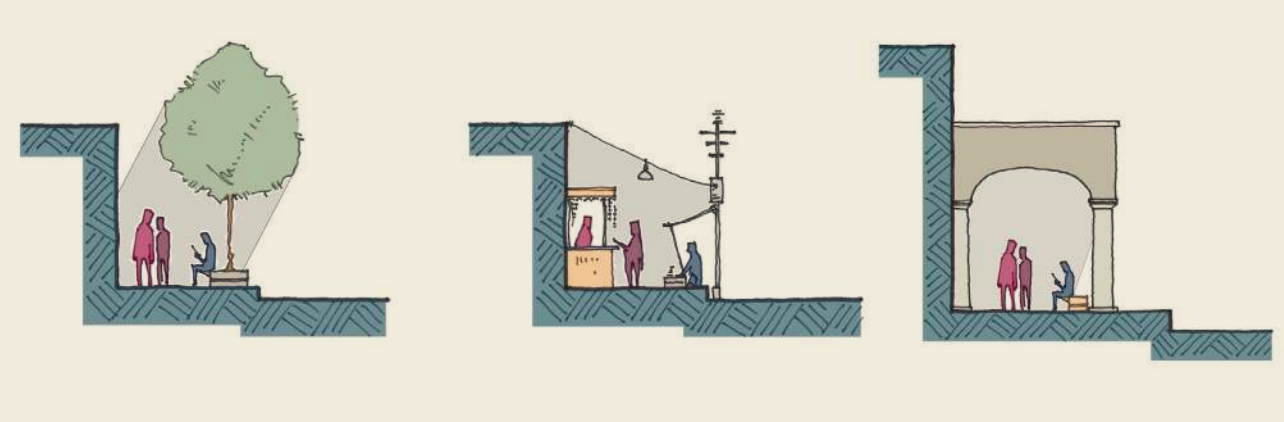


FIGURE 3.19 **SHADOWED WALKWAYS**



**Consider that in a sustainable neighbourhood street spacing and width are mutually dependent.**

*The street network (and parking space) should occupy at least 30 per cent of the land and at least 18 km of street length per km$^2$ (UN-Habitat 2013), which, for a 30-ha neighbourhood means more than 5.5 kilometres of streets with an average width of 16 m.*

### 3.3.3 GREEN AREAS

Green areas and spots represent another kind of urban material for neighbourhood climate control with fundamental properties such as (1) improving outdoor comfort, (2) safeguarding bio-diversity, (3) providing people with accessibility to nature, (3) providing food.

**Differentiate between green area typologies in order to include microclimates and the ecological and social qualities of urban nature. make sure your neighbourhood provides, among others:**

- **urban parks;**
- **tree lined streets;**
- **pocket parks with diffused small green interventions (planters, green shelters, roofs and walls);**
- **urban food gardens.**

*Define the extent of green areas and spots and their spatial distribution taking into account their cooling effect, which can be checked by means of simulations. As a basic reference value, 15-20% of the neighbourhood land should be allocated for green open areas (UN-Habitat 2016).*

**Consider that trees and vegetation in general are also a very effective carbon sink.**

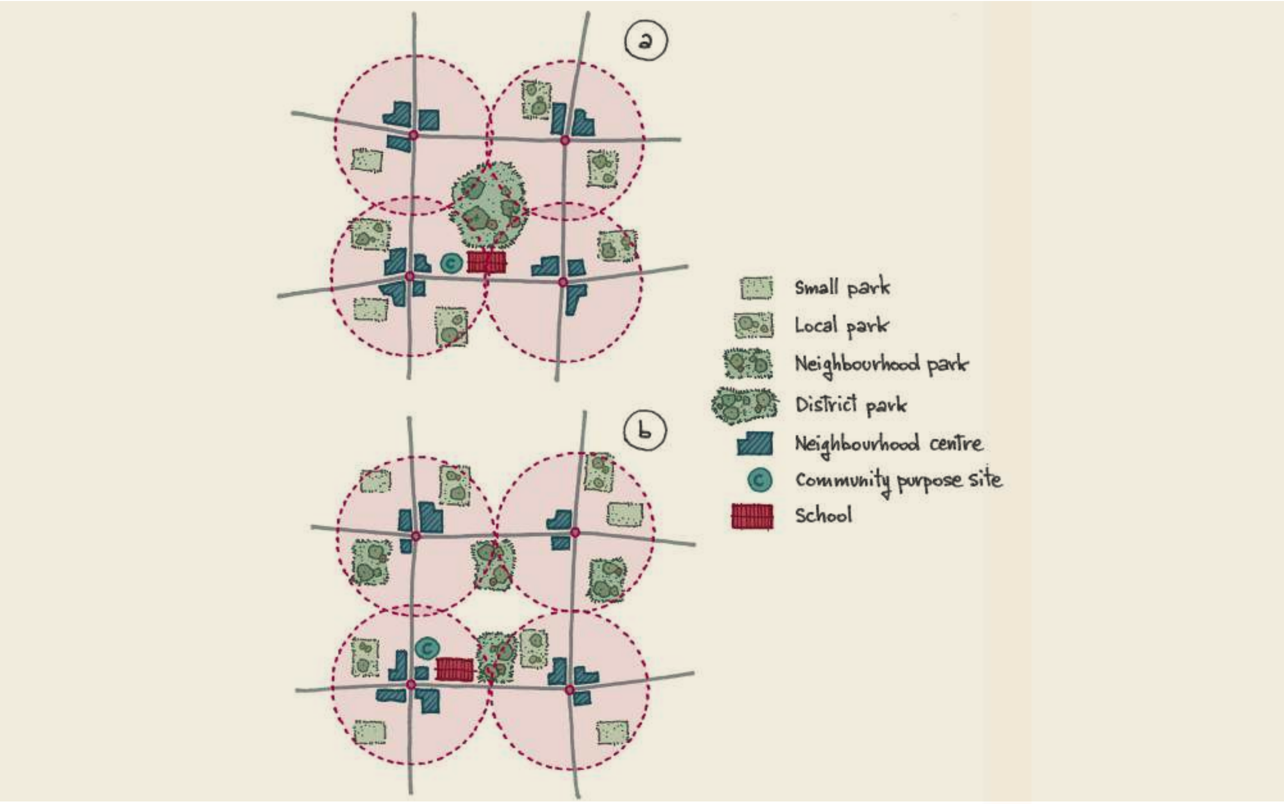
**Parks must be the appropriate size to accommodate the activities for which they will be used, not too small, not too large. Besides neighbourhood parks, local parks up to 3000 m$^2$ should be provided for local children to play in, and should include small intimate spaces which are designed to be places of repose, in order to encourage pedestrian connectivity, and create a sense of place.**

*Local parks should be provided within 150 to 300 metres safe walking distance to all dwellings. Neighbourhood parks of around 3000-5000 m$^2$ should be provided at a maximum 400 m walk from most dwellings (90%). Larger parks (district parks) should be located between or towards the edge of neighbourhoods rather than at the core (Figure 3.20).*

*Make sure the occupants of all the housing can reach a green area within a 5 to 10-minute walk.*

**Urban vegetation (trees in particular) should be planted especially in public areas and close to pedestrian and cycle paths in order to make them more comfortable. All the streets should be tree-lined, but care must be taken to ensure that they do not endanger ventilation.**

FIGURE 3.20 **TWO OPTIONS FOR SPATIAL DISTRIBUTION OF PARKS AND POSITION OF LOCAL SCHOOL. PARKS AND SCHOOL SHARED BETWEEN NEIGHBOURHOODS, AT AN APPROPRIATE DISTANCE THAT ALLOWS THEM TO BE REACHED IN LESS THAN 10 MINUTES' WALK. ADAPTED FROM LNWAG (2009)**



### 3.3.4 WATER BODIES

Water bodies have the potential to cool the urban environment due to their thermal and optical properties, although they should be used with great care, as they can be counterproductive.

**Constructed wetlands (see section 3.5 and Appendix 7) can be included among the water bodies in addition to the stormwater catchment basins.**

*To maximise their effect water bodies should be located in every neighbourhood at the northern/southern corner.*

**Consider the mosquito breeding problem in still water bodies.**

## 3.4 ENERGY SUPPLY

Up to now, energy supply to make the city work has never been considered an issue concerning urban planning. This is no longer the case since we have acknowledged the need to rely mainly or exclusively on renewable energy sources. This paradigm shift, together with the crucial role of energy efficiency, makes the issue of energy supply an important part of the urban designer's work.

The key issue is the decentralisation of energy production combined with the use of renewable energy sources. This approach, besides being a prerequisite for coping with the challenge of climate change, brings additional benefits, such as energy security, improvement of urban air quality (no pollution due to combustion), reduction or elimination of soil contamination due leakages or spills in fossil fuel transport, reduction or elimination of water use for electricity production with thermal plants, creation of local employment and economic activities.

### 3.4.1 COGENERATION

Energy production and distribution technologies at neighbourhood scale can be economically viable and environmentally sound. In lowland tropical climates cogeneration could work for most of the year for providing air conditioning, making it in some cases very cost effective. The electricity produced can be conveyed to the neighbourhood grid, improving its reliability.

**Evaluate the possibility of proposing cogeneration (combined heat and power, CHP) for electricity production and district cooling to supply energy in a more efficient way at the local scale. CHP requires: (1) space for both the CHP units and the absorption chillers; (2) space for fuel storage, if powered with solid biomass; (3) the construction of a network, which is cost-effective only if conceived from scratch in a new development and when servicing non-residential users.**

### 3.4.2 SOLAR AND WIND ENERGY

Renewable energy sources are distributed and usually available with a low power density. This means that in the urban context they need to be integrated into structures designed and constructed for fulfilling other requirements, otherwise they would occupy too much space. This has an impact on the design of these structures.

**Minimise dependence on a greater municipal grid for the energy needs of the community. Take advantage of onsite renewable resources to generate the energy required to make the district operate.**

**Consider that solar PV panels are already a reality in many places in Africa. The success of this technology is related to the fact that they do not need large-scale infrastructure and can be used locally and off grid. This may result in a significant impact on neighbourhood design.**

*At the latitudes of tropical countries, the optimum tilt angle of a PV panel is 0 degrees (horizontal), up to 15 degrees with no significant reduction in productivity. Hence, vertical arrangements of panels on balconies or facades are not applicable.*

*PV systems play a crucial role in zero energy buildings and neighbourhoods, and not only in energy terms, as relying on them places constraints on the maximum building height. The reason for this is that there is a relationship between the building's energy demand, the size of the PV system required to supply it, and the roof area available to install it (see Figure 3.21 for a first evaluation in East African Community climates).*

**Consider that small scale (micro and mini) wind turbines are a very useful addition if coupled with PV panels, because they complement solar production when there is no sun i and they reduce the need for back-up power.**

*The nominal power of small roof wind turbines is usually between 0.5 and 4 kW; mini wind turbines positioned in open spaces such as parking areas, urban farming plots, etc., can reach 20 kW.*

**Consider biomass fuelled CHP production based on the gasification process. It can be a very convenient solution because it allows electricity production to be programmed. It requires space for combustion and storage for biomass. The biomass can be provided by the pruning of trees in the streets and parks.**

**Consider biogas production. Bio-digesters that use organic waste products are another innovative method for achieving local self-sufficiency: organic waste from households and urban agriculture can be used for biogas and fertiliser production, alone or in combination with the organic waste from the local sewerage network. Bio-digestion is convenient**

**at the local scale as it optimizes the closing of cycles and reduces waste production. Disadvantages are mainly:**

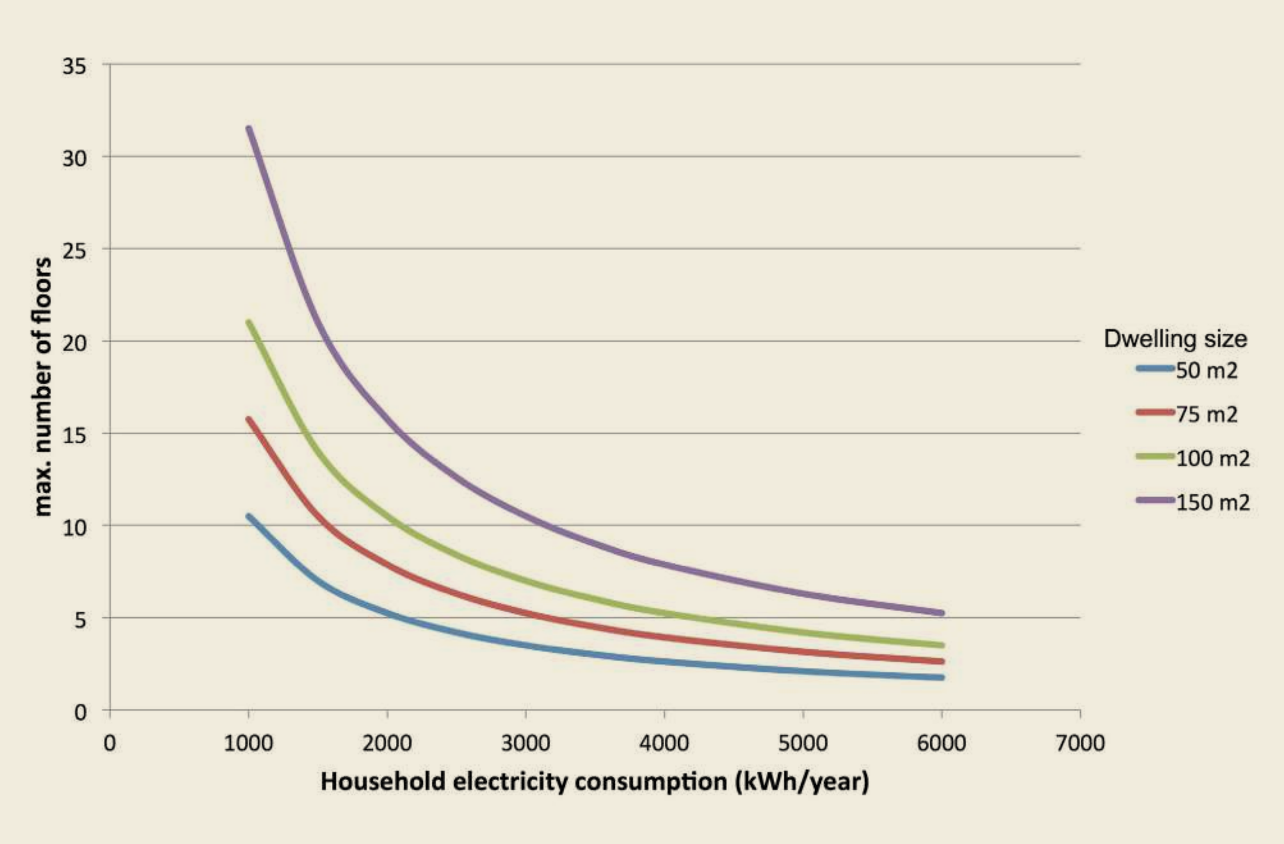
- **design, management and maintenance of the system requires expertise, even if new cheap and easy solutions are emerging;**
- **odour, if located close to the urban context.**

*Using black water as input, 15-30 litres of biogas are produced from anaerobic digestion of sludge per person and per day and a low heating value (LHV) of 6.5 kWh/m$^3$ can be assumed. At household scale, including kitchen waste, the production can reach 30-60 litres of biogas per person per day, which fulfils part of the household's cooking energy needs.*

**Provide location and space for the slurry deriving from the bio-digestion to be dried and treated for use as fertiliser.**

**Take into account the possibility of establishing a smart-grid system at the district scale. Smart-grids or micro-grids are a great option if a reliable centralized energy network is lacking or unreliable. Urban planning can lead the transition to new ways of energy production and distribution. Combining the different renewable energy systems, it is possible to provide a complementary, integrated and stable energy system. Storage is the main challenge and is still under rapid development. Smart grid solutions require technical expertise and control systems, and give opportunities to provide new jobs.**

FIGURE 3.21 **RELATIONSHIP BETWEEN ANNUAL ELECTRICITY CONSUMPTION OF AN AVERAGE DWELLING[33] IN A BUILDING AND THE MAXIMUM NUMBER OF FLOORS IN THE SAME BUILDING FOR BALANCING THE ANNUAL CONSUMPTION OF ALL DWELLINGS IN THE BUILDING AND THE BUILDING'S POTENTIAL ANNUAL ROOFTOP PV PRODUCTION, FOR DIFFERENT DWELLING SIZES. CALCULATION FOR THE AVERAGE ANNUAL SOLAR RADIATION INCIDENT ON HORIZONTAL SURFACE IN EAC, RANGING FROM 1500 TO 1650 KWH/YEAR PER INSTALLED KW, I.E. FROM 200 TO 220 KWH/M$^2$ YEAR, ASSUMING 7.5 M$^2$/KW THE PV AREA.**



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[33] Consider that an average household of 4 people, equipped with high efficiency electric domestic appliances, can have an annual electricity consumption ranging from 3,000 up to 6,000 kWh/year, according to the use of air conditioning and the floor area of the dwelling.

## 3.5 URBAN METABOLISM AND CLOSED CYCLES

A self-sufficient community is a sustainable one. If a neighbourhood can meet most of its needs through onsite processes, closing energy, water and waste cycles, it reduces dependency on the energy, water, food and materials feeding it, and can transform waste into a resource.

### 3.5.1 TAKING INTO ACCOUNT THE EMBODIED ENERGY OF MATERIALS

In a sustainable neighbourhood that aims to rely as much as possible on renewable energy sources for its operation, the embodied energy of construction materials becomes the main source of GHG emissions attributable to the neighbourhood itself, and it should not be overlooked.

**Use local materials with low embodied energy, such as stone, stabilised bricks, timber and bamboo. Minimize the use of materials that require very high temperature processing for production (steel, glass, cement, aluminium and fire-bricks). Consider the re-use of waste materials from other constructions.**

**Minimise the use of construction materials, considering the compactness of buildings through the surface to volume ratio (S/V) indicator and trying to minimise it, for two reasons: i) the larger the S/V the larger the area exposed to sun and the larger the area subject to heat transfer; ii) the larger the S/V the greater the amount of material that has to be used for walls, with the same volume, i.e. with the same number of people accommodated, and the more material used, the greater the embodied energy and GHG emissions.**

**Minimise and recycle construction waste.**

*Plan the recycling or salvaging of at least 50% of construction waste (USGBC 2016).*

### 3.5.2 DESIGNING DECENTRALISED WATER AND WASTEWATER CYCLES

Water is an especially critical issue in many countries in the EAC, and it is exacerbated by the effects of climate change. River and spring flow is less constant and reliable than in the past; areas that are already dry are more and more frequently subjected to prolonged periods of drought; water tables are more and more overexploited and – in urban and peri-urban contexts – are not replenished because of the impervious covering of the soil. Efficient, circular use of the water resources is an essential prerequisite not only for sustainability but also for the basic liveability of new settlements.

In the same way as for energy, water consumption in cities can be reduced if appropriate choices are made during the early stages of settlement design. Through the provision of infrastructures for decentralised urban water management, decentralised water resource management and water services can work more effectively and sustainably than a system of centralised management.

Sustainable water management embraces: conservation of water sources; use of multiple water sources including rainwater harvesting, storm water management and wastewater reuse; and treatment of water as needed, exploiting the energy and nutrient potential of wastewater, rather than treating all water to a potable standard.

Consider that in a sustainable water cycle at neighbourhood scale the following water flows have to be considered and combined:

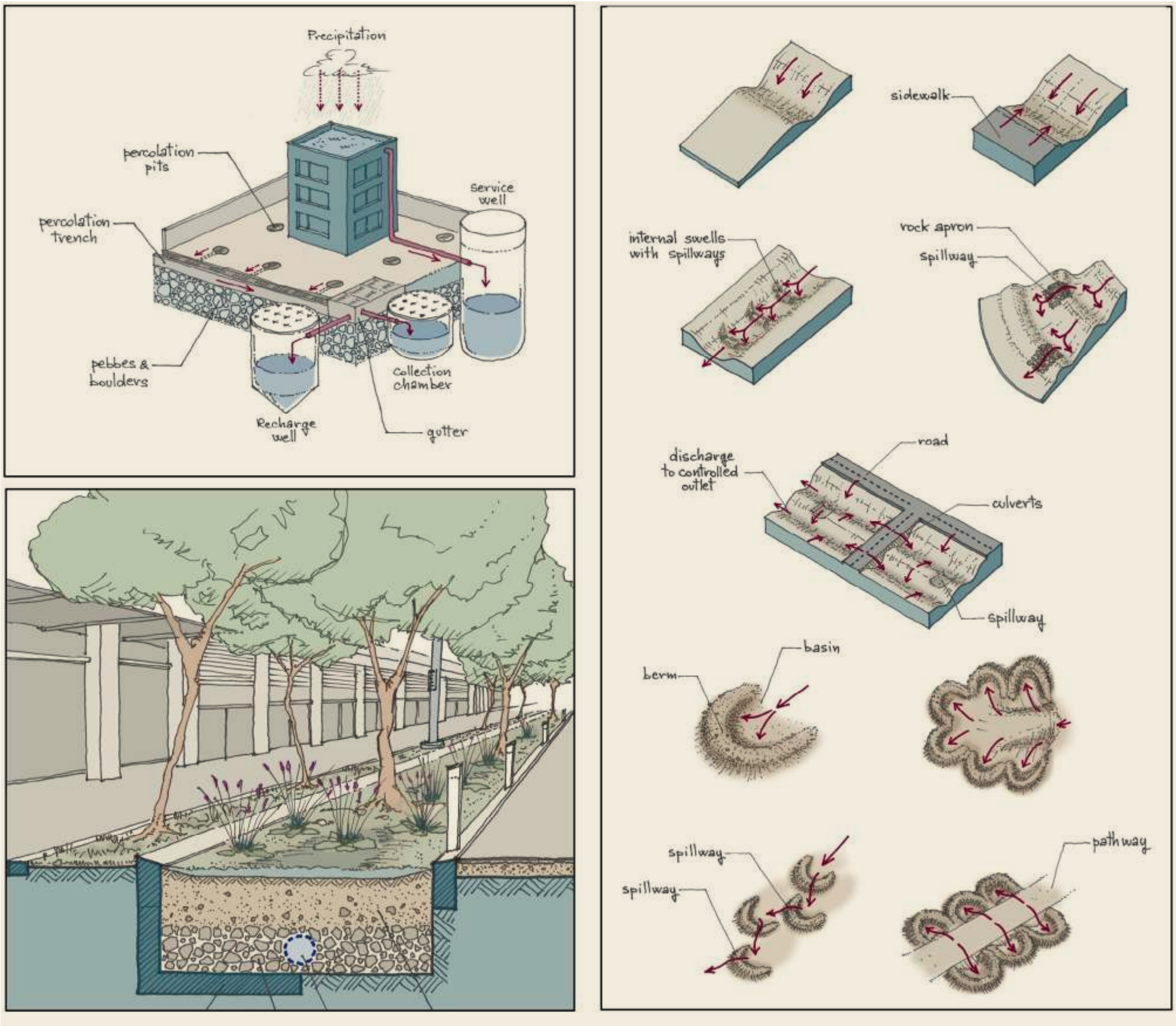
1. Potable water flow from the municipal network, if any;
2. Potable water flow from common neighbourhood wells;
3. Roof rainwater flow to storage;
4. Roof rainwater flow, from storage to domestic uses, i.e. WC flushing, washing machine, irrigation;
5. Roof rainwater flow, filtered and disinfected to make it potable, for domestic uses, i.e. kitchen and bathroom taps;
6. Roof rainwater flow diverted for recharging ground water aquifers;
7. Stormwater flow collected from impervious surfaces;
8. Wastewater flow from households to the treatment system (could be two separate flows, if black water and grey water are not mixed);
9. Treated wastewater flow to green areas (urban agriculture, parks, street greening, etc.);
10. Treated wastewater flow to recharge wells or recharge basins;
11. Treated wastewater flow to water bodies (alternative to flows 9 and 10).

From this it can be seen that many design steps need to be accomplished.

**Minimize dependence on the municipal network for the water needs of the neighbourhood. Collect rainwater from rooftops and store it for non-potable uses such as flushing toilets, onsite irrigation or for local farming; use bio-swales and surface systems instead of storm drains whenever possible Figure 3.22**.

**Consider the opportunity for self-sufficiency of the community offered by rainwater harvesting and local, neighbourhood scale treatment to make it potable, besides using it raw for use in toilets, washing machines, irrigation, and car and street washing.**

FIGURE 3.22 **SUSTAINABLE MANAGEMENT OF RAINWATER AND WASTEWATER**



*Evaluate the rainwater harvesting potential of a neighbourhood's roofs, on the basis of the local precipitation, and compare this figure with the household water demand. In order to balance the water demand with the harvesting potential of the roofs, it may be necessary to limit the maximum height of the buildings, and this needs to be combined with the height limits deriving from building's self-sufficiency in electricity. This evaluation also allows a first estimation of the storage volumes needed and their optimum location. Involve rainwater harvesting experts from the beginning of the design process.*

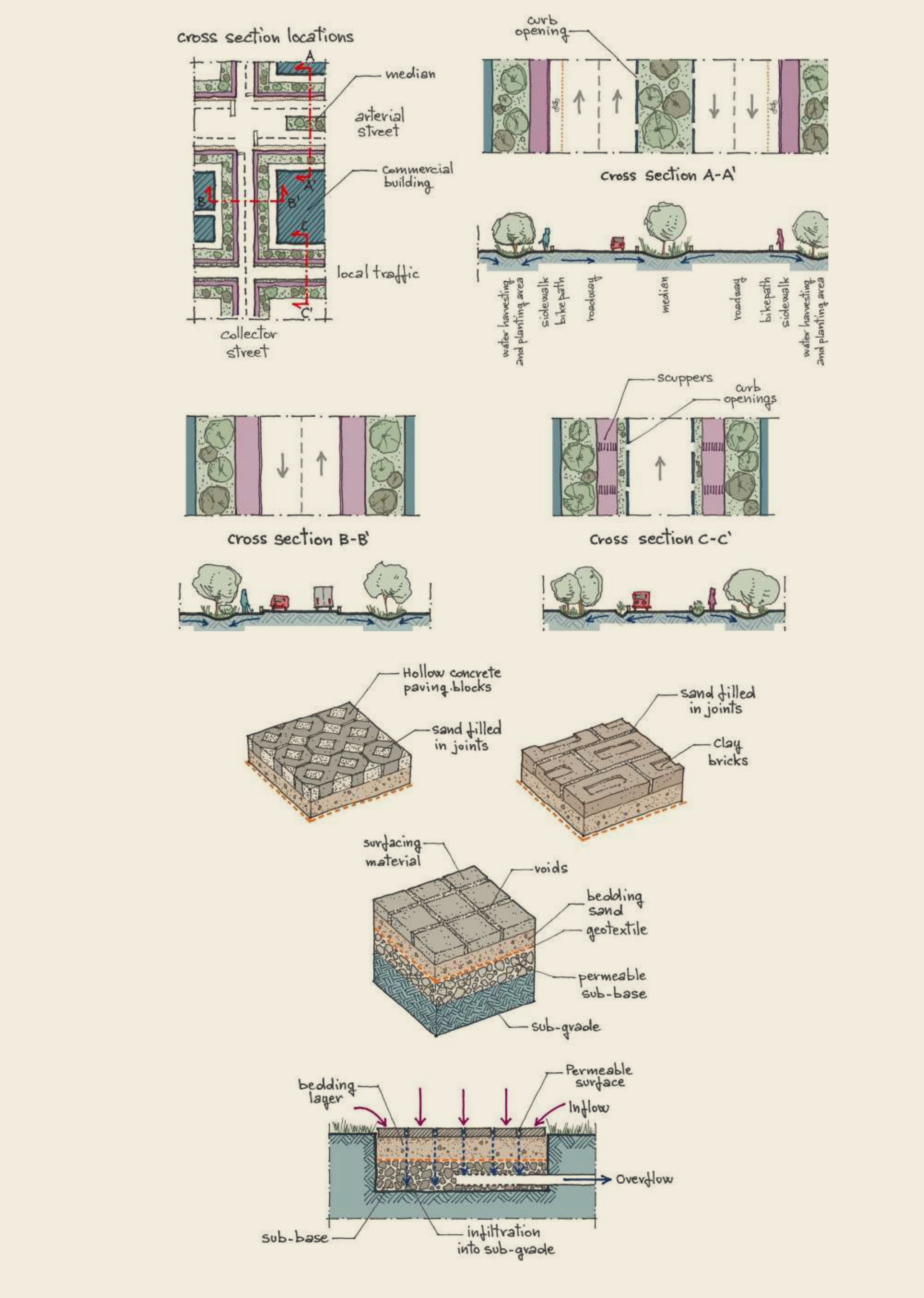
**The location and design of a public open space which incorporates urban water management measures should promote the detention of runoff through the use of swales, depressions, contour banks, rock channels, pebble paths, reed beds or other suitable measures without compromising the principal function of the public open space.**

**Streets should all include runoff mitigation systems such as swales or other pervious surfaces capable of absorbing and storing storm water. therefore, guarantee enough extra space for accommodating sustainable urban drainage systems (Figure 3.23, left).**

**Try to have the largest pervious areas possible, as they reduce runoff, and thus the danger of flooding (Figure 3.23, right); furthermore, replenishing the water tables via percolation makes a water shortage caused by an interruption of the centralised water supply less critical.**

*Calculate the percentage of permeable soils. At least 50% permeability should be assured in residential areas. For instance, open parking lots should be permeable where possible, and the width of roads should be limited to the minimum standards for cars to circulate.*

FIGURE 3.23 **MAXIMISE PERVIOUS SURFACES**



$$Soil\ permeability\ [0-100]=\frac{area\ of\ permeable\ surfaces\ on\ the\ ground\ [m^2]}{total\ area\ [m^2]}\cdot 100$$

*Try to achieve such stormwater control as to be able to cope with at least 95% of precipitation events without their resulting in flooding.*

*Evaluate the potential of the water table to provide a proportion of the neighbourhood's water demand, aiming for the community to be self-sufficient in water, by combining sustainable underground water extraction with rainwater harvesting. Involve a hydro-geologist from the earliest phases of the design process. Evaluate the consequent energy demand for pumping.*

**Treat all waste on site with biological systems. Reclaim as much water as possible for non-potable uses and harvest biomass for use as fertilizer on local farms. Collect sewage sludge, kitchen waste and yard waste and convert it into gas (Figure 3.23) to be used in combination with energy from other onsite renewable resources.**

**If proposing a bio-digestion or a composting plant, y plan its size, location and distance to the urban context carefully.**

**Wastewater is a resource in terms of energy, soil nutrients, irrigation and water table replenishment via percolation; this resource is best exploited at local level. Consider decentralised wastewater treatment as a sustainable option that increases community resilience and creates opportunities for employment. Consider the consequent space needed and the location**.

*Depending on the total volume and the nature of the wastewater and its temperature, the values given in Table 3.2 may indicate permanent area requirements for setting up a treatment plant DEWATS type. Smaller areas (about 3.5 m2 per cubic meter of treated water) are required for other natural treatment systems such as Advanced Ecologically Engineered System (AEES).*

TABLE 3.2 **PERMANENT AREA REQUIREMENTS FOR SETTING UP A TREATMENT PLANT**

| | |
|---|---|
| Septic tank, Imhoff tank | 0.5 $m^2/m^3$ daily flow |
| Anaerobic baffled reactor, anaerobic filter | 1.0 $m^2/m^3$ daily flow |
| Subsurface Horizontal Flow Constructed Wetland | 30 $m^2/m^3$ daily flow |
| Polishing pond | 25 $m^2/m^3$ daily flow |

*Treat and reuse at least 50% of wastewater on-site (USGBC 2014).*

**Evaluate the threat to health that may come from the possible contamination of the water table caused by incompletely treated wastewater. Involve experts in hydro-geology and water-borne diseases.**

**Treated wastewater enhances the effectiveness of green areas for the mitigation of the local climate, and paves the way for the development of urban agriculture, as it provides water and nutrients; this potential, however, must be exploited carefully, as it may have negative effects on health because of the potential for uncontrolled bacterial contamination and mosquito breeding.**

**Balance the extent of green areas (both for leisure and agriculture) with the availability of water and nutrients, on the basis of the degree of self-sufficiency in water of the neighbourhood, and size plots accordingly. Evaluate the level of treatment needed to make wastewater safe for use as a fertiliser or for fertigation. Involve an agronomist and a botanist from the beginning of the design process.**

### 3.5.3 INFRASTRUCTURE FOR SOLID WASTE MANAGEMENT

Solid waste management at neighbourhood scale (Figure 2.6.1) is a very effective way of enhancing its recycling potential, of promoting local employment and entrepreneurial activities and of encouraging social inclusion.

**Consider the provision of solid waste gathering areas at the local scale, both for waste sorting and recycling.**

**Include in the plan at least one recycling or reuse station, dedicated to the separation, collection, and storage of materials for recycling. Evaluate the size and position of the collection and sorting area where the neighbourhood's waste will be conveyed.**

**Consider the possibility of reusing locally both the organic part of solid waste and the vegetation residuals (like leaves) to produce fertilizers, or energy through bio-digestion. Evaluate the percentage of organic waste that can be reused in the neighbourhood for energy production and fertilizer production.**

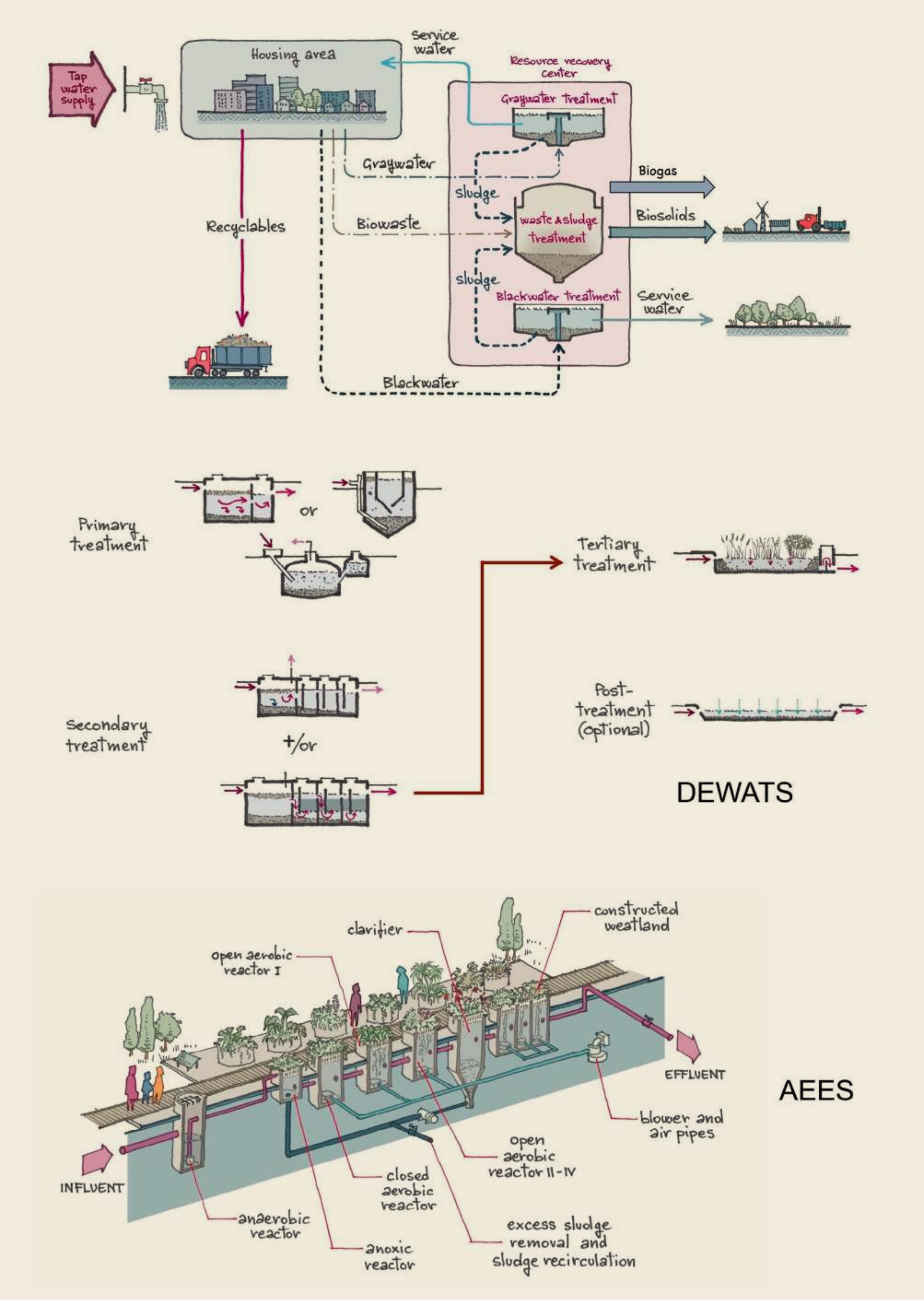
**Include in the plan at least one compost station or location, dedicated to the collection and composting of food and garden waste.**

### 3.5.4 ENHANCING LOCAL FOOD PRODUCTION

Much of the food we consume is transported from great distances to get to us. This process is expensive, wasteful of energy, and yields food of diminished nutritional value. Food sourcing at the local scale should be promoted.

**Consider that urban agriculture improves the food security of the neighbourhood.**

FIGURE 3.24 **DECENTRALISED WASTEWATER TREATMENT SYSTEMS**



**Provide adequate space to grow food locally. link urban agriculture with treated and recycled wastewater and with organic fertilisers deriving from wastewater treatment and from the composting of organic solid waste.**

*Use an iterative process for choosing the land area for urban agriculture, evaluating the potential total demand for vegetables of the neighbourhood (i.e. a sort of food footprint, mimicking the concept of ecological footprint), and checking the consistency of this value with the other conditions, such as the minimum park area to be guaranteed, the availability of usable wastewater and fertiliser produced by the neighbourhood and the density of the neighbourhood.*

*As a first estimate, 20% of the neighbourhood's land can be considered for urban agriculture, which is the value proposed in the Kigali Master plan (KCMP 2007).*

**Provide space for local food markets.**

### 3.5.5 CLOSING ENERGY, WATER AND WASTE CYCLES ON SITE

Energy, water and waste flows, and food production are interconnected. They are intersecting cycles and they must be considered as an integrated system (Figure 2.7.1). The interactions between structure (layout, form, land use, materials, greenery), energy, water and waste can be used for minimising the flow of resources needed for the operation of the neighbourhood and – at the same time – make the neighbourhood more resilient, thus more capable to cope with the challenges of climate change.

Obtaining such a result is a hard task, implying a systemic approach, the involvement of experts in a wide spectrum of fields of knowledge and the capability to integrate all these areas of expertise into a holistic vision.

## 3.6 SOCIAL AND ECONOMIC DOMAINS

An energy efficient development should also follow the sustainability triangle principles, which include economic, environmental and social principles. In particular, social equity is a crucial issue that indirectly affects people's habits and, consequently energy and resource consumption patterns. As described above, closing cycles at the local scale and designing with the principles of proximity in mind, leads to a more efficient use of resources and saves energy as well. The engagement of the inhabitants in the life of the neighbourhood enables them to create a real sense of community, which is not just the juxtaposition of people, but is about exchanging knowledge and learning from each other, sharing best practices and finally making the shared 'space' become a 'place'.

Sustainability is closely connected to the issue of time. It is not by chance that the word "sustainable" in other languages, such as French, is translated as "durable". This has a great impact on economic evaluations or the cost effectiveness of investments which aim to improve the sustainability of a neighbourhood. The return time cannot be measured in a few years, but in the long term. Moreover, it must be considered that many benefits deriving from sustainability measures are very difficult or sometimes impossible to quantify in monetary terms.

### 3.6.1 THE SOCIAL REALM

A sustainable neighbourhood is also (see section 3.9):

- a more inclusive neighbourhood, because of the social mix, and leads – through the employment opportunities that it offers - to a more just and equitable community
- a healthier neighbourhood, because of its comfort, its walkability, the availability of fresh food, and the improved access to safe water and to sanitation
- a more gender-friendly neighbourhood

**Promote local firms, possibly cooperatives of neighbourhood dwellers, for providing urban services: energy, water, wastewater treatment, solid waste management and transport. These will best tackle resilience strategies and find the most suitable local solutions. decentralized approaches to energy production and provision of environmental services are potential sources for local job creation, according to circular economy principles. People involved in the decentralised treatment of wastewater in the collection of waste, or in the generation of on-site energy, can become local agents, and also reference persons for the community, guaranteeing a social mix in the neighbourhood.**

**Provide an appropriate number of suitably sized spaces for handicraft businesses: they could become the backbone of the neighbourhood's economy.**

**Provide an appropriate number of suitably sized spaces for activities related to the shared economy.**

### 3.6.2 THE ECONOMIC REALM

Sustainable neighbourhoods involve benefits that are difficult or impossible to evaluate in monetary terms, such as:

- avoidance of costs due to ill health and those due to the increased resilience of the neighbourhood (lower impact of catastrophic events, such as flooding or water or food shortages);
- amount of money saved on air conditioning because of a climate responsive design;
- overall economic impact of increased employment and of entrepreneurial activity;
- quality of life, created by the availability of parks, by the reliability of basic services, such as energy, water and sanitation and by a reasonable income.

**When evaluating the costs and benefits of each infrastructure in the neighbourhood or comparing design options, always consider that these infrastructures, and the final texture and layout of the neighbourhood will be very long-lasting: the economic analysis cannot be based on short term returns. In the economic evaluation of infrastructures for sustainable development, always consider the entire life cycle. Try to evaluate the long-term indirect economic benefits deriving from the investments in sustainable infrastructures.**

*Evaluate the number of local jobs that can be created and the financial business generated at the community level.*

*Evaluate the cost of infrastructure for decentralised urban services, and consider their expected life span as the maximum return time: this will be the basis for defining the tariffs and checking if they are compatible with the expected income of neighbourhood's households, allowing for the increase in income resulting from the additional employment. Compare these costs with those of conventional service infrastructures.*

## 3.7 TWENTY BASIC RULES FOR SUSTAINABLE NEIGHBOURHOOD DESIGN IN TROPICAL COUNTRIES

The main features characterising a sustainable neighbourhood in tropical climates can be summarised as follows:

### Neighbourhood's form and structure

1. High density; aiming to at least 150 people/ha;
2. Walkable neighbourhood; 400-500 m ped-shed, within which basic services must be reachable, which implies mixed land use and limited land-use specialization: at least 40% of floor space should be allocated for economic use; single function blocks should cover less than 10% of the total land use; at least 18 km of street length per km$^2$, with high connectivity;
3. Mixed income residential buildings; 20 to 50% of the residential floor area should be for low cost housing; and each tenure type should be not more than 50% of the total;
4. Green public space area 15-20% of neighbourhood footprint;
5. Urban agriculture and local food markets;
6. Small and appropriately distributed parking areas, usable for electric car sharing, with PV canopies for charging;
7. Appropriate space allocation for energy production and storage, water, wastewater and solid waste treatment and management;
8. Layout: north-south/east-west grid with a possible offset of no more than 45° to favour penetration of dominant winds, if appropriate;
9. Urban canyons: aspect ratio H/W of north-south canyons between 2 and 3; possibly not less than 1 in east-west canyons. Streets always tree-lined. No fully glazed facades unless sun protected. Pervious pavements;
10. Net zero energy (nZEB) residential buildings, by means of on-site renewable energy production (PV on roofs and, where appropriate, micro wind turbines); this condition limits maximum building height;
11. Embodied energy minimisation: building shape with low surface to volume ratio; use of low embodied energy materials.

### Services

12. Decentralised energy production with renewable energy sources; smart grid and storage;
13. Rainwater harvesting, with two differentiated uses, potable water after treatment, direct use for non-potable (WC flushing, washing machine, plant watering);
14. Stormwater harvested from catchment surfaces and stored in cisterns or conveyed to recharge structure, with potential to restore aquifer extraction;
15. Buildings with dual network for separating grey and black water and provision for grey water recycling;
16. Biogas production from black water treatment system and reuse of appropriately treated water for irrigation (of parks, green spots, trees lining streets, and urban agriculture plots) and aquifer recharging;
17. Solid waste management at neighbourhood scale: domestic organic waste composting or anaerobic fermentation for biogas production; composting of agriculture residuals and landscaping wastes;
18. Wood from tree pruning as fuel for syngas production;
19. Treatment of biogas sludge (from black water and organic waste anaerobic fermentation) for use as fertiliser;
20. Use of biogas and syngas to power electricity generators connected to the mini-grid for contribution to demand-supply matching.

## BOX 3.2 LIFE CYCLE COSTING (CRP 2011)

Life cycle costing estimates the capital and operating costs of an entire development over a period of time. It can include an assessment of both public and private costs, and can be defined in financial, social, and environmental terms. They can be used to assess development projects at any scale.

### Cost Estimates

A life cycle cost assessment can include capital and operating cost estimates for:

- hard infrastructure (e.g., roads water, sewers);
- municipal services (e.g., transportation, re, police, waste management) ;
- private costs (e.g., commuting/transportation, home heating);
- costs of externalities (e.g., air pollution, motor vehicle accidents).

### Cost Assumptions

Costs are calculated based on certain assumptions. These include:

*Costing and revenue variables*

- Unit costs associated with different components of a development (e.g., the cost per meter of a two-lane collector road).
- Revenue sources (e.g., property taxes generated, development fees)

*Physical design elements*

- Land use distribution and density
- Street types and lengths
- Transit infrastructure

*Demographics*

- Household size and composition
- Household income

Life cycle costing models allow different development scenarios to be compared quantitatively over time. Where a basic cost-benefit analysis or development pro-forma may only examine costs in the short term, life cycle costing shows how costs and benefits could change for the development over time.

### When in the process it is used?

Life cycle costing is an evaluative tool. Its primary role is in the assessment of site plans and development programs, and it can reveal whether proposal results in acceptable long-term costs, both public and private. If a standard life cycle costing model is adopted for use by a municipality, targets or maximums for certain costs can guide the design process or serve as a means of assessing new development proposals during the review and approvals process. There is a role for these results in the marketing of a new community. Potential homeowners may be interested to know about long-term costs of ownership and potential savings from owning property in a development that uses more cost-effective infrastructure and building construction methods.

### BEST PRACTICE

*CMHC Life Cycle Costing Tool*

The Canada Mortgage and Housing Corporation (CMHC) has developed a spreadsheet-based "Life Cycle Costing Tool for Community Infrastructure Planning," which is publicly available on the CMHC's website (http://www.cmhc-schl. gc.ca).

"The Life Cycle Costing Tool for Community Infrastructure Planning (the Tool) was created to allow a user to estimate the major costs of community development, particularly those that change with different forms of development (for example, linear infrastructure), and to compare alternative development scenarios. The Tool is geared towards estimating planning level costs and revenues associated with the residential component of a development, although financial impacts of commercial and other types of development can be incorporated provided that infrastructure requirements are specified correctly.

The Tool is well suited to assessing development projects ranging in size from a collection of houses to a block-by-block infill development to an entire subdivision. A good measure of the applicability of the Tool to a given project is whether or not alternatives can be conceived that would result in significantly different densities or infrastructure requirements, or make use of different green infrastructure alternatives"

## 3.8 THE CHECKLIST

The checklist is based on the design tips and is structured accordingly. It provides an initial basis for evaluating a design scheme and its capability of including relevant sustainability topics at the scale of neighbourhood design. It is also a general framework for developing more locally tailored checklists. Hence, the proposed scoring system is purely indicative, and a weighting system based on local challenges and values should be developed: some places might give more relevance to one of the main themes addressed; some places will give the same weight to all of them.

The checklist can also be seen as a support tool to raise awarness of thedesign topics that impact on the overall sustainability of the design of a new neighboorhood. It is simply structured as an organized list of design issues that the designer, the decision maker and evaluator, or even the student of urban design, can use to check if all the relevant topics have been taken into consideration or not.

Public officers could use the checklist as a starting point for the creation of a local evaluation system, based on the values and challenges that their city is facing. Public officers can use this guidebook as a baseline for conceiving a more performance-oriented approach to the implementation of local design codes, where rewarding policies are promoted and special incentives for promoting sustainable technologies are foreseen which will sustain committed actors and diffuse best practices. On the other hand, designers, planners and developers could use the checklist to internalize sustainability values in the conceptual planning phase, as a sort of internal validation procedure.

## REFERENCES

ADG (2010), Active Design Guidelines, Center for Active Design, City of New York - https://centerforactivedesign.org/dl/guidelines.pdf

ADUPC (2014). Abu Dhabi Urban Street Design Manual. Abu Dhabi Urban Planning Council - http://www.upc.gov.ae/template/upc/pdf/Street%20Design%20Manual%20English%20(small)%20FINAL.pdf)

Alexander, C. and S. Ishikawa and M. Silverstein (1977); A Pattern Language, Oxford University Press, New York;

DTUK (2007), Department for Transport UK. Manual for Streets. London: Thomas Telford Publishing.

GTB (2011), Greenfield Tool Box, Calgary Regional Partnership

http://calgaryregion.ca/dam/Website/reports/General/Toolbox/Greenfield/Part-3_-process-tools/Part%203_%20process%20tools.pdf

LNWAG (2009), Liveable Neighbourhoods - a Western Australian Government sustainable cities initiative, Western Australia Planning Commission – Department for Planning and Infrastructure

https://www.planning.wa.gov.au/dop_pub_pdf/LN_Text_update_02.pdf

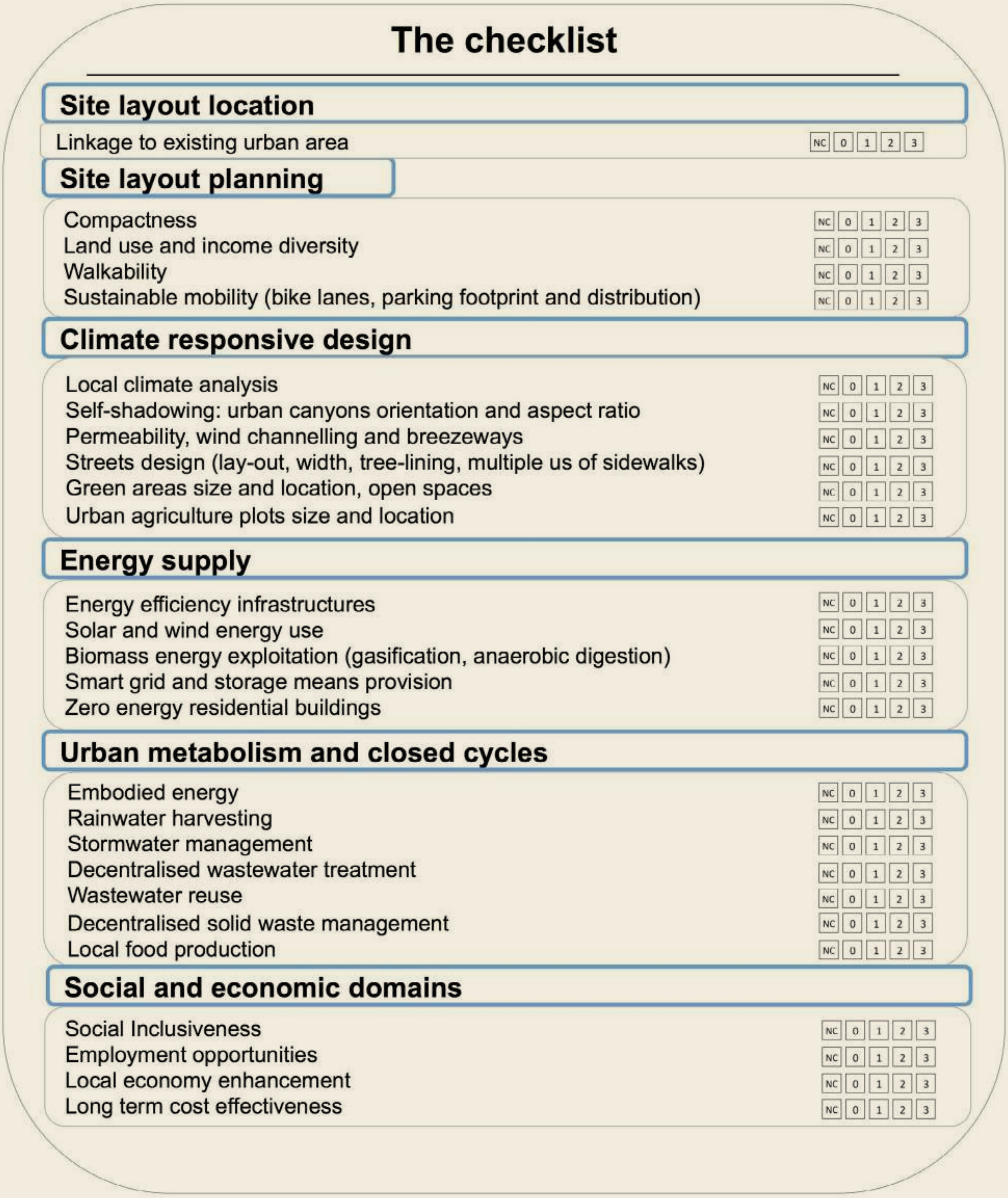
Schubert U. (2001), Ecocity, Urban development towards appropriate structures for sustainable transport - Publishable final report, EU 5th Framework Programme - http://www.transport-research.info/sites/default/files/project/documents/20060821_165050_79344_ECOCITY%20Final%20Report.pdf.

UN-Habitat (2013), A New Strategy of Sustainable Neighbourhood Planning: Five Principles – Urban Planning Discussion Note 3 - http://unhabitat.org/a-new-strategy-of-sustainable-neighbourhood-planning-five-principles/

USGBC (2011), LEED 2009 for Neighborhood Development Rating System - http://www.growsmartri.org/training/LEED%20for%20Neighborhood%20Development%20Rating%20System%20v2009%20(Updat.pdf

USGBC (2014), LEED v4 for Neighborhood Development Plan-http://www.usgbc.org/resources/leed-v4-neighborhood-development-checklist

## CHECKLIST



# The checklist

## Site layout location

Linkage to existing urban area NC 0 1 2 3

## Site layout planning

Compactness NC 0 1 2 3
Land use and income diversity NC 0 1 2 3
Walkability NC 0 1 2 3
Sustainable mobility (bike lanes, parking footprint and distribution) NC 0 1 2 3

## Climate responsive design

Local climate analysis NC 0 1 2 3
Self-shadowing: urban canyons orientation and aspect ratio NC 0 1 2 3
Permeability, wind channelling and breezeways NC 0 1 2 3
Streets design (lay-out, width, tree-lining, multiple us of sidewalks) NC 0 1 2 3
Green areas size and location, open spaces NC 0 1 2 3
Urban agriculture plots size and location NC 0 1 2 3

## Energy supply

Energy efficiency infrastructures NC 0 1 2 3
Solar and wind energy use NC 0 1 2 3
Biomass energy exploitation (gasification, anaerobic digestion) NC 0 1 2 3
Smart grid and storage means provision NC 0 1 2 3
Zero energy residential buildings NC 0 1 2 3

## Urban metabolism and closed cycles

Embodied energy NC 0 1 2 3
Rainwater harvesting NC 0 1 2 3
Stormwater management NC 0 1 2 3
Decentralised wastewater treatment NC 0 1 2 3
Wastewater reuse NC 0 1 2 3
Decentralised solid waste management NC 0 1 2 3
Local food production NC 0 1 2 3

## Social and economic domains

Social Inclusiveness NC 0 1 2 3
Employment opportunities NC 0 1 2 3
Local economy enhancement NC 0 1 2 3
Long term cost effectiveness NC 0 1 2 3

**Legend:**

*NC: not controlled by design and planning; suspended evaluation*
*0: not addressed; negative evaluation*
*1: addressed; sufficient evaluation*
*2: addressed; average evaluation*
*3: addressed; positive evaluation*

# GLOBAL BEST PRACTICES

The aim of this chapter is to provide worldwide examples of best practices whose scope is to improve the sustainability of a neighbourhood. In most cases the best practices proposed do not encompass all the aspects of neighbourhood sustainability, but only one or more of them.

The chapter contains examples divided by topic. When possible, two case studies are enlisted for each topic. The topics are:

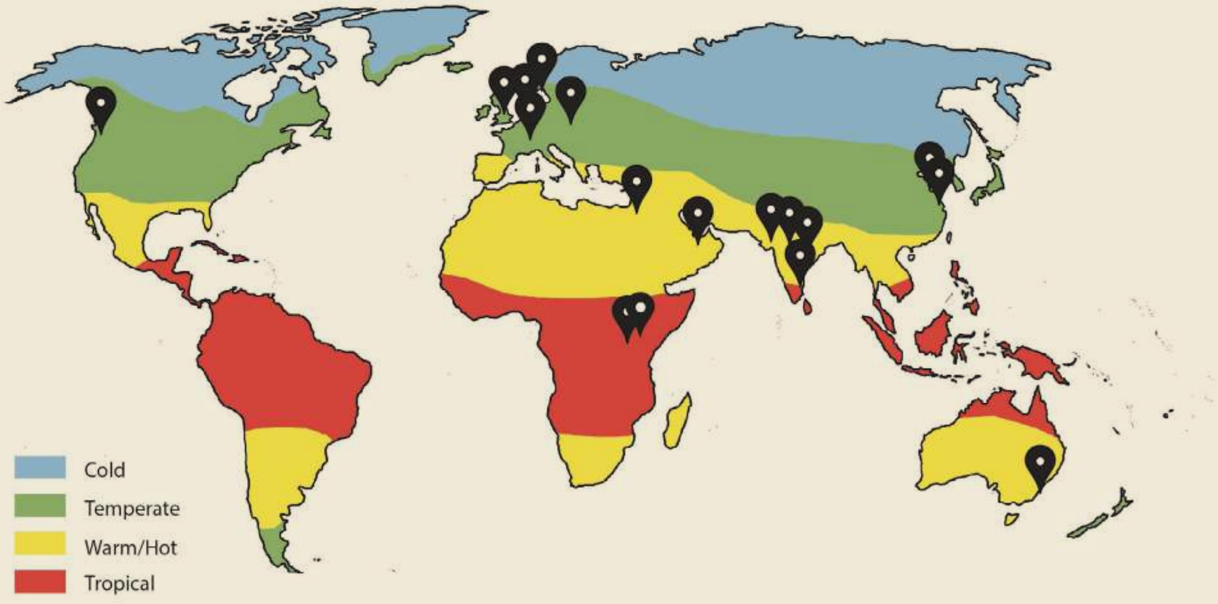
- Closed loop urban metabolism,
- Design for shade and climate attenuation,
- Water harvesting and public spaces,
- Blue and green infrastructure,
- Storm water drainage,
- Slow mobility,
- Energy production,
- Regulations and Guidelines.

For each case study, when available, the following information is provided:

- Location,
- Type of intervention,
- Date of realisation,
- Design team,
- Climate data (temperature, humidity, wind velocity).

# 04 BEST PRACTICES

## LOCATION OF BEST PRACTICES



# 4.1 CLOSED LOOP URBAN METABOLISM

## 4.1.1 QINGDAO ECOBLOCK

| **LOCATION: Qingdao, China** | |
|---|---|
| TYPE OF INTERVENTION: | Sustainable neighbourhood |
| DATE OF REALIZATION: | Project dropped |
| DESIGN TEAM: | Fraker H., UC Berkeley |
| TEMPERATURE: | -5 C (January); +31 C (August) |
| HUMIDITY: | The relative humidity typically ranges from 32% (comfortable) to 95% (very humid) over the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 8 m/s (calm to moderate breeze), rarely exceeding 11 m/s. |

In recent years, China has been developing "superblocks", which are roughly 1 square kilometre areas that contain 2,000-10,000 residential units within them. The city provides the arterial streets and the developer buys the rights to build everything inside the blocks. Harrison Fraker and a team of students at UC Berkeley designed the Qindao EcoBlock Project, an alternative to the superblock system. The EcoBlock prototype can be mass replicated, but is completely off the grid, generates its own electricity and processes its own water and waste. According to the designers, if the Chinese government adopted the EcoBlock, it could save $35 billion in infrastructure costs and $200 billion in environmental costs each year.

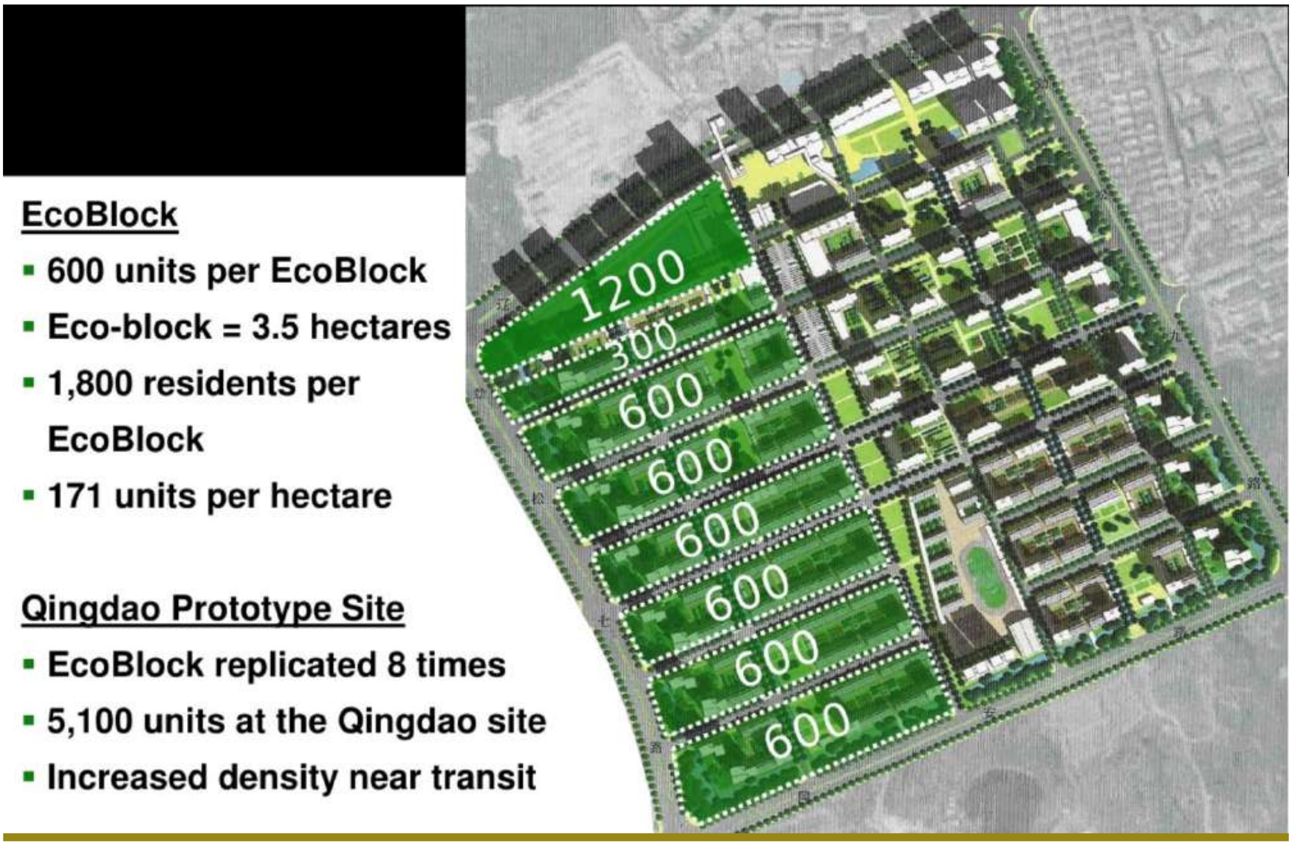
Unfortunately, this project has not yet been implemented.

In such a project "Buildings" does not mean an individual, single homeowner building but a cluster (Figure 4.1) that may have thousands of people living or working therein (high-rise apartment building, office/residence towers, large block or subdivision).

The plan proposed an integrated system of energy generation, water conservation and supply, and waste treatment. With various design features (Figure 4.2) such as building shading, high-performance glazing, passive solar heating, shaded walkways, and energy efficient equipment, the energy consumption was expected to be 40% lower than conventional development. The remaining demand should be covered by the energy supply generated internally through a comprehensive system of building integrated wind turbines (53%), photovoltaics (40%), and anaerobic digesters (7%) which convert waste from sewage sludge, kitchens and green waste, into gas (Figure 4.3). Electric storage systems are part of the system, to give the Ecoblock the chance to be entirely self-sufficient, with no need for connection to the regional grid.

EcoBlocks are also semiautonomous water management/drainage units that receive water, implement water conservation inside the structural components throughout the cluster, capture and store rainfall and stormwater, reclaim sewage for reuse, and recover biogas from organic solids.

FIGURE 4.1 **QINGDAO ECOBLOCK PROTOTYPE PROGRAM DETAILS (SOURCE: FRAKER 2008)**



**EcoBlock**

- 600 units per EcoBlock
- Eco-block = 3.5 hectares
- 1,800 residents per EcoBlock
- 171 units per hectare

**Qingdao Prototype Site**

- EcoBlock replicated 8 times
- 5,100 units at the Qingdao site
- Increased density near transit

FIGURE 4.2 **ECOBLOCK'S TECHNICAL SYSTEM (SOURCE: FRAKER 2008)**

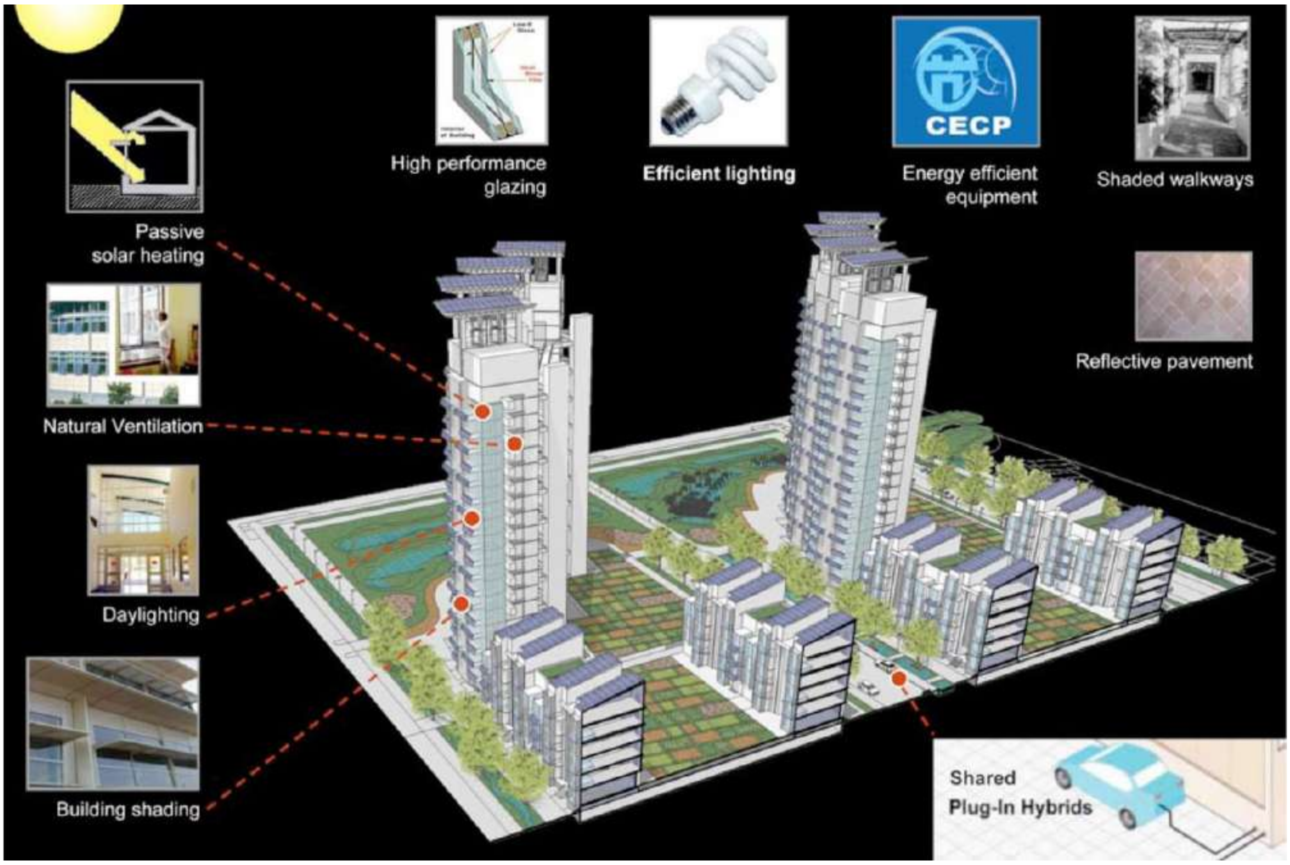
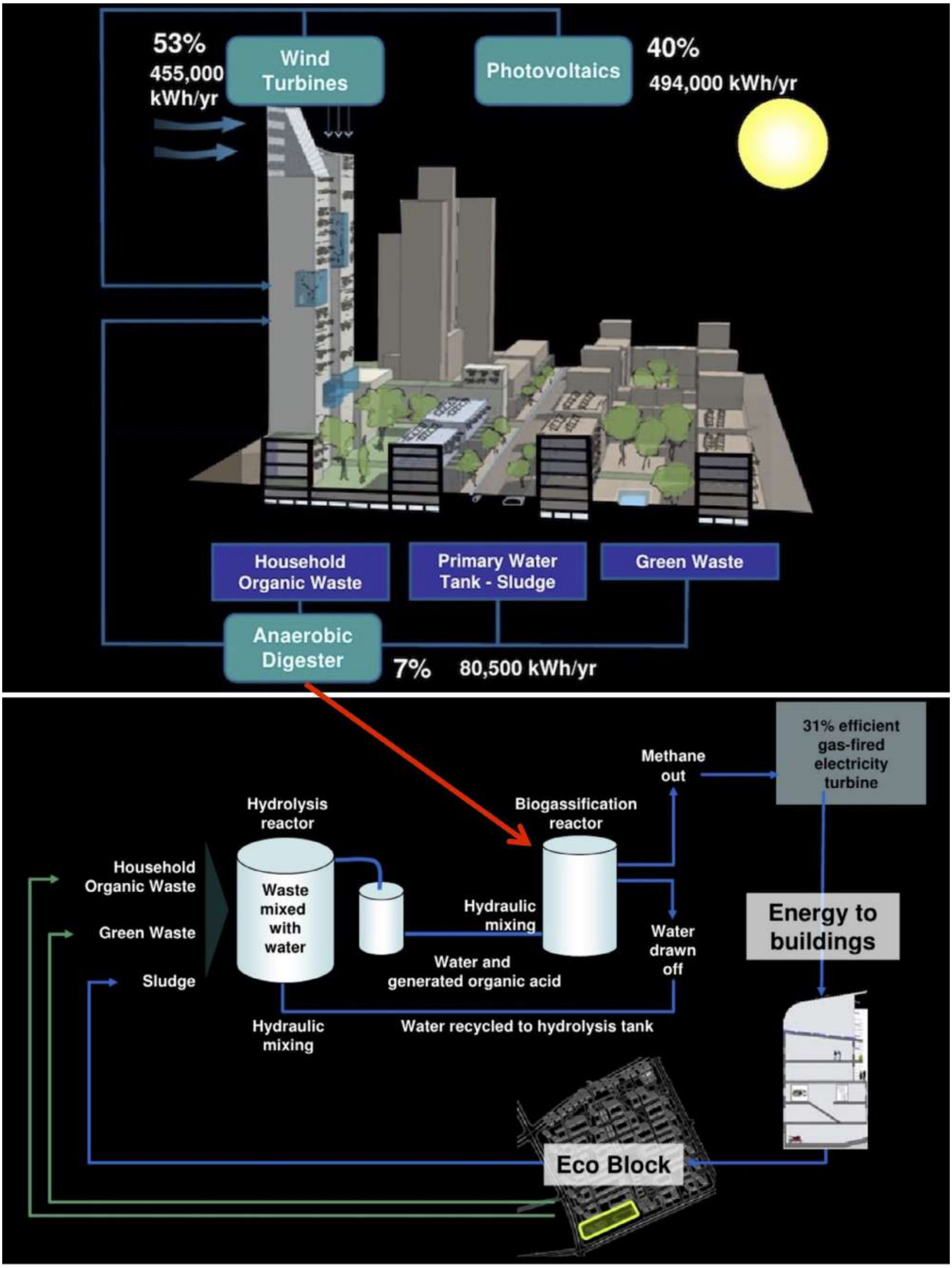


FIGURE 4.3 **INTEGRATED ENERGY GENERATION SYSTEM ADOPTED IN THE PROJECT (SOURCE: FRAKER 2008)**



Water and waste reclamation and reuse is carried out in a double loop consisting of grey and black water reclamation (Figure 4.4). Such a system accomplishes the following objectives:

1. it collects rainwater, makes it potable and mixes it with some potable water from the municipal network, to be used for kitchen, bathroom sinks and for showers;
2. it treats grey and black water to almost potable water quality for several in-house uses although direct potable use is not contemplated, making use of a "Living Machine" system:
3. it reuses treated water for WC flushing and washing machines;
4. in addition to providing water to inhabitants, the double loop system also provides some water flow to the surface water bodies within the city and garden irrigation;
5. it recovers some energy in the form of biogas and heat.

Heat recovery is an important part of the project because household water heating for washing, showers, laundry and washing dishes represents the largest domestic energy expenditure related to water and, consequently, the largest energy recovery which can be done efficiently (e.g., by a heat pump) from a local household or cluster.

Furthermore, at a local cluster/ecoblock scale, aquifer recharge will be accomplished by infiltration of captured stormwater by means of pervious pavements, ponds, wetlands and gardens (Figure 4.5).

Such systems reduce the potential transport of stormwater pollutants, decrease the choking of storm water drains and flooding, improve the quality of ground water and also allow the storing of water that can be reused for other purposes.

The solid waste cycle is shown in Figure 4.6. It can be noted that the waste loop is not completely closed, and about 17% of the complex's waste (primarily non-recyclable solid waste) will have to be sent to the landfill.

Figure 4.7 shows how reliance on electricity and water grids was reduced. The synergic operations of all the mentioned systems, are combined to make Qindao a closed cycle neighborhood. An overall view of the integrated energy-water-waste cycles is shown in Figure 4.8, and the layout of the infrastructure systems in Figure 4.9).

The EcoBlock's additional sustainability initiatives are expected to increase the upfront costs by 5-10% over a standard development. At face value, a completely net-zero energy and water and nearly net-zero waste community would cost just 5-10% more than a standard resource-inefficient development, which seems quite remarkable.

But an extra $7 million in upfront development capital can significantly affect the project's economics: Professor Fraker estimates that this investment will have a 10.1-year payback period. Ten years is a long time for developers anywhere, and light years in China's fast-moving development market, and is likely to be a big deterrent to Chinese developers.

But the real financial barrier with the EcoBlocks is not necessarily this cost increase per se, but rather a mismatch between costs and benefits. All the costs- solar panels, digesters, wind turbines, wastewater treatment facility, etc.- are borne by the developers. On the other hand, most of the benefits are enjoyed by either the tenants or the government.

FIGURE 4.4 **THE WATER CYCLE (SOURCE: FRAKER 2008)**

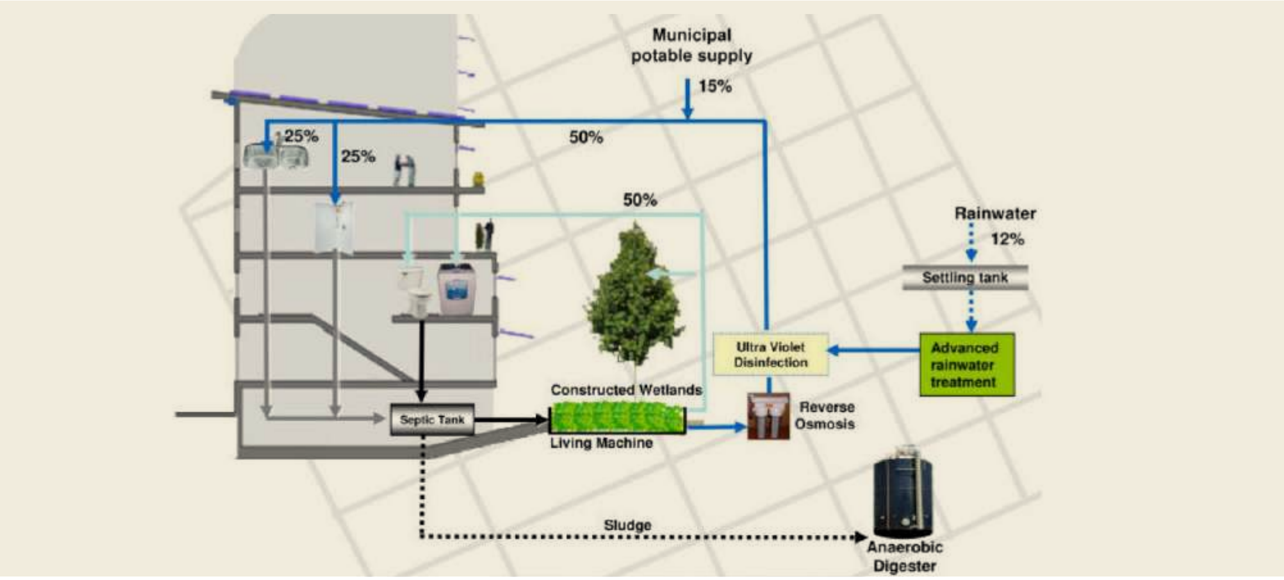


FIGURE 4.5 **CONCEPT OF THE ECOBLOCK'S STRATEGY (SOURCE: FRAKER 2008)**

FIGURE 4.6 **SOLID WASTE CYCLE (SOURCE: FRAKER 2008)**

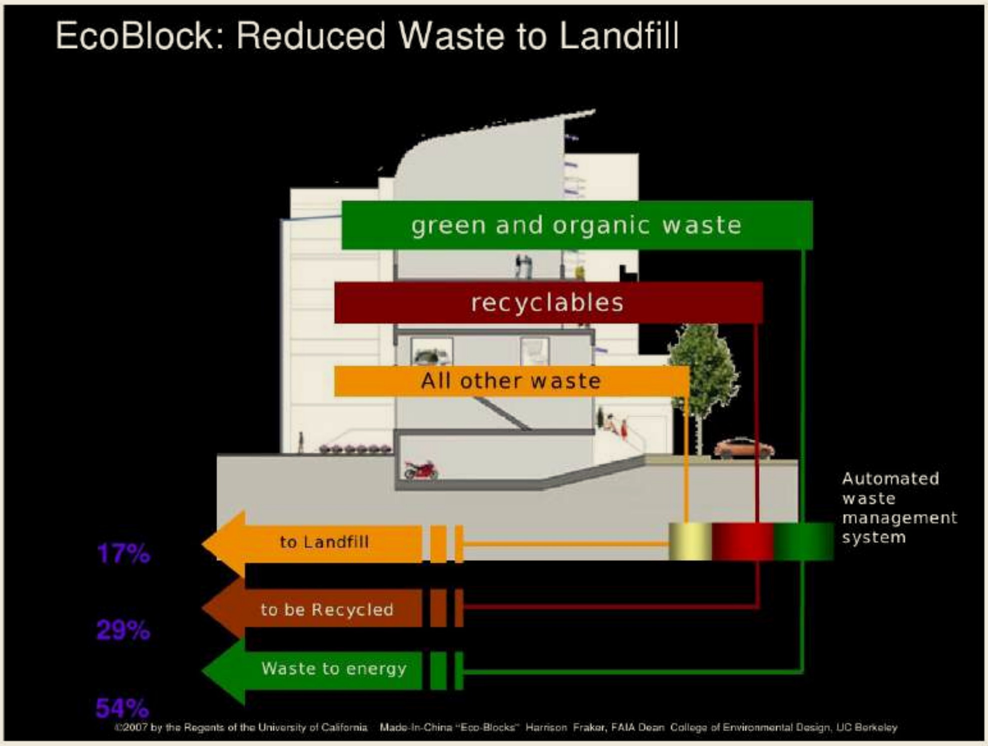
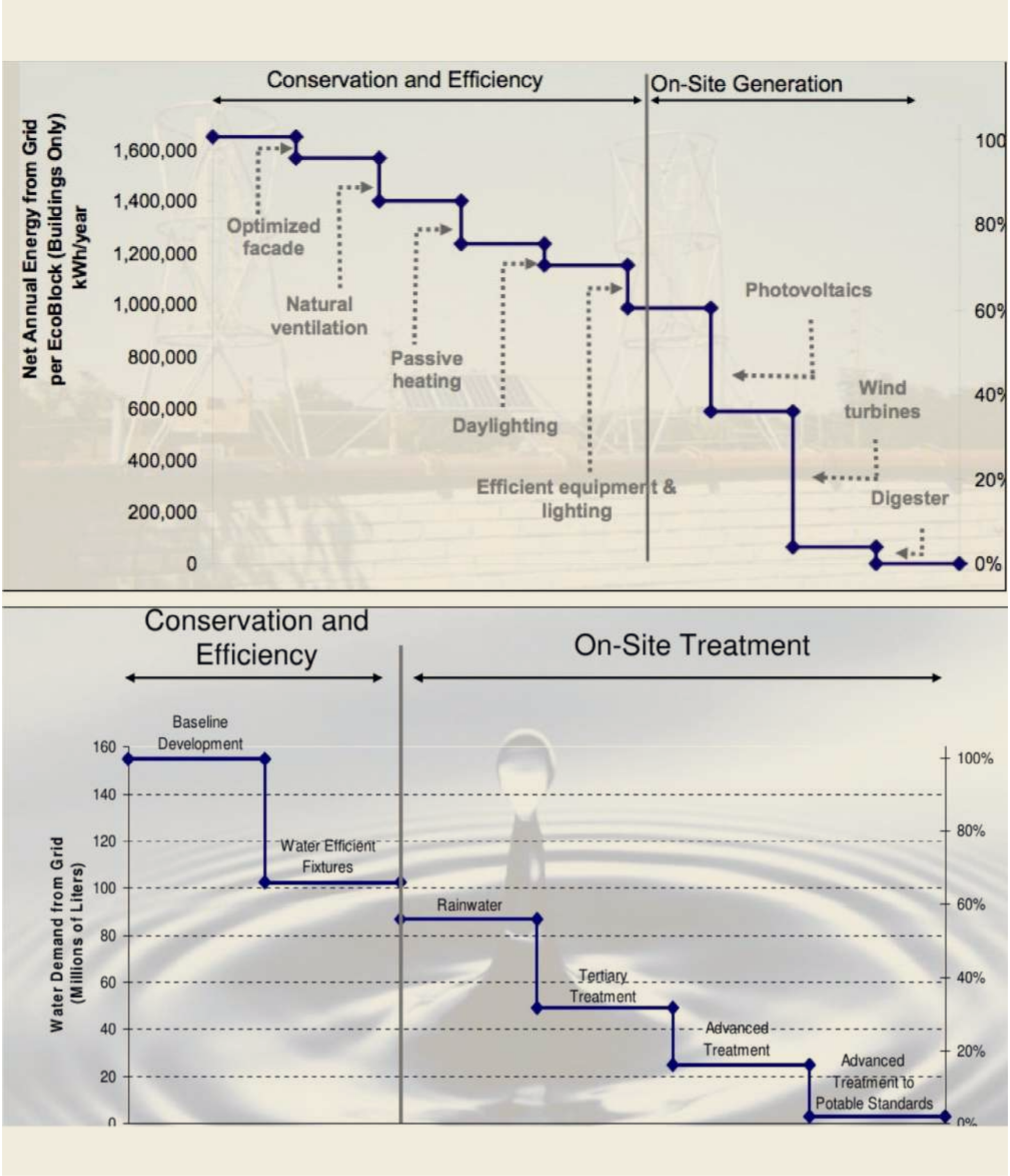


FIGURE 4.7 **REDUCING RELIANCE ON GRID BASED ENERGY AND WATER (SOURCE: THE ECO BLOCK 2008)**



The benefits that flow to the tenant are obvious: a net-zero energy and water community means no monthly electricity or water bills. Theoretically, these money-saving benefits could potentially be capitalized upfront and included in the price of the units. However, that would probably make the units prohibitively expensive for the average urban Chinese resident, limiting the usefulness and scalability of the EcoBlock model. A possible alternative, to keep the cost affordable, is that after completion of the block, users pay the developer a phantom "utility bill" instead of a real utility bill. Essentially, the idea is for those who get the long-term benefits (government, users) to pay the developer, the actor with the most control over the design.

FIGURE 4.8 **CONCEPT OF THE ECOBLOCK'S STRATEGY. (ADAPTED FROM: LIN 2014)**

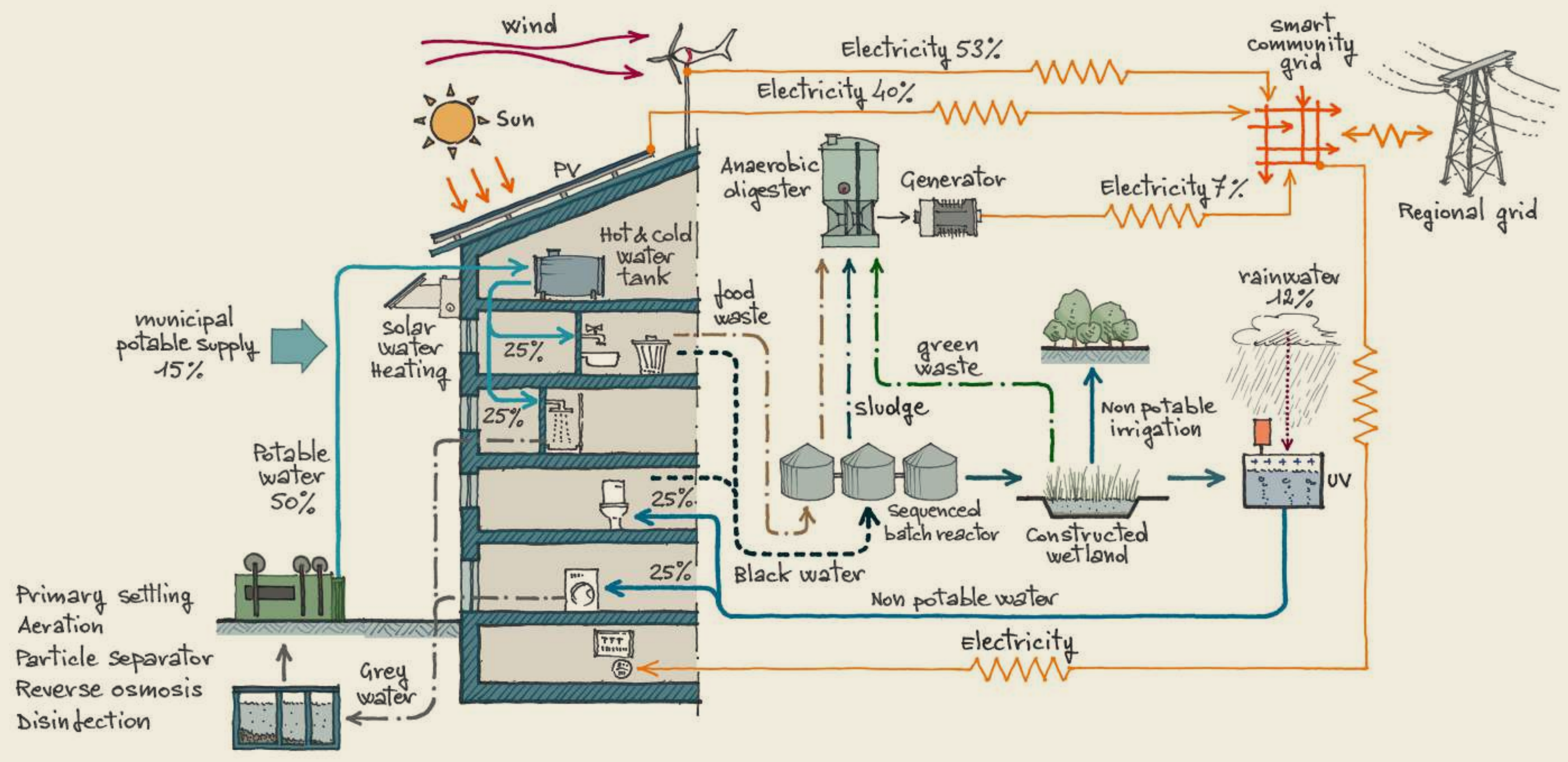


FIGURE 4.9 **INFRASTRUCTURE SYSTEMS LAYOUT.**

## REFERENCES

Brown, G., P., Dykema. 2009. Eco Pattern Districts. A paper for the Portland Urban Architecture Research Laboratory

China green buildings. n.d., http://chinagreenbuildings.blogspot.it/2009/02/ecoblocks.html accessed on 3/3/2017

Lin, Z. 2014. Constructing Utopias: China's Emerging Eco-cities, ARCC/EAAE 2014 | Beyond Architecture: New Intersections & Connections.

Fraker H., Wurster W., 2008. "Eco-Blocks". A Replicable Model for Sustainable Neighborhoods. A Zero Carbon Transit Oriented Neighborhood. Workshop on Future Urban Transpor

http://its.berkeley.edu/sites/default/files/volvocenter/VREF/02_Fraker_Made-in-China%20Ecoblock%20FUT080519.pdf

National Academies of Sciences, Engineering, and Medicine. 2016. Using graywater and stormwater to enhance local water supplies: an assessment of risks, costs, and benefits. National Academies Press.

Novotny V. 2001.Holistic approach for distributed water and energy management in the cities of the future. Proceedings Cities of the Future Conference, IWA, Xi'an, China.

The Eco Block. 2008. China Sustainable Neighborhood Project http://www.raia.com.au/i-cms_file?page=13538/nicole-avril-ecoblock-qingdao-presentation.pdf accessed on 3/3/2017

## 4.1.2 HAMMARBY SJOSTAD

| **LOCATION: Stockholm, Sweden** | |
|---|---|
| TYPE OF INTERVENTION: | Sustainable neighbourhood |
| DATE OF REALIZATION: | 1996-2012 |
| CLIENT: | THE CITY OF STOCKHOLM |
| TEMPERATURE: | -5 C (January); +23 C (July) |
| HUMIDITY: | The relative humidity typically ranges from 42% (comfortable) to 96% (very humid) over the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 6 m/s (moderate breeze), rarely exceeding 9 m/s. |

Hammarby Sjostad is a district in Stockholm, adjacent to the city centre, and is a brownfield site that is being developed as a sustainable neighbourhood. Previously an industrial waterfront, planning for the redevelopment of the site began in 1996. In 2012 the project has been completed and is a 200-hectare development housing approximately 20,000 people in 9000 housing units.

Hammarby Sjöstad was planned with a dense settlement structure of typically 4-5 storey buildings in a compact neighbourhood, but with spacious green courtyards; there is at least 15 m² of courtyard space and a total of 25–30 m² of courtyard space and park area within 300 m of every apartment.

The moderate height of the houses and the sufficiently spacious neighbourhoods allow for both wind-shielded and sunny inner courtyards with ample possibilities and incentives to develop both entrance planting and common courtyard planting, and facilitating small-scale cultivation in micro-garden plots or small greenhouses. At least 15 % of the courtyard space is sunlit for at least 4–5 hours at the spring and autumn equinoxes.

Green roofs have also been established. They are an important part of the stormwater system as well as providing important habitat.

The Hammarby Model is the district's attempt at a balanced, "closed-loop urban metabolism", which accounts for the unified infrastructure of energy, water and waste (see Figure 4.10). In addition to the Hammarby Model infrastructure, the presence of urban-scale density, access to multiple modes of transit with an emphasis on reduced car commuting, the preservation and restoration of existing natural systems, and progressive construction and housing policies make Hammarby Sjostad an effective demonstration that ecological and urban can go together when there is comprehensive planning.

The Hammarby model includes energy conservation measures in which the goal is to reduce heat consumption by 50% and use electricity more efficiently when compared to the Swedish average.

With respect to this, the total energy supply for the members of the community, who live and work in Hammarby Sjostad, is based only on renewable sources (Figure 4.10a): electrical energy is provided by photovoltaic, hydropower and bio-fuel technology, thermal energy is provided by district heating plants.

FIGURE 4.10 **CONCEPT OF THE CLOSED-LOOP URBAN METABOLISM (SOURCE: GLASHUSETT 2007A)**

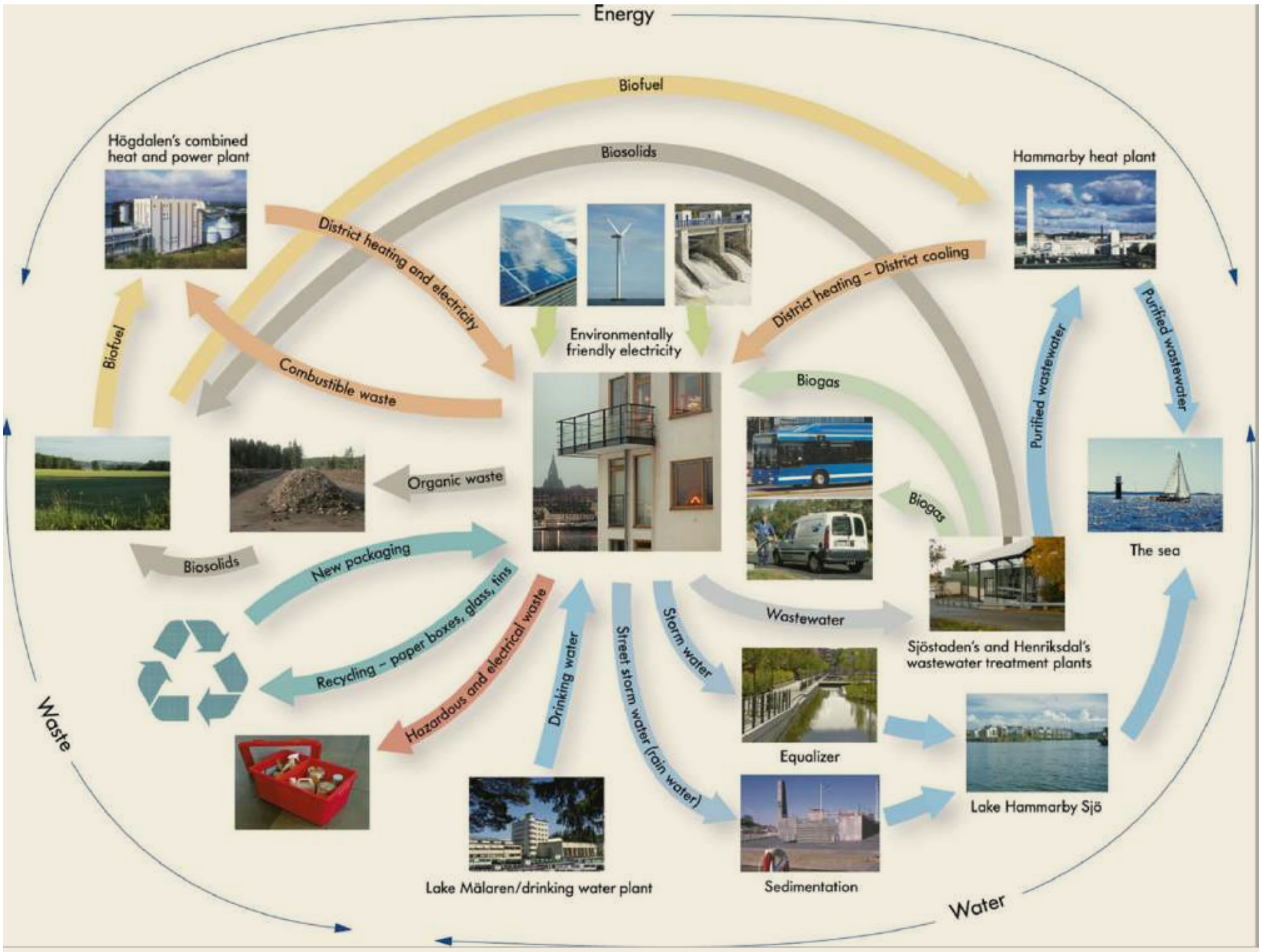
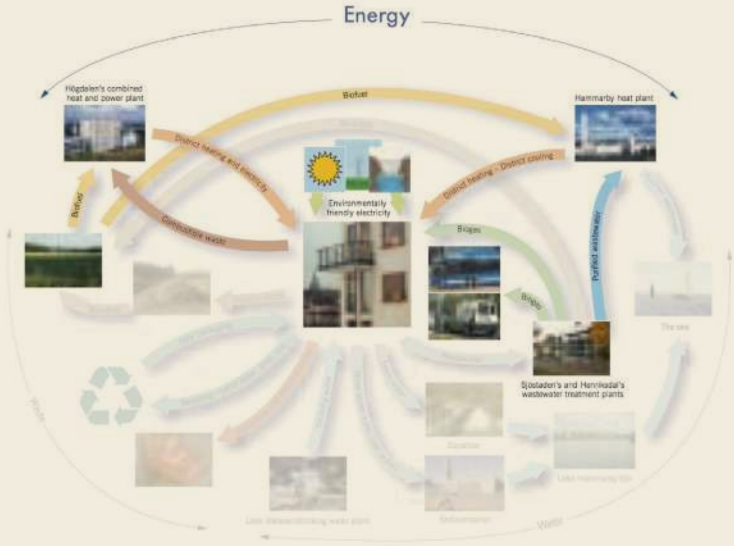


FIGURE 4.10a **THE ENERGY CYCLE (SOURCE: GLASHUSETT 2007A)**

Energy

- Combustible waste is converted into district heating and electricity.
- Biofuel from nature is converted into district heating and electricity.
- Heat from treated wastewater is converted into district heating and district cooling.
- Solar cells convert solar energy into electricity.
- Solar panels utilise solar energy to heat water.



Moreover, in some houses a "smart system" has been implemented, consisting of a display where residents can see in real time their energy consumption and the related cost. Residents can thus be more aware of their energy uses and expenditures.

The water cycle is closed as much as possible (Figure 4.10b).

In order to reduce the amount of runoff entering the drainage system of Hammarby Sjostad, surface water is cleaned locally. The rainwater from surrounding houses and gardens runs into an open drain system that drains out into an attractive channel. The water then runs through a series of basins, known as an equalizer, where the water is purified and filtered through sand filters or in the artificially established wetlands of the area. After this purification process, the water then travels out into Lake Hammarby Sjo, restoring the water levels in the lake.

Roof gardens also serve to reduce roof run-off during storm events, partially by allowing the water to be absorbed, stored and purified through the soil and partially by the transpiration of the plants. In this way, the roof run-off that would otherwise drain into the sewers is absorbed by the roof gardens.

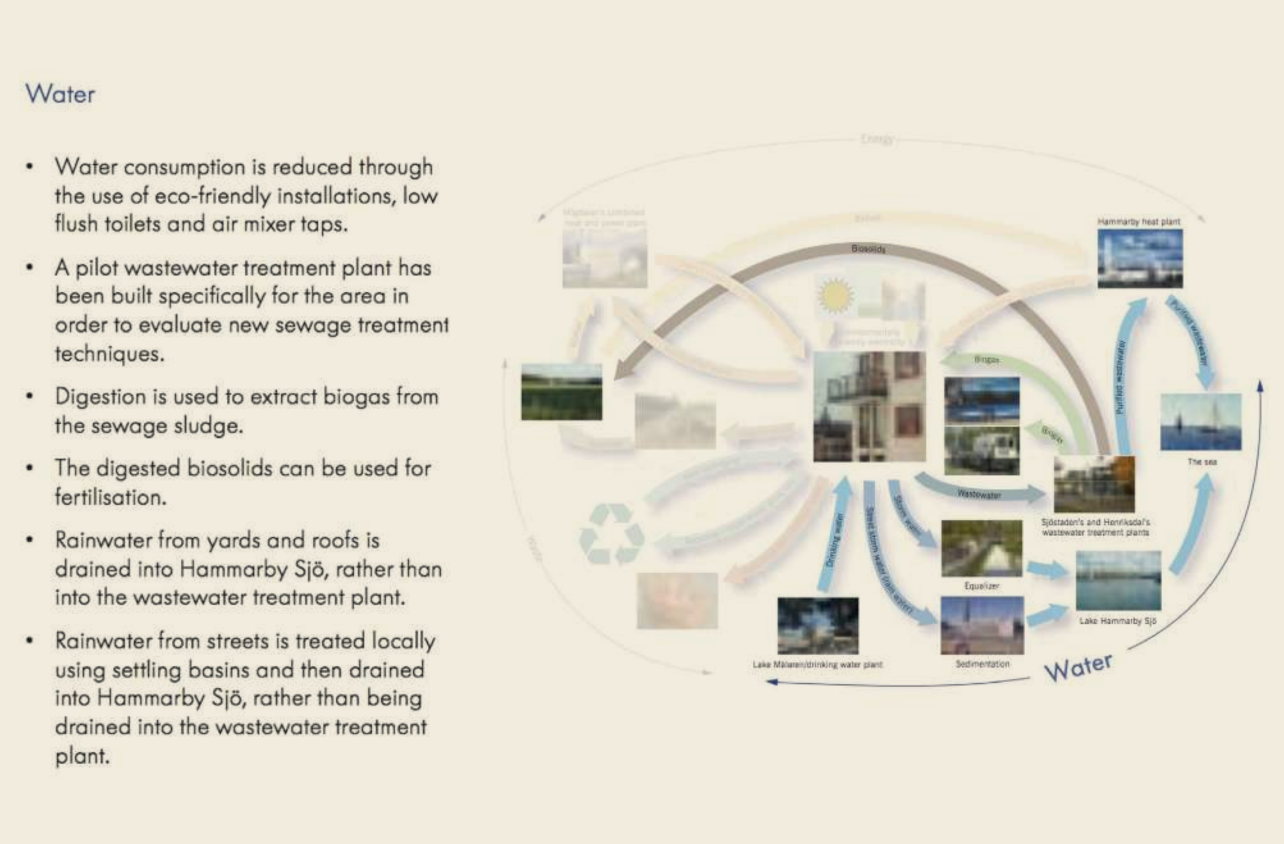
Rainwater and snowmelt from the streets is collected and treated separately in a variety of different ways. The most common way involves draining the water into the wetlands, in which soil and plants handle the contaminants from dirty water or into a closed polishing pond in which the water is stored for several hours, in order to allow the settling of contaminants on the bottom. Water is then drained out into the canals.

To further enhance the traditional ways of recycling and reuse, the district has opened (in 2003) its own pilot sewage treatment centre. The wastewater treatment plant is testing new technologies for recycling waste. The system recycles nutrients from sewage, which are used as fertilizer in agricultural land, and methane, which is used as biogas to supply energy not only for homes, but also for cars and buses.

Waste is separated and then reused and recycled, closing the waste cycle as much as possible (Figure 4.10c).

Hammarby Sjostad uses a vacuum system to sort solid waste and refuse. The heaviest and bulkiest waste portions are sorted and collected via an underground waste collection system. The waste is sucked down through pipes into a block-based recycling room, one portion at a time (see Figure 4.11). The containers are then collected from the room by refuse collection trucks. This one-stop collection helps reduce the amount of vehicle traffic in the area. On collection days, the waste disposal vehicles suck the contents of the chambers out in a clean airtight process.

FIGURE 4.10b **THE WATER CYCLE (SOURCE: GLASHUSETT 2007A)**



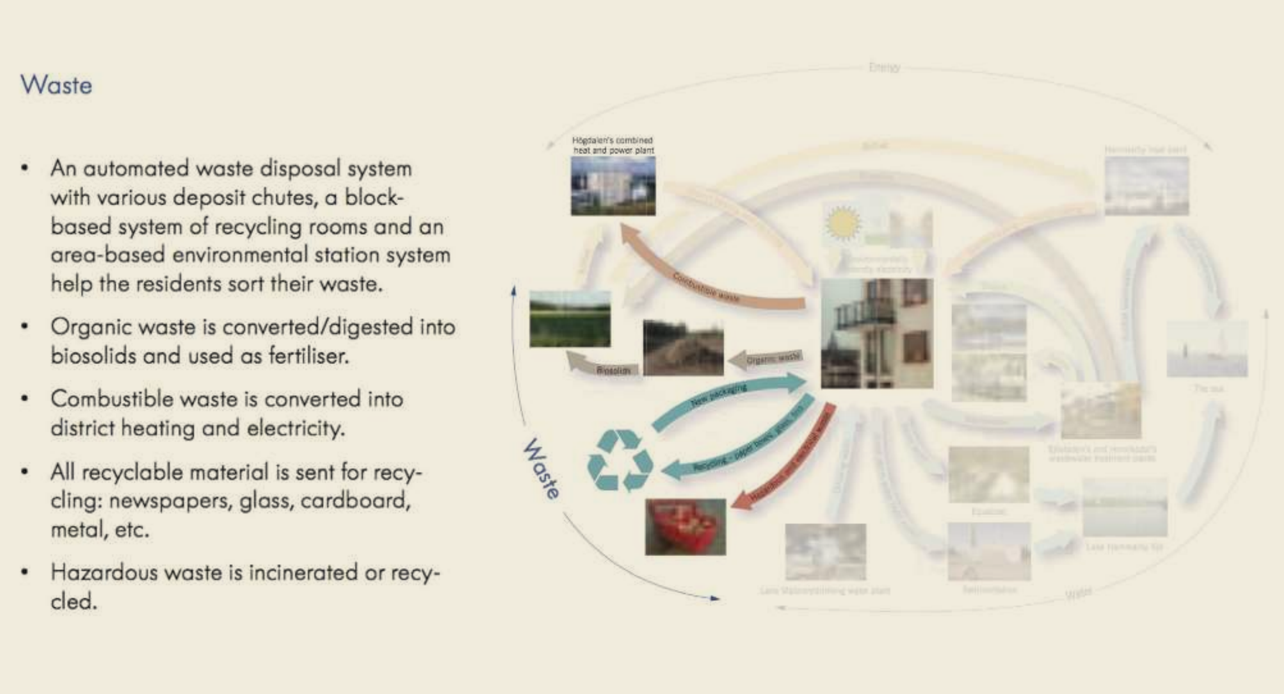
Water

- Water consumption is reduced through the use of eco-friendly installations, low flush toilets and air mixer taps.
- A pilot wastewater treatment plant has been built specifically for the area in order to evaluate new sewage treatment techniques.
- Digestion is used to extract biogas from the sewage sludge.
- The digested biosolids can be used for fertilisation.
- Rainwater from yards and roofs is drained into Hammarby Sjö, rather than into the wastewater treatment plant.
- Rainwater from streets is treated locally using settling basins and then drained into Hammarby Sjö, rather than being drained into the wastewater treatment plant.

Another important part of the project is related to transportation; the district in fact is designed to reduce car travel. In fact, according the walkable neighbourhood principles, all the main local services of the district are accessible within 500 m (see Figure 4.12). Moreover, the transit system in Hammarby Sjöstad is based on a network of pedestrian sidewalks, cycle paths, trams, busses, "shared" vehicles, and ferries linked together by several transit nodes which integrate services directly related to mobility. In this way, 80 % of residents' and workers' journeys are by public transport, on foot or by bicycle.

Moreover, a carpool open to both residents and those working in the district has been launched in the area. Lastly, a new pedestrian avenue linking the district's new green public spaces and new green corridors runs all the way through the southern part of Hammarby Sjöstad. The parks are intended to be attractive environments and serve as footpaths for people, but are also intended to serve as dispersal corridors and living environments for animals and plants.

FIGURE 4.10c **THE WASTE CYCLE (SOURCE: GLASHUSETT 2007A)**

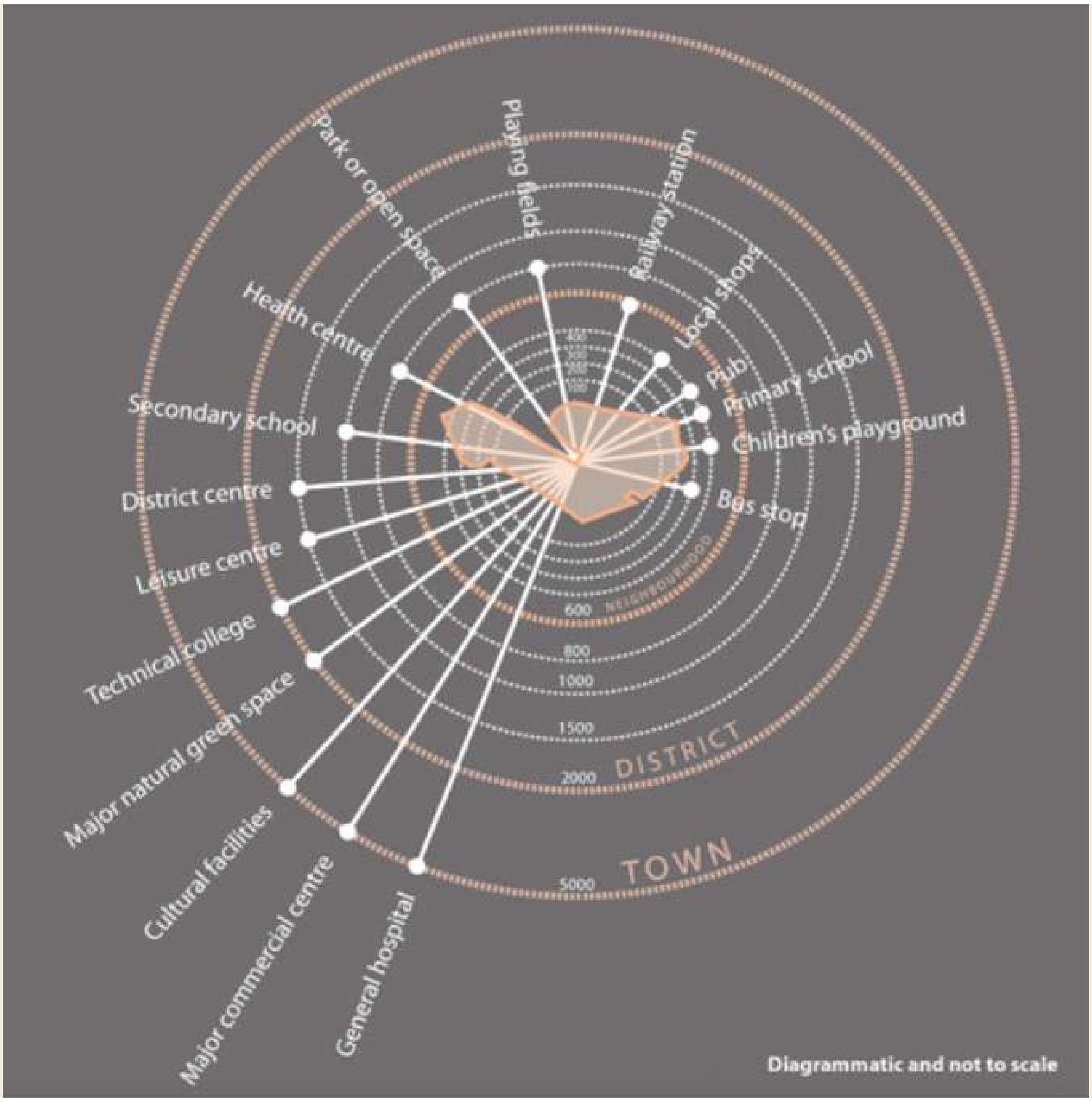


Waste

- An automated waste disposal system with various deposit chutes, a block-based system of recycling rooms and an area-based environmental station system help the residents sort their waste.
- Organic waste is converted/digested into biosolids and used as fertiliser.
- Combustible waste is converted into district heating and electricity.
- All recyclable material is sent for recycling: newspapers, glass, cardboard, metal, etc.
- Hazardous waste is incinerated or recycled.

FIGURE 4.11 **UNDERGROUND WASTE COLLECTION SYSTEM (SOURCE: GRANATIERO 2014)**

FIGURE 4.12 **DISTANCE BETWEEN CITY CENTRE AND SERVICES**



## REFERENCES

Dastur, A. 2005. "How Should Planning Engage the Issue of Sustainable Development? The Case of Hamarby Sjostad, Stockholm".

Engineering, education, environment. n.d. -http://www.mecsrl.net/it/sezione_id,18/sistema-di-raccolta-rifiuti-pneumatica/divisioni.html

Gaffney A., Huang V., Maravilla K., Soubotin N., Hammarby Sjostad Stockholm, Sweden. A case Study.http://www.aeg7.com/assets/publications/hammarby%20sjostad.pdf

GlashusEtt., 2007a. Hammarby Sjöstad. A new environmental and ecological city district project, http://www.thenatureofcities.com/2014/02/12/hammarby-sjostad-a-new-generation-of-sustainable-urban-eco-districts/

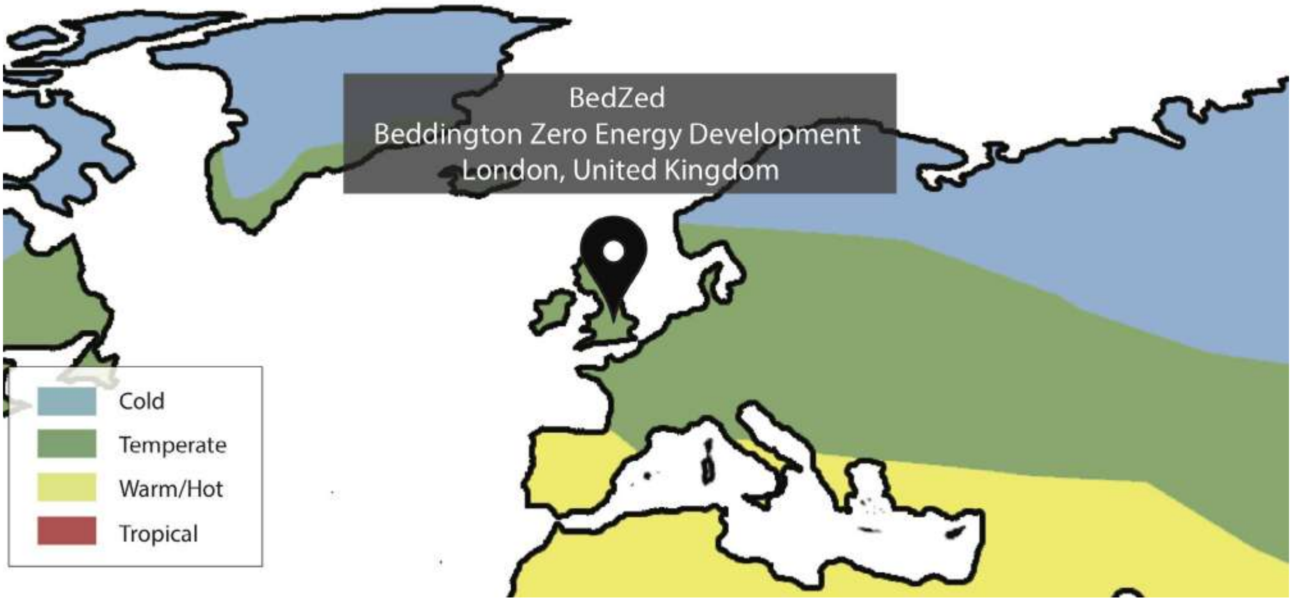
GlashusEtt., 2007b. Hammarby Sjöstad, 2007. A new city district with emphasis on water and ecology,http://bygg.stockholm.se/Alla-projekt/hammarby-sjostad/?acceptcookies=true

GlashusEtt., 2007c. Hammarby Sjöstad – a unique environmental project in Stockholm http://bygg.stockholm.se/Alla-projekt/hammarby-sjostad/?acceptcookies=true

Johansson, R., Svane, O., 2002. "Environmental Management in Large-Scale Building Projects – Learning from Hammarby Sjostad.". http://www3.interscience.wiley.com/cgi-bin/fulltext/100520224/PDFSTART.

## 4.1.3 BEDDINGTON ZERO ENERGY DEVELOPMENT

| **LOCATION: Beddington, United Kingdom** | |
|---|---|
| TYPE OF INTERVENTION: | Sustainable neighbourhood |
| DATE OF REALIZATION: | 1996-2012 |
| DESIGN TEAM: | Bill Dunster Architects (BDA, now ZEDfactory) |
| TEMPERATURE: | -11 C (January); +24 C (July) |
| HUMIDITY: | The relative humidity typically ranges from 45% (comfortable) to 94% (very humid) over the course of the year, rarely dropping below 23% (dry) and reaching as high as 100% (very humid). |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 7 m/s (calm to moderate breeze), rarely exceeding 10 m/s (fresh breeze). |



BedZED is a compact mixed-use urban development with 82 units, 271 habitable rooms, plus, over 2500 m2 of space for offices, studios, shops and community facilities, designed in 1996 in order to realize the UK's largest mixed-use sustainable community. However, contrary to expectations, during the running phase the neighbourhood faced several challenges, which made it less efficient than forecast. Nevertheless, the idea that underlies the project is extremely interesting.

A high occupation density (over 500 people living and working per hectare) is made possible by integrating workspaces and housing within a compact cross-section. The roofs of the workspaces are used as gardens for the adjacent dwellings, giving most units a private garden, at densities that would normally allow only a balcony. The workspaces are in the shade zone of the dwellings, and are lit by large triple-glazed skylights (Figure 4.13).

Most of BedZED's homes have sunspaces behind big, south facing glazed facades (Figure 4.13). These sunspaces are found on all three storeys. During sunny periods, and even under a light overcast of clouds, the air within them is warmed by the sun – the greenhouse effect. During summer, when the air temperature inside the sunspaces can become uncomfortably hot, the exterior windows in the sunspaces can be opened to allow cooling.

In the design project all of the energy required at BedZED should have been supplied by renewable technology on-site by 777 m2 of solar photovoltaic (PV) panels, and a 130-kW woodchip-burning combined heat and power (CHP) plant (Figure 4.14). The woodchip, deriving from London parks' tree pruning, was combusted in a gasifier, providing gas fuel for an internal combustion engine driving an electricity generator. Heat from the gasifier and engine was used to heat the water circulating through the district heating system.

Unfortunately, the CHP plant frequently had to be taken out of service for modification and maintenance. Interior condensation and build-up of tar was a real problem, partly attributable to the plant having to shut down every night and restart every morning instead of running continuously. This stopping and starting was a condition imposed by council planners concerned about noise.

For this reason, in 2005 CHP was removed and replaced by three conventional natural gas-fired boilers which supply heat for the district heating scheme. So, starting from 2005, 80% of the electricity is drawn from the national grid and all of the hot water is provided by backup condensing boilers using natural gas.

This was a major setback, meaning the zero-fossil fuel ambition was only achieved for a few years.

BedZED design was faced with two water problems that are very common in London: flooding, due to a lack of capacity in the drainage systems; and insufficient water supplies, due to a low amount of per capita rainfall and a high per capita level of water consumption.

The Sustainable urban Drainage Systems (SuDS) was designed to tackle the flooding problems, by means of permeable paving, green roofs seeded with drought-resistant sedum, and a soakaway ditch in which rainwater slowly soaks into the ground and local watercourses, minimizing the surface water draining into the local sewers. Such systems reduce flooding and boost biodiversity, creating a feeding ground and migration corridor for birds and insects.

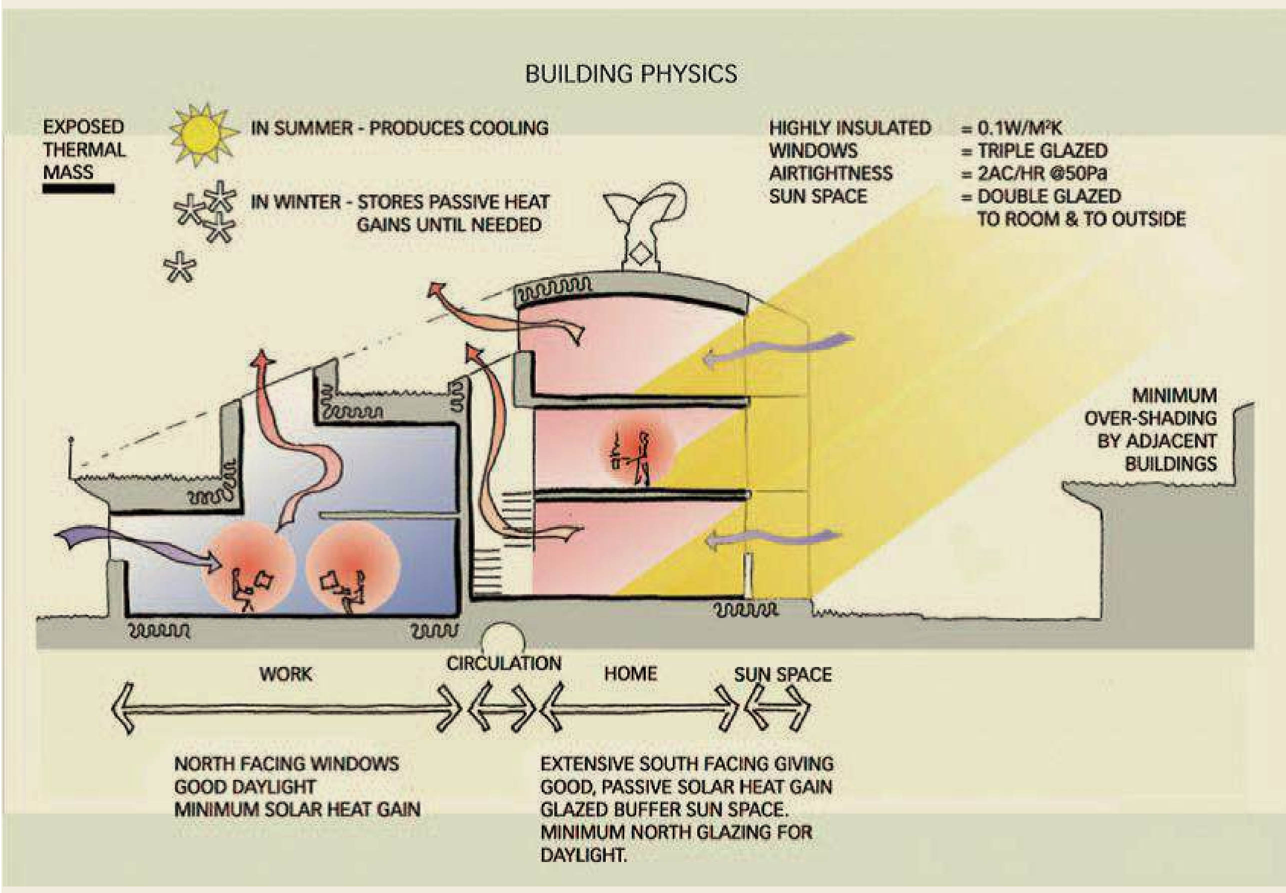
Rainfall was treated on-site and used to flush the toilets, with excess water going to the soakaway ditch. Between 2002 and 2007, a green water treatment plant (Figure 4.15) based on "Living Machine" technology (or AEES, Advanced Ecologically Engineered System) was installed, using a mixture of biologically active sludge and reed beds. Unfortunately, this water recycling facility was unable to clean the water sufficiently.

Lastly, good practice measures to reduce water consumption have been incorporated, including restrictors to prevent excess flows, mains pressure showers to avoid power-showers, meters visible to consumers and very low or dual flush toilets.

BedZED was designed to encourage its residents to use greener forms of transport and to radically reduce greenhouse gas emissions from travel compared to a conventional suburban housing development. The original plan aimed to:

- reduce parking spaces (fewer than one per home, compared to a planning guideline at the time of 1.5 spaces per home);
- provide the first London car club, which makes it easier for people to get rid of their own car and share one of three maintained by a company, and pay per mile, so incentivizing further reductions in mileage;

FIGURE 4.13 **SECTION OF A BEDZED BUILDING (SOURCE: ARUP 2003)**



- provide free electric car-charging points along two of the four parking areas;
- design a "living streets", or home zone, layout that gives priority to pedestrians and cyclists;
- have good links to public transport, with a bus stop opposite the development and two train/tram stations within easy walking distance; and
- ample provision for cyclists with secure parking and storage space inside the homes.

The neighbourhood residents drive 64% less than the local average. Although some of this can be attributed to a higher than average proportion of social tenants, it is also evidence of significant behaviour changes.

FIGURE 4.14 **BIO-FUELLED COMBINED HEAT AND POWER PLANT (SOURCE: ARUP 2003)**

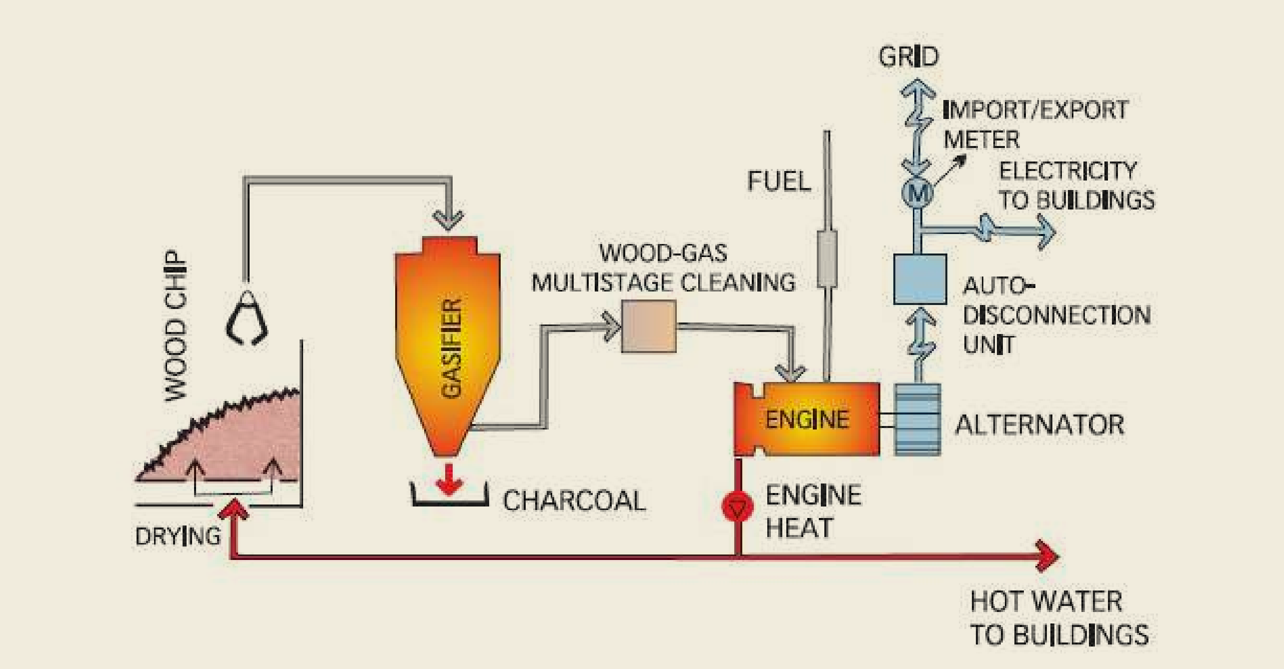
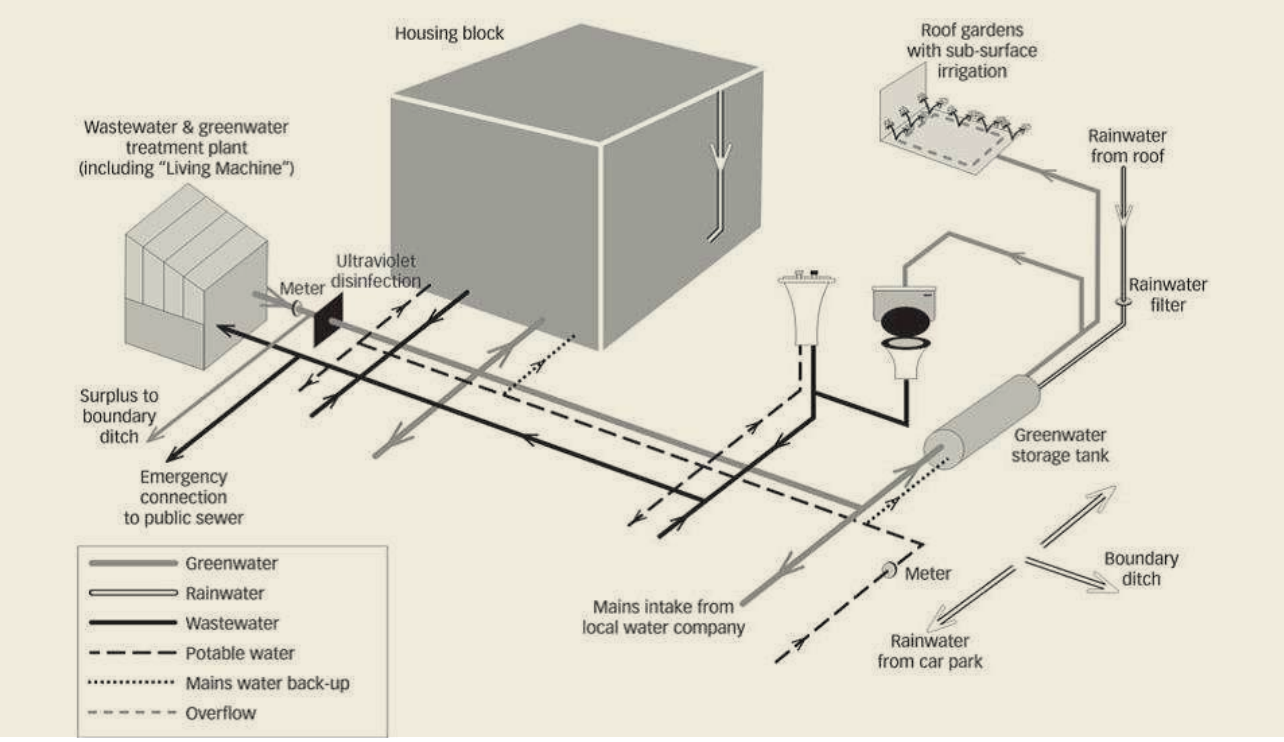


**FIGURE 4.15 – WASTE WATER TREATMENT PLANT (SOURCE: CHANCE 2008)**



## REFERENCES

ARUP 2003, republished from Toolkit for Carbon Neutral Developments Part II, BioRegional.

Bioregional, 2016. The bedzed story, The UK's first large-scale, mixed-use eco-village - http://www.bioregional.com/wp-content/uploads/2016/04/The-BedZED-Story.pdf

Chance, T., 2008. Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond. Environment & Urbanization, Vol. 21. http://journals.sagepub.com/doi/pdf/10.1177/0956247809339007

Dunster, B. 2007. The ZEDbook (Zed Book).

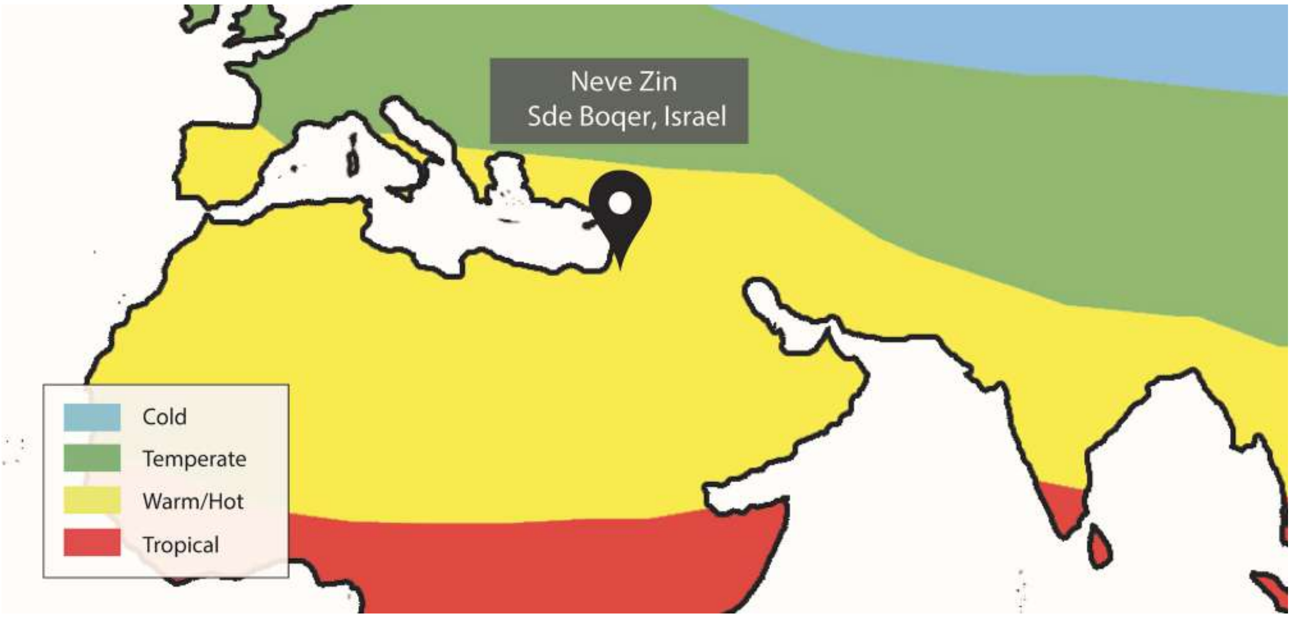
Dunster, B. 2010. Zedfactory. MD Mostafavi, Gareth (Ed.), Ecological Urbanism, 274-279.

Twinn C., 2003. BedZED, The ARUP Journal - http://host.uniroma3.it/docenti/marino/Teo&Tec/comunicazioni/dunster%20bed_zed/Dunster_ZedFactory%202.pdf

## 4.2 DESIGN FOR SHADE AND CLIMATE ATTENUATION

### 4.2.1 NEVE ZIN SDE BOQER

| **LOCATION: Israel** | |
|---|---|
| TYPE OF INTERVENTION: | Urban design for shade and climate attenuation |
| DATE OF REALIZATION: | 1990 |
| DESIGN TEAM: | Desert Architecture Unit of the J. Blaustein Institute for Desert Research |
| TEMPERATURE: | +4 C (January); +38 C (July) |
| HUMIDITY: | The relative humidity typically ranges from 15% (very dry) to 82% (humid). |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 6 m/s (light air to moderate breeze), rarely exceeding 19 m/s (gale). |



Neve Zin is a neighbourhood in the Sde Boqer kibbutz in the Negev desert of Israel. The project's aim was to develop a masterplan for faculty and workers at the J. Blaustein Institute for Desert Research. The masterplan's main effort is to promote climate-conscious building design that depends not only on individual buildings, but on their urban context - on the relationship of one to another, and to the spaces created between them. The plan and its guidelines are adapted to the climatic conditions of the desert highlands in a number of key ways. Street layout, zoning, and massing controls created an urban fabric which generates microclimates that mediate the extreme desert conditions.

The site includes 79 private detached single-family houses, (plots of around 600-700 square metres), and each building plot has been guaranteed full solar access in winter, to maximise the potential for passive solar heating and encourage its utilization.

Solar rights are ensured by limiting the height of each building in relation to the winter sun, and in this way restricting the shadows cast on the adjacent plot to the north. An imaginary "bulk plane" (see Figure 4.16) sloping upward at a prescribed angle from the adjacent plot's southern setback line defines the volumetric limits of the building or any other obstruction, ensuring solar access to each house throughout a winter day.

A pedestrian realm is created in which paths are protected from sun, winds and dust. Water and maintenance-intensive public landscaping is limited to small areas, while private gardens are sized to residents' preferences.

Building plots are clustered in groups of four, with each plot containing a point at its outer corner on which the individual house must stand. In this way, public paths are tightly defined by the protecting walls of adjacent buildings, while open space at the centre of each cluster is reserved for private landscaping.

Vehicular streets are oriented in an east-west orientation. While maintaining a pedestrian character, they are wide enough to separate neighbouring north and south plots, making it easier to ensure solar rights.

FIGURE 4.16 **DIAGRAM OF THE IMAGINARY "BULK PLANE" (SOURCE: MESA 2010)**

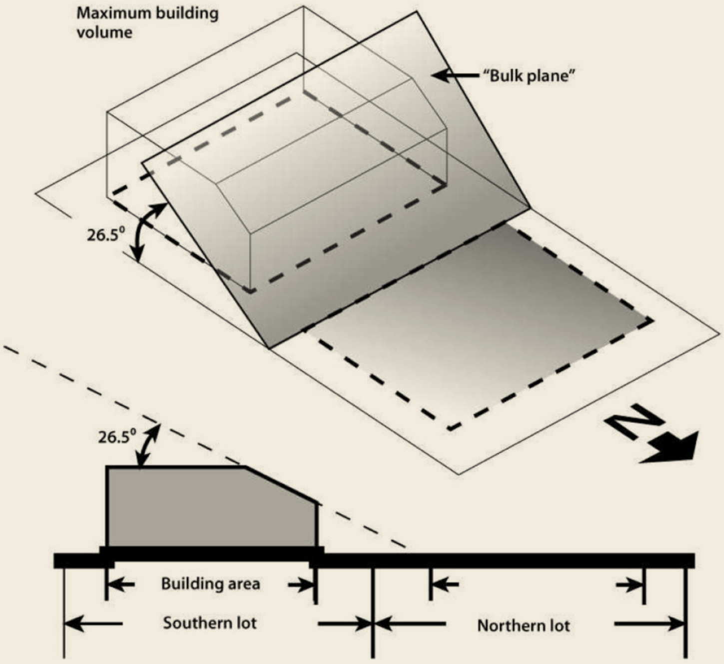
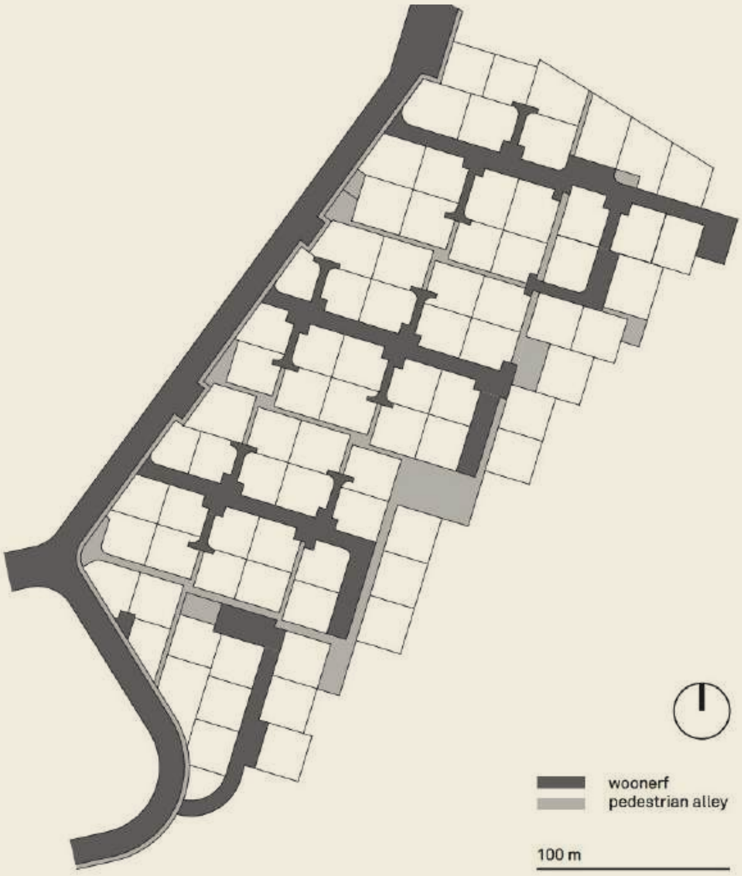


FIGURE 4.17 **PEDESTRIAN CIRCULATION (SOURCE: WASTVEDT 2013)**



Pedestrian walkways, on the other hand, are oriented north-south. Only 2.5 meters wide, they are shaded during morning and afternoon hours on a summer day by flanking walls, and will be further protected by vine-covered trellises specified in the master plan.

The Neve Zin neighbourhood is divided by two types of streets, narrow north-south pedestrian alleys and wide east-west vehicular streets (see Figure 4.17). The alleys, only 2.5 meters wide, are shaded by flanking walls, providing benefits for pedestrian comfort. The shading effect is increased by overhead trellises supporting deciduous vines.

The wider streets are woonerfs, which slow down cars with landscaping and by forcing them to share the road with pedestrians. The streets create blocks of four plots each. The plan also controlled the layout of each block, pushing the houses to the far corners of their plots. This created maximum back yards at the centres of the blocks and minimal front yards along the streets. Public spaces are minimal and compact, consisting of slightly widened street intersections. These spaces are mostly paved with brick while vegetation is limited to small, sheltered areas.

The overall effect of these different strategies is to create a neighbourhood that promotes a shaded pedestrian realm in summer and solar access in winter.

## REFERENCES

Etzion Y., "A desert solar neighborhood in Sede-Boker Israel," Architectural Science Review, Vol. 33, pp. 103-109, 1989.

Mesa, N., A., Arboit, M., de Rosa, C., 2010. La sustentabilidad energético-ambiental como base para el desarrollo urbano en zonas de oasis andinos, Cuad. Urbano 9, Resistencia - http://www.scielo.org.ar/scielo.php?script=sci_arttext&pid=S1853-36552010000100002

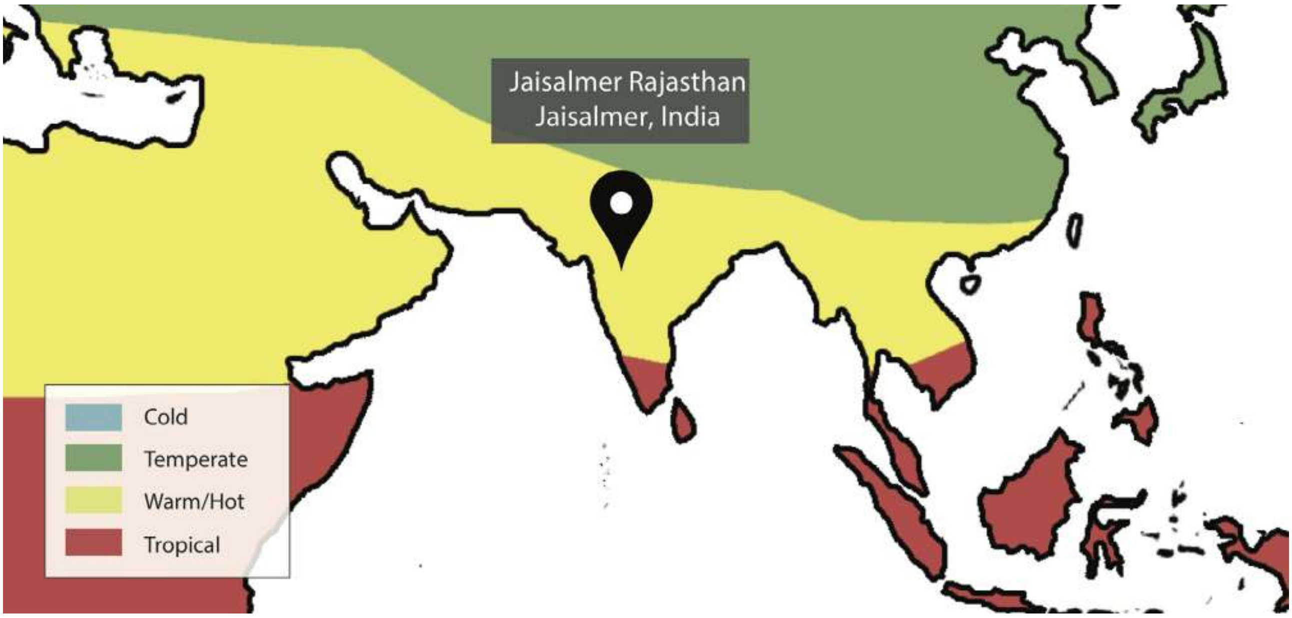
Pearlmutter, D., 2000. Patterns of sustainability in desert architecture, Arid lands newsletter 47 - https://ag.arizona.edu/OALS/ALN/aln47/pearlmutter.html

The "Neve-Zin" Desert Solar Neighborhood http://www.bgu.ac.il/CDAUP/neve-zin.htm

Wastvedt T., 2013. Urban Microclimates. Case studies in outdoor climate control - http://www.mit.edu/people/spirn/Public/Ulises-11-308/UrbanMicroclimates.pdf

## 4.2.2 JAISALMER RAJASTHAN, INDIA

| **LOCATION: Rajasthan, India** | |
|---|---|
| TYPE OF INTERVENTION: | Urban design for shade and climate attenuation; ancient city |
| DATE OF REALIZATION: | 1990 |
| TEMPERATURE: | +8 C (January); +45 C (May) |
| HUMIDITY: | The relative humidity typically ranges from 19% (dry) to 92% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 6 m/s (calm to moderate breeze), rarely exceeding 30 m/s (violent storm). |



Jaisalmer is a town in northwest India which was founded in 1156 AD by Maharawal Jaisal Singh, a Rajput king. The city is designed to protect its inhabitants from the extreme conditions of the local climate. The indigenous architecture is the result of a long process of design evolution which has created a form closely optimised to its setting.

The city is relatively contained, with a population of 58,000, and is closely bordered by the Thar Desert. The old fort at the centre of the city sits atop a hill, which aided its defence in its early days but has also left it exposed to the summer dust storms.

The buildings in Jaisalmer employ various techniques to create a microclimate in the streets and public spaces of the city. At a large scale the streets themselves are laid out to prevent winds from entering and building up. The main streets run east-west provide protection from the primarily south-west summer winds. The streets are also narrow and winding, preventing the breezes that do enter from building up speed along their length.

Along the streets there is very little if any setback, and the streets themselves are very narrow, limiting direct solar radiation from penetrating down to the bottom of the street canyon. Built from local sandstone, the building facades are highly sculpted and crenelated, with ledges, jharokhas (traditional enclosed balconies), and awnings. Each of these details casts shadows on the building's facade, reducing the amount of solar radiation which is absorbed by the main mass of the building's walls (see Figure 4.18).

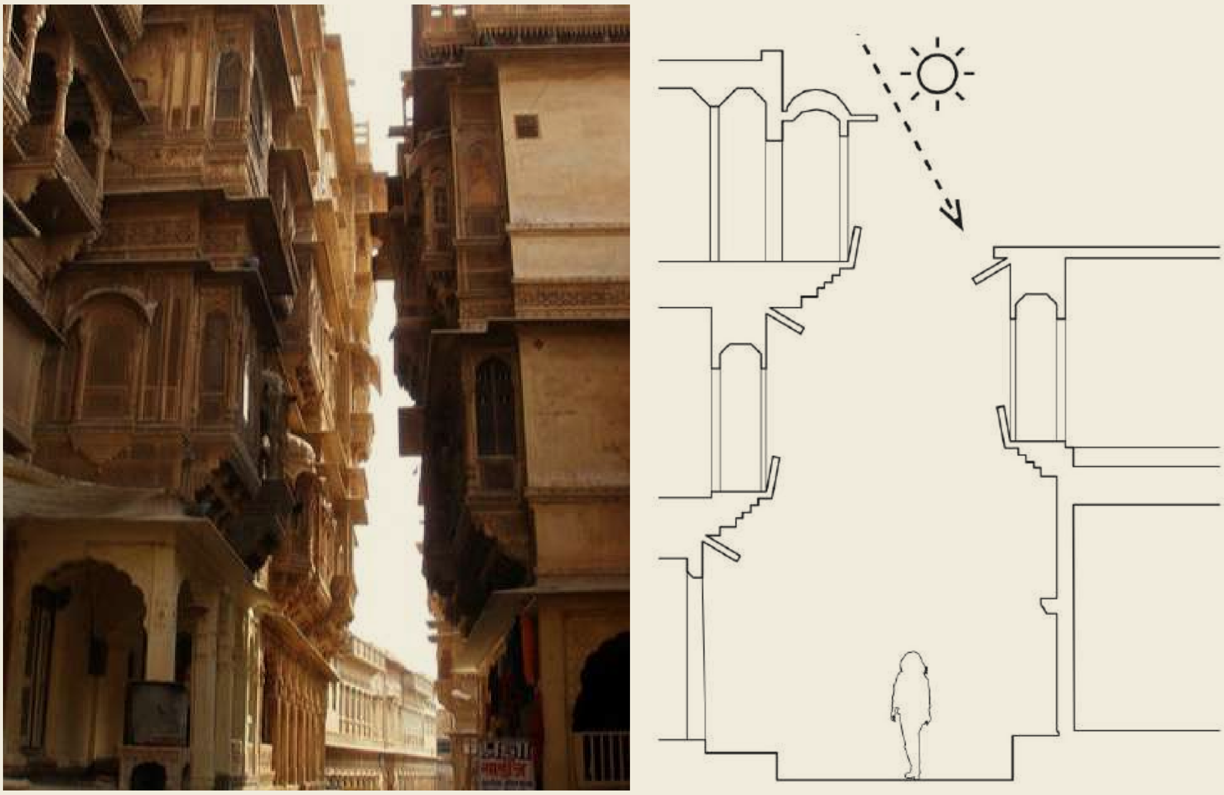
Jaisalmer is an excellent example of the power of traditional architecture. The design of the city and its buildings has evolved over the course of centuries into the highly specific and effective solutions seen today.

## REFERENCES

Wastvedt T., 2013. Urban Microclimates. Case studies in outdoor climate control - http://www.mit.edu/people/spirn/Public/Ulises-11-308/UrbanMicroclimates.pdf

Talwar, A., 2014. Jaisalmer, the golden city. http://www.slideshare.net/aasthatalwar3/jaisalmer-study

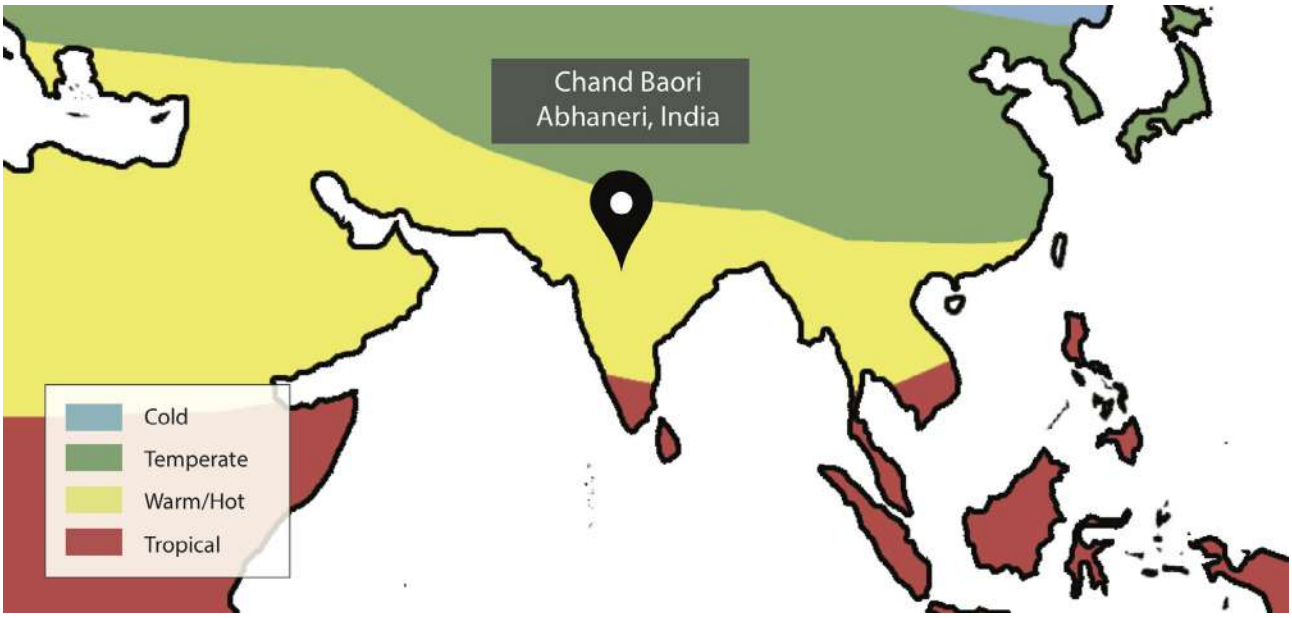
FIGURE 4.18 **A TAPERING STREET CANYON (SOURCE: WASTVEDT 2013)**



## 4.3 WATER HARVESTING AND PUBLIC SPACES

### 4.3.1 CHAND BAORI

| **LOCATION: Abhaneri, India** | |
|---|---|
| TYPE OF INTERVENTION: | Water harvesting |
| DATE OF REALIZATION: | 9th century |
| TEMPERATURE: | In summer, the maximum temperature is around 42 °C and the minimum temperature is around 37 °C. In winters, the maximum temperature is around 27.5 °C and the minimum temperature is around 15.5 °C. |
| PRECIPITATION: | The average annual rainfall is approximately 32 cm with 10-12 days of rainy days per year. |
| HUMIDITY: | The relative humidity typically ranges from 20% (low humid) to 80% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 1 m/s to 4 m/s. The prevailing wind direction is the West, South-West. |



Chand Baori is a stepwell situated in the village of Abhaneri near Jaipur (Figure 4.19) in the Indian state of Rajasthan, and realized in the 9th century by King Chanda of Nikumbha Dynasty.

Such stepwells were mainly designed to harvest rainwater in a season of plentiful rains, preserve it through repeated dry seasons, and enable people to access the water. Stepwells were thus designed to be several storeys deep, each storey connected to the next through vertical flights of steps all around the internal circumference and linked horizontally by pillared halls whose stone walls were beautified with a profusion of sculptures and friezes.

Chand Baori stepwell was created to meet the following three objectives:

- to harvest and collect rainwater,
- to serve as an adjunct to the temple, as an object of sheer visual beauty,
- to be a venue for the performing arts.

Built in an era when water was literally worshipped as a life-giving resource, it is an example of how collections of water are in the form of rivers, lakes, ponds – and in this case a water-harvesting reservoir.

Moreover, since the perceived temperature at the bottom of the well, is almost 5-6 degrees cooler than the ambient temperature, Chand Baori was also used as a community gathering place for locals during periods of intense heat.

FIGURE 4.19 **VIEW OF THE STEPWELL (SOURCE: KAUSHIK 2012)**

## REFERENCES

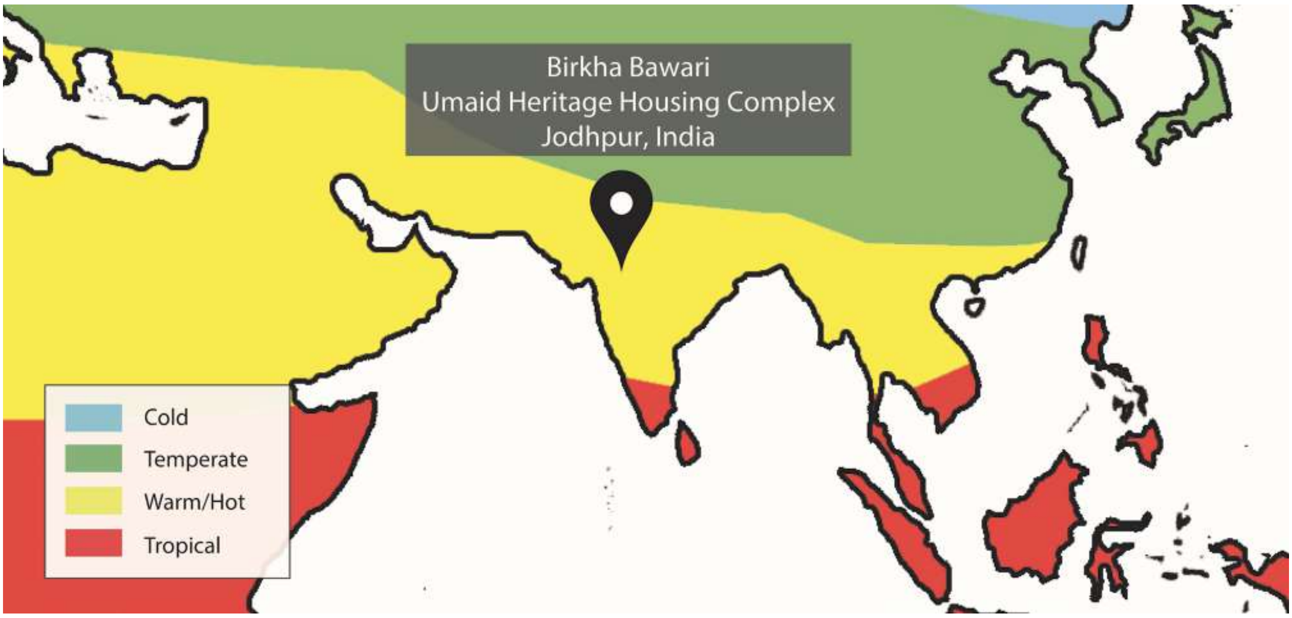
Chadha A., 2016, Chand Baori – Hidden wonder of Rajasthan - http://www.gounesco.com/chand-baori-hidden-wonder-of-rajasthan/

Livingston, M., 2002. Steps to water: the ancient stepwells of India. Princeton Architectural Press.

Kaushik, 2102, Chand Baori Step Well in Rajasthan, India - http://www.amusingplanet.com/2012/10/chand-baori-step-well-in-rajasthan-india.html

### 4.3.2 BIRKHA BAWARI, UMAID HERITAGE HOUSING COMPLEX

| **LOCATION: Jodhpur, India** | |
|---|---|
| TYPE OF INTERVENTION: | Water harvesting |
| DATE OF REALIZATION: | 2010 |
| TEMPERATURE: | In summer, the maximum temperature is around 42 °C and the minimum temperature is around 37 °C. In winters, the maximum temperature is around 27.5 °C and the minimum temperature is around 15.5 °C |
| PRECIPITATION: | The average annual rainfall is approximately 32 cm with 10-12 rainy days per year. |
| HUMIDITY: | The relative humidity typically ranges from 20% (low humid) to 80% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 1 m/s to 4 m/s. The prevailing wind direction is the West, South-West. |



The Birkha Bawari is a monumental open rainwater harvesting structure, placed in the Umaid Heritage residential complex located in the city of Jodhpur,and constructed in 2010 in accordance with vernacular architecture.

The Birkha Bawari structure acts as a recreational space for inhabitants as well as storage of rainwater – and is a good example of sustainable urban development in a low rainfall region, demonstrating the value of water by conserving rainwater.

The rainwater is collected from the open areas through the natural slopes as well as from the roof tops of houses which in turn are connected with the natural slope of the site through drainage conduits.

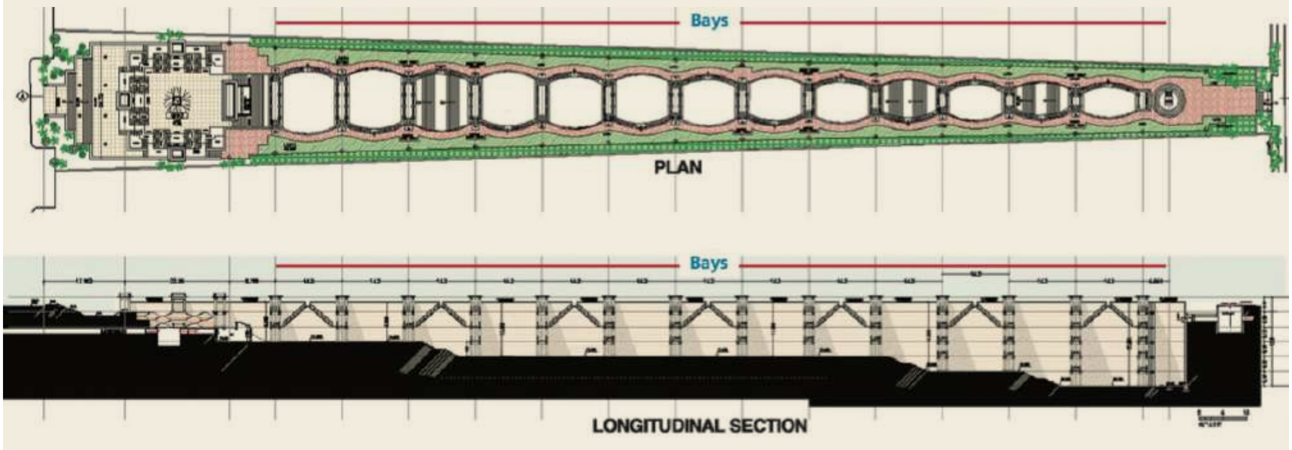
The Birkha Bawari consists of longitudinal open rainwater storage structure (see Figure 4.20). The system consists of series of constructed tanks making it a linear 135-metre long structure, which holds 17.5 million litres of harvested rainwater annually and serves as a reliable source of water for meeting water requirements for landscaping in an otherwise water scarce region.

Rainwater comes from either side of the structure (Bawari) and first enters into the hidden settlement tank – (see Figure 4.21) from there, water flows to the series of tanks the deepest being 18 metres below ground level. In such an open tank, instead of the conventional retaining walls for countering the pressure of the earth, the concept of tunnels or barrel-vaulted roofs has been re-interpreted as retaining walls in the form of upended 'barrel vaults'. The novel composite structure for the subterranean harvesting structure has been created by a series of segments of slender 'vaulted walls' placed opposite one another and held against each other by a trabeated (pillars and beams) structure. The vaults on opposite sides nullify each other's thrust and counter-balance each other. The vertical walls as well as the pillar and beams also shade the stored water from the sun, thereby minimising evaporation and algae formation.

Traditionally, a Bawari can hold water for a long time because of almost negligible water evaporation when compared to other water bodies, as the depth of the tank also provides the water with shade and helps in reducing evapotranspiration losses. The structure is spread over 5750 m².

FIGURE 4.20 **BIRKHA BAWARI STRUCTURE (SOURCE: MRIDUL N.D.)**

FIGURE 4.21 **PLAN AND SECTION (SOURCE: NATIONAL WATER SUPPLY & DRAINAGE BOARD 2015)**



## REFERENCES

Centre for Science and Environment 2014.Urban Rainwater Harvesting, case studies from different agro-climatic regions. – https://www.researchgate.net/publication/276271522_Urban_Rain_water_harvesting-_case_studies_from_different_agroclimatic_regions

Mridul A., - http://www.amridul-architect.com/index.php?option=com_content&view=article&id=28&Item id=247

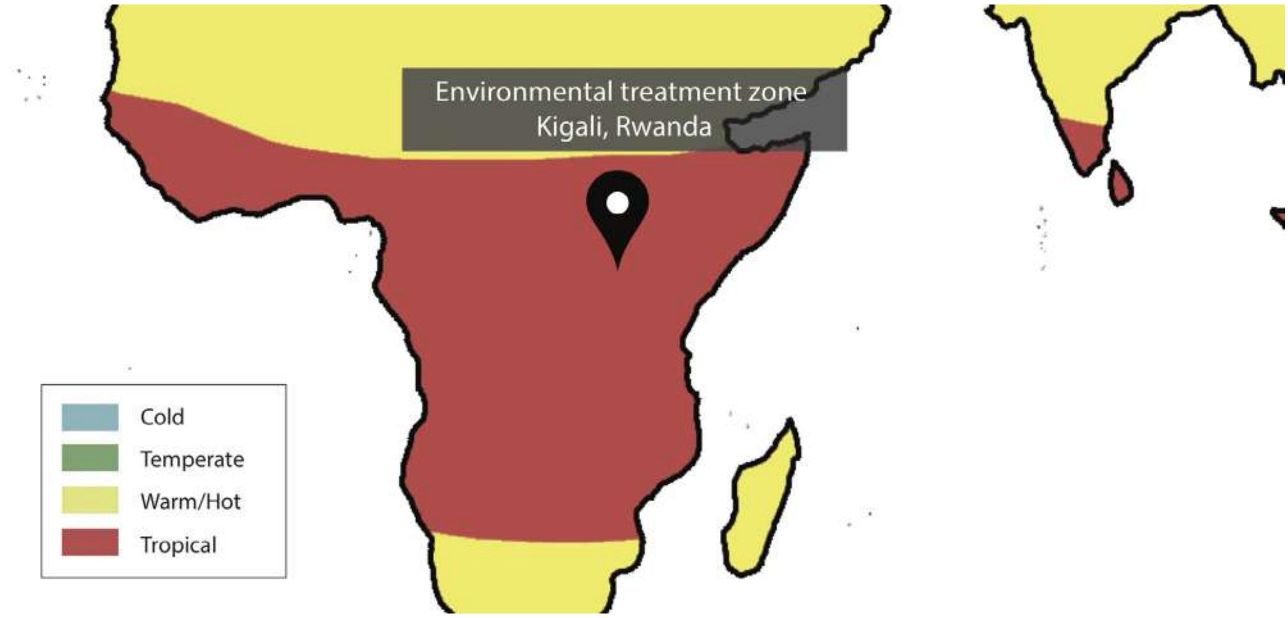
National Water Supply & Drainage Board 2015, URWH at various scales

http://nwsdbrws.org/wp/wp-content/uploads/2015/04/URWH-at-various-scales-swales-and-Bioretentions.pdf

## 4.4 URBAN AGRICULTURE

### 4.4.1 ENVIRONMENTAL TREATMENT ZONE IN KIGALI

| **LOCATION: Kigali, Rwanda** | |
|---|---|
| TYPE OF INTERVENTION: | Masterplan |
| DATE OF REALIZATION: | 2007 |
| CLIENT: | Rwanda Ministry of Infrastructure |
| TEMPERATURE: | +15 C (July) +29 C (January) |
| HUMIDITY: | The relative humidity typically ranges from 38% (comfortable) to 100% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 6 m/s (calm to moderate breeze), rarely exceeding 111 m/s (hurricane). |



The Kigali Conceptual Master Plan provides a long-range vision for how development might occur over the next 50-100 years to accommodate another 2-3 million people. While this might seem like a long time into the future, urban planning experience shows that by establishing a long-range plan for key infrastructure and systems early on, future incremental growth can be guided with care, thoughtfulness, concern for real human needs, citizen participation, cost effectiveness and efficiency.

Environmental sustainability plays a crucial role in the development of the Kigali Conceptual Master Plan.

Among the other features, the plan is remarkable i for promoting urban agriculture: around 20% of the land has been designated as agricultural (Figure 4.22).

The plan Urban Agriculture in Kigali: Vision 2020 aims to help the Rwanda economy make the transition from an emphasis on subsistence agriculture to a knowledge and technology based economy with a highly productive agricultural sector. The achievement of this plan involves supporting the residents through the transition by designing the urban sphere with sensitivity to their needs through the change process; and using urban design strategies to enhance the growth of productive, value added farming or helping farmers to move out of farming into alternative economic strategies. It also means using urban design strategies that recognise that the transitional process will require residents to use a multitude of simultaneous "livelihood strategies" that will necessitate their on-going involvement with farming.

The plan's objectives are to:

- Maximise the use of the urban sphere to help support the residents' transition from the rural/agricultural sphere;
- Use urban agriculture as a technique to address both practical needs and enhance ecological/environmental benefits to the urban landscape;

- Support the use of agriculture in zones of Kigali that should not be densely developed;
- Honour the cultural and agricultural heritage of Rwanda by using it as a structuring and design feature of the urban landscape where possible.

Attention should be paid to the layout of the particular "clusters", in which each household is recommended to plant "fruit trees" and have a kitchen garden in the plot (Figure 4.23).

## REFERENCE

Kigali Conceptual Masterplan, OZ Architecture, 2007. http://abdshc.com/wp-content/uploads/2015/06/KIGALI_CONCEPTUAL_Master_Plan.pdf

FIGURE 4.22 **LAND USE IN KIGALI MASTER PLAN**

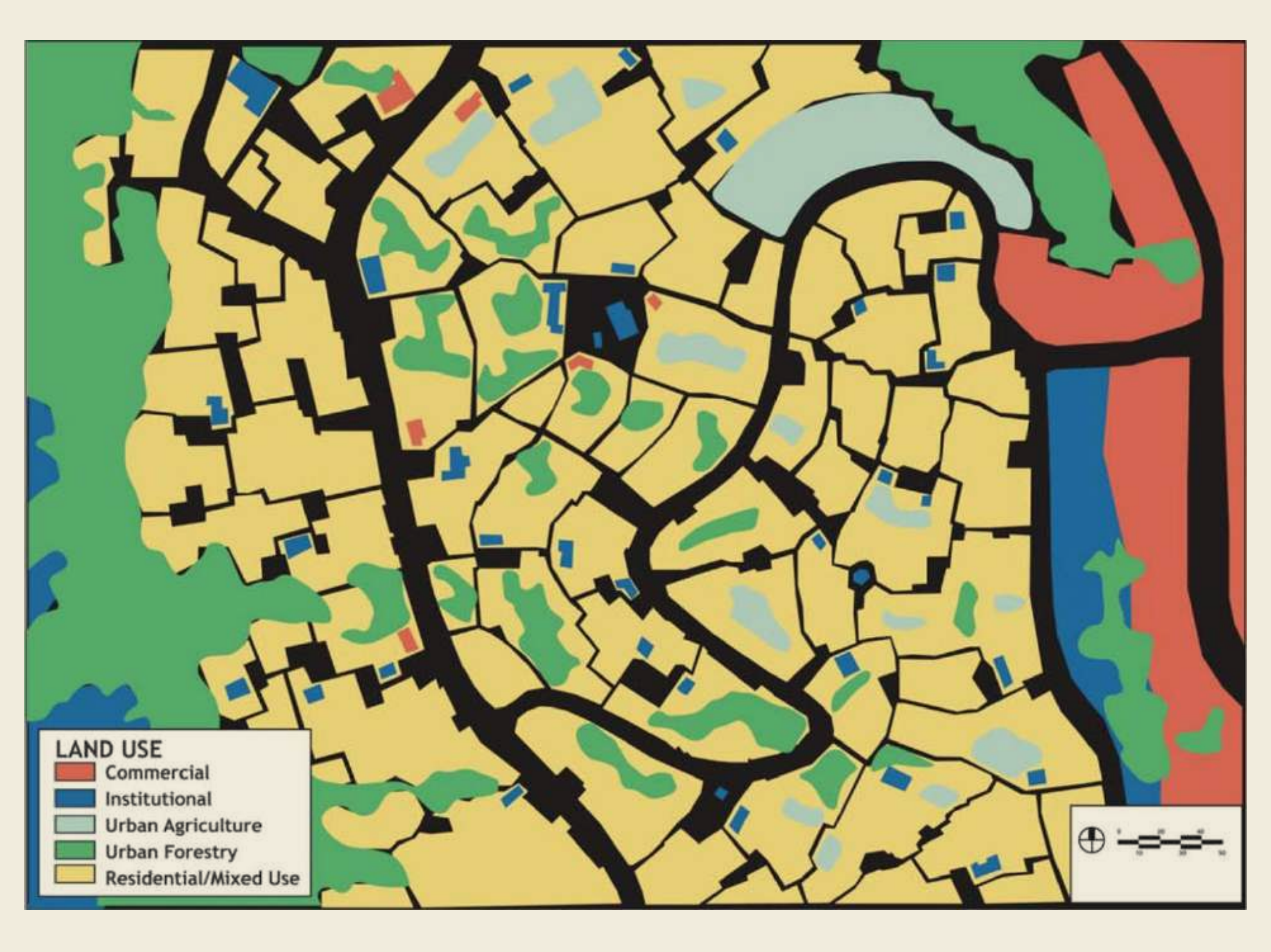
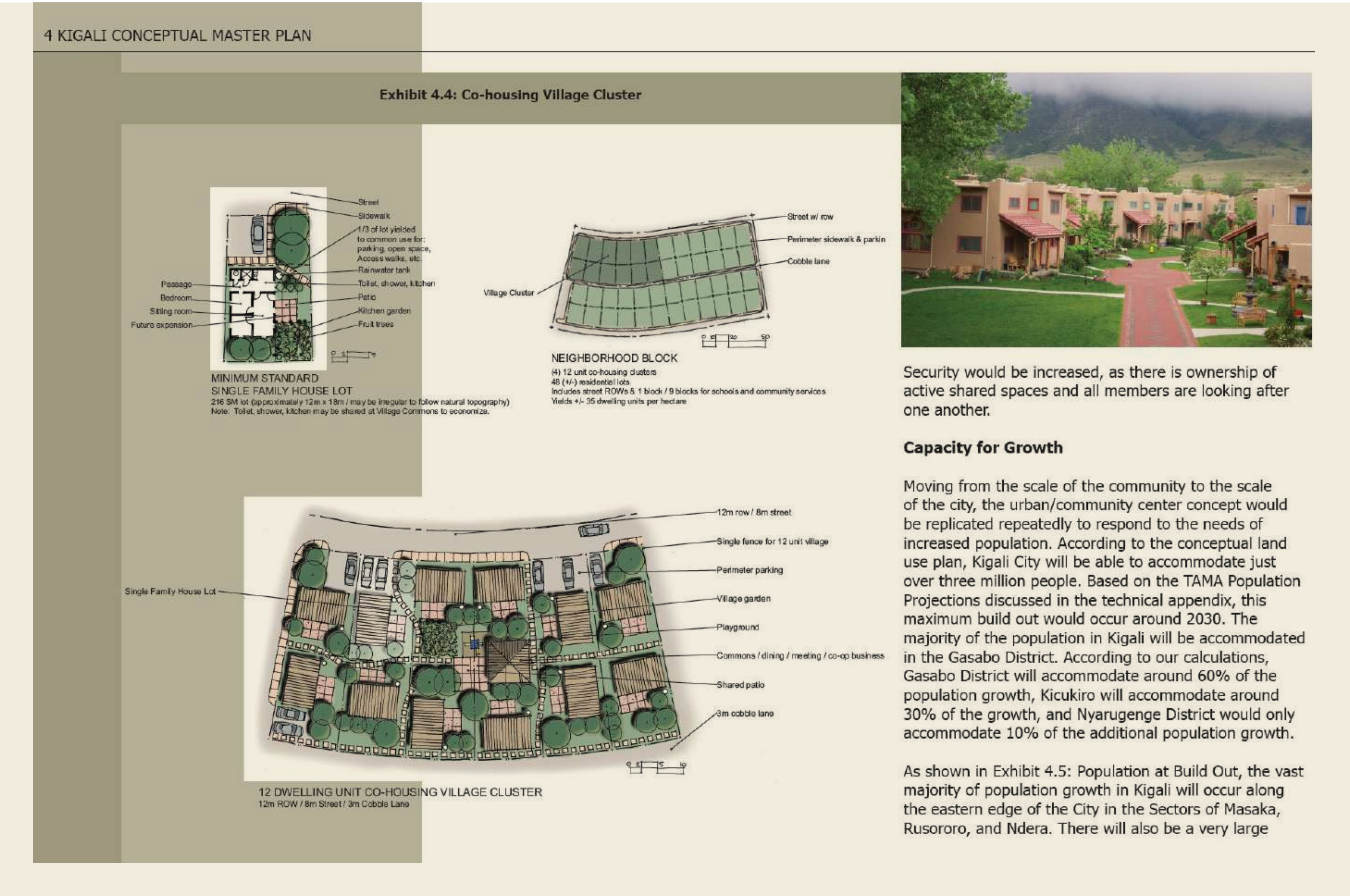


FIGURE 4.23 **DETAIL OF MASTERPLAN**



4 KIGALI CONCEPTUAL MASTER PLAN

**Exhibit 4.4: Co-housing Village Cluster**

MINIMUM STANDARD
SINGLE FAMILY HOUSE LOT
216 SM lot (approximately 12m x 18m / may be irregular to follow natural topography)
Note: Toilet, shower, kitchen may be shared at Village Commons to economize.

NEIGHBORHOOD BLOCK
(4) 12 unit co-housing clusters
48 (+/-) residential lots
Includes street ROWs & 1 block / 9 blocks for schools and community services
Yields +/- 35 dwelling units per hectare

12 DWELLING UNIT CO-HOUSING VILLAGE CLUSTER
12m ROW / 8m Street / 3m Cobble Lane

Security would be increased, as there is ownership of active shared spaces and all members are looking after one another.

**Capacity for Growth**

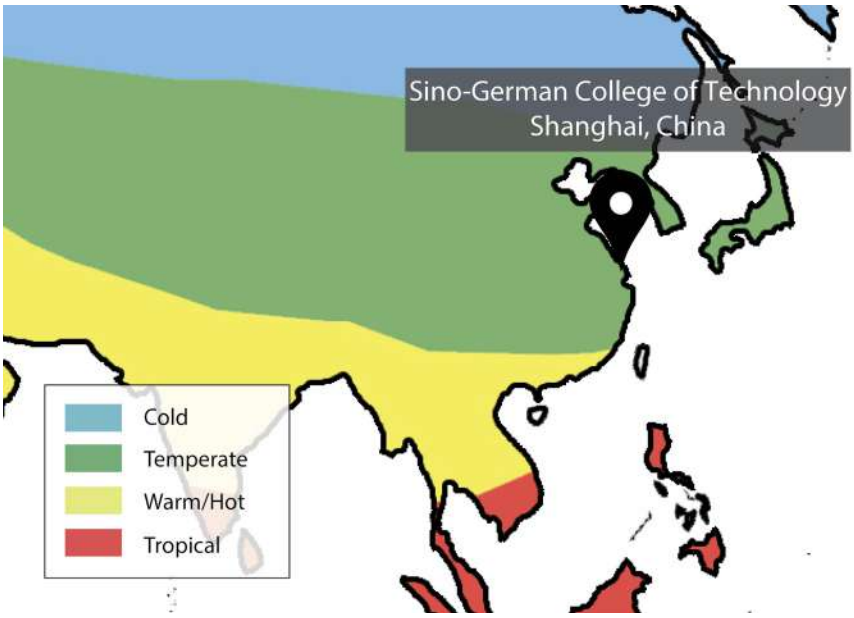
Moving from the scale of the community to the scale of the city, the urban/community center concept would be replicated repeatedly to respond to the needs of increased population. According to the conceptual land use plan, Kigali City will be able to accommodate just over three million people. Based on the TAMA Population Projections discussed in the technical appendix, this maximum build out would occur around 2030. The majority of the population in Kigali will be accommodated in the Gasabo District. According to our calculations, Gasabo District will accommodate around 60% of the population growth, Kicukiro will accommodate around 30% of the growth, and Nyarugenge District would only accommodate 10% of the additional population growth.

As shown in Exhibit 4.5: Population at Build Out, the vast majority of population growth in Kigali will occur along the eastern edge of the City in the Sectors of Masaka, Rusororo, and Ndera. There will also be a very large

# 4.5 WASTEWATER TREATMENT

## 4.5.1 SINO-GERMAN COLLEGE OF TECHNOLOGY

| **LOCATION: Shanghai, China** | |
|---|---|
| TYPE OF INTERVENTION: | DEWATS at public institutions |
| TEMPERATURE: | +2 °C (January); + 32 °C (August) |
| HUMIDITY: | Shanghai is known for hot and humid summers, but surprisingly its winters can be bitterly cold. The city is also vulnerable to typhoons in the summer and autumn. |



The Fenxian campus of the Sino-German College of Technology at East China University of Science and Technology is located one hour's drive from Shanghai. It is an engineering college and its campus was planned for 6,500 teachers and students.

The challenge for the school's authorities was to find a reliable and efficient solution for treating their wastewater in accordance with the Environmental Standard. Tight budget constraints for initial investment and operation restricted the possible wastewater-treatment options.

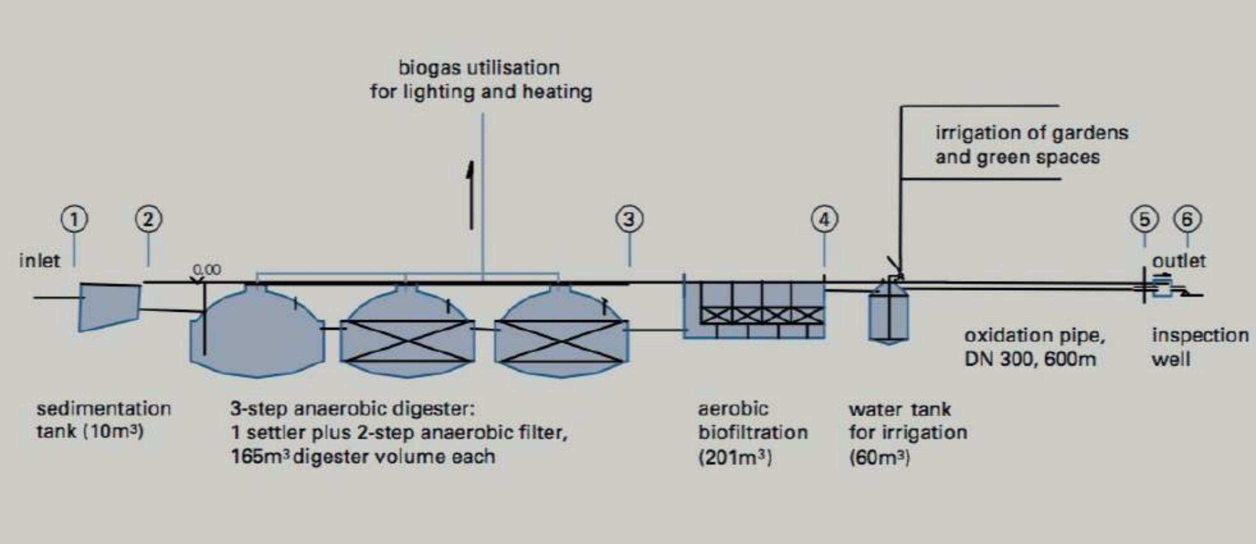
The campus wastewater consists of toilet effluent from the teaching buildings, as well as polluted water from machinery-maintenance processes.

The chosen DEWATS consists of a module for grease separation and sedimentation, a three-step anaerobic digester with filter, an underground sand filter (bio-filtration) and an irrigation tank (Figure 4.24). The effluent is used to irrigate compound gardens, while biogas is used to light campus street lamps and water heating. The project costs were calculated at 960,000 RMB (US$ 115,942).

## REFERENCE

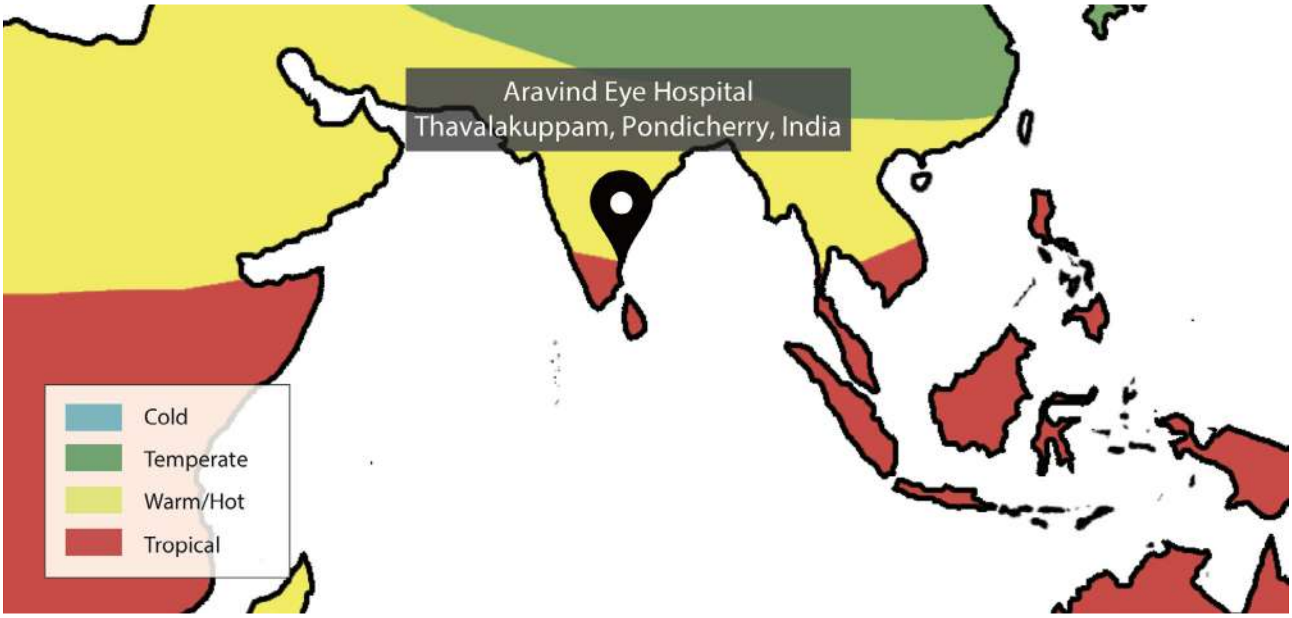
Gutterer, B., Sasse, L., Panzerbieter, T., & Reckerzügel, T. 2009. Decentralised wastewater treatment systems (DEWATS) and sanitation in developing countries. Leicestershire, UK: Water, Engineering and Development Centre (WEDC), Loughborough University, UK, in association with Bremen Overseas Research (BORDA), Germany.

FIGURE 4.24 **CONCEPT OF THE DEWATS SOLUTION AT THE SINO- GERMAN COLLEGE OF TECHNOLOGY IN SHANGHAI (SOURCE: GUTTERER 2009)**



## 4.5.2 ARAVIND EYE HOSPITAL IN THAVALAKUPPAM

| **LOCATION: Pondicherry, India** | |
|---|---|
| TYPE OF INTERVENTION: | DEWATS at public institutions |
| TEMPERATURE: | The average maximum temperature is 36 °C. Minimum temperatures are in the order of 28–32 °C. |
| HUMIDITY: | The relative humidity typically ranges from 60% to 80% over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 2 m/s to 5 m/s. |



The Aravind Eye Hospital in Thavalakuppam belongs to the Tamil Nadu-based Aravind Eye Care System. The philosophy of the Aravind System is to provide services to rich and poor alike, while achieving financial self-sustainability. This is achieved through high-quality, large-volume care and efficient management.

The hospital in Thavalakuppam has the capacity to treat 750 in patients (600 free admissions and 150 paid) and an additional 900 out-patients. Three hundred paramedical staff are housed in 26 residential quarters.

Due to the water scarcity in the region, the hospital management expressed a keen interest in a wastewater-treatment solution that permits the reuse of treated water.

The chosen DEWATS solution was designed to treat approximately 300 m$^3$/d of domestic wastewater from toilets, bathrooms and kitchens. Water reuse (due to high water scarcity) and efficient land use had the highest priority in the selection of a treatment-process.

The grey water and the black water generated in the hospital premises first enter two separate chambered settlers. The settlers for black water treatment are integrated with the anaerobic baffled reactors. The partially treated black water then undergoes secondary anaerobic treatment through baffled reactors. The black water and grey water is collectively passed through anaerobic filter and then to the series of horizontal gravel filters planted with Canna indica. Final treatment is done through polishing ponds where the water is also stored for further reuse. See Figures 4.25 and 4.26.

The effluent of the DEWATS-plant irrigates a garden with 300 trees planted in avenues, 250 coconut trees, 50 mango trees and 4,200 m$^2$ of lawns, covered with Korean grass and flowering plants. The construction cost of the described system was about US$ 200,000.

## REFERENCE

Gutterer, B., Sasse, L., Panzerbieter, T., & Reckerzügel, T. 2009. Decentralised wastewater treatment systems (DEWATS) and sanitation in developing countries. Leicestershire, UK: Water, Engineering and Development Centre (WEDC), Loughborough University, UK, in association with Bremen Overseas Research (BORDA), Germany.

FIGURE 4.25 **SCHEMATIC DRAWING OF THE DEWATS AT ARAVIND EYE HOSPITAL (SOURCE: GUTTERER 2009)**

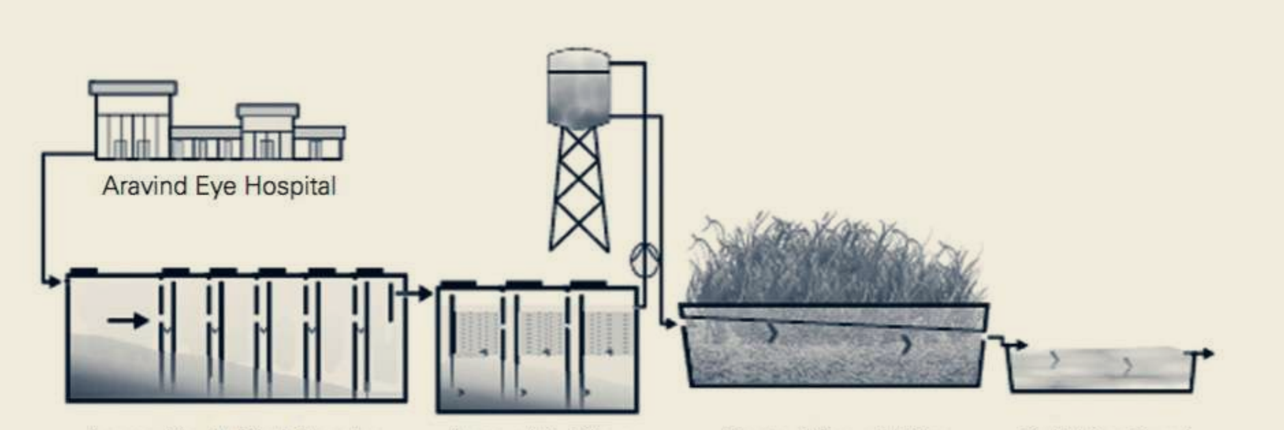


FIGURE 4.26 **PLANTED GRAVEL FILTERS AND POLISHING POND OF ARAVIND EYE HOSPITAL'S DEWATS (SOURCE: GUTTERER 2009).**

## 4.6 STORMWATER DRAINAGE

### 4.6.1 FIGTREE PLACE

| **LOCATION: Newcastle, Australia** | |
|---|---|
| TYPE OF INTERVENTION: | Water sensitive urban development demonstration project |
| DATE OF REALISATION: | 2000 |
| CLIENT: | City of Newcastle |
| TEMPERATURE: | +6 °C (July) +29 °C (January) |
| HUMIDITY: | The relative humidity typically ranges from 37% (comfortable) to 97% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 8 m/s (calm to fresh breeze), rarely exceeding 12 m/s (strong breeze). |

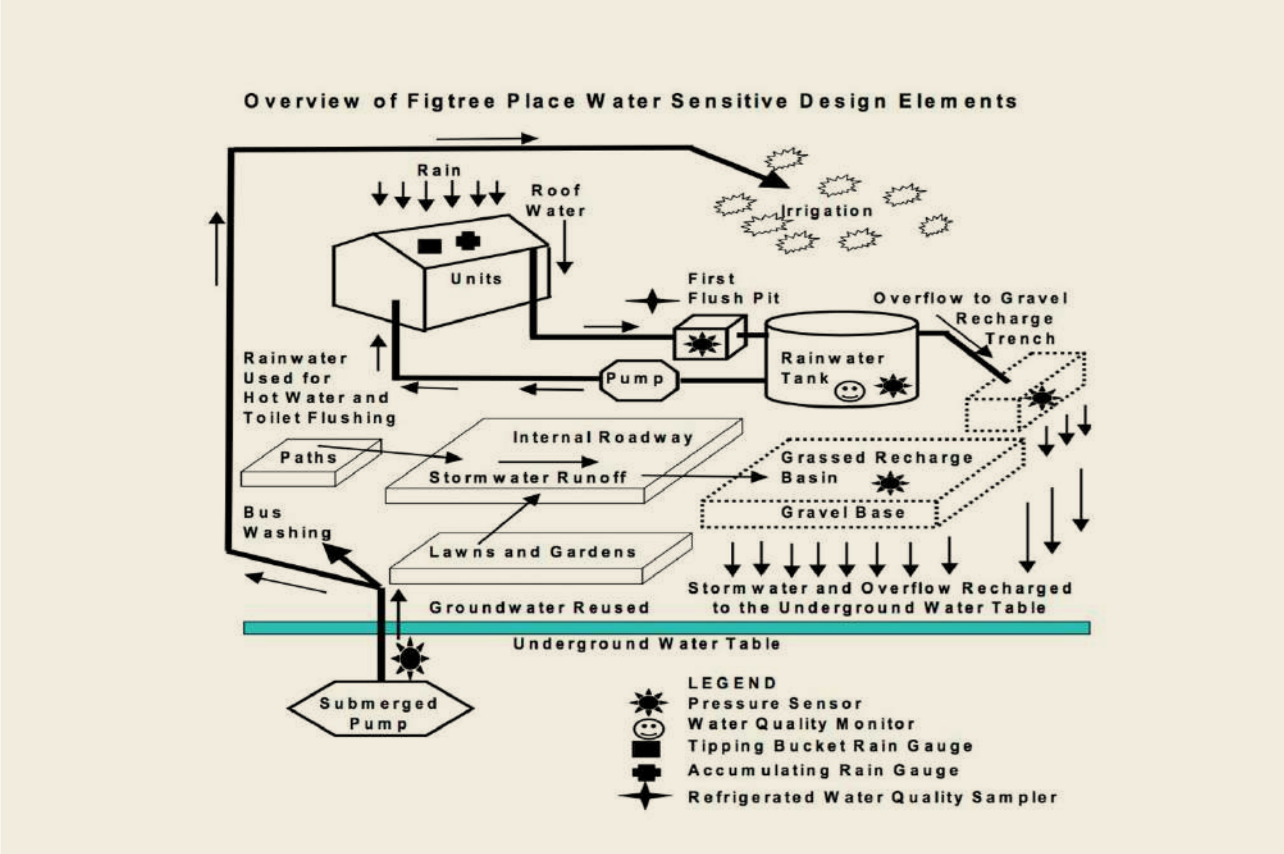
Figtree Place is a water sensitive urban redevelopment consisting of 27 residential units located in Hamilton, an inner suburb of Newcastle, Australia. The site uses rainwater tanks, infiltration trenches and a central basin where treated stormwater enters in the unconfined aquifer for water retention and retrieval.

Rainwater collected from roofs flows via stormwater pipes through a "first-flush" pit into each rainwater storage tank (Figure 4.27). Pumps with pressure cells supply rainwater from tanks for use in storage hot water systems and for toilet flushing. If a rain tank's capacity is exceeded, overflow is directed to a gravel trench which supplies recharge to the unconfined aquifer.

Stormwater runoff from paths, lawns and gardens is directed into the Detention Basin via internal roadways. The Detention Basin recharges the unconfined aquifer and provides an open space recreation area during dry spells. The Detention Basin has been sized to contain, without overflow, all storms up to and including the "once in 50 years" event.

Reinforced concrete underground rainwater tanks are used at Figtree Place. The "first flush" pit associated with each of these tanks is designed to separate the first 2 mm of rainfall from the inflow. The four rainwater tanks are rectangular with capacities ranging from 9000 l to 15,000 l. Each rain tank contains an inlet from a "first-flush" pit, a clean-out chamber for removal of sludge, a low water level monitor, an outlet for domestic supply and a pipe conveying overflow to a recharge trench. The low water level monitor activates a system which enables water to be drawn from mains supply whenever the water level in the tank is low. Measurement of internal water use at Figtree Place (partly occupied) showed a 65% reduction in expected mains consumption. Based on these performances, it is anticipated that long- term internal water saving of about 45% will be recorded at Figtree Place.

FIGURE 4.27 **FIGTREE PLACE WATER SENSITIVE DESIGN CONCEPT (SOURCE: COOMBES 2000)**



## REFERENCES

Coombes, P. J., Argue, J. R., & Kuczera, G. 2000. Figtree Place: a case study in water sensitive urban development (WSUD). Urban Water, 1(4), 335-343 - https://www.researchgate.net/profile/Peter_Coombes/publication/222691044_Figtree_Place_A_Case_Study_in_Water_Sensitive_Urban_Development_WSUD/links/5433af100cf22395f29e2720.pdf?origin=publication_list

Coombes P.J; Donovan I; and Cameron C. 1999. Water Sensitive Urban Redevelopment: Implementation issues for the Central Coast and Lower Hunter. Central Coast and Lower Hunter Environmental Management Strategy, Lake Macquarie City Council.

### 4.6.2 POTSDAMER PLATZ

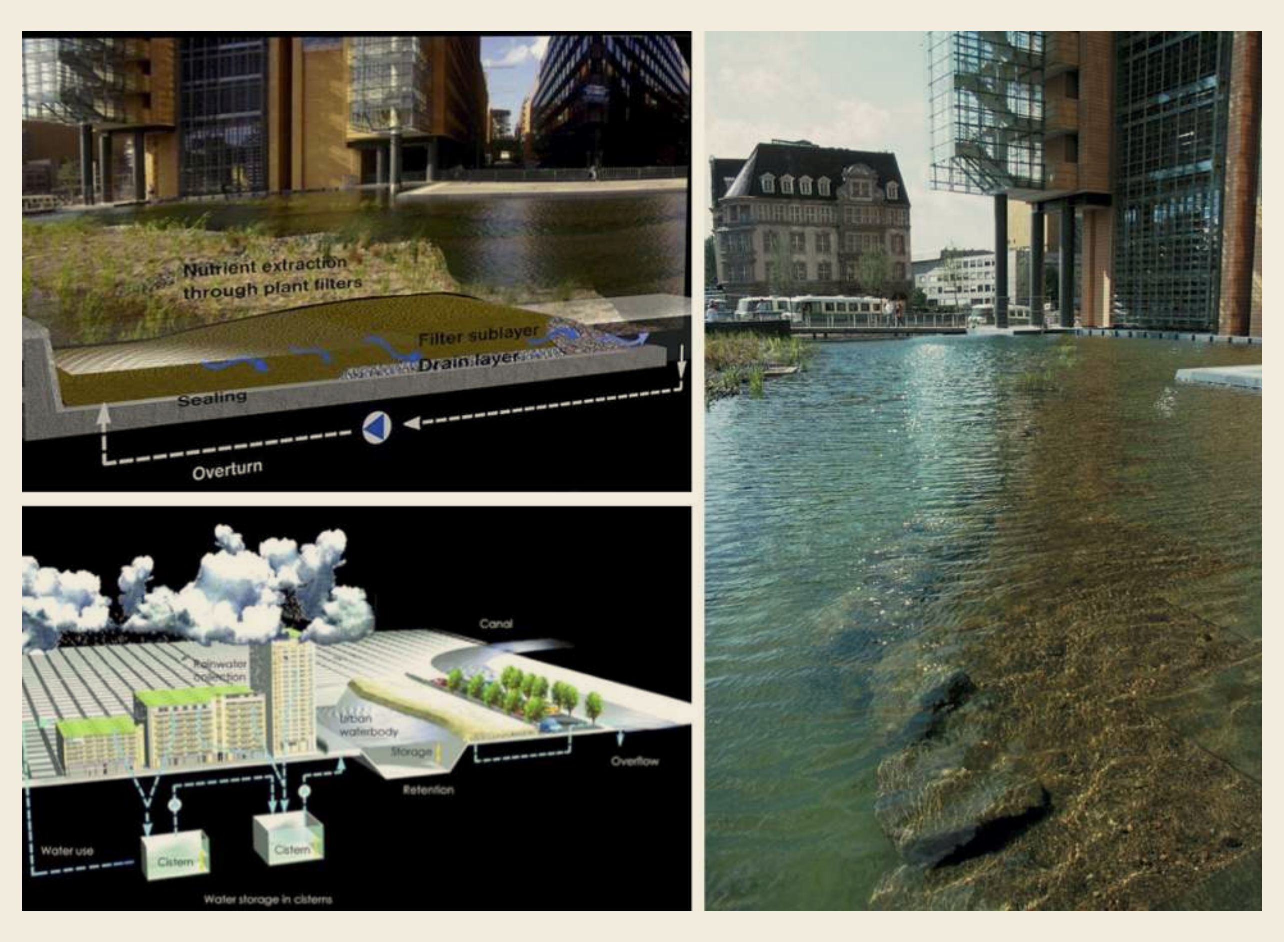
| **LOCATION: Berlin, Germany** | |
|---|---|
| TYPE OF INTERVENTION: | Run-off water treatment |
| DATE OF REALISATION: | 2000 |
| TEMPERATURE: | -3 C (January) +23 C (August) |
| HUMIDITY: | The relative humidity typically ranges from 60% (comfortable) to 80% (humid) over the course of the year. |

The example of the construction-site of the Potsdamer Platz Project shows the importance of integrating all aspects of water management into the initial planning process. With respect to this, a system has been applied in Potsdamer Platz that uses natural water cleansing techniques to improve the water quality near its source while improving bio-diversity and enabling seamless aesthetic integration with its surroundings.

The stormwater management strategy comprises the collection, treatment, storage and reuse of all the run-off from the surfaces and roofs of the surrounding high density urbanized environment.

Pivotal to this design is the inclusion of a cleansing biotope that filters the collected stormwater run-off from the roofs and urban hardscape, and channels it into an urban lake before it is discharged into the river (Figure 4.28). This biotope performs a functional, aesthetic and ecological role. The cleansing biotope cleans the water biologically through biological uptake and mechanically with technical filters, all without the use of chemicals. The harvested and cleaned rainwater from the cleansing biotope is then used to flush toilets and water green areas. The excess water is than collected in underground tanks and pools, attractively designed so as to invite public interaction.

FIGURE 4.28 **USE OF STORMWATER AT THE POTSDAMER PLATZ (SOURCES: RAMBOLL STUDIO DREISEITL AND NAP 2016)**



## REFERENCES

Landascape architectas - http://landarchs.com/potsdamer-platz-in-berlin-becomes-a-sustainable-ecofriendly-urban-square/

National Academies of Sciences, Engineering, and Medicine. 2016. Using graywater and stormwater to enhance local water supplies: an assessment of risks, costs, and benefits. National Academies Press.

Ng, L., Syariffudin, E. The Holistic Design of Rainwater Harvesting Systems in Three Urban Projects - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.738.6107&rep=rep1&type=pdf

Ramboll Studio Dreiseitl - http://www.dreiseitl.com/index.php? id=82&lang=en

Schimidt, S. 2001. Rainwater Haversting in Germany–New Concepts for the Substitution of Drinking Water, Flood Control and Improving the Quality of the Surface Waters. 3º Simpósio sobre Sistemas de Captação de Água de Chuva. Anais. Campina Grande.

Urban green-blue grids for sustainable and resilient cities - http://www.urbangreenbluegrids.com/projects/potsdamer-platz-berlin-germany/

## 4.7 SLOW MOBILITY

### 4.7.1 VAUBAN

| **LOCATION: Freiburg, Germany** | |
|---|---|
| TYPE OF INTERVENTION: | Slow mobility |
| DATE OF REALISATION: | 1998 - 2010 |
| TEMPERATURE: | -0.1 C (January) +26.1 C (August) |
| PRECIPITATION: | The average rainfall is 887 mm. |
| HUMIDITY: | The relative humidity over the year is almost equal to 80%. |
| WIND: | Over the course of the year typical wind speeds vary from 6 m/s to 10 m/s. |

TThe mobility concept in Vauban plans to reduce traffic in the neighbourhood to a minimum.

The district has been designed to make access by non-motorized modes safe and pleasant, with a dedicated network of streets free of motorized traffic.

A key principle of the Forum Vauban masterplan was that car use should be less convenient than the alternatives. Vauban limits car use through parking-free residential streets, spatially and fiscally separated parking and filtered permeability to prevent through traffic.

The preference for walking and cycling can be partly attributed to the layout of the district. Building on previous experience, the plan departs from the simple inherited grid (originally the area hosted barracks) and creates a network, which incorporates the principle of "filtered permeability". It means that the network geometry favours the active modes of transport and, selectively, "filters out" the car. This is accomplished by reducing the number of streets that run through the neighbourhood (see Figure 4.29). Instead, most local streets are crescents. While they are do not continue for cars, they connect to a network of pedestrian and bike paths, which permeate the entire neighbourhood. For this reason, the residential buildings in Vauban have a net density of approximately 95 units per hectare. Several large green spaces separate the residential blocks, providing recreation areas for the many young families in Vauban and contributing to urban cooling.

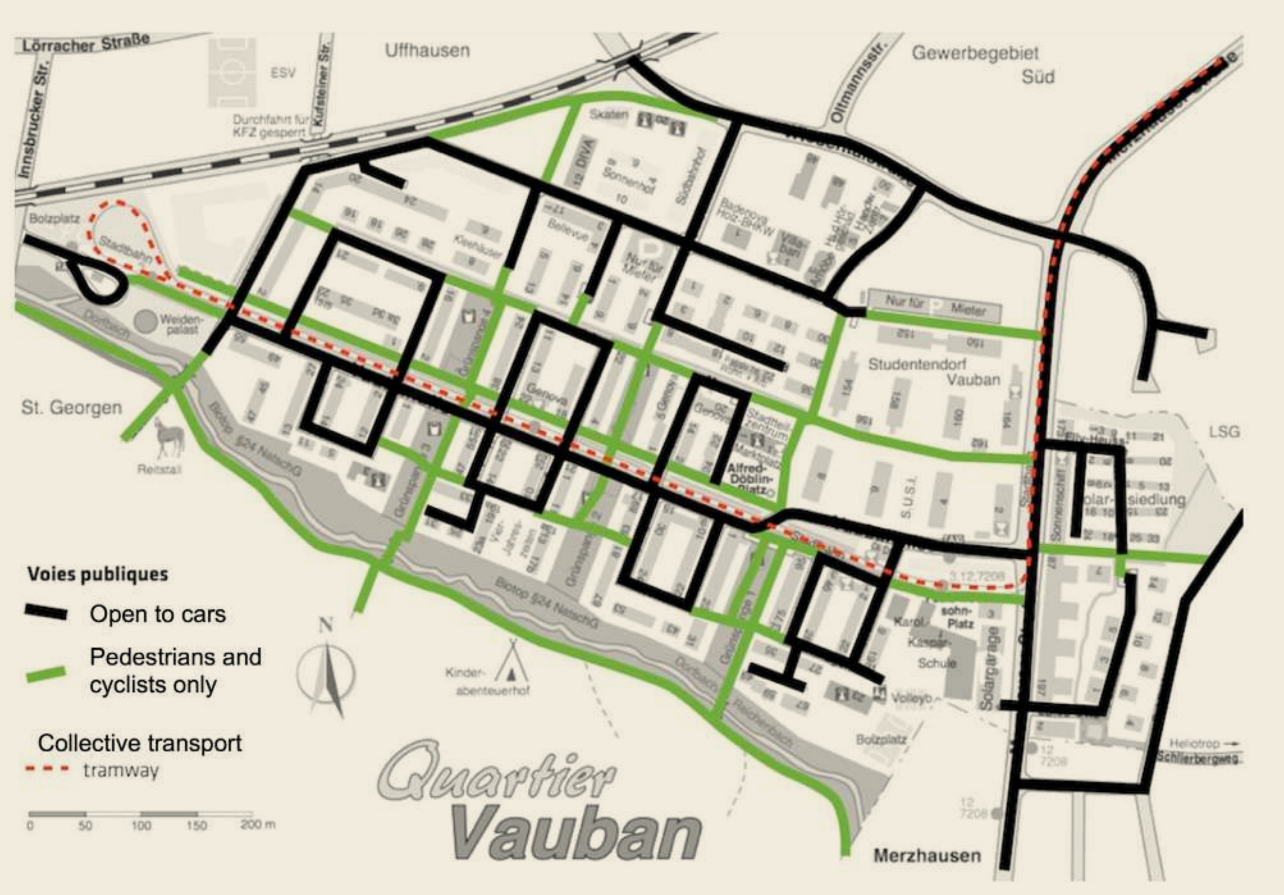
Vehicles must be driven at walking pace, giving priority to other road users, and may stop only for the purposes of picking up and dropping off.

The overall residential parking space to unit ratio is less than 0.5, provided with underground and street parking in three parts of the development.

In accordance with the overall purpose, no home is more than 400 m from a tram stop.

Additional greenery and walking trails on the southern boundary of the site provide another leisure area for families, minimizing the need to travel out of the district in search of pleasant recreation areas.

FIGURE 4.29 **MOBILITY PLAN (SOURCE: VIVRE EN VILLE 2014)**



## REFERENCES

Broaddus, A. 2010. A Tale of Two Eco-Suburbs in Freiburg, Germany: Parking Provision and Car Use. Paper presented at TRB 2010 Annual Meeting.

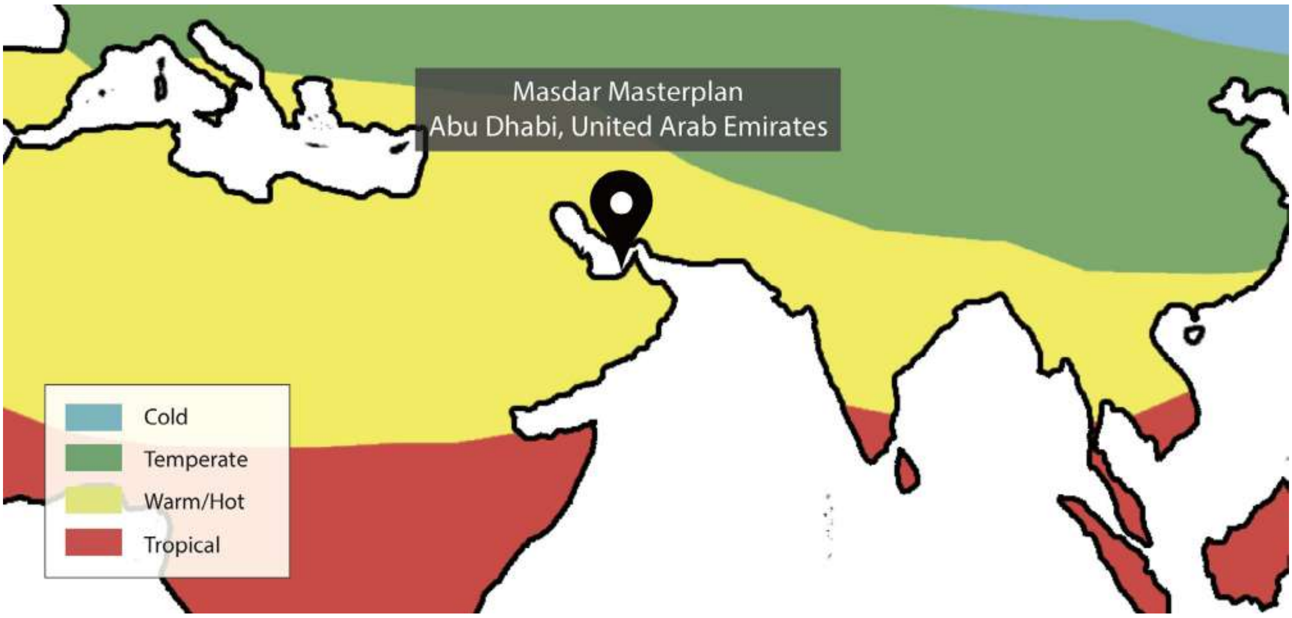
Foletta, N., Field, S. 2011. Europe's vibrant new low car (bon) communities. ITDP, New York - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.232.6967&rep=rep1&type=pdf

Tue - Best Practice Case, Freiburg-Vauban (& Rieselfeld) - https://static.tue.nl/fileadmin/content/onderzoek/Eindhoven_Energy_Institute_EEI/EnergyDays/Serie_1_2008_2010/2010_02_11/Frey_Part4.pdf

VIVRE EN VILLE (2014). Objectif écoquartiers: Principes et balises pour guider les décideurs et les promoteurs. - http://objectifecoquartiers.org/media/337746/venv_2014_objectifecoquartiers.pdf

## 4.7.2 MASDAR

| LOCATION: Abu Dhabi, United Arab Emirates | |
|---|---|
| TYPE OF INTERVENTION: | City masterplan |
| DATE OF REALISATION: | Design phase |
| DESIGN TEAM: | Foster and Partners |
| TEMPERATURE: | 13.2 C (January), +42.9 C (August) |
| HUMIDITY: | The relative humidity typically ranges from 56% to 69% over the year. |
| WIND: | Over the course of the year typical wind speeds vary from 3 m/s to 4 m/s from N-W side. |



TThe goal of Masdar City is to create a walkable, vibrant mixed-use community through the creation of interconnected neighbourhoods and public places designed to be friendly to pedestrians and cyclists (Figure 4.30).

The initial design phase banned traditional automobiles, as travel will be accomplished via public mass transit, and a mix of electric vehicles and other clean-energy vehicles for mass transit inside the city. The majority of private vehicles will be restricted to parking lots along the city's perimeter.

The temperature in the streets should be generally 15 to 20 °C cooler than the surrounding desert. The temperature difference is due to Masdar's unique construction (Figure 4.31). A 45-meter-high wind tower modelled on traditional Arab designs sucks air from above and pushes a cooling breeze through Masdar's streets. Buildings are clustered close together to create streets and walkways shielded from the sun.

The absence of motor vehicles coupled with the described strategies and Masdar's perimeter wall, designed to keep out the hot desert winds, allows for narrow and shaded streets that help funnel cooler breezes across the city.

Public spaces, parks and streetscapes will be designed to encourage walking and outdoor activity throughout the day while planting, shading and water strategies will all contribute further to reducing the radiant temperature and to maximising cooling breezes to extend the time that people can spend outdoors.

## REFERENCES

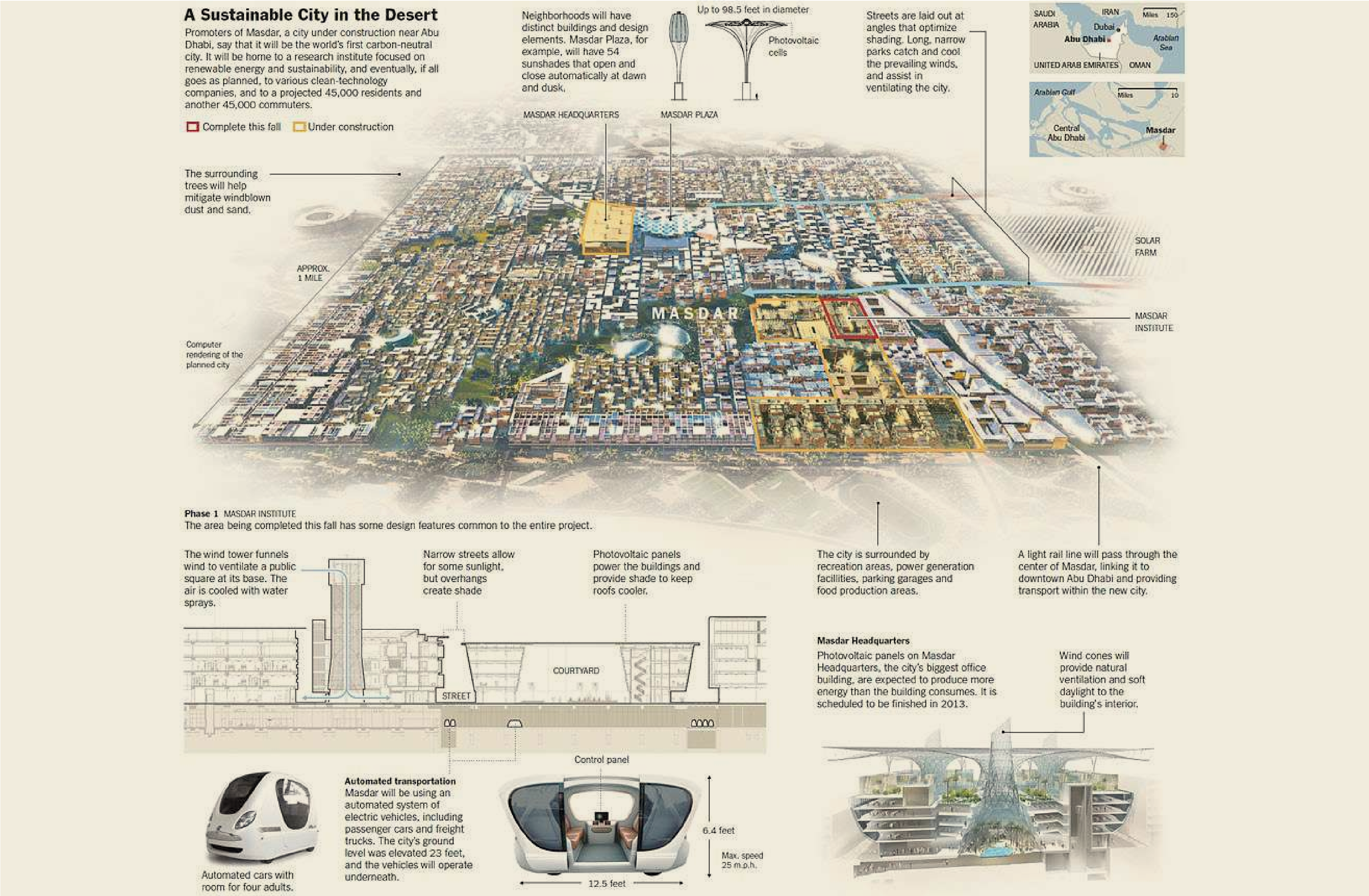
The economist. 2008 – http://www.economist.com/node/12673433?story_id=12673433

The Masdar Digest. 2016. - Issue 19http://www.masdar.ae/en/media/detail/the-masdar-digest-issue-19

Open Buildings - http://openbuildings.com/buildings/masdar-city-profile-5400

FIGURE 4.30 **MASDAR MASTERPLAN**

FIGURE 4.31 **MASDAR MASTERPLAN CONCEPT (SOURCE: OPEN BUILDINGS N.D.)**



**A Sustainable City in the Desert**

Promoters of Masdar, a city under construction near Abu Dhabi, say that it will be the world's first carbon-neutral city. It will be home to a research institute focused on renewable energy and sustainability, and eventually, if all goes as planned, to various clean-technology companies, and to a projected 45,000 residents and another 45,000 commuters.

🟥 Complete this fall 🟨 Under construction

The surrounding trees will help mitigate windblown dust and sand.

Neighborhoods will have distinct buildings and design elements. Masdar Plaza, for example, will have 54 sunshades that open and close automatically at dawn and dusk.

Streets are laid out at angles that optimize shading. Long, narrow parks catch and cool the prevailing winds, and assist in ventilating the city.

**Phase 1** MASDAR INSTITUTE
The area being completed this fall has some design features common to the entire project.

The wind tower funnels wind to ventilate a public square at its base. The air is cooled with water sprays.

Narrow streets allow for some sunlight, but overhangs create shade

Photovoltaic panels power the buildings and provide shade to keep roofs cooler.

The city is surrounded by recreation areas, power generation facilities, parking garages and food production areas.

A light rail line will pass through the center of Masdar, linking it to downtown Abu Dhabi and providing transport within the new city.

**Masdar Headquarters**
Photovoltaic panels on Masdar Headquarters, the city's biggest office building, are expected to produce more energy than the building consumes. It is scheduled to be finished in 2013.

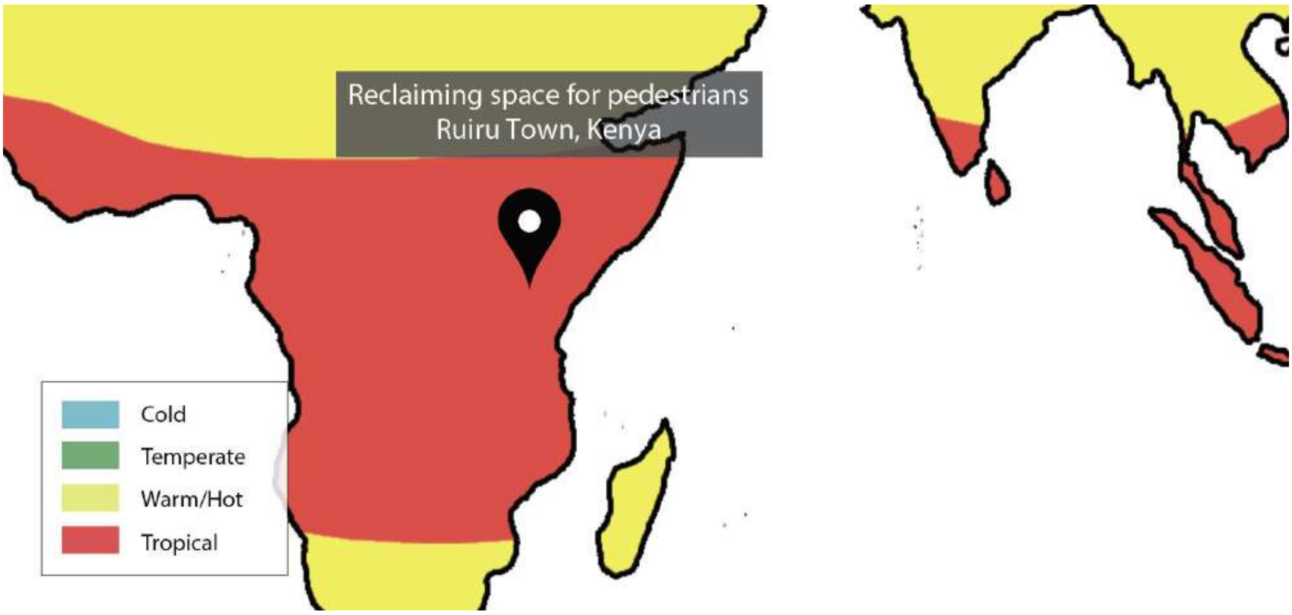
Wind cones will provide natural ventilation and soft daylight to the building's interior.

**Automated transportation**
Masdar will be using an automated system of electric vehicles, including passenger cars and freight trucks. The city's ground level was elevated 23 feet, and the vehicles will operate underneath.

Automated cars with room for four adults.

## 4.7.3 RECLAIMING SPACE FOR PEDESTRIANS

| **LOCATION: Ruiru Town, Kenya** | |
|---|---|
| TYPE OF INTERVENTION: | Space for pedestrians |
| DATE OF REALIZATION: | Design phase |
| DESIGN TEAM: | |
| TEMPERATURE: | With an average temperature of 21.0 °C, March is the hottest month of the year. At 17.2 °C on average, July is the coldest month of the year. |
| HUMIDITY: | |
| WIND: | The predominant average hourly wind direction is from the east throughout the year. |



UN-Habitat, through a collaboration with the University of Nairobi, is supporting the town of Ruiru, in Kiambu county that adjoins Nairobi in developing a "Sustainable Urban Mobility Plan". The idea of the SUMP is to create an "implementable" plan backed by the consensus of all stakeholders, including government, local businesses and residents. The SUMP targets improvements in walking and cycling facilities with the overall objective of making the town accessible for all.

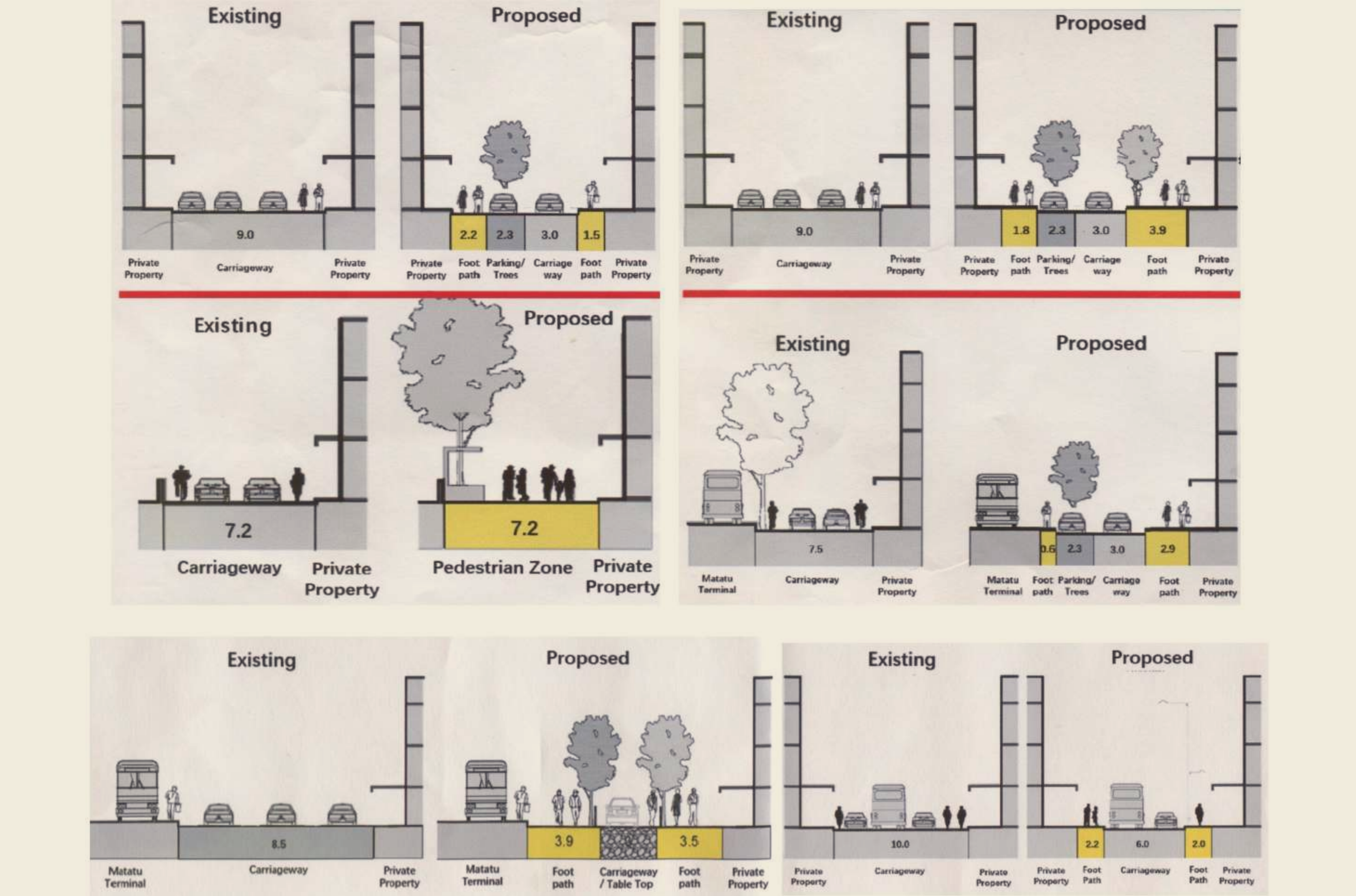
Participatory workshops with stakeholders in the town including local government, transport service providers, businesses and residents led to identifying the need to improve public spaces adjoining a busy matatu (informal mini-busses) terminal in the growing town. The proposed modification will incorporate better walking facilities, safer pedestrian crossings and space for attractive and better managed street vending that will encourage local economic activities (Figure 4.32). Besides the reorganization of traffic flows and parking spaces, as well as the incorporation of large sidewalks and the preservation of trees and bushes, the proposal includes the transformation of selected streets into pedestrianized zones. The main characteristics of these areas include the absence of cars to allow the appropriation of the streets by pedestrians, a larger green canopy, designated spaces for street vendors, well-designed pavements to create a signature look for the streets, as well as large, pleasant resting areas such as parklets or benches for seating.

## REFERENCES

Institute for Transportation and Development Policy, 2016. Reclaiming streets for pedestrians in Ruiru, Workshop report. https://go.itdp.org/download/attachments/47652389/Report%20on%20Ruiru%20Workshop%20160418.pdf?api=v2

Stefanie Holzwarth, Urban Mobility Unit UN-Habitat, 2016. Towards Sustainable Urban Mobility - SUMP for Ruiru, Kenya, http://www.urban-mobility-solutions.eu/fileadmin/editor-content/Event_Presentations/Berlin__April_2016/Stefanie_Holzwarth_UN-Habitat.pdf

FIGURE 4.32 **RUIRU TOWN, RUIRU TOWN, EXISTING AND PROPOSED DESIGN OF THE TOWN'S STREETS.**



## 4.8 ENERGY PRODUCTION

### 4.8.1 SCHLIERBERG SOLAR ESTATE

| **LOCATION: Freiburg, Germany** | |
|---|---|
| TYPE OF INTERVENTION: | Sustainable neighbourhood, energy production |
| DATE OF REALIZATION: | 2000-2006 |
| DESIGN TEAM: | Rolf Disch |
| TEMPERATURE: | -3 C (February) +25 C (July) |
| HUMIDITY: | The relative humidity typically ranges from 44% (comfortable) to 96% (very humid) over the course of the year. |
| WIND: | Over the course of the year typical wind speeds vary from 0 m/s to 5 m/s (calm to gentle breeze), rarely exceeding 8 m/s (fresh breeze). |

The solar housing development "Am Schlierberg" in Freiburg is one of the first energy-plus housing estates in the world. On the site of the former French Vauban barracks, a new, mixed use urban neighbourhood with a total of 2,000 flats and community needs facilities for approx. 5,000 people has come into existence since 1997.

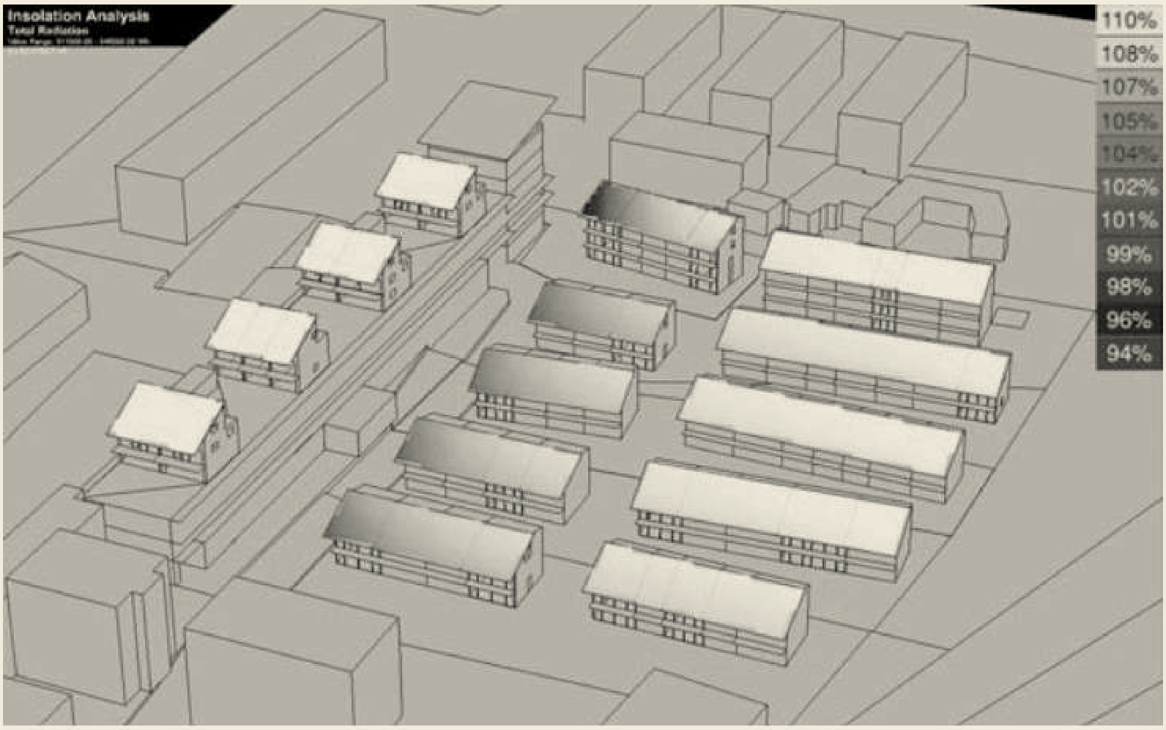
The solar settlement is a trend-setting pilot project for solar building and living. The development is known as a "Surplus energy house" construction, since photovoltaic facilities on the buildings' roofs generate more energy than the inhabitants of the houses consume. The surplus energy is then fed into the general electricity network.

The layout of the project is based on solar orientation (Figure 4.33). The terraced houses face south and the distance between buildings is governed by the need to allow solar radiation to passively heat each house and provide solar insolation. The 2 to 3-storey wood construction buildings are in rows aligned to the south and are built in accordance with the stringent requirements of passive house standards. An individual design, the use of natural building materials and striking colours give the settlement a distinctive look.

All south facing roofs of the different buildings are covered with standard large area Photovoltaic (PV) modules. The total system size is 445 kWp.

The orientation and housing density on the estate were designed to take account of living quality, unobstructed solar radiation on the photovoltaic roofs throughout the year, summer shade and winter sun on the southern façades.

FIGURE 4.33 **SOLAR POTENTIAL (SOURCE: HEINZE 2009)**



The terraced houses are of different widths and extend over two or occasionally three storeys, so that the living areas vary from 75 to 200 $m^2$ (Figure 4.34).

Energy for the project is provided mostly by the sun, though in the case of electricity no onsite storage is provided so energy is fed into the grid and extracted as needed. Heat energy is generated by a local network of solar hot water evacuated-tubes located on the Sonnenschiff. The hot water is then used for heating water and the living spaces. Electricity is generated by solar energy plants or PV panels mounted on the housing units. The electricity produced is fed into the public grid and a profit is made because of the higher rates paid to solar energy producers. Any additional energy required in the winter months is provided by a wood-chip and natural gas fuelled power station.

The optimised passive house standard and the additional power generation lead to a reduction of the supplementary expenses for the users. Designed as passive houses, the dwellings consume very little energy. The small remaining amount of energy required can be provided by the photovoltaic yields from the roofs. This high energy-efficiency on site reduces the consumption of renewable energy and the requirements for the transport and storage of energy in grids (low mismatch factor[34]). The low consumption results from a whole group of measures: the compact houses were built in compliance with the passive house standard. The high insulation standard—the average U-value for the building envelope is 0.28 W/$m^2$ K —together with efficient ventilation heat recovery are key to low consumption. Electricity-saving appliances and appropriate user behaviour reduce domestic power consumption. Water-saving tap fittings were installed. Finally, all the houses on the estate are connected to a local heating network supplied by cogeneration from a combined heat and power plant operating with woodchips and natural gas.

In total 445 kWp of grid-connected PV is installed. The string inverters are mounted right under the roof deck on the exterior walls of the buildings. The total annual solar electricity production is 420,000 kWh. This, together with the energy efficient building design, allows for 2 million kWh primary energy savings per year. This is the equivalent of 200,000 litres of oil per year.

The aim of the project was to apply German Passive House and Plus Energy House directives as well as show sustainable construction principles through material selection, appliance choice, energy consumption, transportation options, and construction method. Therefore, the disposition, building design as well as layout all reflect the attention to energy consumption. The project shows how the complex relationship between a building's position, orientation, layout, use, energy production and consumption can have a positive impact, producing energy which can be fed into the national grid.

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[34] *Amount of renewable energy production which is not consumed instantaneously and thus is fed into the grid.*

FIGURE 4.34 **VIEW OF SOLAR HOUSE DEVELOPMENT (SOURCE PV UPSCALE)**

## REFERENCE

Heinze, M., & Voss, K. 2009. Goal: Zero Energy Building exemplary experience based on the solar estate solarsiedlung freiburg am schlierberg, Germany. Journal of Green Building, 4(4), 93-100 - http://www.enob.info/fileadmin/media/Projektbilder/EnOB/Thema_Nullenergie/Journal_of_green_Building_GOAL_ZERO_ENERGY_BUILDINGx.pdf

PV upscale. n.d. Solarsiedlung am Schlierberg - http://www.pvupscale.org/IMG/pdf/Schlierberg.pdf

# A1 PRINCIPLES OF URBAN CLIMATOLOGY

## 1. ENERGY AND WATER BALANCE OF AN IDEAL VOLUME

The most important flows in climatology are the solar flow of energy, and the hydrologic flow of water.

According to the first law of thermodynamics, energy can be neither created nor destroyed, only converted from one form to another. Thus, for any system the equation stands as:

$$\mathit{Energy\ Input} = \mathit{Energy\ Output} + \mathit{Energy\ Storage\ Change} \qquad \text{eqn. A1.1}$$

The energy storage term may be positive, negative or zero. For example, if energy is being accumulated in a soil-atmosphere system an increase in soil and/or air temperature will derive.

Four different energy forms are relevant to climatology: radiant, thermal, kinetic and potential, and they can be transformed one into another. This means, for example, that if the input is entirely radiant energy, the output can be any of the four or some or all of them. Specifically, heat can be transferred in three forms[35]:

- sensible heat, which is driven by temperature differences;
- radiant heat, which is transferred by electromagnetic waves;
- latent heat, which is the heat released or absorbed by a body when there is a phase change (water is transformed into vapour and vice versa, water into ice and vice versa, etc.).

The equation for water is similar:

$$\mathit{Water\ input} = \mathit{water\ output} + \mathit{water\ storage\ change} \qquad \text{eqn. A1.2}$$

where the water output consists of water evaporated and runoff.

## 1.1 ENERGY BALANCE OF A SURFACE

The energy balance of a surface is usually defined with respect to an active layer of infinitesimally small thickness. In this case the storage of energy in the layer can be ignored.

The global solar radiation incident on a horizontal surface, $S\downarrow$, consists of both direct $S_b\downarrow$ and diffuse $S_d\downarrow$ radiation, so that:

$$S\downarrow = S_b\downarrow + S_d\downarrow \qquad \text{eqn. A1.3}$$

The reflected solar radiation $R\uparrow$ depends on the value of $S\downarrow$ and the surface albedo ($\alpha$, see Box 2.1 for definition and Table A1.1 for typical values), so that:

$$R\uparrow = \alpha\, S\downarrow \qquad \text{eqn. A1.4}$$

Thus, the net solar radiation budget K is given by[36]:

$$K = S\downarrow - R\uparrow = S\downarrow - \alpha\, S\downarrow = S\downarrow (1-\alpha) \qquad \text{eqn. A1.5}$$

The incoming long-wave radiation $L\downarrow$ emitted by the atmosphere is a function of sky emissivity[37] and the absolute temperature of the sky, according to the formula:

$$L\downarrow = \varepsilon_{sky}\, \sigma\, T^4_{sky} \quad [\mathrm{W/\ m^2}] \qquad \text{eqn. A1.6}$$

where:

$\varepsilon_{sky}$ is the sky emissivity, dimensionless

$\sigma$ is the Stefan-Boltzmann constant = $5.7 \times 10^{-8}$ [W/m² K⁴]

$T_{sky}$ is the absolute temperature of the sky [K]

For a first approximation evaluation, neglecting the effect of humidity, $L\downarrow$ can be calculated with:

$$T_{sky} = T_{air}$$

$$\varepsilon_{sky} = (1 + k \bullet n)8.733 \bullet 10^{-3} \bullet T_{air}^{0.788} \qquad \text{eqn. A1.7}$$

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[35] For more information on heat transfer, see UN-Habitat, SUSTAINABLE BUILDING DESIGN FOR TROPICAL CLIMATES - Principles and Applications for Eastern Africa, 2014 – Appendix 1 - http://unhabitat.org/books/sustainable-building-design-for-tropical-climates/

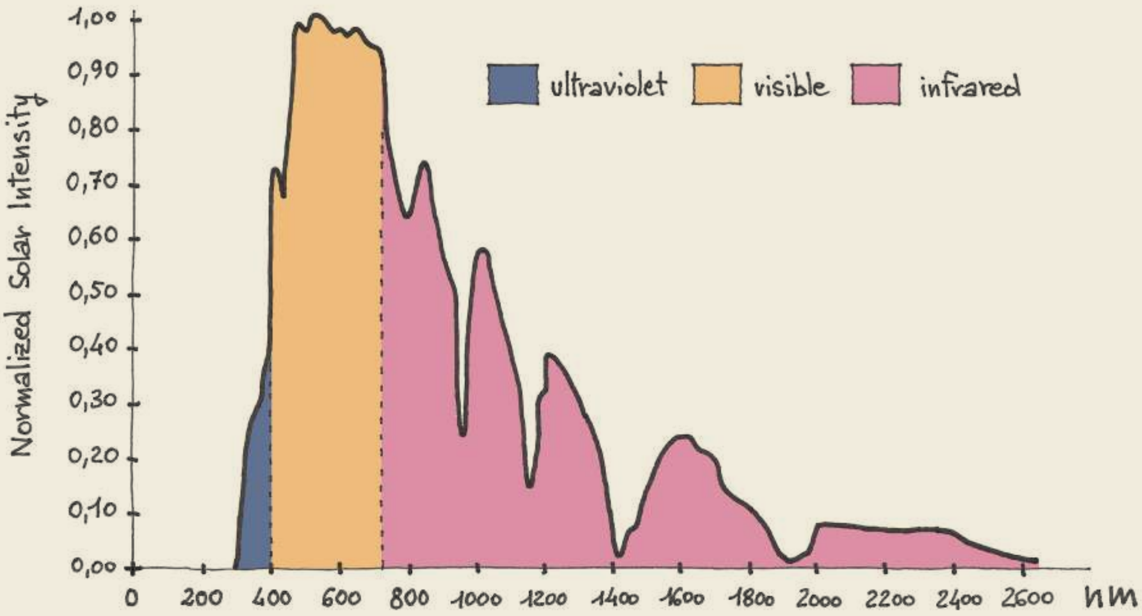
[36] Eqn. A1.4 stands only when the active layer is horizontal and placed in a bare flat landscape, i.e. it does not "see" any other surface and thus cannot receive any reflected solar radiation. For example, eqn. A1.6 cannot be used for a surface sited at the bottom of a valley.

[37] The emissivity of a surface is the ratio of the radiant flux emitted from the real body and that emitted from the blackbody at the same temperature (thus, for a blackbody $\varepsilon = 1$); it is dimensionless

## SOLAR REFLECTANCE OR ALBEDO

Solar reflectance, or albedo, is the ratio of the reflected radiation from the surface to the radiation incident upon it. It is measured on a scale from zero for no reflection of a perfectly black surface to 1 for perfect reflection of a white surface. Solar energy is composed of ultra-violet (UV) rays, visible light, and infrared energy, each reaching the Earth in different percentages: 5% of solar energy is in the UV spectrum, 43% is visible light, and the remaining 52% is infrared (see Figure A1.1). As almost 50% of the radiation is visible light, solar reflectance is correlated with the colour of a material (see table A1.1).

FIGURE A1.1 **SOLAR ENERGY VERSUS WAVELENGTH REACHING EARTH'S SURFACE ON A CLEAR DAY (EPA 2008)**



where:

$T_{air}$ = absolute air temperature [K]

k = constant depending on cloud type; it can be assumed = 0.26

n = cloud amount, with n = 1 for complete cloud cover and n = 0 for clear sky.

If the effect of humidity is taken into account, then $\varepsilon_{sky}$ can be derived from the graphs in Figure A1.2.

The long-wave radiation L↑ emitted by the surface, also depends on its absolute temperature and emissivity ($\varepsilon_G$, see Table A1.1 for typical values):

$$L\uparrow = \varepsilon_G \, \sigma \, T_G^4 \qquad \text{eqn. A1.8}$$

where:

L↑ = radiant heat flux [W/m²];

$\varepsilon_G$ = emissivity, or emittance, of the surface

$T_G$ = absolute temperature of emitting surface [K].

In open, flat space, the difference between these two long-wave fluxes is the surface net long-wave radiation budget L:

$$L = L\downarrow - L\uparrow \qquad \text{eqn. A1.9}$$

In open, flat space, the emitting surface "sees" the entire sky dome. If this is not the case, i.e. if the sky view is partially obstructed by mountains, buildings, etc., then the long-wave flux from sky becomes:

$$L\downarrow^* = L\downarrow \bullet \text{SVF} \qquad \text{eqn. A1.10}$$

where SVF is the Sky View Factor, i.e. the fraction of the sky dome seen from the surface (SVF is equal to 1 for a flat surface and decreases with the increase of sky view obstructed).

The net all-wave radiation Q is the most important energy flux. The daytime budget may be written:

$$Q = S\downarrow - R\uparrow + L\downarrow - L\uparrow = K - L \qquad \text{eqn. A1.11}$$

TABLE A1.1 THE ALBEDO AND THERMAL EMISSIVITY OF SOME TYPICAL NATURAL AND MAN-MADE MATERIALS

| Surface | Albedo (α) | Emissivity (ε) |
|---|---|---|
| | **man-made** | |
| asphalt# | 0.05–0.20 | 0.95 |
| concrete# | 0.10–0.35 | 0.71–0.90 |
| brick# | 0.20–0.40 | 0.90–0.92 |
| stone* | 0.20-0.35 | 0.85-0.95 |
| corrugated iron# | 0.10–0.16 | 0.13–0.28 |
| tile* | 0.10-0.35 | 0.90 |
| fresh white paint# | 0.70–0.90 | 0.85–0.95 |
| red, brown, green* | 0.20-0.35 | 0.85-0.95 |
| black* | 0.02-0.15 | 0.90-0.98 |
| clear glass (zenith angle < 40°)* | 0.08 | 0.87-0.94 |
| clear glass (zenith angle 40 to 80°)* | 0.09-0.52 | 0.87-092 |
| urban areas (range)* | 0.10-0.27 | 0.85-0.95 |
| urban areas (average)* | 0.15 | " |
| | **natural** | |
| desert* | 0.20-0.45 | 0.84-0.91 |
| forest# | 0.07–0.20 | 0.98 |
| grass# | 0.15–0.30 | 0.96 |
| soil (wet) # | 0.10–0.25 | 0.98 |
| soil (dry) # | 0.2–0.4 | 0.9–0.95 |
| water (small zenith angle)* | 0.03-0,10 | 0.92-0.97 |
| water (large zenith angle)* | 0.10-1.0 | 0.92-0.97 |

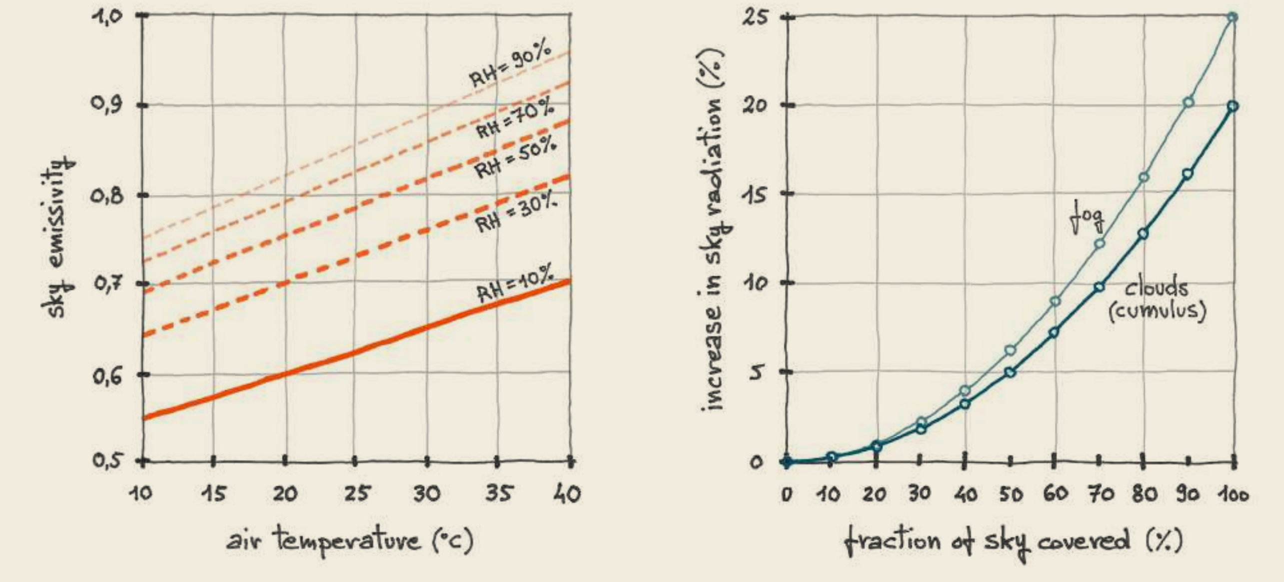
* After Oke, Boundary Layer Climates, Methuen & Co, London, 1978

\# After E. Erell et al., Urban Microclimate, Earthscan, New York, 2011

Notes: 1. The albedo of tropical rainforests lies in the lower part of this range, while that of coniferous or deciduous forests is in the upper part.

2. The moisture content affects the colour of the soil, thereby the albedo.

FIGURE A1.2 THE VARIATION OF SKY EMISSIVITY WITH AIR TEMPERATURE AND RELATIVE HUMIDITY UNDER CLEAR- SKY CONDITIONS (LEFT), AND THE PERCENTAGE INCREASE IN LONG-WAVE RADIATION AS A FUNCTION OF CLOUD OR FOG COVER (RIGHT). (ADAPTED FROM: ERELL 2011)

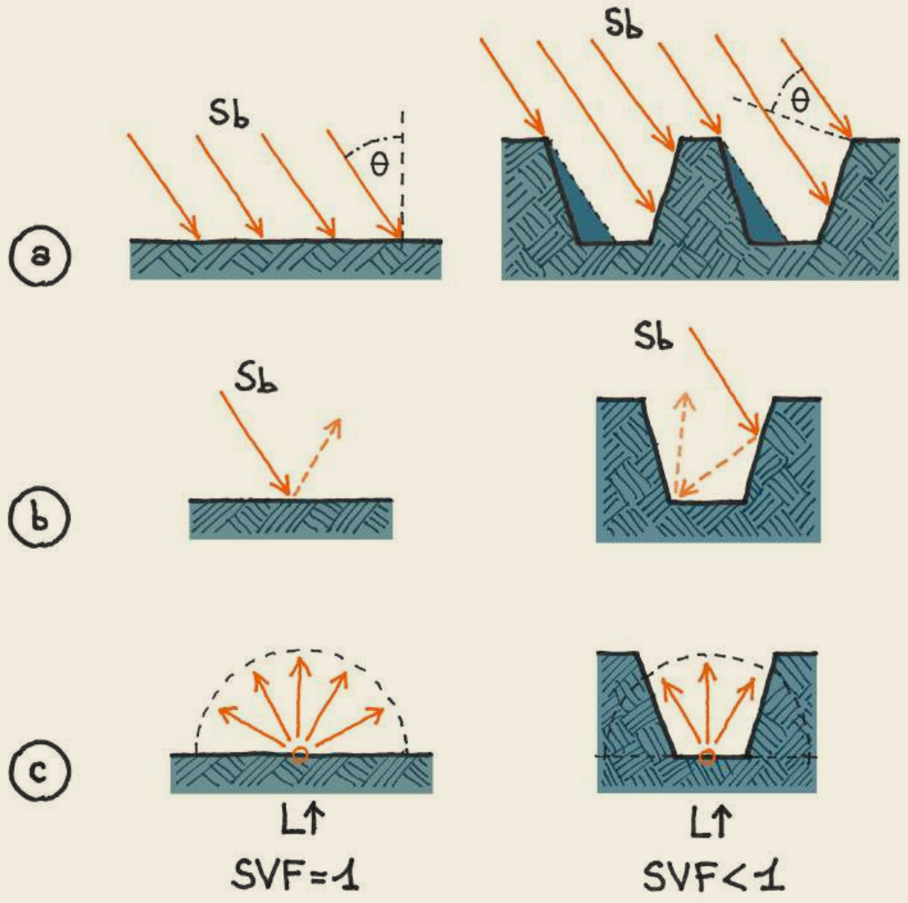


## ALBEDO AND SURFACE GEOMETRY

Albedo is determined not only by the colour of the surface (dark-coloured ⟶ low albedo, light coloured ⟶ high albedo, see Table A1.1) but also by its geometry.

Ridge and furrow geometry provides a radiative 'trap' for both the ingoing and outgoing short and long-wave radiation (Figure A1.3). The radiative "trapping" capability of a grooved surface is a function of the Sky View Factor (SVF).

FIGURE A1.3 **ROLE OF SURFACE GEOMETRY IN RADIATION EXCHANGE. COMPARISON OF HORIZONTAL AND CONVOLUTED (E.G. BY RIDGE AND FURROW) SURFACES IN TERMS OF (A) RECEIPT OF DIRECT BEAM SHORT-WAVE RADIATION Sb (b) REFLECTION OF Sb, AND (C) EMISSION OF LONG-WAVE RADIATION $L\uparrow$.**



At night, with no solar radiation:

$$Q = L\downarrow - L\uparrow = L \qquad \text{eqn. A1.12}$$

In tropical regions the annual solar radiation budget K is predominant over the long-wave radiation budget L.

The radiant energy reaching or leaving the surface must be balanced by the same amount of energy leaving or reaching the surface by convection, conduction or evaporation. Thus, taking into account the heat exchanges with the atmosphere (convective $Q_H$, and latent $Q_E$) and conduction through the soil below ($Q_G$), the energy balance of the surface is given by (see Figure A1.4):

$$Q = Q_H + Q_E + Q_G \qquad \text{eqn. A1.13}$$

## 1.2 ENERGY BALANCE OF A VOLUME

The formulation of the surface energy balance as in eqn. A1.13 is consistent with the assumption of an active surface of infinitesimally small thickness, i.e. massless. In reality, the system subject to energy fluxes is a volume of finite thickness. In this situation it is necessary to include changes of energy storage ($\Delta Q_S$), so that the energy balance becomes (Figure A1.5):

$$Q = Q_H + Q_E + Q_G + \Delta Q_S \qquad \text{eqn. A1.14}$$

## 1.3 WATER BALANCE

Energy flow makes possible the evaporation of water from open water surfaces and the soil, and the transpiration from vegetation. The total loss of water to the air is called *evapotranspiration, E*.

In the case of an 'ideal' grassed site with a moist soil on level terrain (Figure A1.7), the annual water balance can be written in the same way as eqn. A1.14 for energy, i.e:

$$p = E + \Delta r + \Delta S \qquad \text{eqn. A1.15}$$

where **p** is the annual amount of precipitation, $\Delta r$ is the *net run-off* (water streams entering or leaving the surface), which may have a positive or a negative sign and $\Delta S$ is the net change in *soil moisture content.*

Soil moisture is also an important factor in the energy balance of a surface because of its impact on radiative, conductive and convective flows, besides the potential latent heat effects. For example, the presence of moisture can alter the surface albedo (generally decreasing it), thus changing K and Q, and the thermal properties of a soil are changed by adding water, affecting heat transfer and storage.

## 1.4 CLIMATE OF A VOLUME

The local climate of a volume soil-air (Figure A1.9) is the result of its energy and water balance, which the temperature of the surface of the soil derives from, which, in turn, controls the air temperature and – combined with other parameters – its humidity.

FIGURE A1.4 **SCHEMATIC SUMMARY OF THE FLUXES INVOLVED IN THE RADIATION BUDGET AND ENERGY BALANCE OF AN "IDEAL" SITE, CLEAR SKY, IN DAYTIME (ABOVE) AND LATE AT NIGHT (BELOW).**

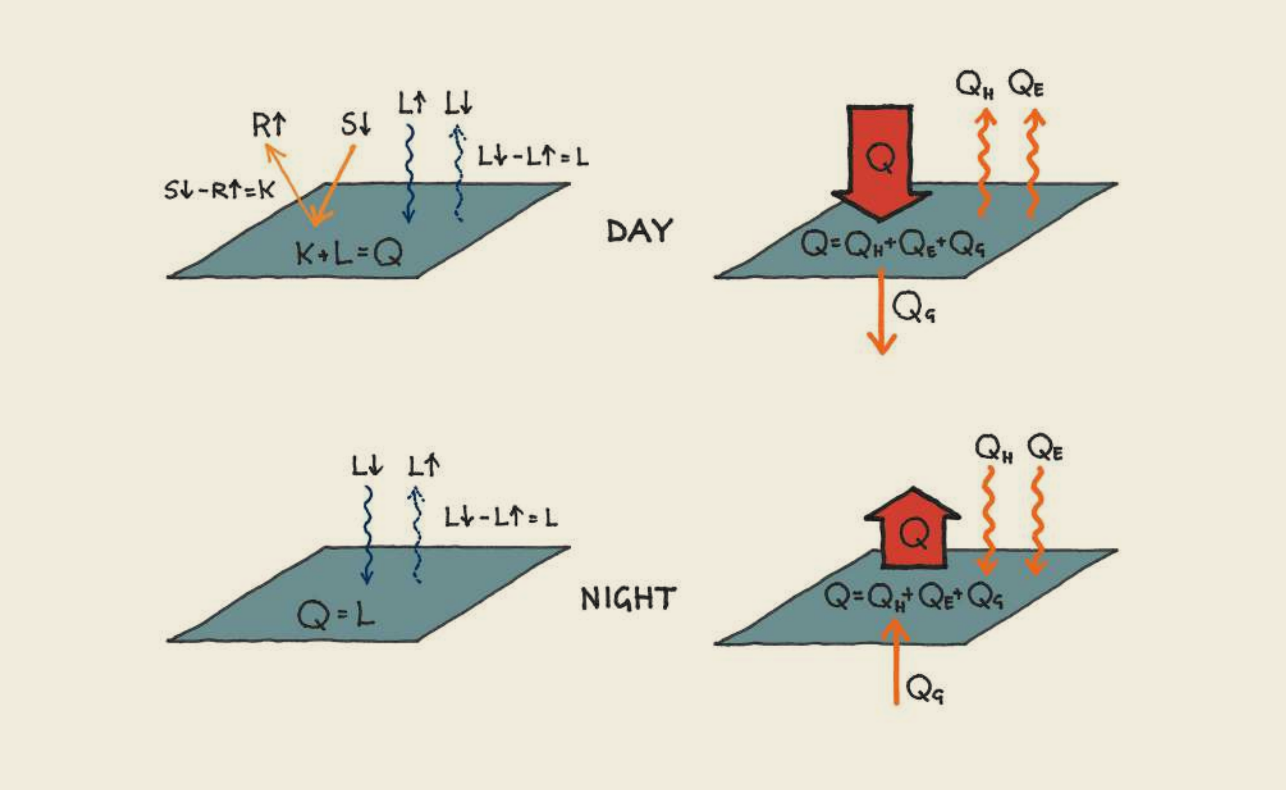
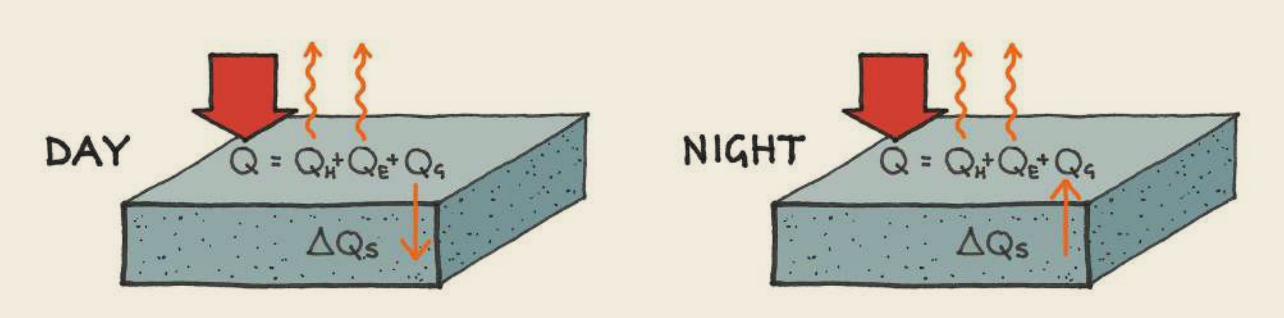


FIGURE A1.5 **SCHEMATIC DEPICTION OF THE ENERGY BALANCE OF A SLICE OF BARE SOIL (CLEAR SKY) IN DAYTIME AND LATE AT NIGHT.**



## ENERGY FLUX AND SOIL TEMPERATURE

As a practical application of the above mentioned general concepts, Figure A1.6 illustrates the case of an 'ideal' bare soil site during a cloudless summer day. During most of the daytime the energy received is more than the energy dissipated (i.e. input exceeds output). The resulting energy surplus causes a temperature increase of the surface. The maximum temperature does not coincide with the time of maximum energy input. The temperature continues to rise after the time of maximum input because for a few hours it still exceeds the loss, thus the energy budget is still accumulating a surplus. The maximum temperature occurs at the time when input and output are equal. Thereafter more heat is being extracted than is being added (output exceeds input) and the temperature starts dropping. It continues to drop as long as the rate of loss is greater than the rate of gain. The minimum temperature also occurs at the time when input and output balance. This explains why minimum temperatures are recorded just after sunrise, and maximum in mid¬-afternoon.

FIGURE A1.6 **THE RELATIONSHIP BETWEEN SURFACE ENERGY EXCHANGE AND THE DIURNAL SURFACE TEMPERATURE REGIME (ADAPTED FROM OKE 1978)**

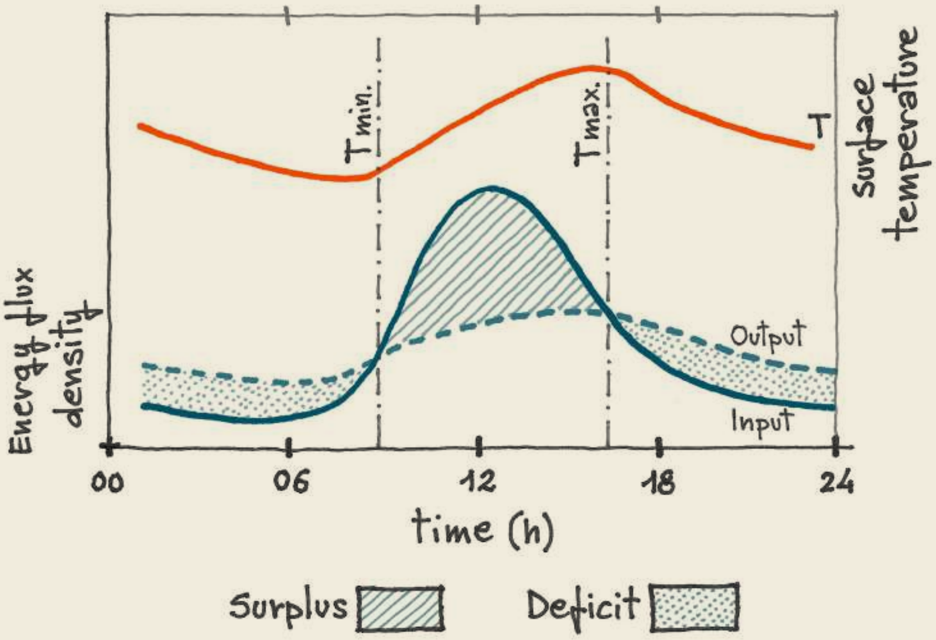
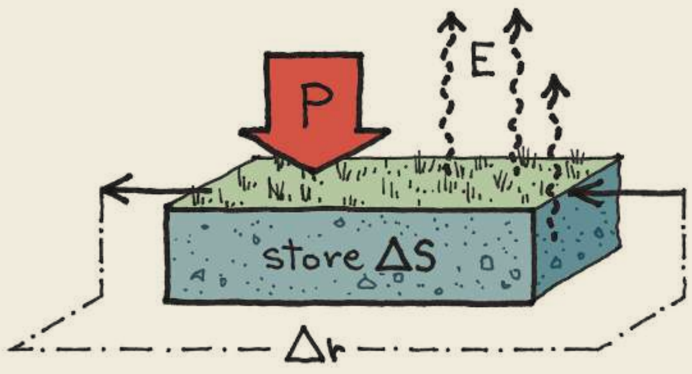


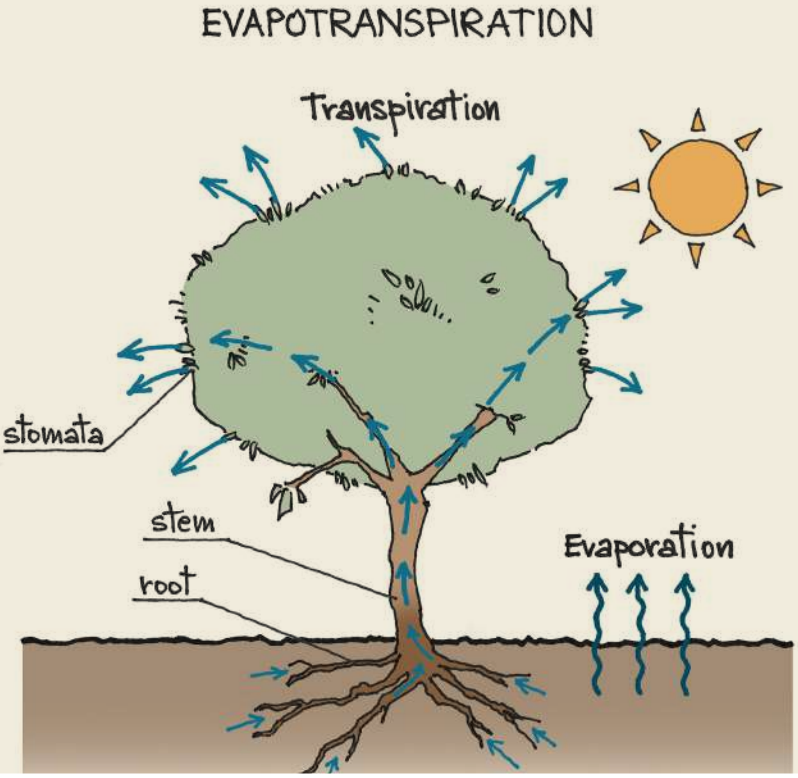
FIGURE A1.7 **DIAGRAMMATIC REPRESENTATION OF THE COMPONENTS OF THE WATER BALANCE OF A SOIL-PLANT COLUMN.**



## BOX A1.4 EVAPOTRANSPIRATION

Plants absorb water through their roots and emit it through their leaves; this movement of water is called transpiration. Water reaching the surface of the leaves then evaporates, which requires heat. Evaporation also occurs from the soil around vegetation and from trees and vegetation as they intercept rainfall on their leaves and other surfaces. Together, the processes of evaporation and transpiration are referred to as evapotranspiration (Figure A1.8).

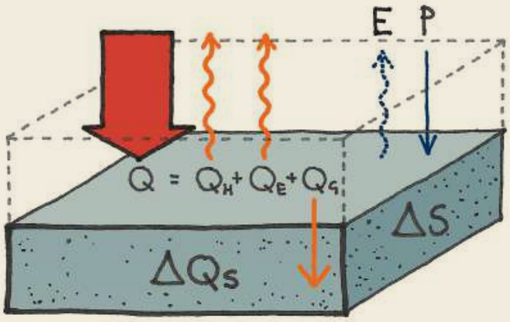
FIGURE A1.8 **THE EVAPOTRANSPIRATION PROCESS**



In summary, the energy balance of the above examined volume, i.e. its local climate, depends on the following factors:

- Global solar radiation incident on a horizontal surface, $S\downarrow$;
- Surface albedo, $\alpha$, and emissivity, $\varepsilon$ - determining the net amount of radiant energy absorbed by the surface;
- Convective heat exchanges, $Q_H$ - depending on soil temperature and on the temperature and velocity of incoming air flow (wind and breezes);
- Latent heat exchanges, $Q_E$ - depending on the evapotranspiration properties of the surface and on the temperature and velocity of the incoming air flow.

FIGURE A1.9 **ENERGY AND WATER EXCHANGES OF SOIL-AIR VOLUME (NO RUNOFF, NO WIND)**



## 2. AIR MOVEMENT

Air movement, i.e. the velocity and direction of wind and breezes, is the second most important parameter, after the net radiant energy budget, in the energy balance of a soil-air volume. Usually, wind data are recorded at airports or, less frequently, at meteorological centres, but these data need to be adapted to each specific case, as wind velocity and direction is modified by the topography of the area in which the air-soil volume is located.

### 2.1 REGIONAL WINDS

The effect of topography on the regional winds is remarkable and can be assessed quantitatively. On flat ground, without obstructions, wind speed varies as a function of two parameters: surface roughness of the ground and height (Figure A1.10).

Airflow over non-uniform terrain cannot be easily generalised. Each hill, depression, rock, hedge, etc. perturbs the wind flow pattern (Figure A1.11) and the wind profile (Figure A1.12), so that the wind climate of every landscape is unique.

It is possible to isolate some predictable specific cases but generally the wind pattern can be predicted only by means of simulations, either digital or in a wind tunnel.

FIGURE A1.10 **INFLUENCE OF THE ROUGHNESS OF TERRAIN ON THE VERTICAL WIND VELOCITY PROFILE (ADAPTED FROM: LIKSO 2014). HORIZONTAL ARROWS REPRESENT WIND SPEED AS A PERCENTAGE OF THE UNDISTURBED GEOSTROPHIC WIND.**

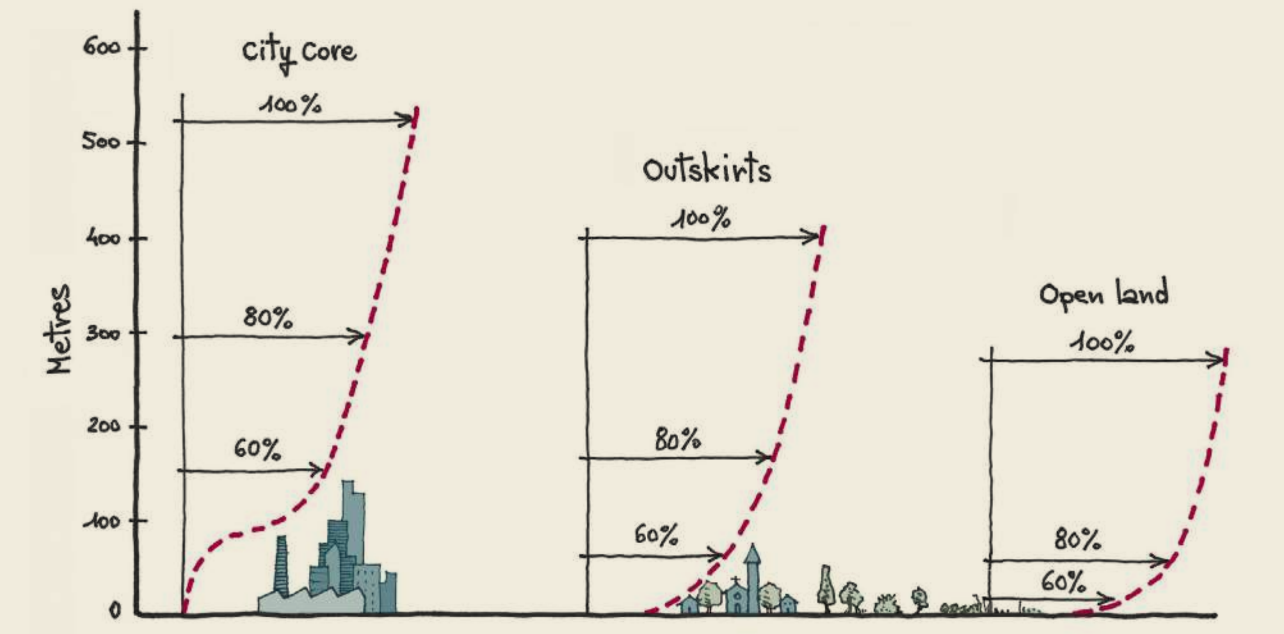


FIGURE A1.11 **MODIFICATION OF EXISTING AIRFLOW DUE TO (A) AN ISOLATED HILL, (B) A VALLEY, AND (C) A TOPOGRAPHIC CONSTRICTION (OKE 1978).**

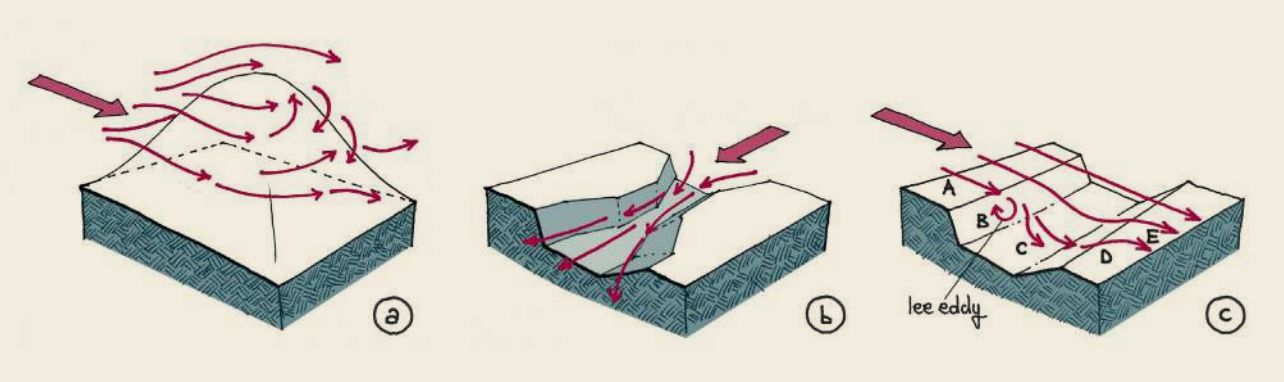
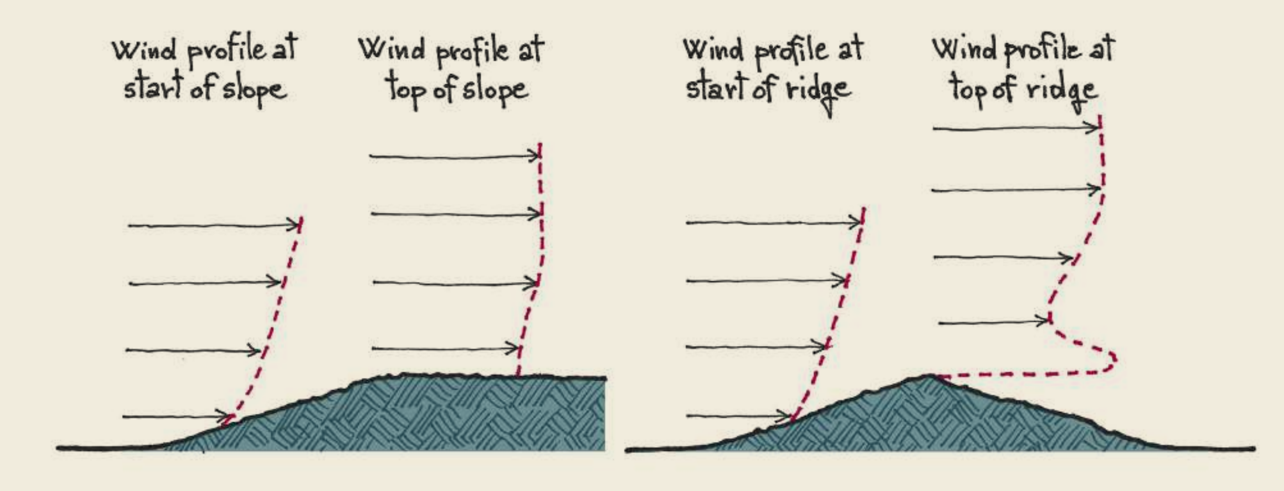


FIGURE A1.12 **MODIFICATION OF THE WIND PROFILE CAUSED BY A SLOPE (LEFT) AND A RIDGE (RIGHT)**



## 2.2 LOCAL WINDS

In the preceding sections we have considered the energy balance of simple horizontal surfaces. The real world, however, is a patchwork of surface slopes and types.

Consequently, the coexistence of contrasting thermal environments results in the development of horizontal gradient forces, which – in absence of regional winds – will cause air motion across the boundary between the surfaces.

### 2.2.1 SEA/LAKE BREEZE

Land and water surfaces have different thermal responses because of their different properties, and this is the driving force behind the breeze circulation system typical of ocean or lake shorelines.

Compared with land surfaces, a water body shows very little diurnal change in surface temperature, mainly because water has a large thermal inertia due to its higher heat capacity.

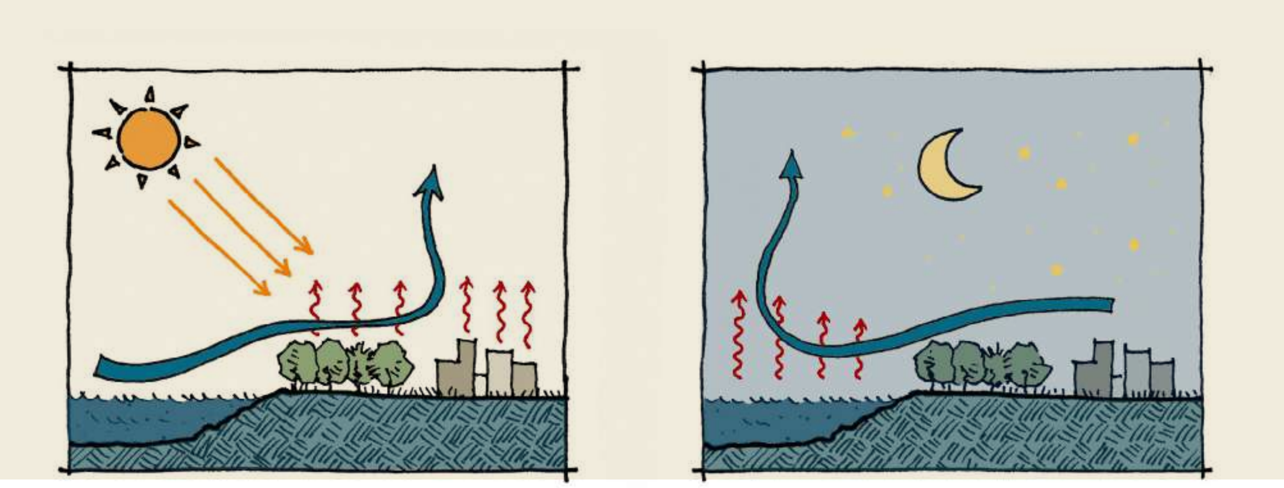
The land-water temperature differences and their diurnal inversion (land is warmer than water by day and cooler than water by night) produce corresponding land-water pressure differences. These in turn result in a system of breezes across the shoreline, reversing their direction between day and night (Figure A1.13), if there is no large-scale air motion overriding them.

### 2.2.2 AIR MOVEMENT IN VALLEYS

In valleys, especially those in mountainous regions, thermal differences generate a local wind system, when clear days and weak large-scale air motions occur.

The characteristics of these winds result from the orientation and geometry of the valley. Deep, straight valleys with a north-south axis are the most suitable for the development of such wind systems. In valleys with other orientations or characterised by complex geometries the flow pattern may lack symmetry or be incomplete.

FIGURE A1.13 **GROUND-WATER TEMPERATURE DIFFERENCE; SEA (LEFT) AND LAND (RIGHT) BREEZE (ADAPTED FROM: UN-HABITAT 2014)**



Let us consider a valley with a direct north-south axis (Figure A2.14). By day the sun warms up the slopes and the bottom of the valley; consequently, the layer of air above the warm surfaces also warms up and becomes warmer than the air in the centre of the valley. As a result, an upslope flow (called anabatic) occurs and a closed air circulation develops across the valley (1).

The upward air movement commonly gives rise to the formation of what are called convective anabatic clouds along the valley ridges. In tropical valleys this may lead to greater precipitation along the ridges than in the valley floor.

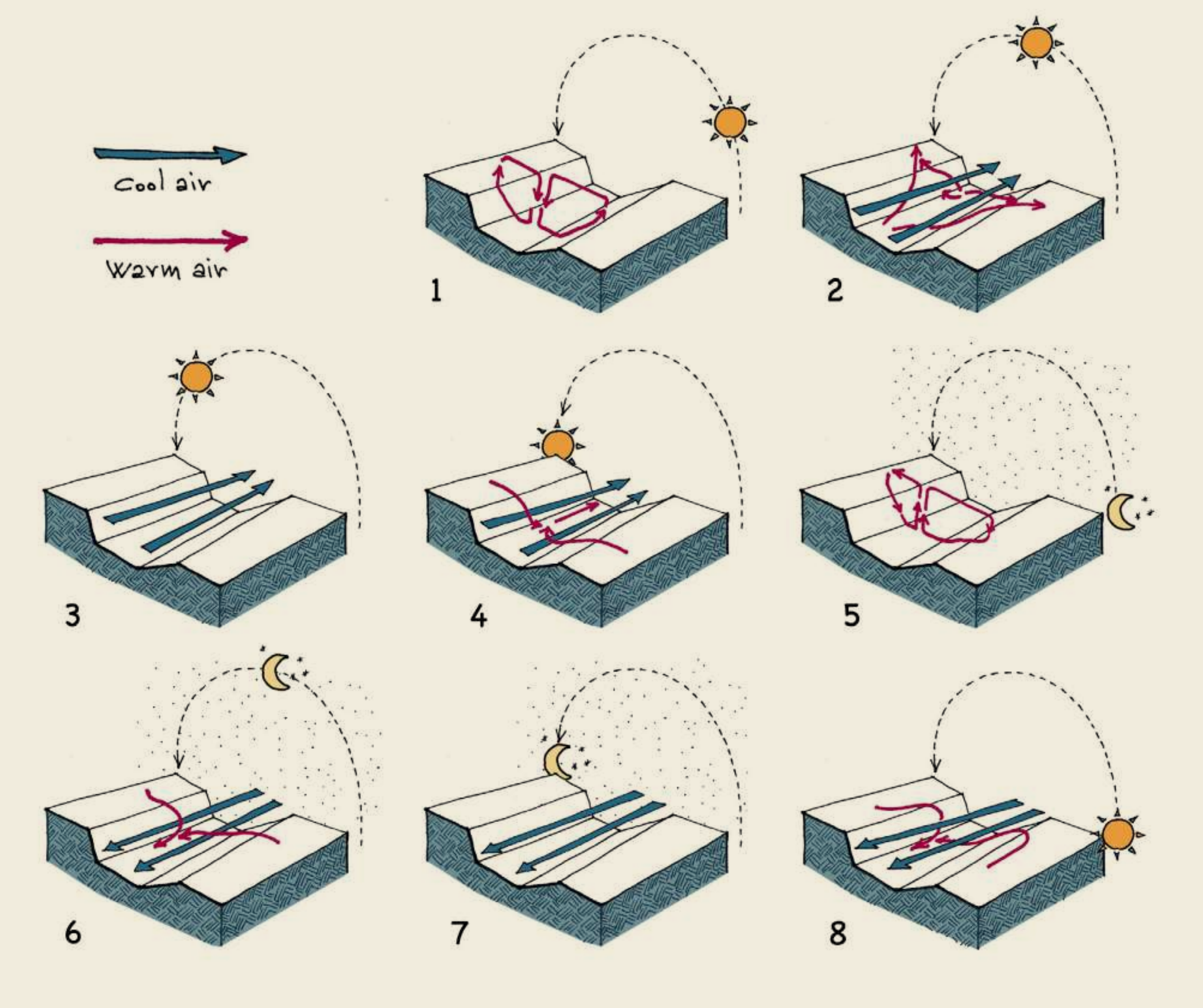
During the day a pressure decrease in the valley drives an upslope air movement along the valley axis (2) that fully develops in the late afternoon (3).

In the early evening, the valley slopes start to cool down, cooling the air, and downslope winds start along the valley sides (4). The valley wind is decreasing (it has been blowing from the plains up the valley). The pressure drop is still in the up-valley direction.

From late evening through the first half of the night, downslope winds are present (5). The system is in a state of transition from valley wind to mountain wind. At night the valley surfaces cool by emission of long-wave radiation. The lower layers of air cool down and slide down-slope because of gravity, and a gentle wind (called katabatic) flows downhill. During the night, cold air flows down the slopes and collects in the valley. The net cooling of the air in the valley results in a pressure increase, which eventually becomes large enough to drive a circulation along the valley axis towards the plains; at night, mountain wind is present along with downslope winds (6).

From late at night until morning, the downslope winds along the valley sides die out, but the mountain wind, blowing along the valley axis in the down-valley direction, persists (7).

FIGURE A1.14 **AIR MOVEMENT IN A VALLEY (ADAPTED FROM: UN-HABITAT 2014)**

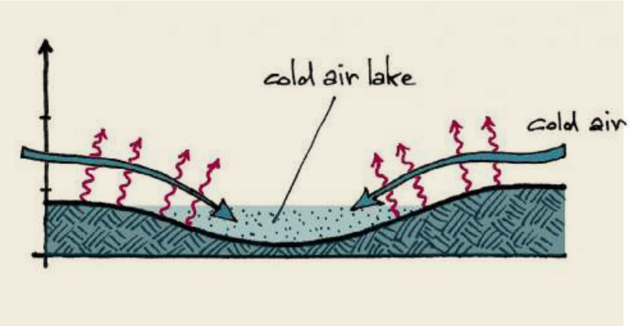


In the morning at sunrise, upslope winds are beginning (up the slopes of the sidewalls) and mountain wind is still present in valley (8).

### 2.2.3 COLD AIR LAKE

The orography has an impact on air temperature. On clear, calm nights the ground cools down due to the long-wave radiation towards the sky dome (L↑ > L↓), and a layer of cold air in contact with the surface is generated. On a slope, the layer of cold air flows down by gravity and collects in hollows in the ground or in depressions. In this way so-called cold air lakes are formed (Figure A1.15).

FIGURE A1.15 **COLD AIR LAKE (ADAPTED FROM: UN-HABITAT 2014)**



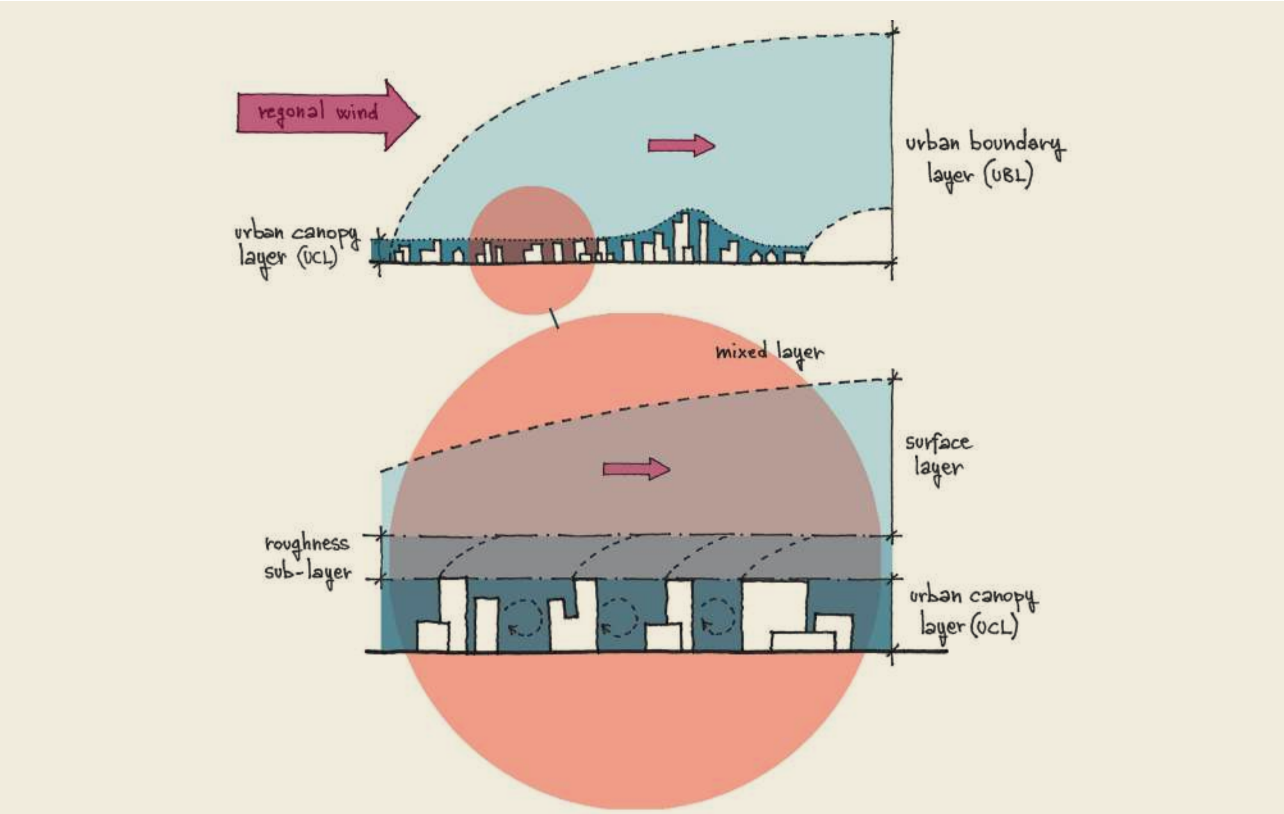
## 2.3 MODIFICATION BY URBAN AREAS

Urbanisation causes a significant change in the climate of an area. Radiative, convective, moisture and aerodynamic characteristics are transformed, thus energy flows are changed. Urbanisation causes a modification of local climate and creates new microclimates within the urban area. Each neighbourhood is characterised by its own local climate, which can differ to a greater or lesser extent from the pre-existing natural one, depending on its design.

### 2.3.1 URBAN BOUNDARY LAYER

When wind flowing from the countryside encounters a city, the urban boundary layer (UBL) develops (Figure A1.16 top). The UBL is defined as the volume of air above the city influenced by its surface characteristics and by the activities taking place in it. From the upwind edge of the city, the UBL grows in height, generally extending upwards to about ten times the height of the buildings beyond the urban area which are in the downwind direction (Erell 2011).

FIGURE A1.16 **SCHEMATIC SECTION OF THE URBAN ATMOSPHERE, SHOWING THE DEVELOPMENT OF THE URBAN BOUNDARY-LAYER (UBL) RELATIVE TO THE URBAN CANOPY-LAYER (UCL), WHICH REACHES THE AVERAGE BUILDING HEIGHT (TOP). THE MIXED LAYER AND ROUGHNESS SUB-LAYER ARE TRANSITION ZONES ABOVE AND BELOW THE SURFACE LAYER, RESPECTIVELY (ERELL 2011).**



### 2.3.2 URBAN CANOPY LAYER

The UBL may be further divided into a number of sub-layers (Figure A1.16, top and bottom). Beneath roof-level is the urban canopy layer (UCL), which is produced by micro-scale processes taking place in the streets ("canyons") between buildings. Its climate is a combination of microclimates each determined by the characteristics of its immediate surroundings.

The height of the UCL is approximately equivalent to that of the mean height of the main roughness elements (buildings and trees), $z_H$ (see Figure A1.17). Horizontal effects may persist up to a few hundred meters; vertical effects take place in the in the roughness sublayer (RSL), that extends from ground level to the height where the blending action is complete. Rule-of-thumb estimates and field measurements indicate that the height of the RSL can be as low as $1.5z_H$ at densely built (closely spaced) and homogeneous sites but greater than $4z_H$ in low-density areas (Oke 2006).

The height $z_0 + z_d$ is the base of the wind profile development above the urban area (see Figure A1.17 and eqn. A1.16); $z_0$ is the roughness length (see Table 2.2 for order of magnitude) and $z_d$ is the zero-plane displacement height, whose value is roughly equal to 2/3 mean height of the buildings (Erell 2011).

The wind speed Vz at the height z can be estimated with (Erell 2011):

$$V_z = \frac{V_*}{k} \ln\left[\frac{z - z_d}{z_0}\right] \qquad \text{eqn. A1.16}$$

where:

$V_* = \sqrt{\frac{\tau}{\rho}}$ is the friction velocity (ρ is the air density and τ is the shear stress)

k is the von Karman constant, approximately = 0.4

The value of the friction velocity can be determined by means of wind speed measurements.

### 2.3.3 CLIMATIC SCALES

According to Oke (Oke 2006), the layers identify two climatic scales (Figure A1.18):

*Local scale* – This includes landscape features such as topography and type of urban development (surface cover, size and spacing of buildings, activity, etc.) but excludes microscale effects. Typical scales are one to several kilometres. This local scale corresponds to the "Local Climate" previously defined for a natural environment.

FIGURE A1.17 **WIND SPEED PROFILE, URBAN CANOPY LAYER AND ROUGHNESS SUBLAYER. $V_C$: WIND SPEED AT THE TOP OF THE CANOPY LAYER; $V_S$: WIND SPEED AT THE TOP OF ROUGHNESS SUBLAYER**

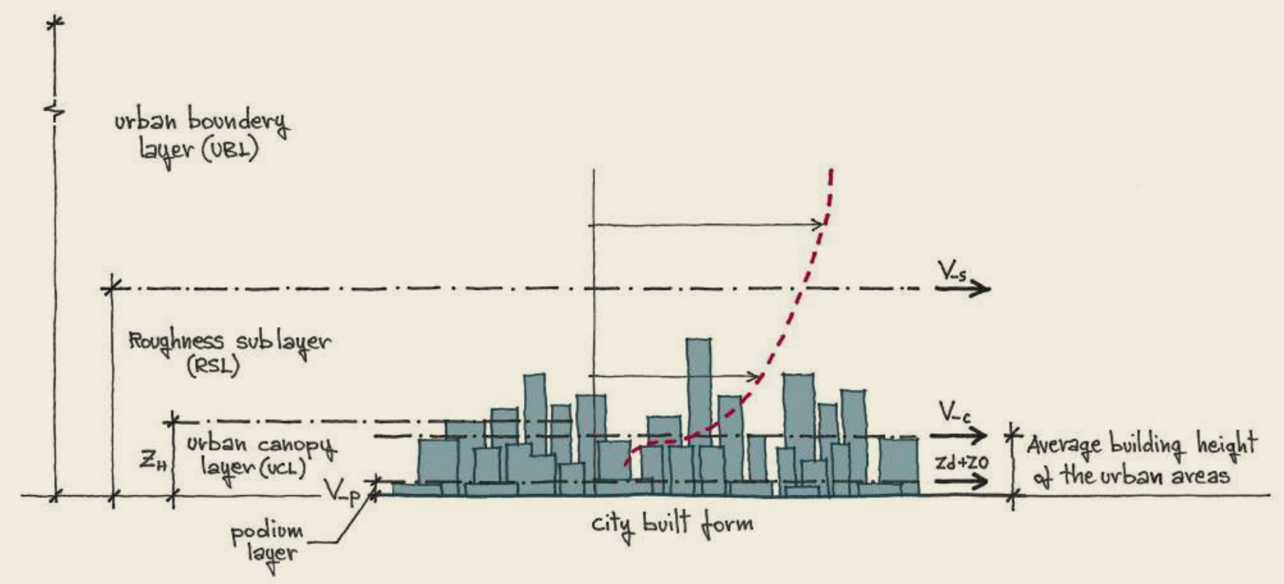
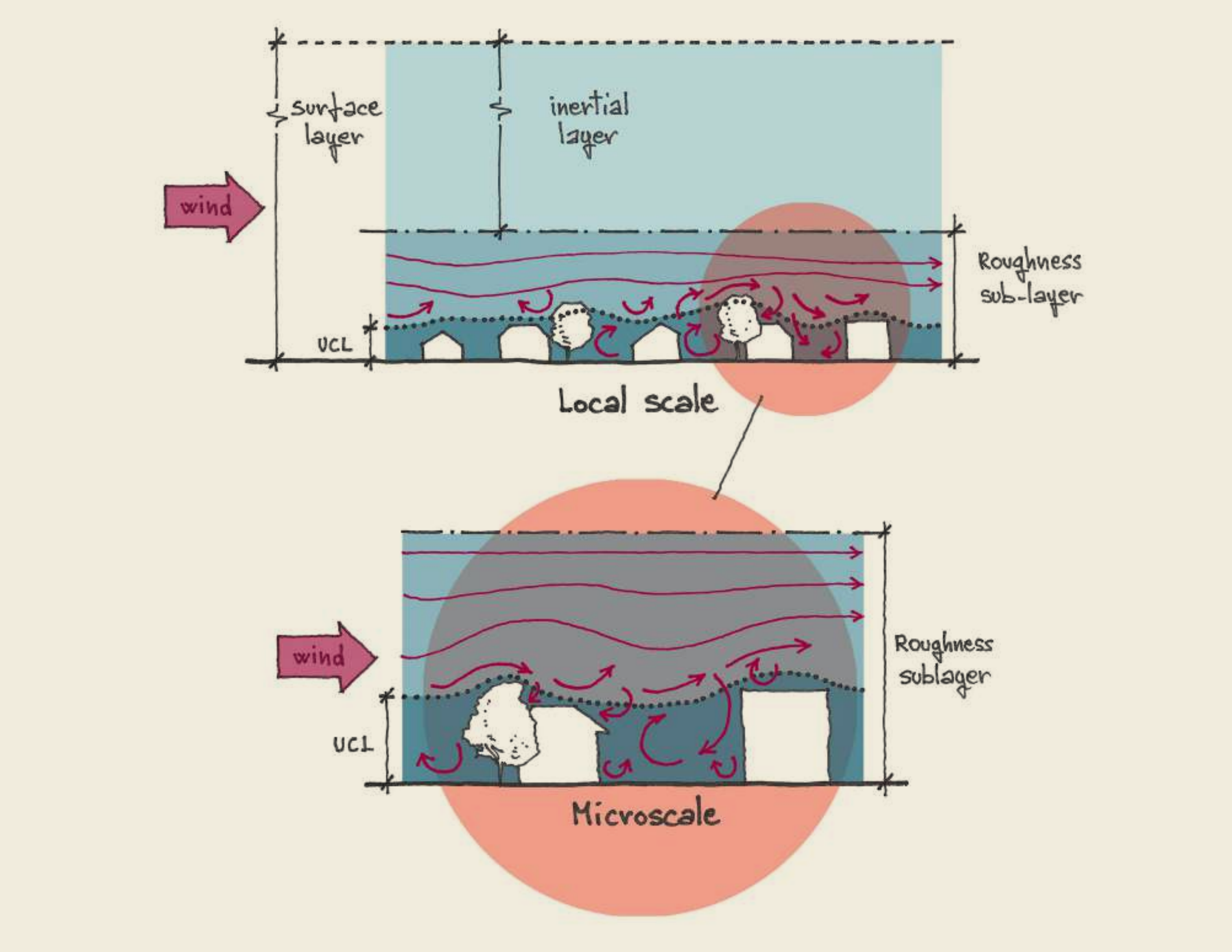


TABLE A1.2 **TYPICAL VALUES OF $Z_0$ FOR SOME URBAN SURFACE FORMS (ERELL 2011)**

| Urban surface form | H (m) | z0 (m) |
|---|---|---|
| Low height and density | 5-8 | 0.3-0.7 |
| Medium height and density | 7-11 | 0.4-1.4 |
| Tall and high density | 11-18 | 1.0-2.2 |
| High-rise | > 18 | > 2.0 |

FIGURE A1.18 **SCHEMATIC OF CLIMATIC SCALES AND VERTICAL LAYERS FOUND IN URBAN AREAS. UCL, URBAN CANOPY LAYER.**



*Microscale* – Every surface and object has its own microclimate on it and in its immediate vicinity. Typical scales of urban microclimates relate to the dimensions of individual buildings, trees, roads, streets, courtyards, gardens, etc. Typical scales extend from less than one metre to hundreds of metres.

## 3. URBAN CANYON

An urban canyon is defined as a three-dimensional space bounded by a street and the buildings that abut the street (Emmanuel 2005). It is a repetitive element characterising the urban geometry. Urban canyons cause multiple reflection and absorption of solar radiation reducing the albedo, restrict the view of the sky dome (characterized by the sky view factor SVF, see Figure A1.19) and generally constrain the free movement of air. The geometry of long urban canyons is usually specified by the height of building/width of street (H/W) ratio, or aspect ratio.

The canyon can also be seen as an air volume (Figure A1.20) with three sides being active surfaces (walls and floor), and three open sides (the two ends of the canyon and the top, imagined as a sort of "lid"). This approach allows the interactions between buildings, between buildings and the street, and between air and buildings to be taken into account, recognizing the three-dimensional nature of the urban canopy. For example, in an urban development with a grid-like street pattern there are two canyon orientations offset by 90°, each characterized by its own microclimate, because of the different solar incidence angles and the different wind flow incidence angle. These differences must be added to those due to the differences in their construction materials and canyon geometry.

FIGURE A1.19 **SKY VIEW FACTOR AND ASPECT RATIO (ADAPTED FROM: EMMANUEL 2005)**

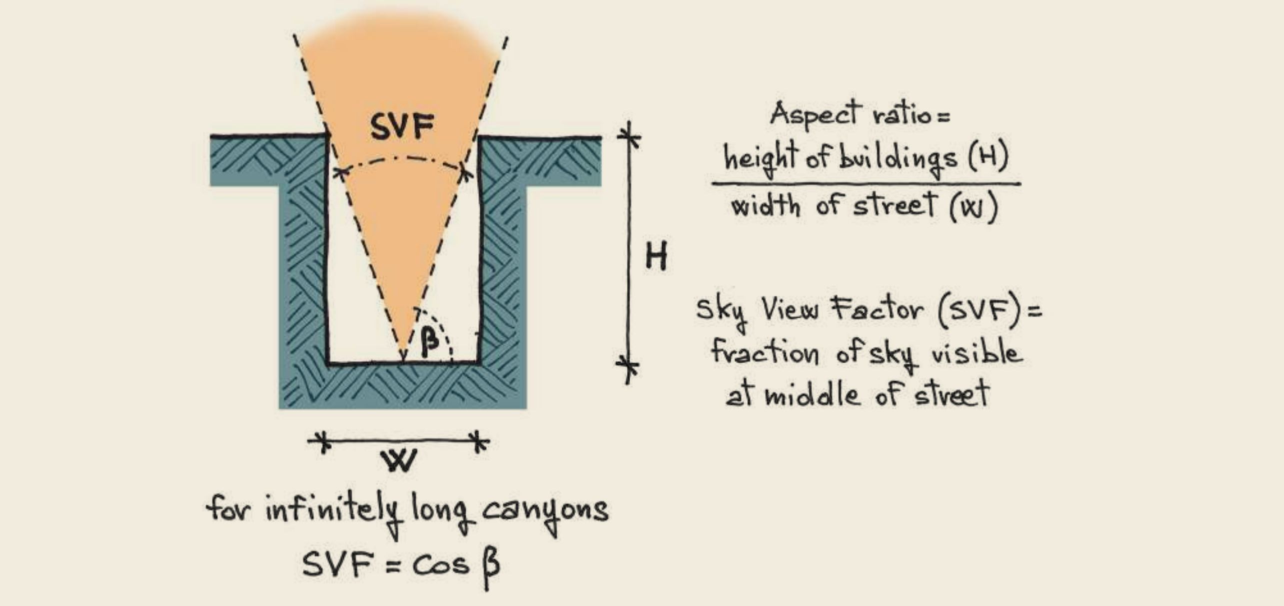
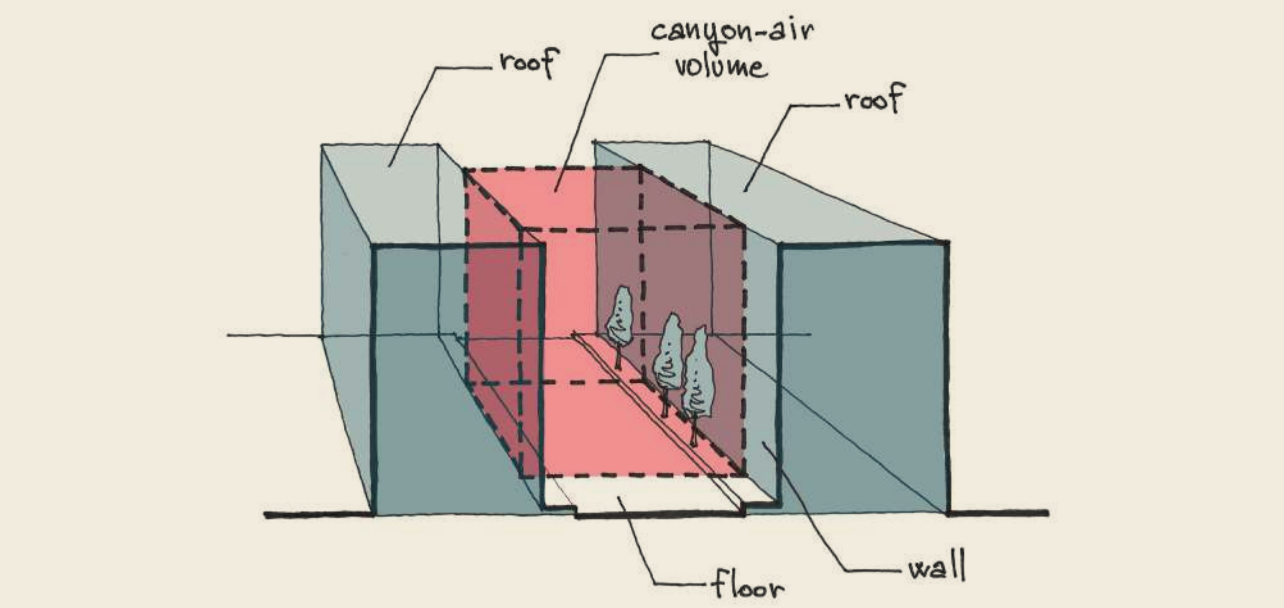


FIGURE A1.20 **SCHEMATIC CROSS-SECTION OF THE URBAN/ATMOSPHERE INTERFACE INCLUDING AN URBAN CANYON AND ITS CONTAINED CANYON-AIR VOLUME (ADAPTED FROM: OKE 1978)**



## 3.1 ENERGY AND WATER BALANCE OF THE URBAN CANOPY LAYER

The energy balance of a building-air volume such as that illustrated in Figure A1.21 is given by:

$$Q + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A \qquad \text{eqn. A1.17}$$

Where:

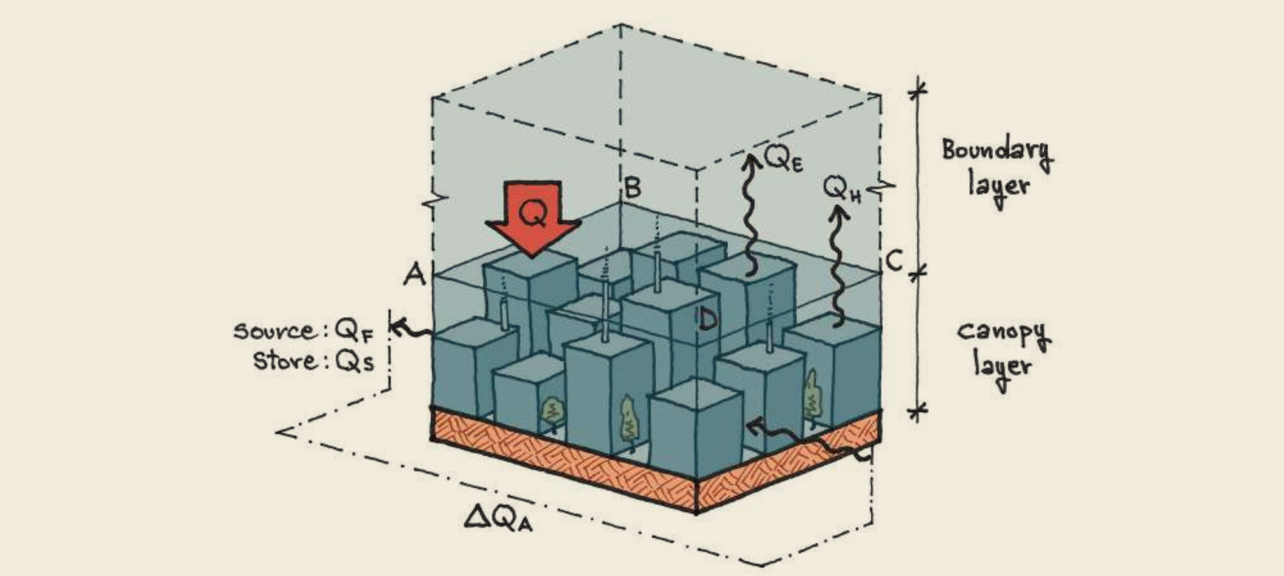
Q is the net all-wave radiation of the volume, which depends on the amount of solar radiation incident on the surfaces of the volume (thus is critical in tropical climates), on the albedo of the canopy layer (i.e. the urban texture), and on the emissivity of the materials. Q is the most important single component of the energy balance;

$Q_F$ is the total internal anthropogenic heat release, whose main constituent, in a tropical urban context, is the heat released by motorised traffic, to which must be added the heat for cooking and – in mid-to-high income and in commercial areas – the heat released by the air conditioning systems and by electric and electronic devices;

$Q_H$ and $Q_E$ are the convective and latent heat exchanges with the external air;

$\Delta Q_S$ is the heat storage changes in the ground, the buildings and the air;

FIGURE A1.21 **SCHEMATIC DEPICTION OF THE FLUXES INVOLVED IN THE ENERGY BALANCE OF AN URBAN BUILDING-AIR VOLUME (ADAPTED FROM: OKE 1978).**



$\Delta Q_A$ the net horizontal exchange of sensible and latent heat.

There are three possible conditions:

1. $Q + Q_F$ exceeds $Q_H + Q_E + \Delta Q_A$ – there is a net energy storage gain ($+\Delta Q_S$) in the volume and a warming of the volume: air temperature increases, as does the temperature of the masses contained in the volume (ground and buildings).
2. $Q + Q_F$ is less than $Q_H + Q_E + \Delta Q_A$ – the volume loses energy, thereby depleting its energy store ($-\Delta Q_S$). This situation will result in a cooling of the volume.
3. $Q + Q_F = Q_H + Q_E + \Delta Q_A$ – there is no net exchange in the energy status of the volume ($\Delta Q_S = 0$), or its temperature.

All of these conditions occur during the course of a day: the first in daytime, the second at night, the third at the transition day-night and vice versa (see also Box A1.3).

The unbalance of condition 1 should be minimised as much as possible by means of appropriate neighbourhood design, to avoid the high air and surface temperatures that determine high thermal discomfort, outdoors and indoors, which induces or increases the need for mechanical cooling. It should be noted that air conditioning units release heat into the volume, increasing the amount of anthropogenic heat $Q_F$, and thus the air temperature: a vicious circle.

In order to mitigate condition 1, the unbalance should be tackled on both sides of eqn. A1.17, i.e.:

- by reducing the net radiant energy Q absorbed by the volume, manipulating the albedo through the geometry of the buildings and the canyons and the characteristics of the construction materials
- by reducing the anthropogenic heat release with appropriate building design and measures that reduce the need for motorised traffic
- by increasing the convective losses $Q_H$, i.e. favouring air movements by exploiting prevailing winds and creating microclimates in which air motion is induced by local temperature differences
- by increasing latent heat exchange, i.e. favouring evapotranspiration and evaporation with appropriate use of vegetation and water bodies.

It is worth highlighting the contradictory role of $\Delta Q_S$, the heat storage changes, in the buildings in condition 1. If the buildings are massive, $\Delta Q_S$ can be high, which means that the air temperature increase during the day is limited, but at night the release of the large amount of energy stored will keep the air temperature quite high. If, on the other hand, the buildings are lightweight, $\Delta Q_S$ is small and air temperature during the day will rise more, but at night it will drop, because of the small amount of heat released by the buildings. The best strategy to implement in neighbourhood design depends on the climatic zone, i.e. on the characteristics of the meso-climate. For example, high $\Delta Q_S$ (massive buildings) may be a good strategy in a hot arid climate, while small $\Delta Q_S$ (lightweight buildings) may be a good strategy for a hot humid climate.

The water balance (Figure A1.22) is given by:

$$p + F + I = E + \Delta r + \Delta_S + \Delta_A \qquad \text{eqn. A1.18}$$

where:

*p* is the annual amount of precipitation

*F* is the water released to the atmosphere as water vapour, by combustion due to motorised traffic only, in a tropical urban context;

$I$ is the urban water supply piped in from rivers or reservoirs or by tankers;

$E$ is the evapotranspiration

$\Delta r$ is the net run-off (water streams entering or leaving the surface)

$\Delta s$ is the water storage changes in the ground, the buildings and the air;

$\Delta A$ is the net moisture advection to/from the urban settlement-air volume (water droplets and water vapour).

This balance applies to volumes that extend to sufficient depths for the vertical heat and water exchange to be negligible.

Usually, when a rural area is urbanized, significant changes take place in the water balance.

The water input is increased by the contribution of $F$ and $I$, and $p$ is also altered because of the urban heat island, air pollution and the changed amount of moisture in the air.

$E$ is reduced because of the removal of vegetation.

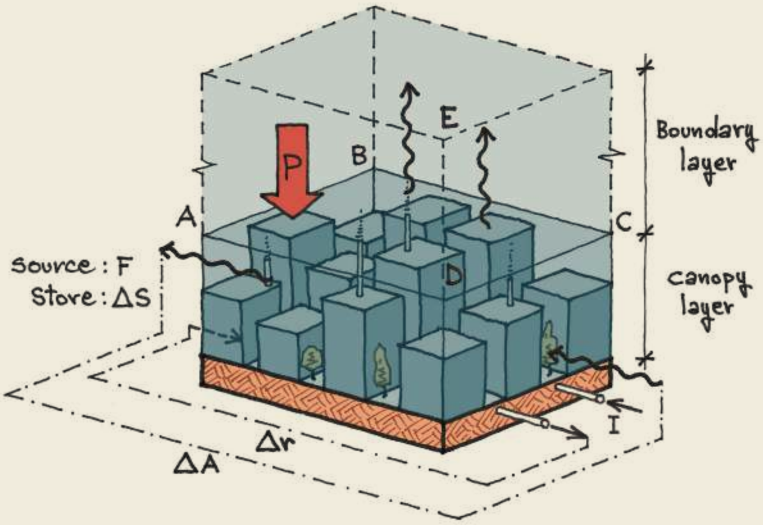
$\Delta r$ is increased because of the larger amount of impervious surfaces (buildings and streets) and, for the same reason, $\Delta s$ is reduced (less water percolating in the sub-soil).

In order to restore the original water balance, which is far more sustainable than the urban one, some mitigation actions are the same as for the energy balance: reduce the amount of fossil fuel combustion (i.e. reduce traffic), which produces water vapour, and increase evapotranspiration by means of an increase of urban greening.

Specific to the water cycle, however, are measures that aim to reduce runoff and increase underground water storage, both of which are linked to a reduction in the extent of impervious surfaces. Harvesting rainwater for urban use can also contribute to the reduction of runoff.

Furthermore, because of the evaporation process, which transforms sensible into latent heat without changing the temperature, the availability of moisture affects the amount of radiant energy transformed into sensible heat, which causes the air temperature to rise. Thus water (precipitation, water bodies, fountains) and vegetation, and the potential for evaporative cooling they embody, have a major effect on air temperature near the surface.

FIGURE A1.22 **SCHEMATIC DEPICTION OF THE FLUXES INVOLVED IN THE WATER BALANCE OF AN URBAN BUILDING-AIR VOLUME (ADAPTED FROM: OKE 1978).**



## 3.2 IMPACT OF URBAN GEOMETRY ON ALBEDO

Several studies have been carried out to assess the effect of urban geometry upon albedo. The main results were summarised by Erell et al. (Erell 2011) reported as below:

- In dense areas, a large proportion of incoming solar radiation is reflected at roof level, and the effect of multiple reflections in the urban canyon is proportionately smaller; urban albedo is high. Urban albedo is also high in very low-density urban forms, because reflections from road surfaces are not intercepted by adjacent wall surfaces. Maximum absorption (or lowest albedo) occurs in medium-density configurations.
- For a given street width, taller buildings create deeper urban canyons; this tends to increase the mutual reflection and absorption of radiation among building facets, and thus reduces albedo (see Figure A1.23).
- Numerical modelling has shown: i) the albedo of relatively deep canyons (H/W>1) is less than about 0.2 for typical construction materials such as masonry; ii) increasing the window-to-wall ratio results in a lower canyon albedo, for a wide range of sun angles.
- When the roof surfaces of buildings in a city block are all at the same height, there is less likelihood that reflections off any roof surface will be intercepted by another building. Uniform building heights will therefore result in higher albedo, while buildings of varying heights will create a rougher (and less reflective) overall surface, absorbing more of the incoming solar radiation.
- While the reflectivity of most natural surfaces is almost independent of incidence angle (except for very acute solar zenith angles), the albedo of an urban area changes substantially with solar position. This is because the albedo of a city is not simply the area-weighted average of the albedo of individual surfaces, but is affected by the geometric relationship between surfaces such as walls, roofs and the ground. As a general rule, the albedo of an urban area increases with angle of incidence.

## 3.3 IMPACT OF URBAN GEOMETRY ON AIR MOVEMENTS

As in the case of naturally non-uniform terrain, when wind encounters a man-made obstacle its pattern is altered. Figure A1.24 shows the mean streamlines [38]as

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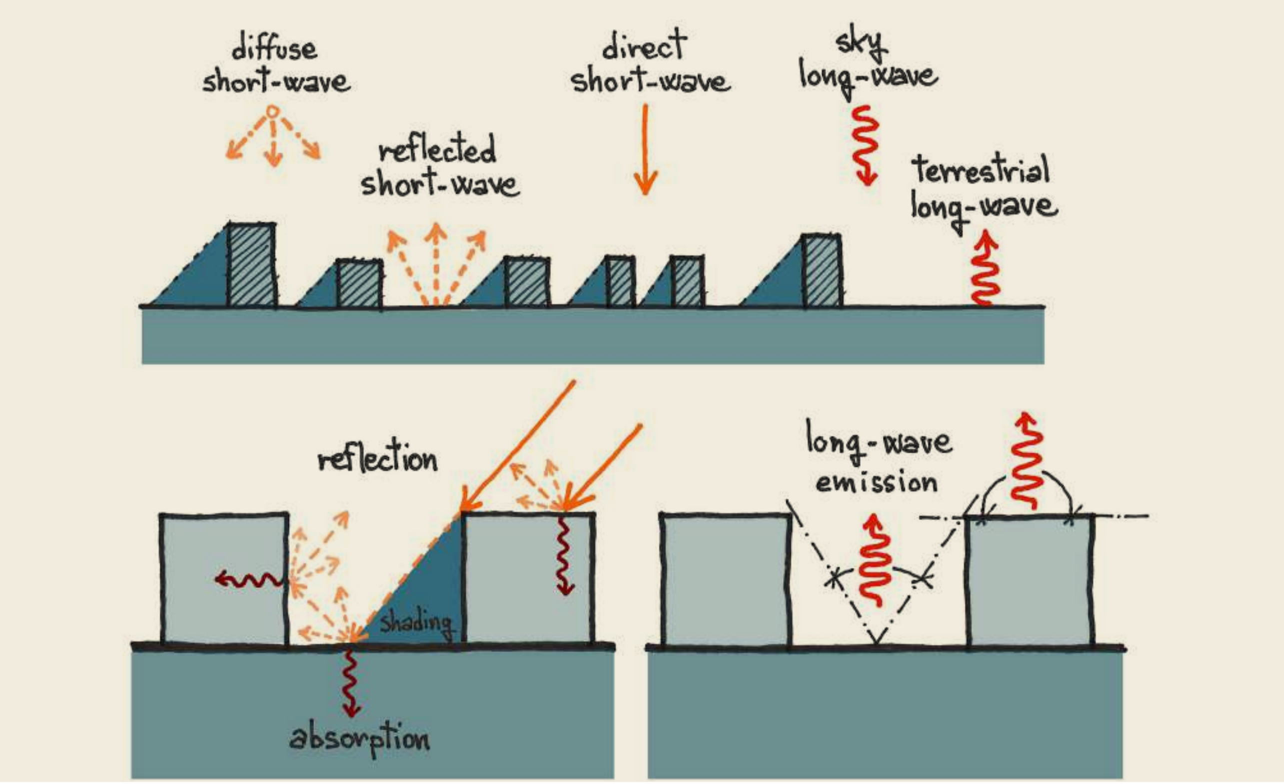
[38] The streamlines are the lines that are parallel to the direction of flow at all points and therefore indicate the flow at a given time.

FIGURE A1.23 **GENERIC EFFECTS OF URBAN SURFACE GEOMETRY ON THE PENETRATION, ABSORPTION AND REFLECTION OF SOLAR RADIATION, AND ON THE EMISSION OF LONG-WAVE RADIATION (ADAPTED FROM: ERELL 2011)**



airflow encounters a solid barrier placed normal to its original direction.

The air flow is modified even before the obstacle is reached. After the barrier the flow's organisation breaks down into a turbulent condition in the low pressure or wake zone which extends downwind from the barrier. Immediately behind the barrier the pressure is low and a vortex is formed. This part of the wake is known as the cavity zone. The large eddy structure is dissipated into smaller turbulent eddies of the wake zone, before finally settling down and reassuming conditions similar to those of the upwind flow.

If the barrier is not solid, the effect of barrier density upon the distance of downwind shelter is illustrated in Figure A1.25 from measurements at height of ≈ 0,25 h in the vicinity of shelterbelts.

An isolated flat-roofed building placed normal to the wind gives rise to effects very similar to those described above for the solid barrier (Figure A1.24), as shown in Figure A1.26.

If, instead of being isolated, the building is part of an urban area with buildings of similar size upwind and downwind, then the flow may be as in Figure A1.27: with winds normal to the buildings a vortex-flow develops between them.

If the buildings are oriented at an angle to the wind, the vortex takes on a 'cork-screw' motion with some along-street movement (Figure A1.28). If the flow is parallel to the buildings, shelter is destroyed and channelling of the wind may cause a jet-like effect so that speeds are greater than in the open.

The situation is different if the canyon is asymmetrical (i.e. the buildings on each side are of different heights), as in Figure A1.29, or if a particularly tall building is just above the general roof-level, as in Figure A1.30, right. In the latter case the oncoming wind impacts against the windward face of the tall building and produces a stagnation point in the centre at about three quarters of the building height, a strong vortex between the buildings and corner streams around the taller building.

Finally, as in the case of sea and lake breezes, local air movements can be triggered by temperature differences, as in the case of Figure A1.31, where – in absence of wind – air moves because one of the two walls of the canyon is hotter than the other, being heated by solar radiation.

FIGURE A1.24 **(A) STREAMLINES AND (B) GENERALISED ZONES ASSOCIATED WITH THE TYPICAL PATTERN OF AIRFLOW INDUCED BY A SOLID BARRIER PLACED NORMAL TO THE FLOW. DIMENSIONS EXPRESSED AS MULTIPLES OF THE BARRIER HEIGHT, H (ADAPTED FROM: OKE 1978).**

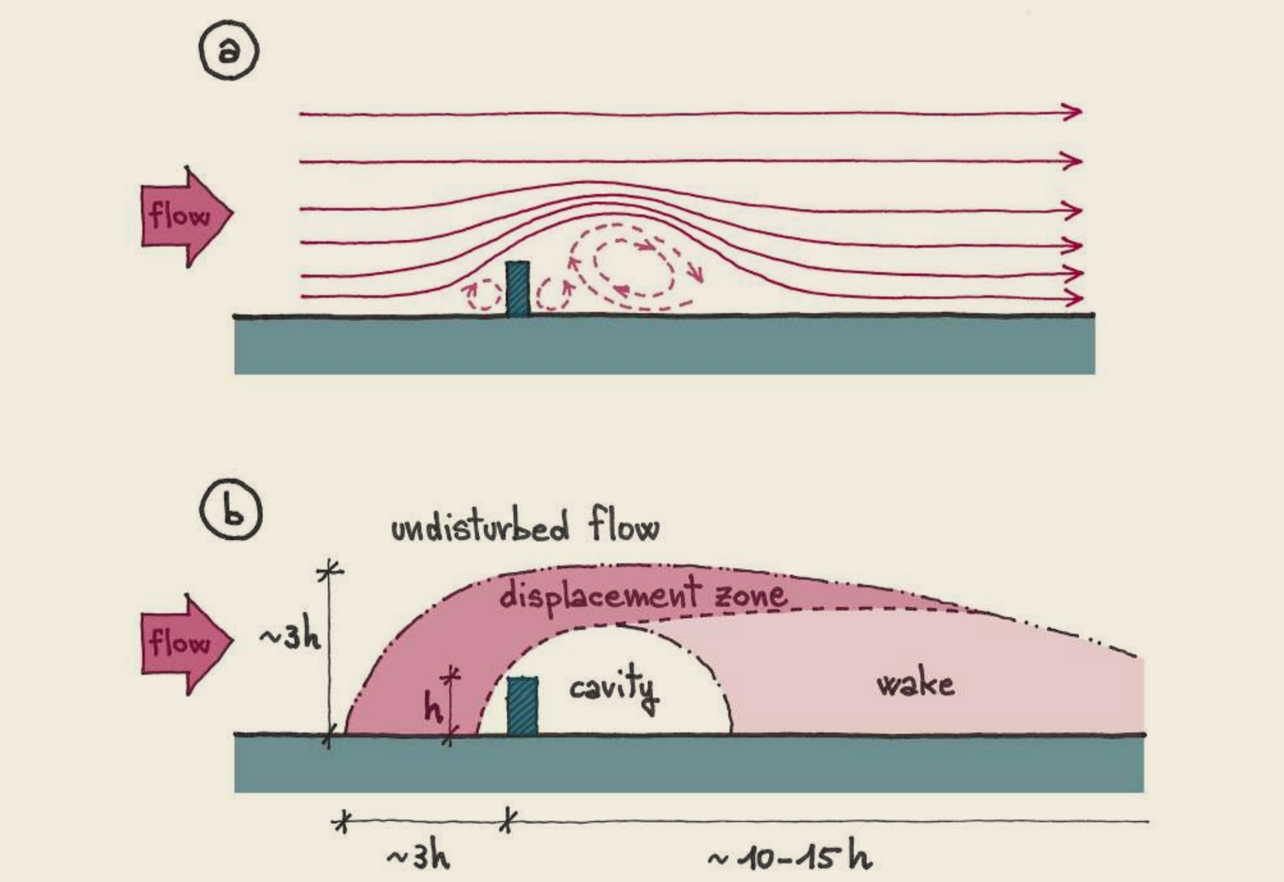


FIGURE A1.25 **WIND SPEED REDUCTION IN THE VICINITY OF SHELTERBELTS WITH DIFFERENT DENSITIES h (ADAPTED FROM: OKE 1978)**

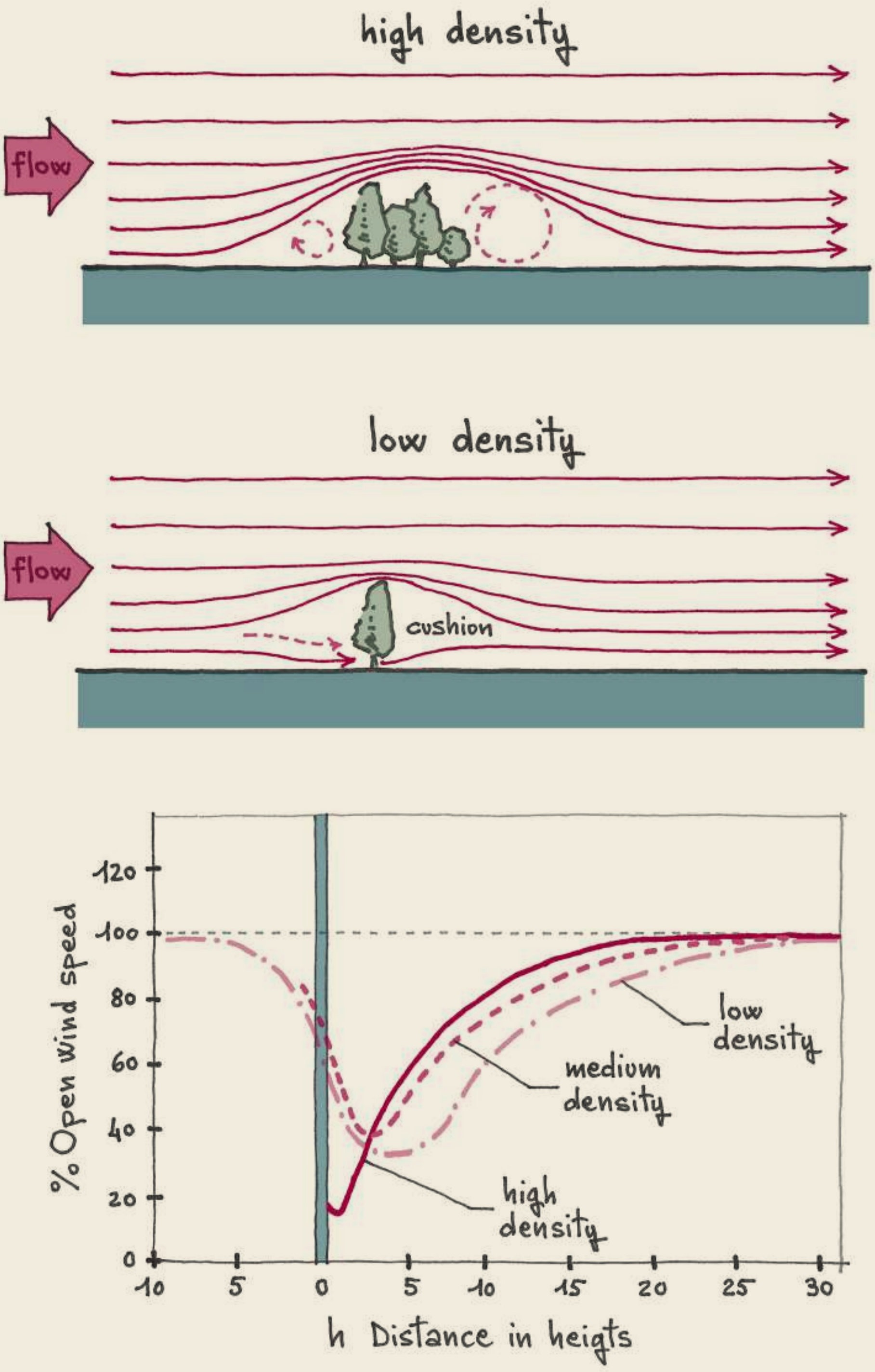


FIGURE A1.26 **(A) AIRFLOW IS DEFLECTED OVER THE TOP OF THE BUILDING AND A VORTEX IS FORMED DOWNWIND; (B) THE AIR 'PUSHING' AGAINST THE BUILDING TRANSFORMS KINETIC ENERGY INTO PRESSURE RISE OVER MUCH OF THE WINDWARD WALL, CREATING A STAGNATION AREA (WIND VELOCITY ≈ 0); WIND DIRECTION IS REVERSED IN THE CLOSE LEEWARD ZONE AND THE ORIGINAL WIND PROFILE IS PROGRESSIVELY RE-ESTABLISHED AT A GROWING DISTANCE FROM THE BUILDING. (C) AND (D) STREAMLINES SHOWING THE HORIZONTAL COMPONENTS OF THE AIRFLOW AROUND THE BUILDING h (ADAPTED FROM: OKE 1978).**

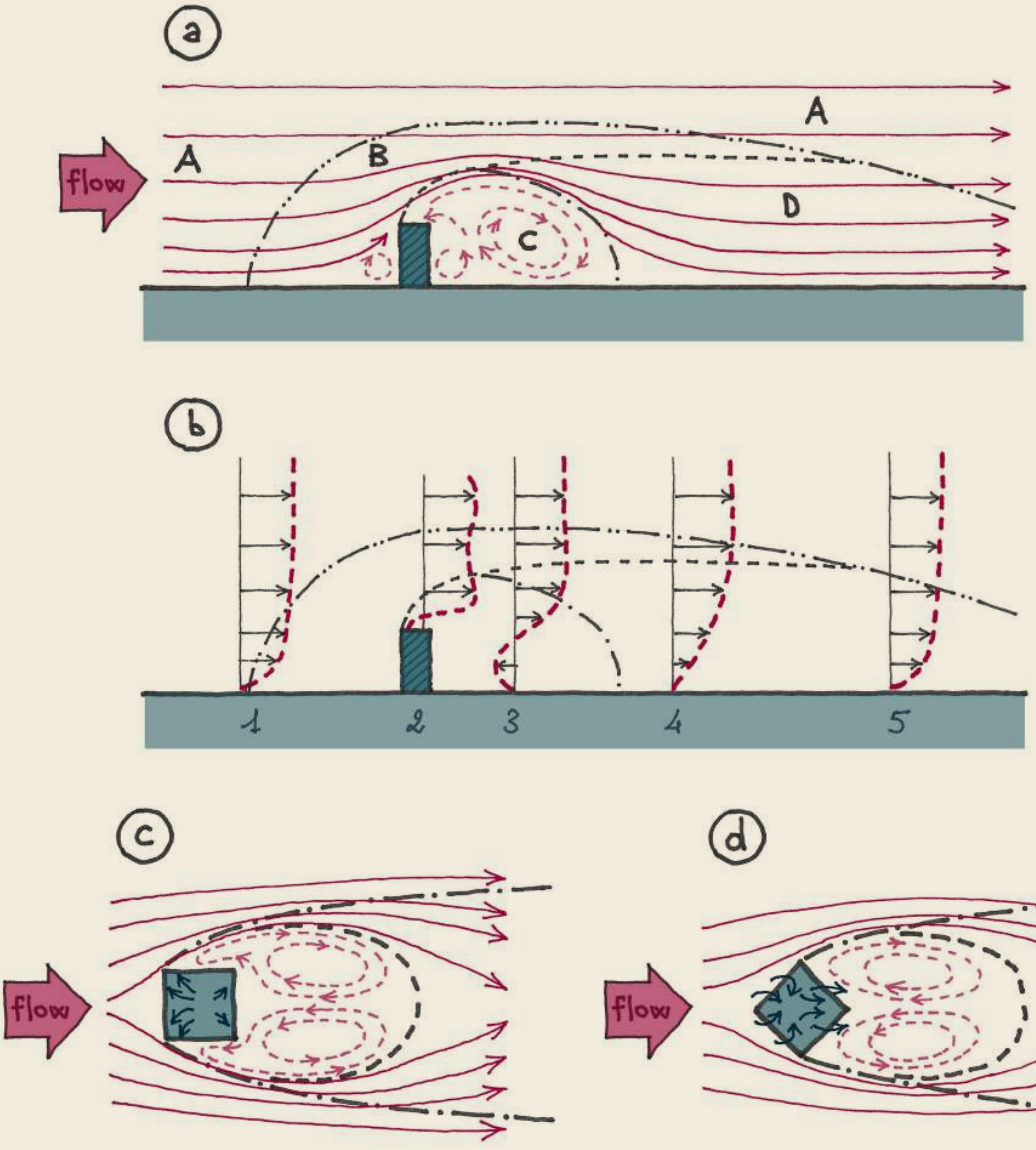


FIGURE A1.27 **FLOW REGIMES ASSOCIATED WITH DIFFERENT URBAN GEOMETRIES H (ADAPTED FROM: ERELL 2011).**

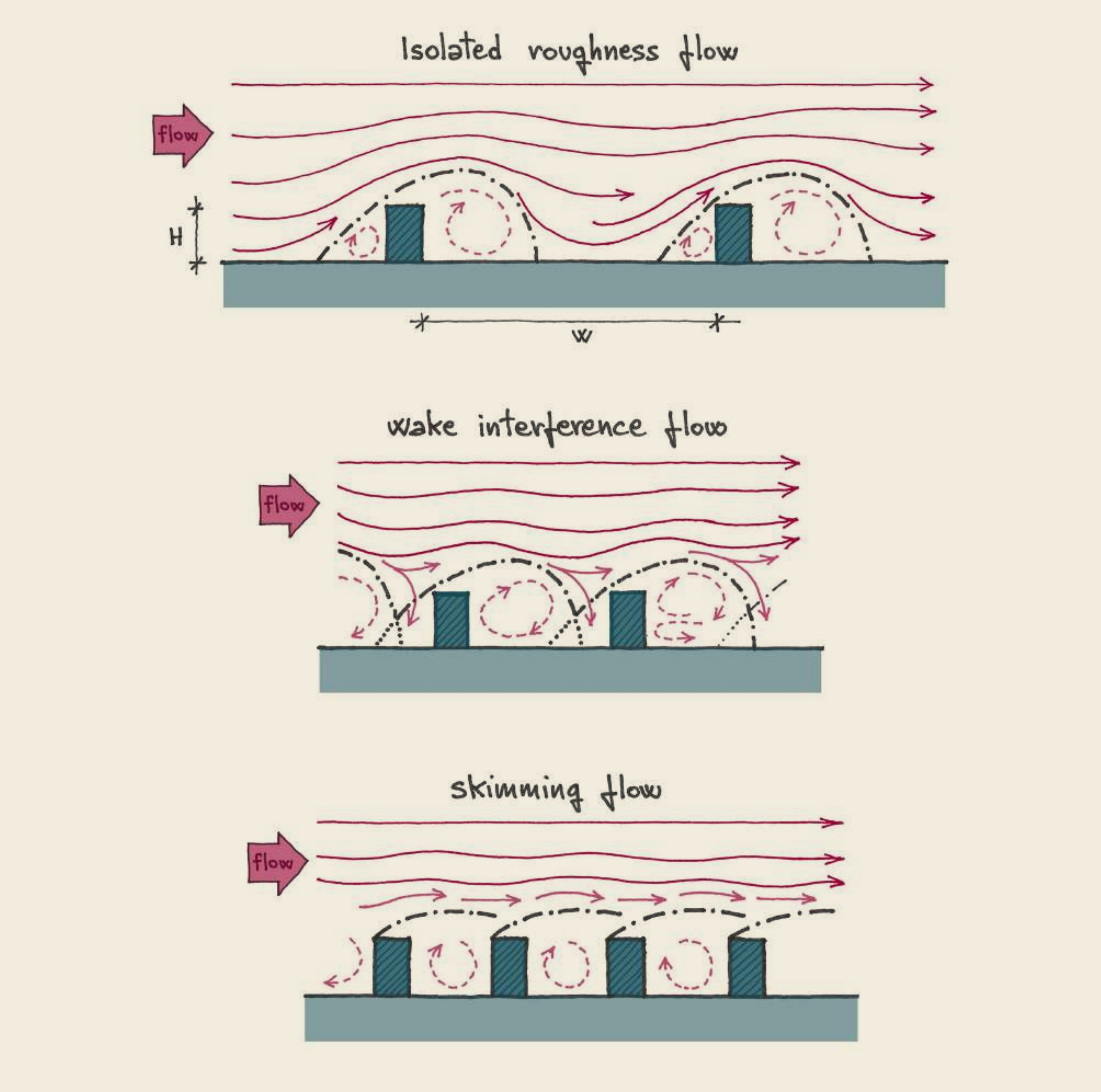


FIGURE A1.28 **FLOW PATTERNS IN THE URBAN CANYON, ACCORDING TO THE WIND DIRECTION AT ROOF HEIGHT: PARALLEL, PERPENDICULAR AND AT AN ANGLE WITH THE CANYON AXIS (ADAPTED FROM: PIJPERS-VAN ESCH 2015)**

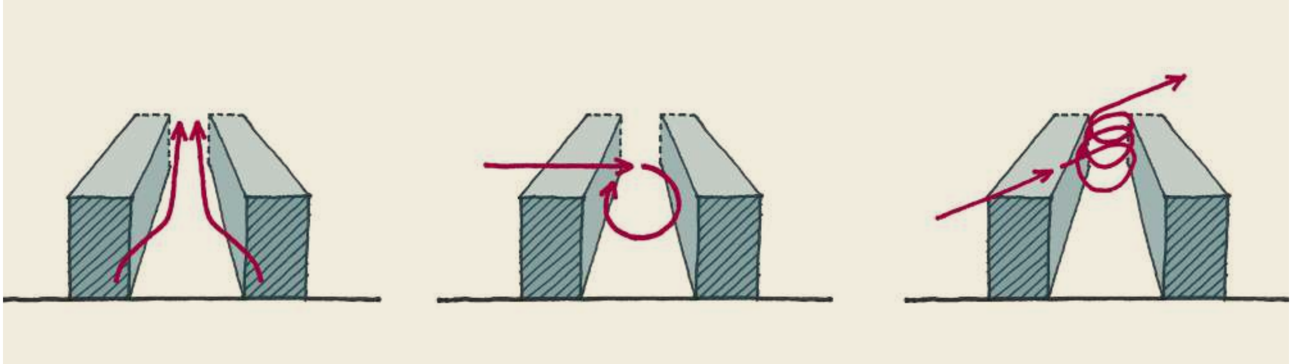


FIGURE A1.29 **SCHEMATIC OF VORTEX SHAPE IN ASYMMETRICAL AND SYMMETRICAL CANYONS. THE WIND DIRECTION IS PERPENDICULAR TO THE CANYON AXIS (ADAPTED FROM: PIJPERS-VAN ESCH 2015)**

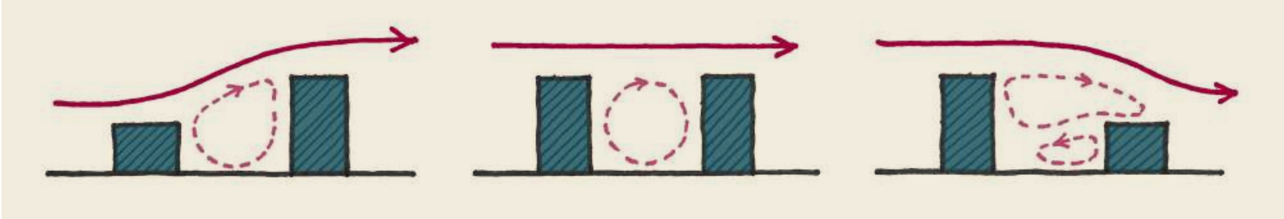


FIGURE A1.30 **FLOW PATTERNS OVER AND BETWEEN BUILDINGS APPROXIMATELY THE SAME HEIGHT (LEFT), AND IN THE VICINITY OF A, RELATIVELY, MUCH TALLER BUILDING (RIGHT) (ADAPTED FROM: OKE 1978).**

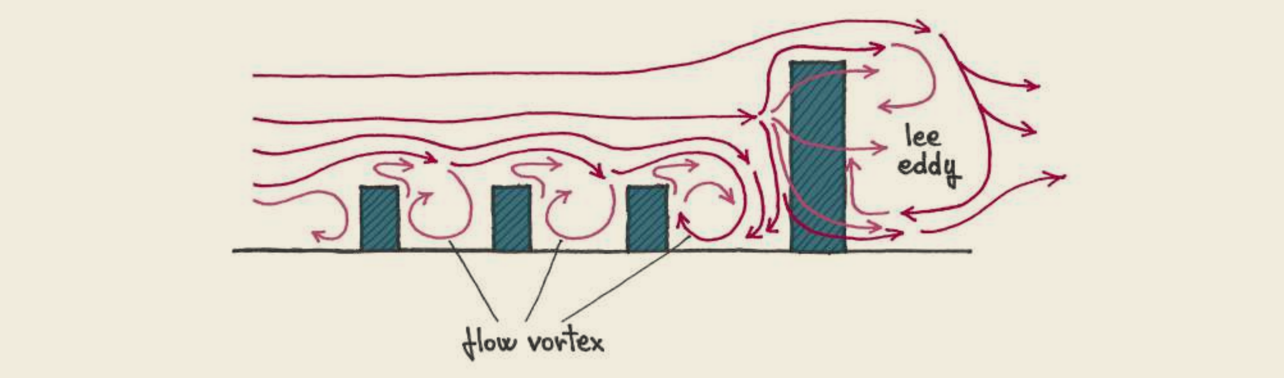
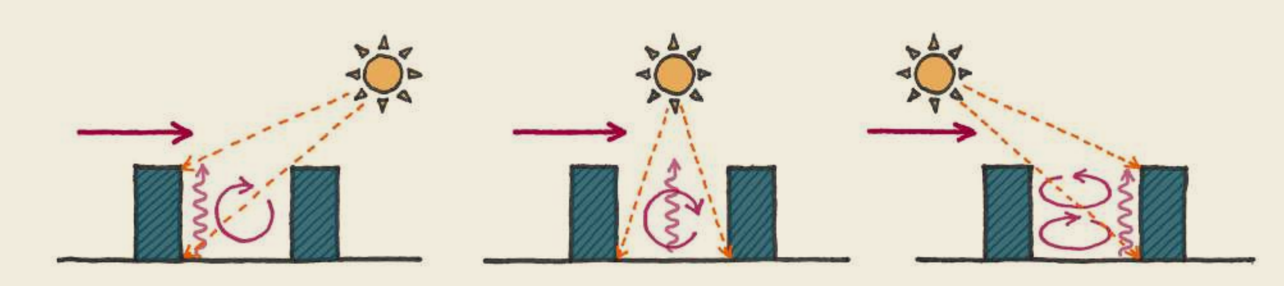


FIGURE A1.31 **INFLUENCE OF DIFFERENTIAL HEATING OF THE CANYON SURFACES ON THE OCCURRING FLOW PATTERN (ADAPTED FROM PIJPERS-VAN ESCH 2015**



## REFERENCES

Emmanuel, M. R., (2005), An Urban Approach to Climate-Sensitive Design - Strategies for the Tropics, Taylor & Francis, 2005

EPA (2008), Reducing Urban Heat Islands: Compendium of Strategies – Urban Heat Island basics, http://www2.epa.gov/heat-islands/heat-island-compendium

Erell, E., Pearlmutter, D., Williamson T., (2011) Urban Microclimate, Earthscan, New York,

Likso, T., (2014) Estimation of wind speed in the suburban atmospheric surface layer - http://www.slideshare.net/tanjalikso/iamg2014-likso

Oke, T. R. (2006), Initial Guidance to Obtain Representative Meteorological Observations at Urban Sites, WMO/TD - No. 1250 - https://www.wmo.int/pages/prog/www/IMOP/publications/IOM-81/IOM-81-UrbanMetObs.pdf

Oke, T.R., (1978) Boundary Layer Climates, Methuen & Co, London

Pijpers-van Esch, M., (2015) Designing the Urban Microclimate, Delft University of Technology, Faculty of Architecture and the Built Environment - http://journals.library.tudelft.nl/index.php/faculty-architecture/article/view/pijpers/pdf_pijpersvanesch

UN-Habitat (2014), Sustainable Building Design for Tropical Climates - http://unhabitat.org/books/sustainable-building-design-for-tropical-climates/

# A2

# PRINCIPLES OF OUTDOOR THERMAL COMFORT

## 1. COMPONENTS OF THE ENERGY BALANCE FOR OUTDOOR COMFORT

It is a common belief that air temperature and humidity are the only determinants of thermal sensation, but this is not the case, especially in the outdoor environment. Other factors are also important and, in order to be aware of the environmental conditions that need to be kept under control in order to manipulate outdoor thermal sensation, it is important to recall the main principles governing human thermal comfort.

A person's perception of thermal comfort in an environment is influenced by six basic parameters (Figure A2.1): physical activity (i.e. metabolic heat released), insulation provided by clothing, air temperature and humidity, relative air velocity and mean radiant temperature, deriving from the temperatures of the surfaces/objects surrounding the subject (sun, sky, walls, ceilings, floors, windows, etc.);the amount of time spent in that environment and the average seasonal temperature are also influential[39].

To better understand how to control thermal comfort, it must be recalled that the main (but not the only) condition on which comfort is based is the body's energy balance, i.e. the balance between the amount of heat produced by the body, as consequence of its basic metabolism and its activity, and the amount of heat released into the environment (Figure A2.2).

In a bare open space (Figure A2.4) the energy balance that must be satisfied in order to reach a condition of comfort[40] is given by:

$$(M + S_b\downarrow + S_d\downarrow + \alpha_T S\downarrow + L\downarrow + LT\uparrow) - (L\uparrow + L_B \rightarrow + Q_{H,L}) = 0 \quad \text{eqn. A2.1}$$

where:

$M$ = the amount of energy released into the environment by the body

$S_b\downarrow$ = direct solar radiation

$S_d\downarrow$ = diffuse solar radiation

$S\downarrow = S_b\downarrow + S_d\downarrow$ = total solar radiation

$\alpha_T$ = albedo of terrain

$L\downarrow$ = Long-wave radiation from the sky

$L_T\uparrow$ = Long-wave radiation from the terrain

$L\uparrow$ = Long-wave radiation emitted by the body towards the sky

$L_B\rightarrow$ = Long-wave radiation emitted by the body towards the terrain

$Q_{H,L}$ = convective and latent heat loss of the body

The first term in brackets in eqn. A2.1 represents all the energy gains, while the second term represents the energy losses.

---

[39] *For more information on thermal comfort, see UN- Habitat, SUSTAINABLE BUILDING DESIGN FOR TROPICAL CLIMATES - Principles and Applications for Eastern Africa, 2014 – Appendix 2 - http://unhabitat.org/books/sustainable-building-design-for-tropical-climates/*

[40] *The fact that the energy balance is fulfilled is a necessary but not sufficient condition for thermal comfort, according to the ISO Standard 7730. Other two conditions regarding the skin temperature and wettedness must be met. The fulfilment of the energy balance, however, is by far the most important condition, whose fulfilment provides if not full comfort, an acceptable one.*

FIGURE A2.1 **THE PARAMETERS DETERMINING THERMAL COMFORT (ADAPTED FROM: HSE 2016)**

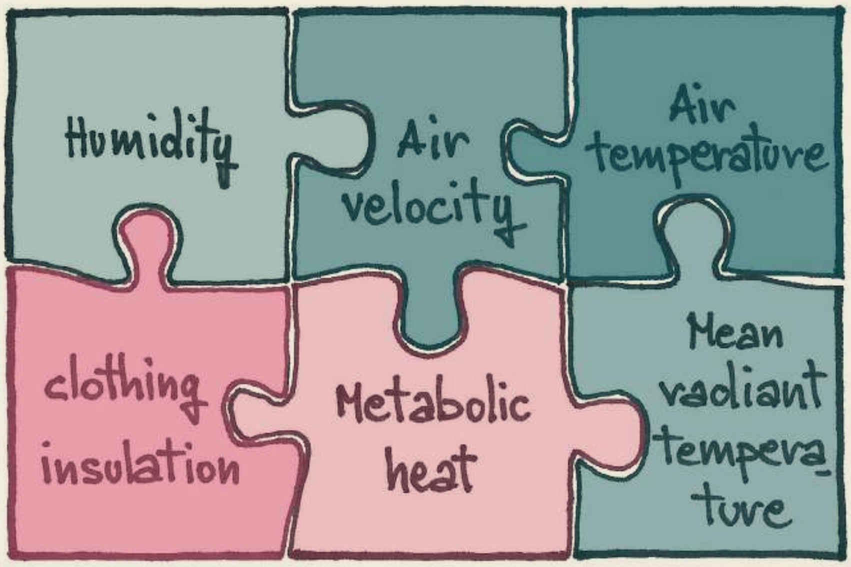
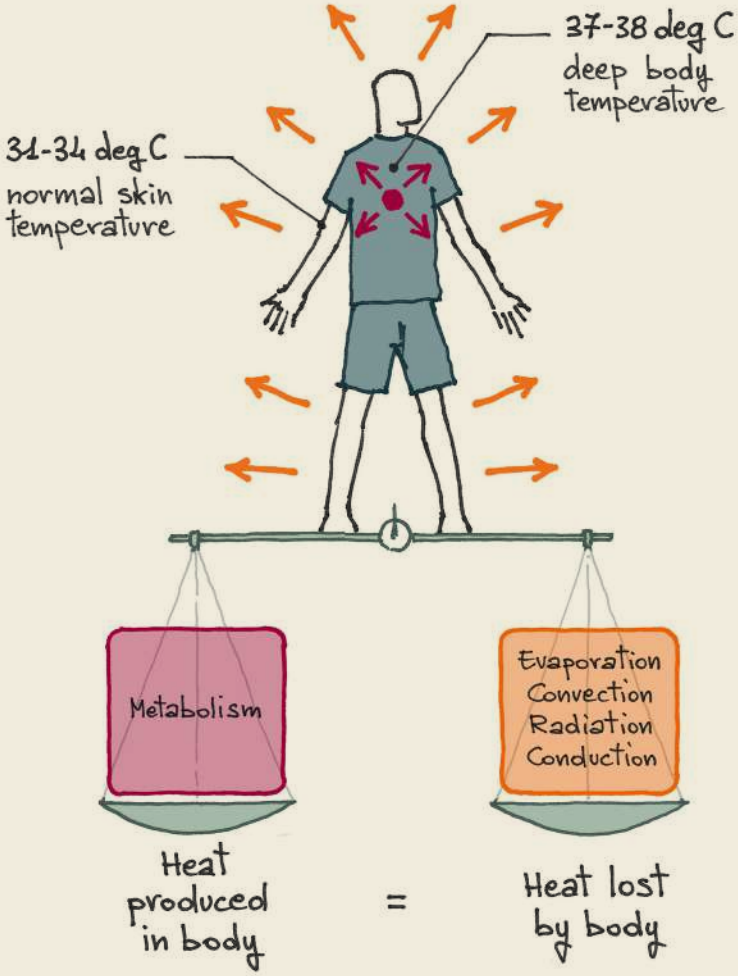


FIGURE A2.2 **THERMAL COMFORT CAN BE MAINTAINED WHEN THE HEAT PRODUCED BY METABOLISM EQUALS THE HEAT LOST FROM THE BODY**



## RELATIONSHIP BETWEEN OUTDOOR THERMAL COMFORT, THE ENERGY CONSUMPTION OF A BUILDING AND NEIGHBOURHOOD DESIGN

Thermal comfort is based on the energy balance between the heat produced and the heat released into the environment, with the aim of keeping the internal temperature of the body at a constant (36-38 °C). Similarly, in order to keep the internal temperature of a building constant (20 °C in the cold period, 26 °C in the hot) the heat produced and the heat released must be balanced.

Common to the human body and the building are the modes of heat exchange with the environment: conduction, convection and radiation (Figure A2.3).

The body has an advantage over a building, in that it is also capable of releasing heat by evaporation (from breath, transpiration and sweat). In a hot environment, when it is not possible for the body to release all the heat produced by means of conduction, convection and radiation, evaporation provides the necessary extra heat loss to achieve the heat balance. In a building, however, it is necessary to use mechanical cooling, with the consequent energy consumption – unless the climate is hot arid and evaporative cooling is used. In this case the building behaves like the human body.

An isolated building and a person outdoors in the same environment are subject to the same air temperature, humidity and velocity, and to the same radiation. Therefore, the higher heat stress of the body (i.e. higher unbalance between heat produced and heat released, which needs to be balanced with evaporation), corresponds to a higher unbalance in the building, which needs to be balanced with mechanical cooling.

Thus, the more uncomfortable the outdoor environment, the greater the amount of energy required to achieve comfort inside the building.

By creating a design appropriate for the neighbourhood, it is possible to control the outdoor environment and make it as comfortable as possible, achieving, at the same time, beneficial effects on the energy consumption of the buildings.

Outdoor comfort depends on the energy balance of the neighbourhood, which, in contrast to the buildings, can rely not only on the principles of conduction, convection and radiation, but also on evaporation (from vegetation, soil, water bodies…), in the same way as the human body.

FIGURE A2.3 **MODES OF HEAT EXCHANGE OF THE HUMAN BODY AND OF A BUILDING**

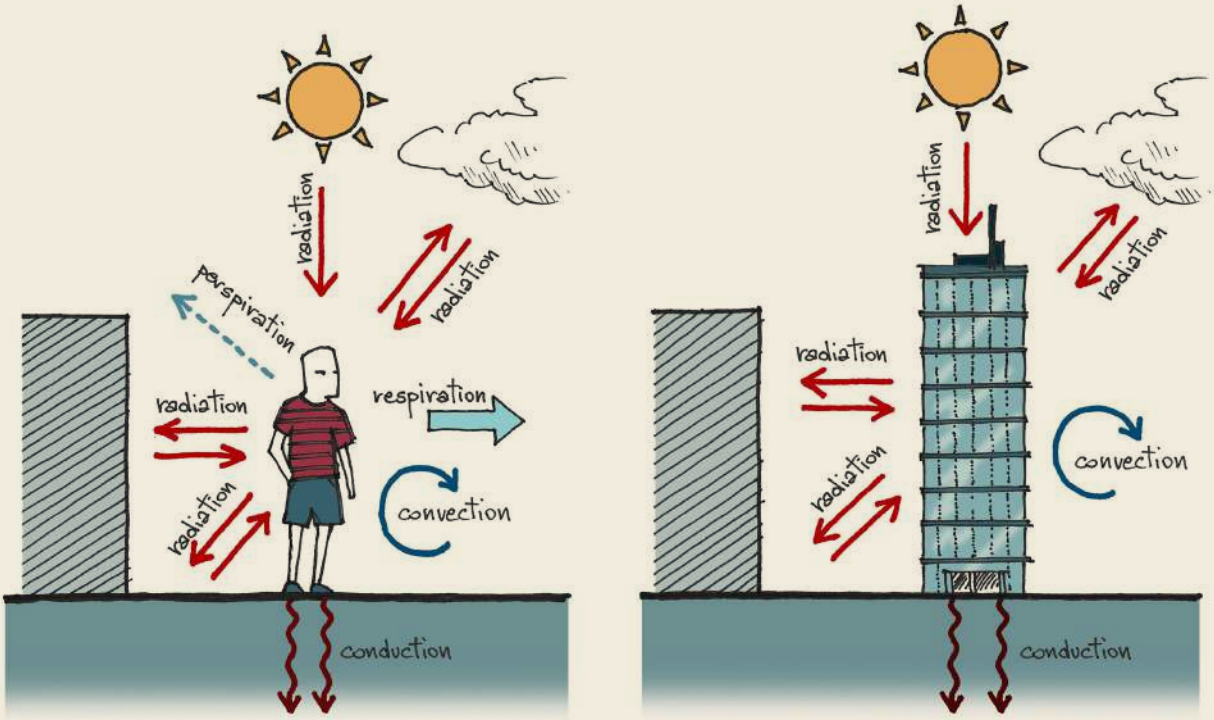
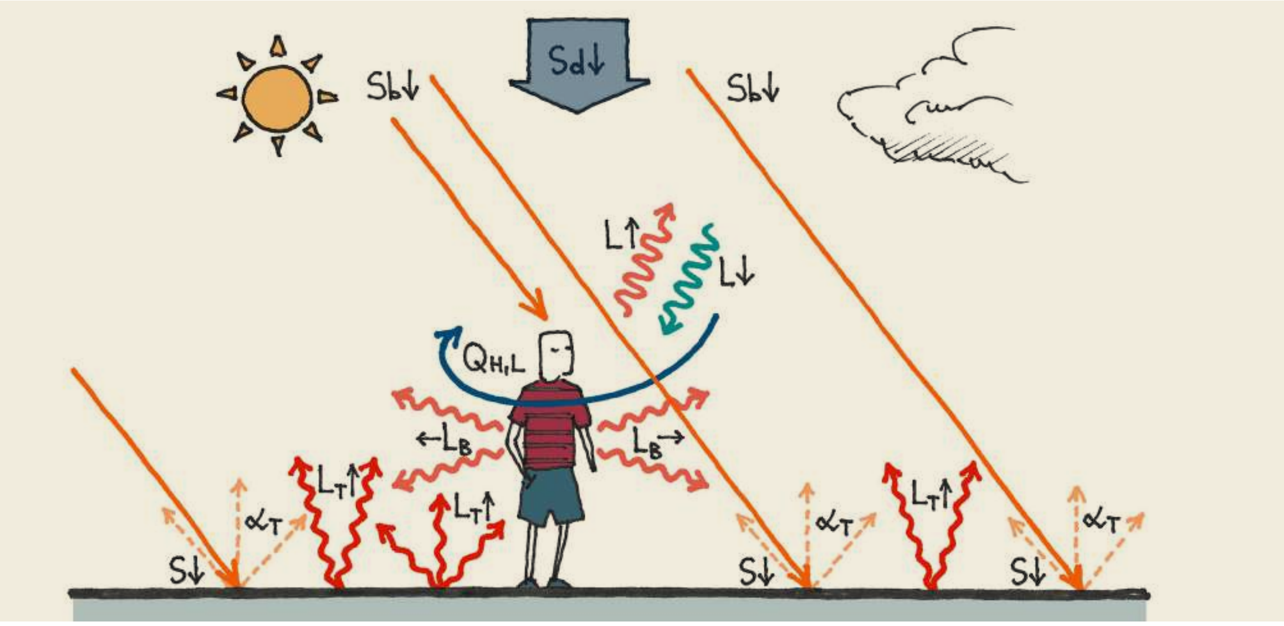


FIGURE A2.4 **THERMAL COMFORT ENERGY BALANCE IN A BARE OPEN SPACE**



In a landscaped space (Figure A2.5), constructions and trees have different albedo and temperature, thus eqn. A2.1 becomes:

$$(M + S_b{\downarrow} + S_d{\downarrow} + \alpha_H S{\downarrow} + \alpha_V S{\downarrow} + \alpha_T S{\downarrow} + L{\downarrow} + L_H{\rightarrow} + L_V{\rightarrow} + L_T{\uparrow}) - (L{\uparrow} + L_B{\rightarrow} + Q_{H,L}) = 0$$ eqn. A2.2

where:

$\alpha_H$ = albedo of constructions

$\alpha_V$ = albedo of trees

$L_H \rightarrow$ = Long-wave radiation from constructions

$L_V \rightarrow$ = Long-wave radiation from trees

$L_B \rightarrow$ = Long-wave radiation emitted by the body towards the terrain and the surrounding surfaces

In an urban canyon (Figure A2.6) eqn. A2.2 becomes:

$$(M + S_b{\downarrow} + S_d{\downarrow} + \alpha_W S{\downarrow} + \alpha_R S{\downarrow} + L{\downarrow} + L_W{\rightarrow} + L_R{\uparrow}) - (L{\uparrow} + L_B{\rightarrow} + Q_{H,L}) = 0$$ eqn. A2.3

where:

$\alpha_W$ = albedo of wall surface

$\alpha_R$ = albedo of road surface

$L_W \rightarrow$ = Long-wave radiation from wall surface

$L_R\uparrow$ = Long-wave radiation from road surface

Some significant considerations can be derived from equations A2.1, A2.2 and A2.3 and from the corresponding Figures A2.4, A2.6 and A2.6:

1. Discomfort in the tropics is closely related to the radiation regime. Being in shade, i.e. avoiding direct solar radiation is a prerequisite for comfort (on a sunny day the main component is $S_b\downarrow$).
2. In an open space the presence of trees is crucial for thermal comfort not only because they provide shade, but also because of the low value of $L_V \rightarrow$, due to the fact that leaves do not warm up, as a consequence of their evapotranspiration. On the other hand, control of the albedo $\alpha_T$ and $\alpha_H$ of terrain and constructed surfaces is critical.
3. The comfort provided by a tree is far superior to that provided by a roof or a canopy, because the latter, hit by the sun, warms up more than the leaves, thus radiating more towards a subject below it.
4. Open spaces covered with grass or any kind of vegetation significantly improve thermal comfort, as: i) due to the low albedo, the reflected component of solar radiation is low and ii) due to the cooling effect of transpiration, the long-wave radiation emitted is low.
5. In an urban canyon, the colour of the buildings' facades (walls of the canyon) and of the road surface, i.e. the value of $\alpha W$ and $\alpha R$, is a crucial parameter for thermal comfort: the higher the albedo, the higher the first term of equation A2.5; i.e. high albedo (light coloured surfaces) increases the amount of heat received. On the other hand, high albedo means that the walls will not absorb much heat during the day, heat that, consequently, will not be released as long-wave radiation during the night. If no direct solar radiation reaches the walls and the road, their colour is far less important, the reflected component $\alpha_W S\downarrow + \alpha_R S\downarrow$ becomes negligible, and the energy gains are greatly reduced, as is the long-wave radiation in the canyon at night.

FIGURE A2.5 **THERMAL COMFORT ENERGY BALANCE IN A LANDSCAPED OPEN SPACE**

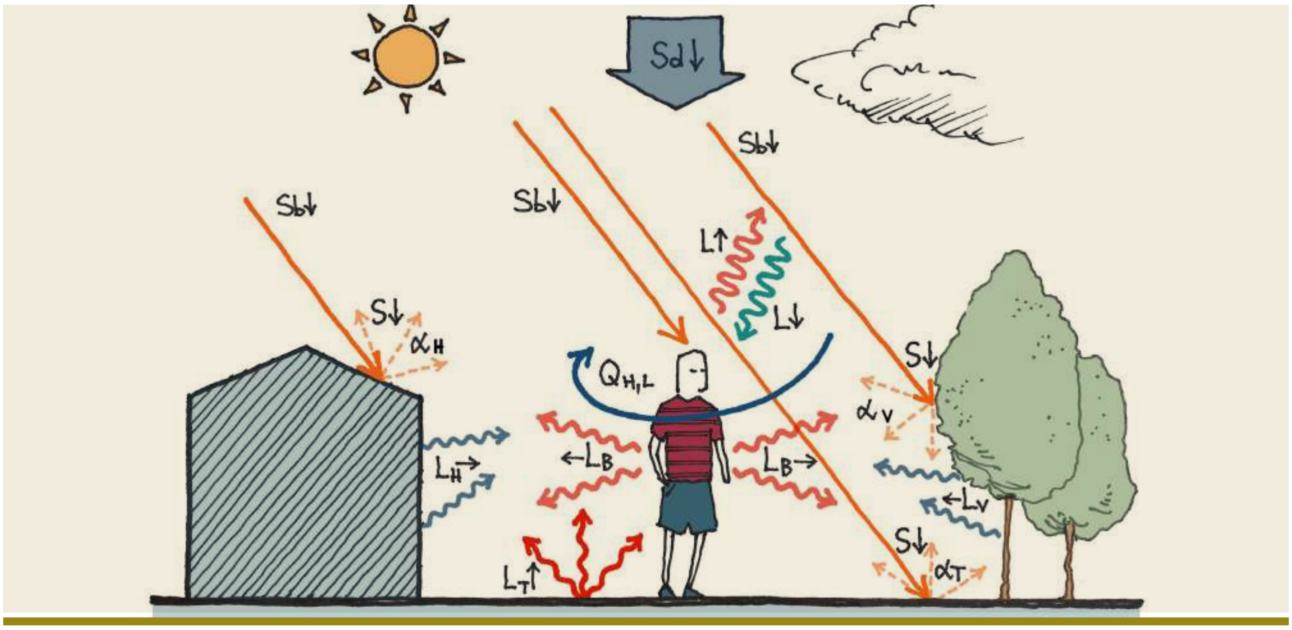
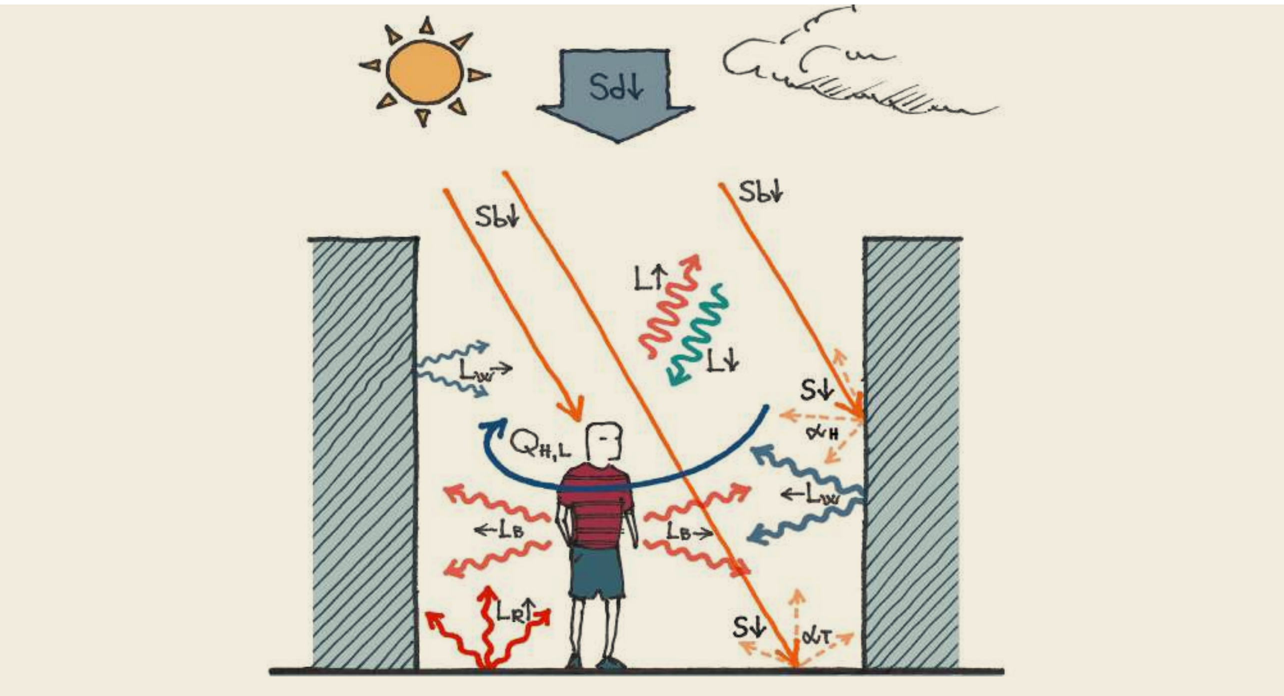


FIGURE A2.6 **COMPONENTS OF THERMAL COMFORT ENERGY BALANCE IN AN URBAN CANYON**



6. To avoid night-time temperatures being too high, if shading is not possible, heat storage in the urban built mass must be kept to a minimum in a hot humid tropical climate, where the daily temperature variation is small.
7. The presence of wind is crucial for enhancing heat losses by convection, if the air temperature is lower than the temperature of the surfaces, and evaporation.

Some urban design guidelines for improving outdoor comfort in tropical cities can be derived:

- Provide shade for streets and outdoor activities with vegetation or – if this is not possible – with other shading devices (e.g. textiles), which prevent the heating-up of urban canyons
- Enable natural ventilation in urban spaces in hot humid climates
- Keep to a minimum the urban built mass for night-time comfort in a hot humid climate, and keep it high in a hot arid climate.

## 2. THERMAL COMFORT INDICES FOR THE OUTDOOR ENVIRONMENT

Among the various indices developed for the indoor environment, the most well established is the Predicted Mean Vote (PMV) developed by P. O. Fanger in the early seventies (Fanger 1972). It is widely used nowadays and is an ISO standard (7730).

Theoretically, the indices developed for indoor conditions can also be applied to outdoor environments, but the sensation of thermal comfort is perceived very differently indoors and people tend to accept a much wider range of thermal conditions outdoors than indoors. There are many reasons for this, among which is the fact that the climatic variables may be much more diverse than in indoor settings, especially in relation to air movements and shortwave radiation from sun and sky.

The human body does not have any selective sensors for the perception of individual climatic parameters, but can only register (by thermoreceptors) and make a thermoregulatory response to the temperature (and any changes) of the skin and of the blood flow passing the hypo-thalamus. These temperatures, however, are influenced by the integrated effect of all climatic parameters, which are in a kind of interrelationship, i.e. they affect each other. When there is little wind, for instance, the mean radiant temperature[41] has roughly the same importance for the heat balance of the human body as the air temperature. On days with higher wind velocities, air temperature is far more important than the mean radiant temperature because it now dominates the increased convective heat exchange.

Thus, to apply PMV to outdoor conditions, Jendritzky and Nübler (Jendritzky 1981) added complex outdoor radiation exchanges (as shown in Figures A2.3 to A2.5) and the model is known as Klima-Michel Model (KMM).

Besides the adaptation of existing indices developed for the indoor environment, other indices specifically designed to cope with the outdoor environment were developed; among them, frequently used in urban climatology studies, is the Physiological Equivalent Temperature (PET), developed by Mayer & Höppe (Mayer 1987).

PET was developed as an index taking into account all basic thermoregulatory processes and is based on a thermo-physiological heat balance model called Munich Energy Balance Model for Individuals (MEMI). PET is defined as the air temperature at which, in a typical indoor setting[42], the heat budget of the human body [43] is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed. In this way PET enables a person to compare the integral effects of complex thermal conditions outside with his or her own experience indoors. As shown in Table A2.1, in the case of warm and sunny outdoor conditions, the PET value would be 43 °C. This means that an occupant of a room with an air temperature of 43 °C reaches the same thermal state as in the warm and sunny outdoor conditions. Moving out of the direct solar irradiation into the shade this would result in a reduction of PET by 14 °C, to 29 °C. The same outdoor air temperatures thus result in a very different thermal strain, which can be quantified very clearly by the PET values. Large differences between air temperature and PET also arise from the effect of wind velocity. It is found that an increase of air temperature by 1 °C corresponds to the PET value rising at about 1 °C; but an increase of wind speed from 0.5 to 1.5 m/s has an effect of decreasing PET by about 2 °C (School of Architecture 2010).

PET is one of the recommended indices in German guidelines for urban and regional planners (VDI, 1998) and is used for the prediction of changes in the thermal component of urban or regional climates. By using the free Software named RayMan, PET can be calculated easily. The comparison of PMV with PET is shown in Figure A2.7. The range of thermal perception and physiological stress of both indices are also shown.

Another index proposed more recently is the Universal Thermal Climate Index. The UTCI also adopts the concept of an equivalent temperature. The UTCI equivalent temperature for a given combination of wind, radiation, humidity and air temperature is then defined as the air temperature of the reference environment, which produces the same strain index value.

The reference environment is characterised by:

- wind speed of ≈ 0.3 m/s at 1.1 m),
- mean radiant temperature equal to air temperature,
- vapour pressure that represents a relative humidity of 50%. At high air temperatures (>29 °C) the reference humidity is taken as a constant at 20 hPa.

The representative outdoor activity is that of a person walking at a speed of 4 km per hour (≈1.1 m/s). So, the rate of metabolic heat production is assumed to be 2.3 MET (≈135 W/m$^2$).

Equal physiological conditions are based on the equivalence of the dynamic physiological response predicted by the model for the actual and the reference environment. As this dynamic response is multidimensional (body core temperature, sweat rate, skin wettedness etc. at different exposure times), a strain index is calculated by principal component analysis as single dimensional representation of the model response.

The different values of the UTCI are categorized in terms of thermal stress, as shown in Table A2.2.

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[41] *The mean radiant temperature (Tmr) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.*

[42] *Without wind and solar radiation, mean radiant temperature = air temperature, air velocity = 0.1 m/s, relative humidity ≈ 50%*

[43] *Work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo*

TABLE A2.1 **EXAMPLES OF PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET) VALUES FOR DIFFERENT CLIMATE SCENARIOS (ADAPTED FROM: HÖPPE 1999). TA AIR TEMPERATURE; TMR MEAN RADIANT TEMPERATURE; V AIR VELOCITY; RELATIVE HUMIDITY IS IN ALL SCENARIOS ABOUT 50%.**

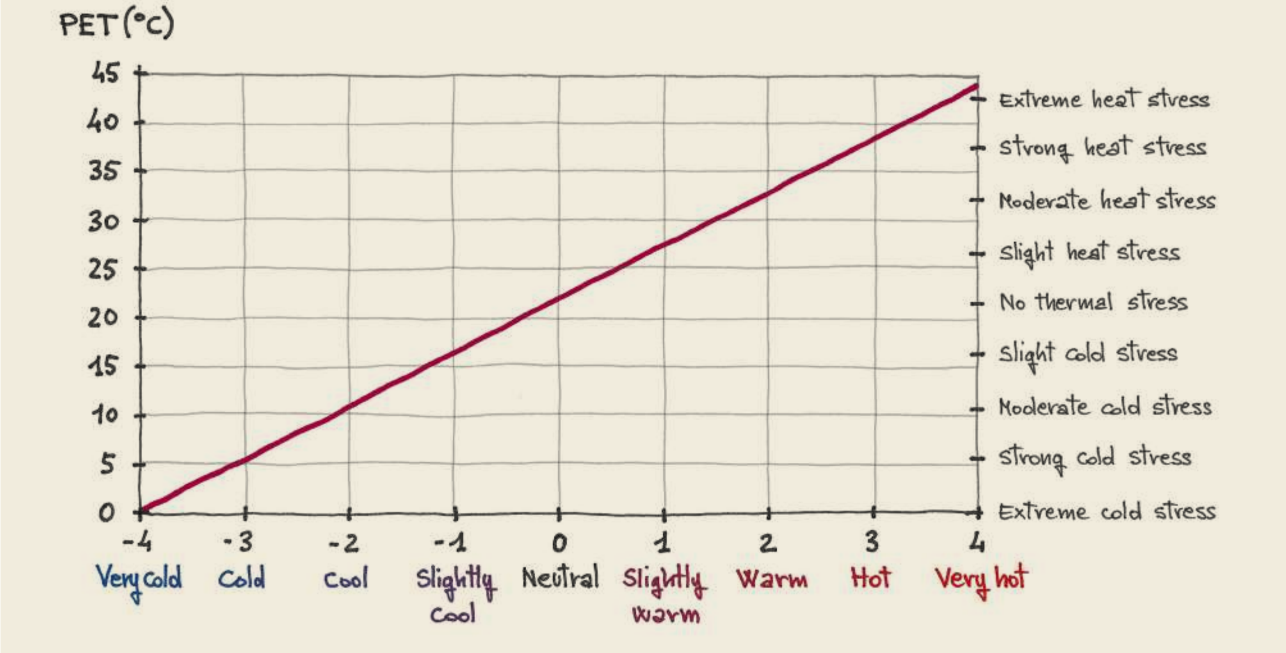
| Scenario | Ta (°C) | Tmr (°C) | V (m/s) | PET (°C) |
|---|---|---|---|---|
| Typical room | 21 | 21 | 0.1 | 21 |
| Winter, sunny | -5 | 40 | 0.5 | 10 |
| Winter, shade | -5 | -5 | 5.0 | -13 |
| Summer, sunny | 30 | 60 | 1.0 | 43 |
| Summer, shade | 30 | 30 | 1.0 | 29 |

TABLE A2.2 **UTCI EQUIVALENT TEMPERATURE CATEGORIZED IN TERMS OF THERMAL STRESS.**

| UTCI (°C) range | Stress Category |
|---|---|
| above +46 | extreme heat stress |
| +38 to +46 | very strong heat stress |
| +32 to +38 | strong heat stress |
| +26 to +32 | moderate heat stress |
| +9 to +26 | no thermal stress |
| +9 to 0 | slight cold stress |
| 0 to -13 | moderate cold stress |
| -13 to -27 | strong cold stress |
| -27 to -40 | very strong cold stress |
| below -40 | extreme cold stress |

*Software for calculating the UTCI is available on the project's website (www.utci.org).*

FIGURE A2.7 **RANGES OF PMV AND PHYSIOLOGICAL EQUIVALENT TEMPERATURE PET FOR DIFFERENT GRADES OF THERMAL PERCEPTION AND PHYSIOLOGICAL STRESS; INTERNAL HEAT PRODUCTION (ADAPTED FROM: HONJO 2009)**



# REFERENCES

Fanger, P.O. (1972) Thermal comfort, McGraw-Hill, New York.

Honjo, T. (2009); Thermal Comfort in Outdoor Environment, Global Environmental Research, (13:43-47)

Höppe, P. (1999), The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment, International Journal Biometeorol; 43:71–75

HSE – Health and Safety Executive (2016), http://www.hse.gov.uk/temperature/thermal/factors.htm, accessed on 19/12/2016

Jendritzky, G.; W. Nübler (1981), A model analysing the urban thermal environment in physiologically significant terms. Meteorology and Atmospheric Physics, 29: 313-326.

Mayer, H.; Höppe, P. (1987) Thermal comfort of man in different urban environments. Theor. Appl. Climatol, 38: 43-49.

School of Architecture, Chinese University of Hong Kong (2010), Urban Climatic Map and Standards for Wind Environment - Feasibility Study – Executive summary - http://www.pland.gov.hk/pland_en/p_study/prog_s/ucmapweb/ucmap_project/content/reports/executive_summary.pdf – accessed on 15/12/2016

# A3

# OBSTRUCTION PROFILE CONSTRUCTION

## 1. OBSTRUCTION PROFILE CONSTRUCTION USING A GRAPHICAL METHOD

The stereographic obstruction protractor shown in Figure A3.1 can be used for drawing the projection of the horizontal and vertical lines of the contour of a building on a polar chart.

The curved lines connecting A to A' represent the horizontal edges of the building, according to the angle β, which is the angle lying in a vertical plane orthogonal to the building's façade, formed by the horizontal line passing through the chosen reference point P and the line joining this point with the upper edge of the building (Figure A3.2, left). The corresponding values can be read on the semi-axis of the diagram (from the centre, point P, to point B in Figure A3.2, right). The semi-circle ABA' represents half of the sky dome.

The radial lines branching out from the centre in the semi-circle ABA' represent the vertical edges of the building. These lines indicate the value of the angle α, lying in the horizontal plane orthogonal to the building's façade and formed by the horizontal line passing through point P and the line joining this point with the outer edge of the building (Figure A3.3, left). The values of α are readable on the external circumference of the diagram and are symmetric with respect to B (Figure A3.3, right).

To explain how the method works, let us apply it to a north south axis, symmetrical urban canyon, such as, for example, the one depicted in Figure A3.4.

Consider, as our selected reference point, its middle point on the ground level (red dot), calculate or measure the angles β and α as indicated in Figure A3.5, left, and plot them on the protractor (β individuates the curved line, and α the radial line); the cross points between the β = 69.8° curved line and the α = 73° (+ and -) radial line individuate the limits of the curved line. The obstruction profile of the east wall, as seen from a point at ground level in the middle of the canyon, is drawn as shown in Figure A3.5, right (red line).

The corresponding profile of the west wall being symmetrical, the resulting overall obstruction profile from the middle of the canyon, at ground level, is the one plotted in Figure A3.6.

The same procedure can be followed for drawing the obstruction profile of a non-symmetrical canyon or as seen by a differently positioned point at ground level or at any level. Examples are given in Figures A3.7, A3.8, and A3.9

The method can be applied to any kind of obstructed view, as shown in Figure A3.10 for the case of a courtyard.

A catalogue of obstruction profiles of an urban canyon of infinite length as seen, at ground level, from three points (at 0.5 W, 0.25 W and 0.0 W from one of the walls, where W is the distance between walls) and for nine aspect ratios (H/W ranging from 0.5 to 2.5, by steps of 0.25) is provided in Appendix 3a. If the canyon is of finite length, the corresponding obstruction profile is obtained by intercepting the curve in the protractor with the radial line at an angle α given by the azimuth of the vertical line representing the edge of the building, as shown in Figure A3.11.

For evaluating the obstruction profile from a point in a wall, at any height, the procedure is the same as calculating the obstruction profile from the base of the wall, i.e. at ground level of a virtual canyon with an increased aspect ratio (H'/W), as shown in Figure A3.12. Thus, the catalogue in Appendix 3a can also be used in this case.

FIGURE A3.1 – STEREOGRAPHIC OBSTRUCTION PROFILE PROTRACTOR

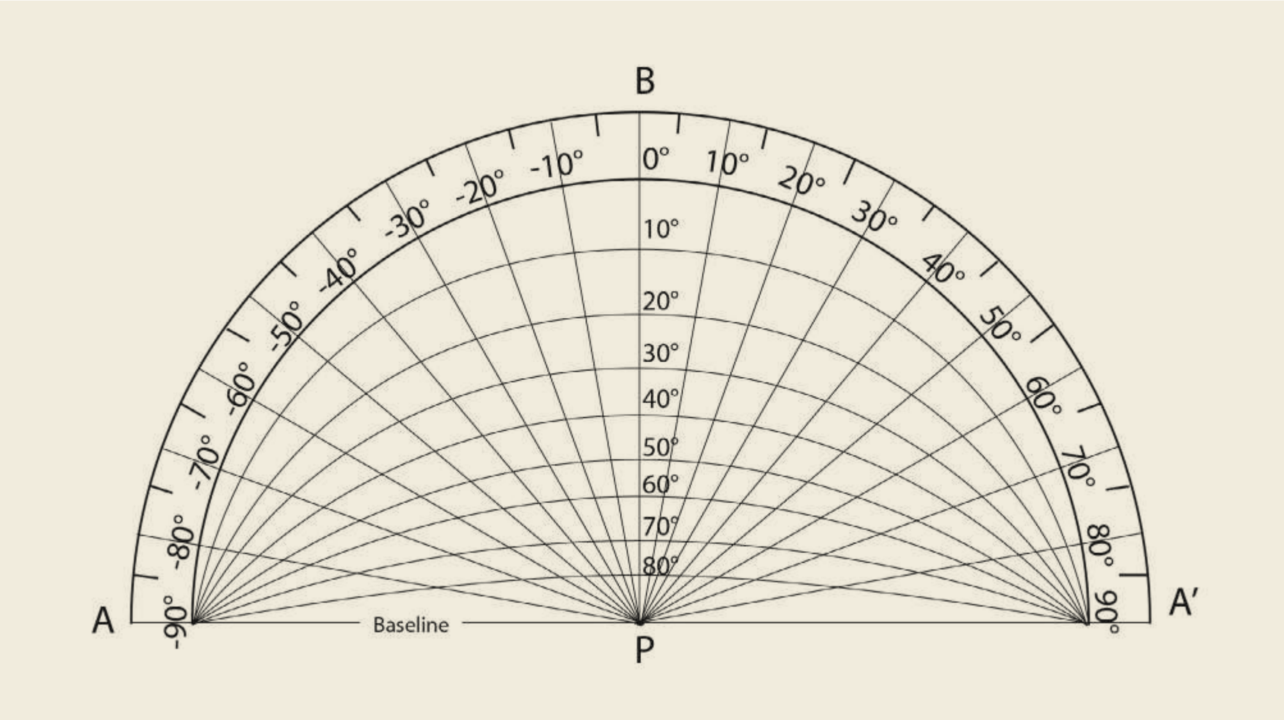


FIGURE A3.2 REPRESENTATION ON THE POLAR CHART OF THE HORIZONTAL EDGE OF THE BUILDING

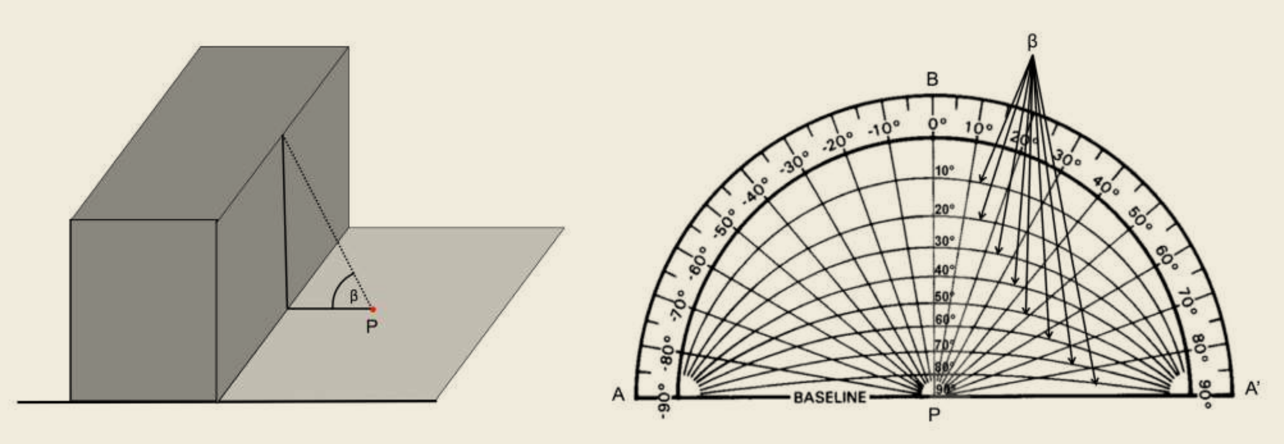


FIGURE A3.3 REPRESENTATION ON THE POLAR CHART OF THE VERTICAL EDGE OF THE BUILDING

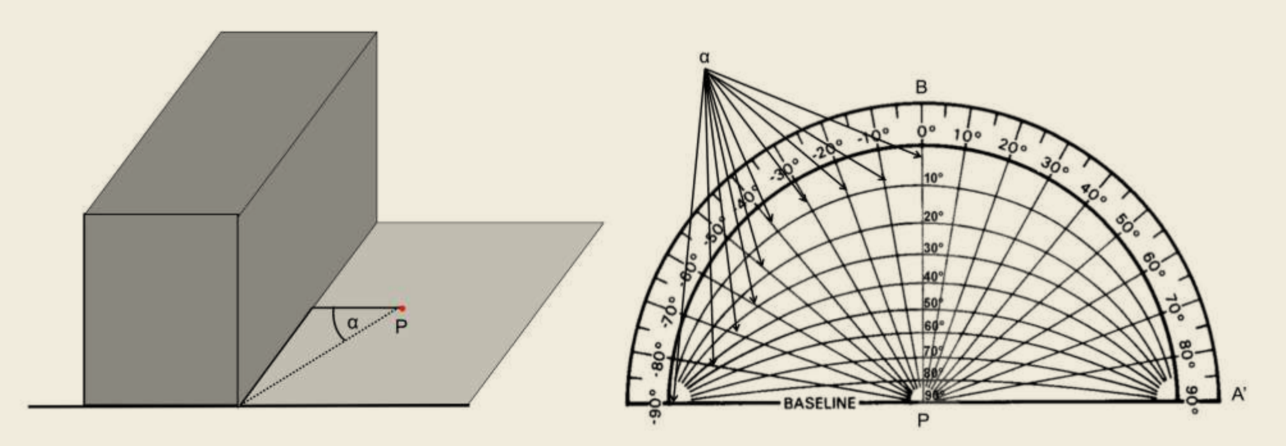


FIGURE A3.4 **EXAMPLE OF SYMMETRICAL URBAN CANYON**

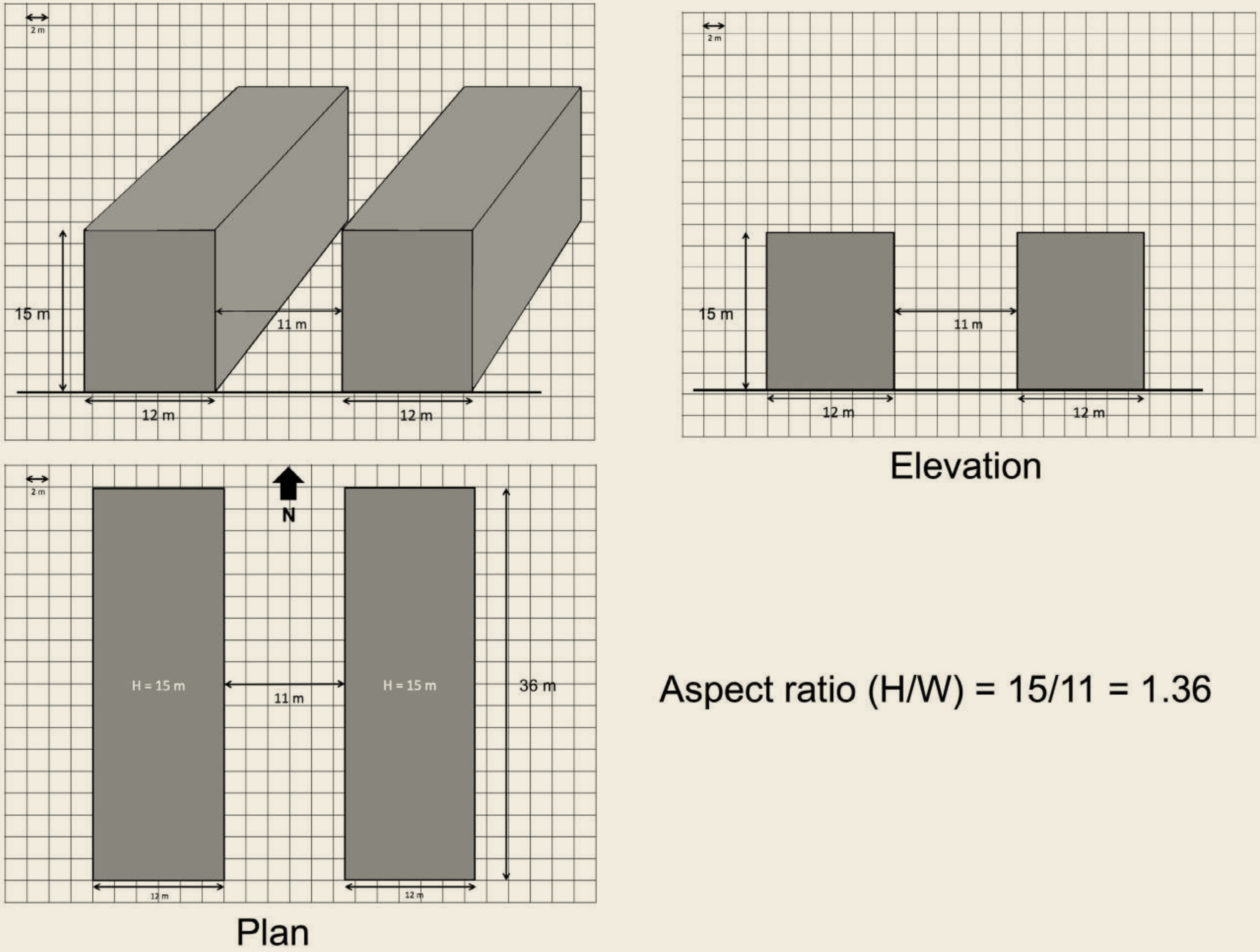


FIGURE A3.5 **LEFT: CALCULATION OF β AND α ANGLES; RIGHT: β AND α ANGLES PLOTTED ON THE PROTRACTOR AND IDENTIFICATION OF THE OBSTRUCTION PROFILE OF THE EAST SIDE OF THE CANYON.**

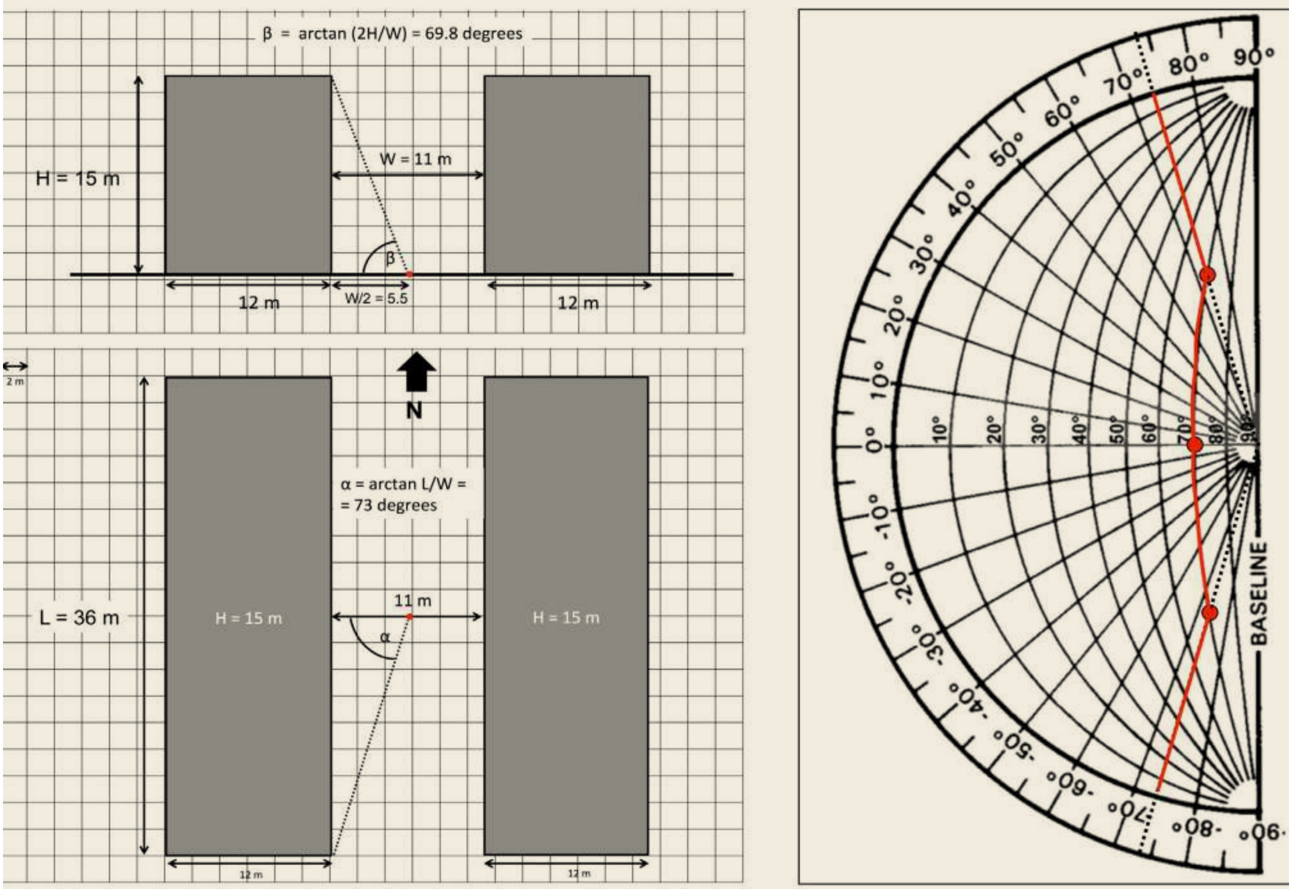


FIGURE A3.6 **OVERALL OBSTRUCTION PROFILE FROM THE MIDDLE OF THE CANYON, AT GROUND LEVEL.**

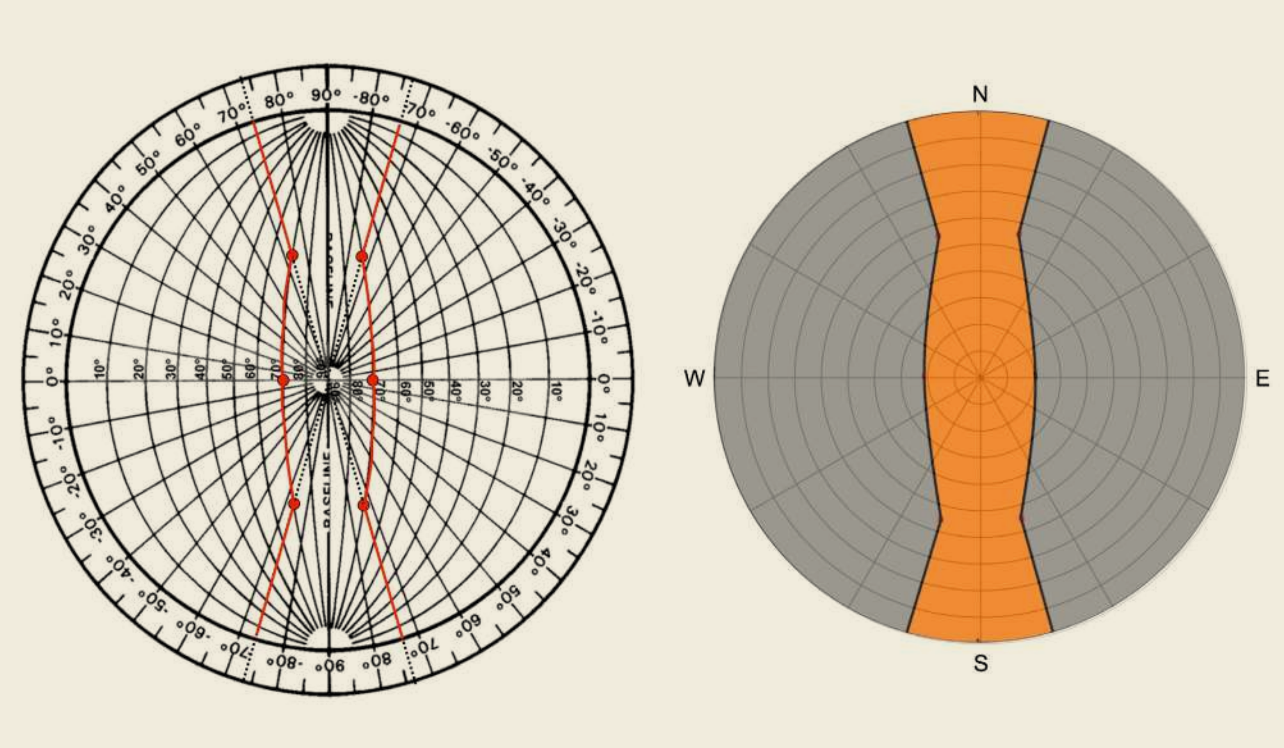


FIGURE A3.7 **ASYMMETRIC CANYON. OBSTRUCTION PROFILE AS SEEN FROM A POINT POSITIONED AT GROUND LEVEL, HALF-LENGTH, CENTRE STREET.**

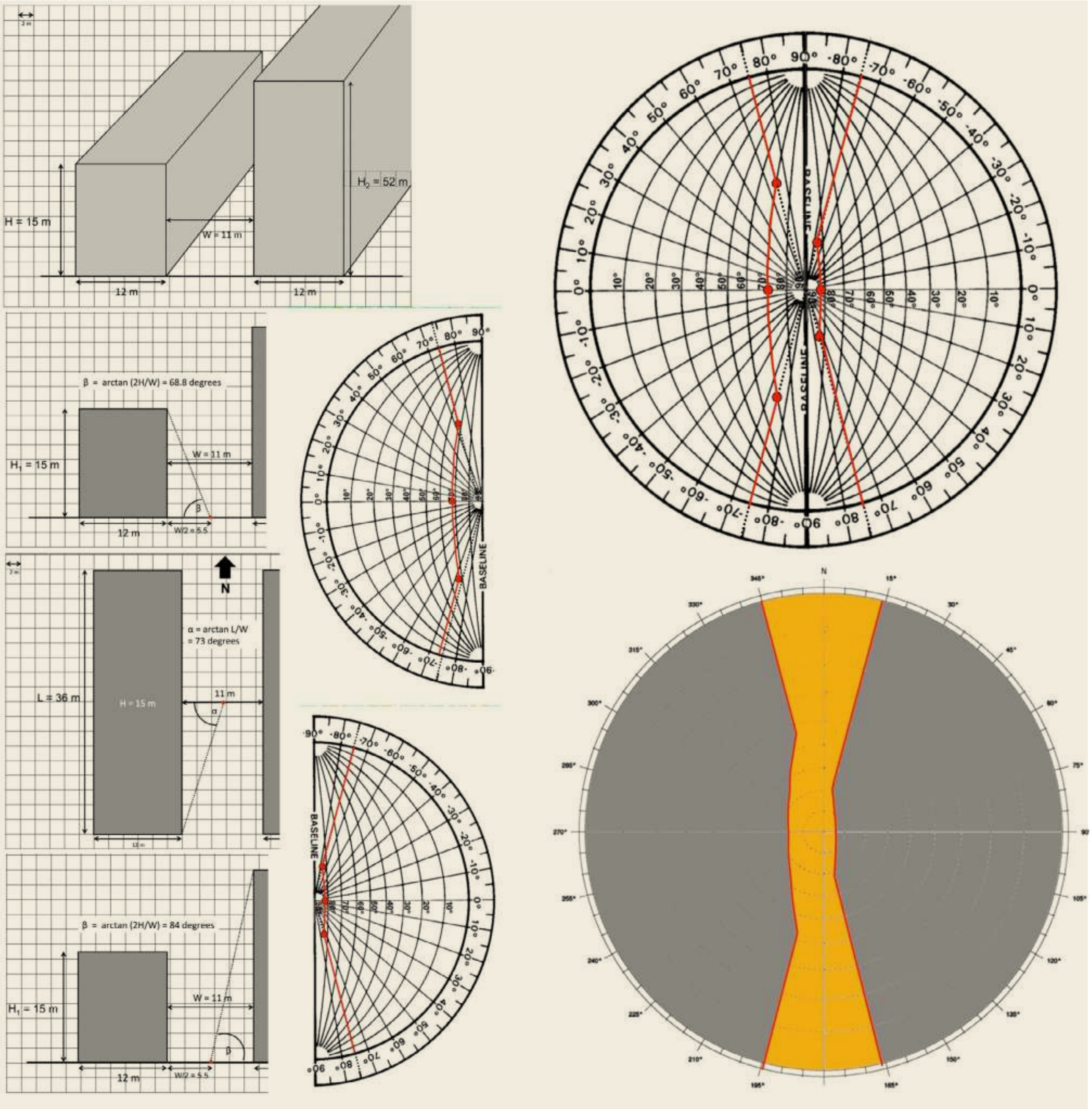


FIGURE A3.8 **OBSTRUCTION PROFILE AS SEEN FROM A POINT POSITIONED AT GROUND LEVEL, HALF-LENGTH, AT THE BOTTOM OF WEST WALL.**

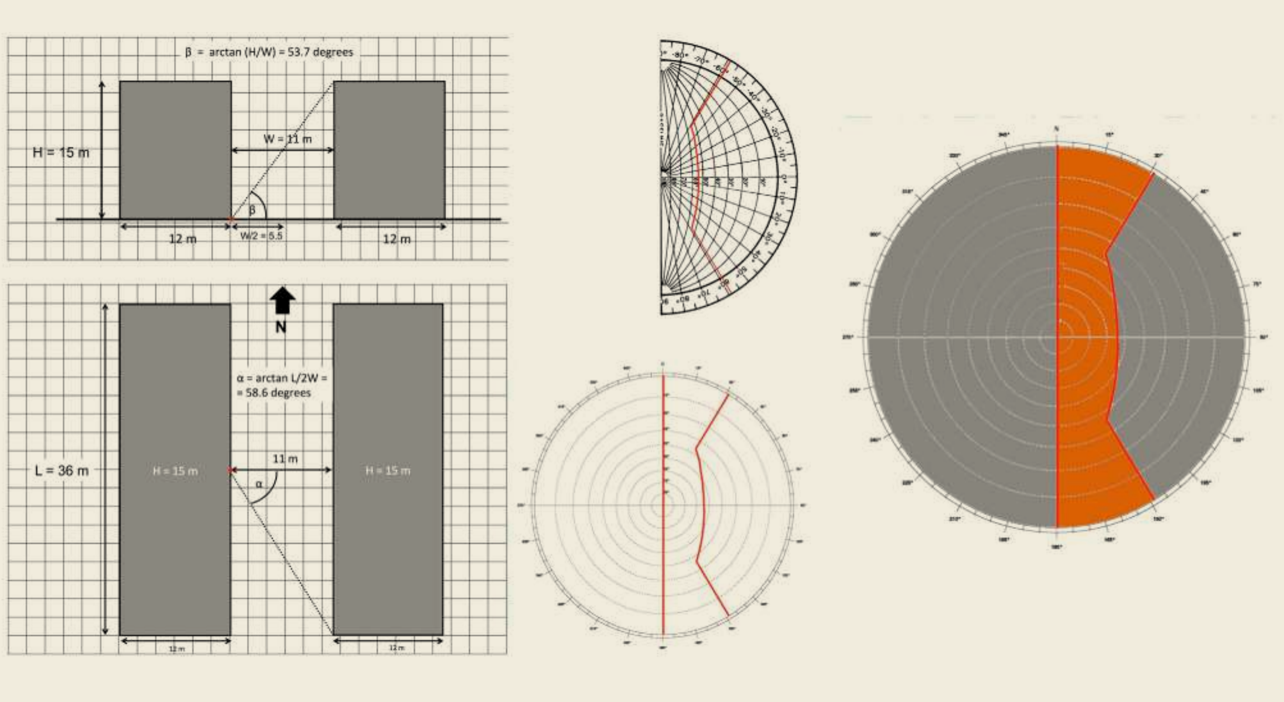


FIGURE A3.9 **OBSTRUCTION PROFILE AS SEEN FROM A POINT POSITIONED AT TWO METRES FROM THE GROUND, HALF-LENGTH, IN THE MIDDLE OF A SYMMETRIC CANYON.**

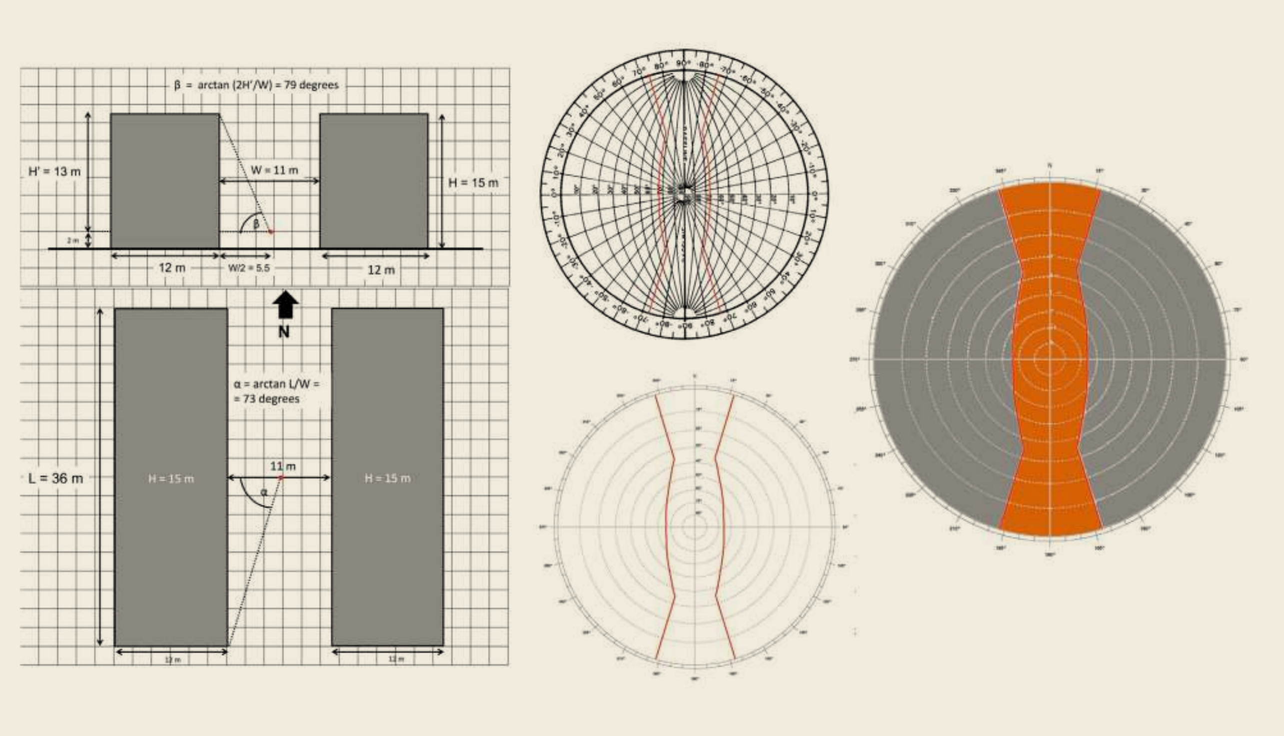


FIGURE A3.10 **OBSTRUCTION PROFILE OF A COURTYARD FROM A POINT IN THE MIDDLE, AT GROUND LEVEL.**

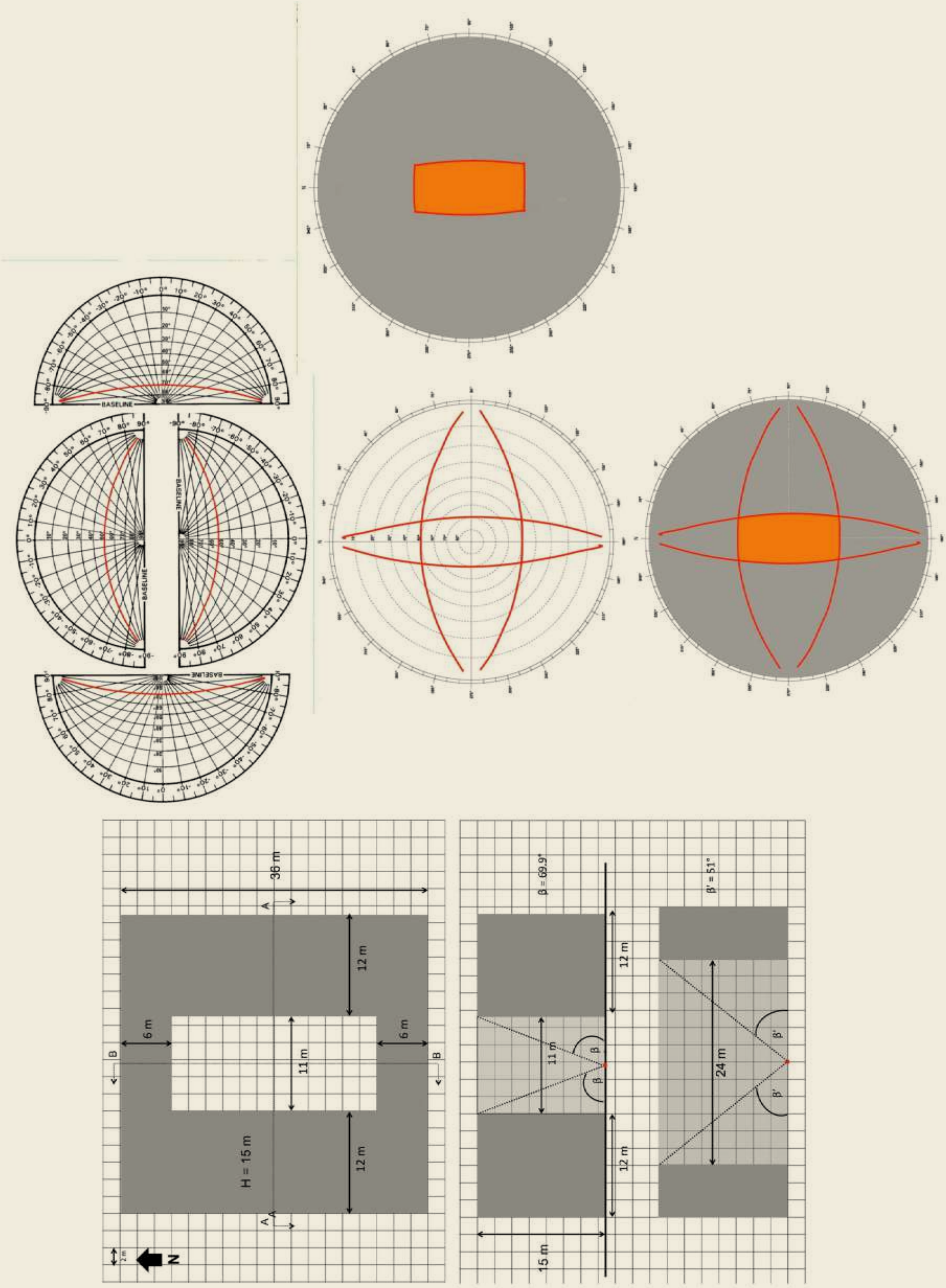


FIGURE A3.11 **GRAPHICAL PROCEDURE FOR TRANSFORMING THE OBSTRUCTION PROFILE OF AN URBAN CANYON OF INFINITE LENGTH INTO THE PROFILE OF A CANYON OF FINITE LENGTH.**

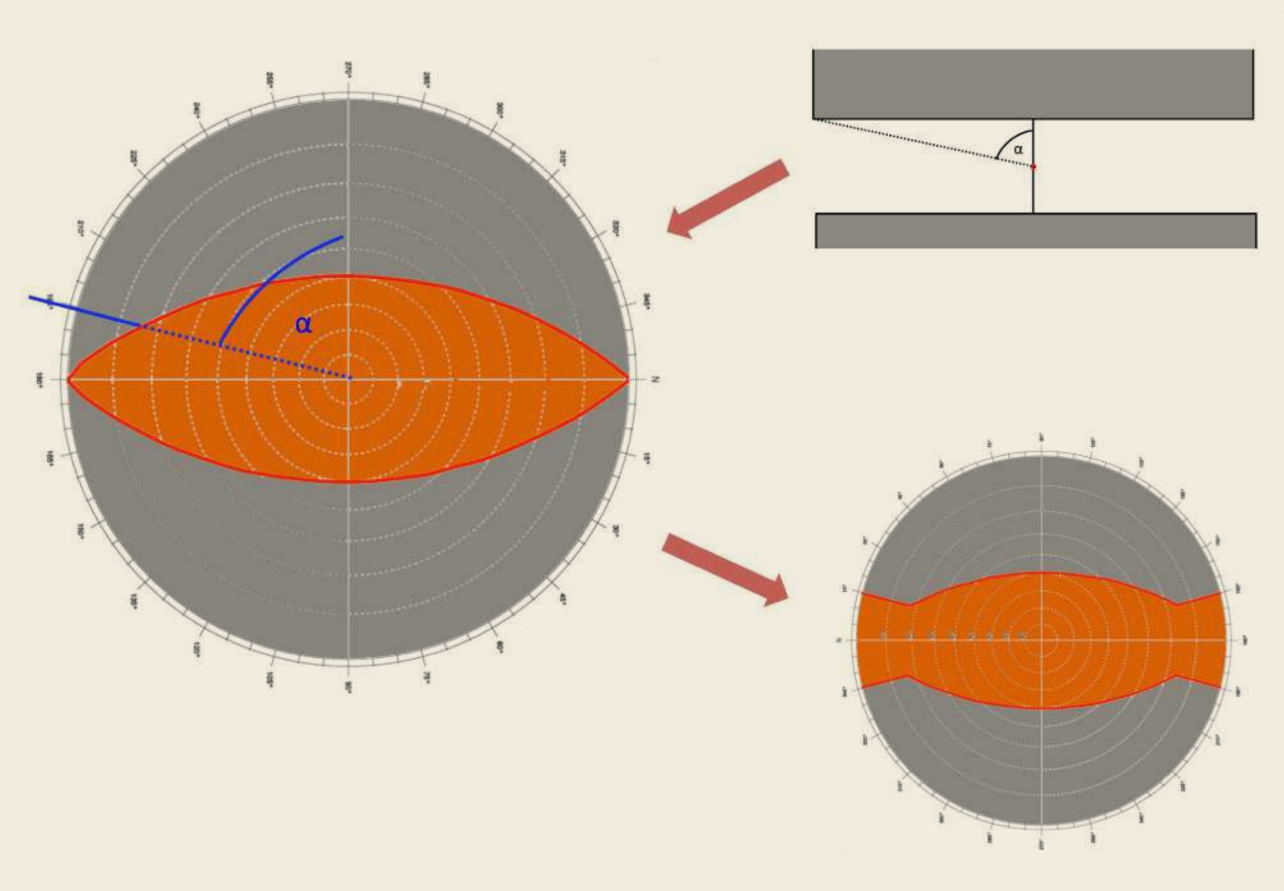
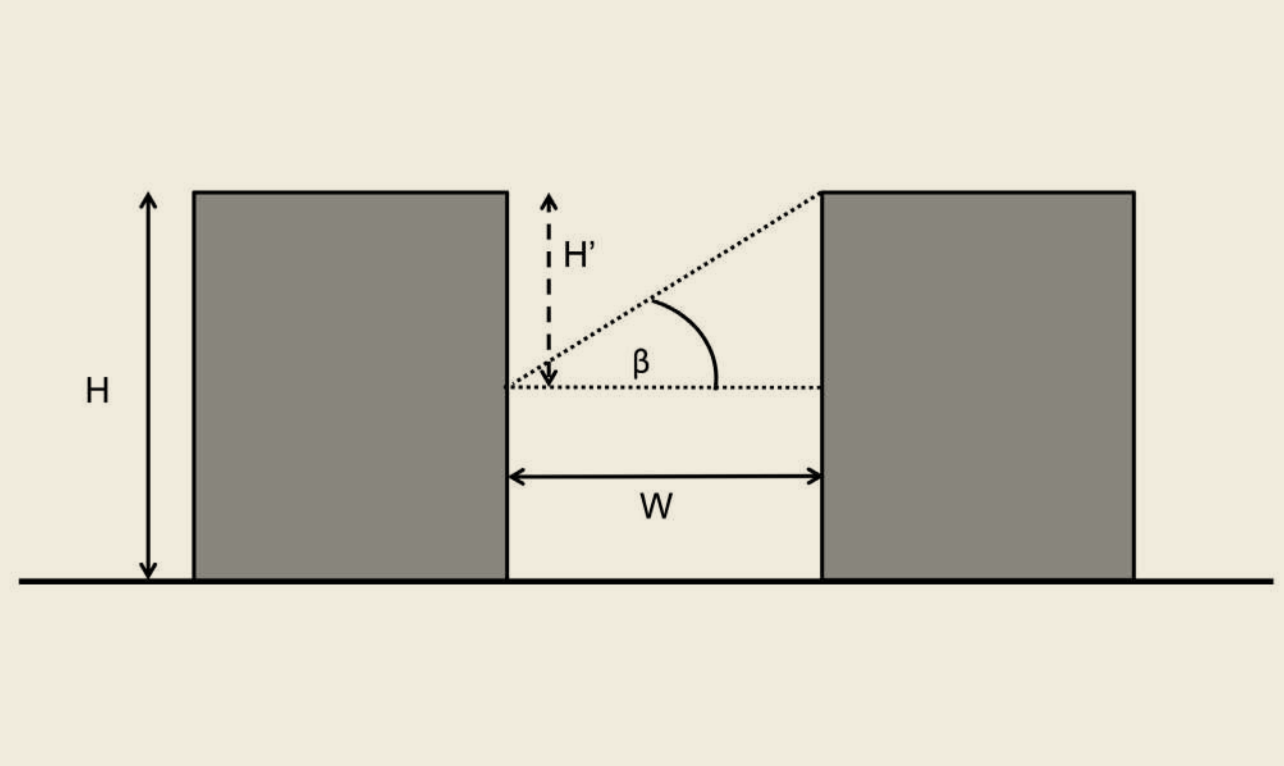
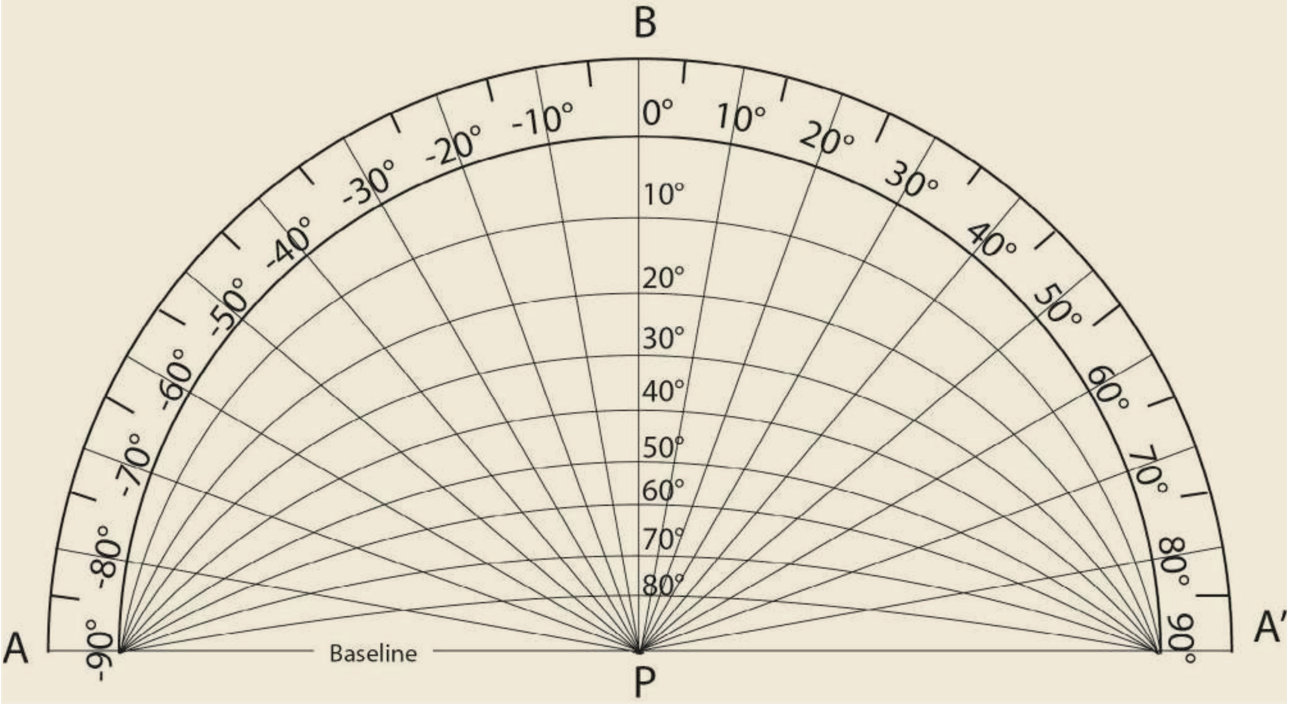
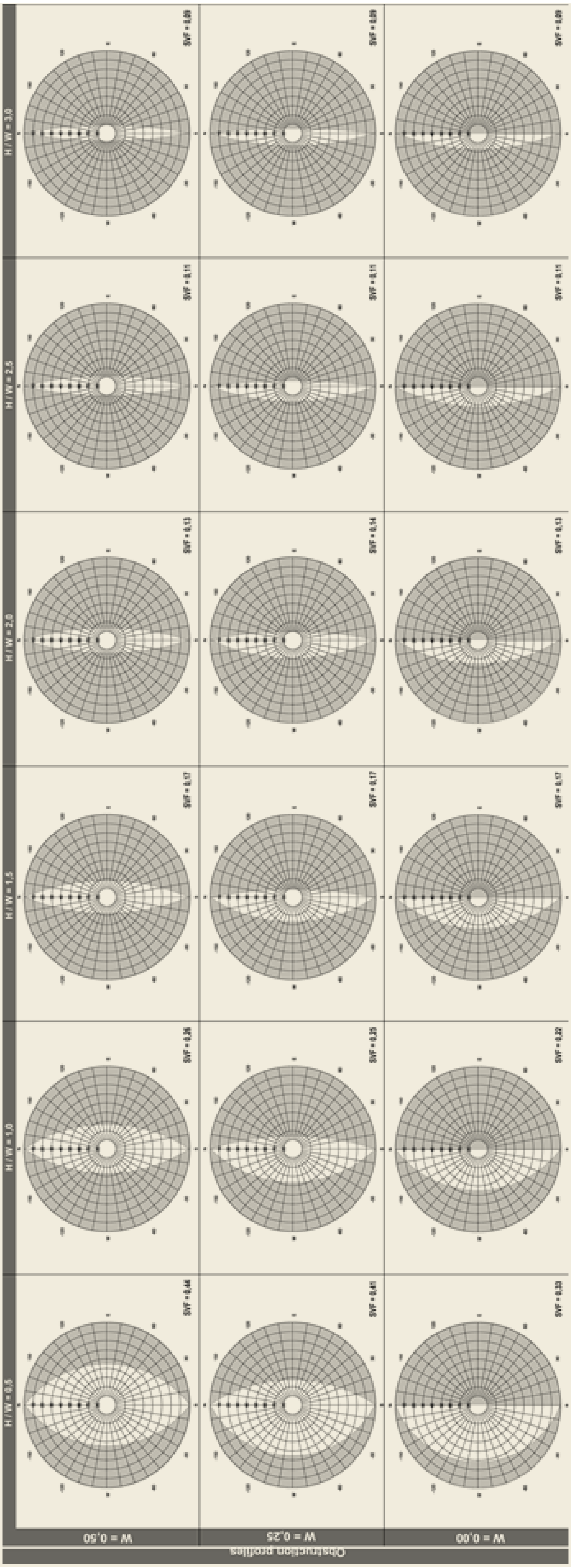


FIGURE A3.12 **OBSTRUCTION PROFILE CONSTRUCTION FROM A POINT ON THE SURFACE OF THE CANYON WALL.**



# A3a OBSTRUCTION PROFILES

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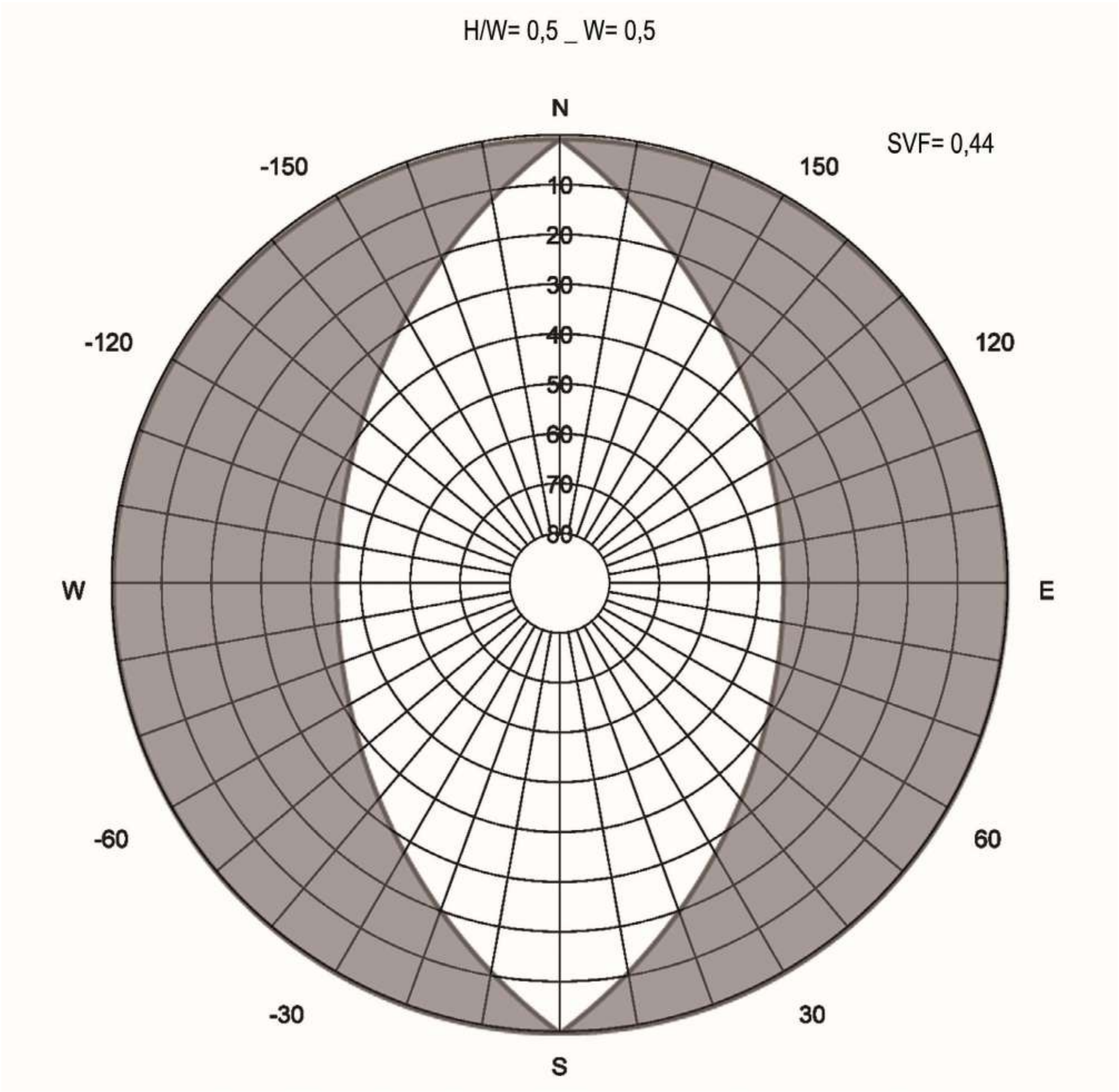
Obstruction profiles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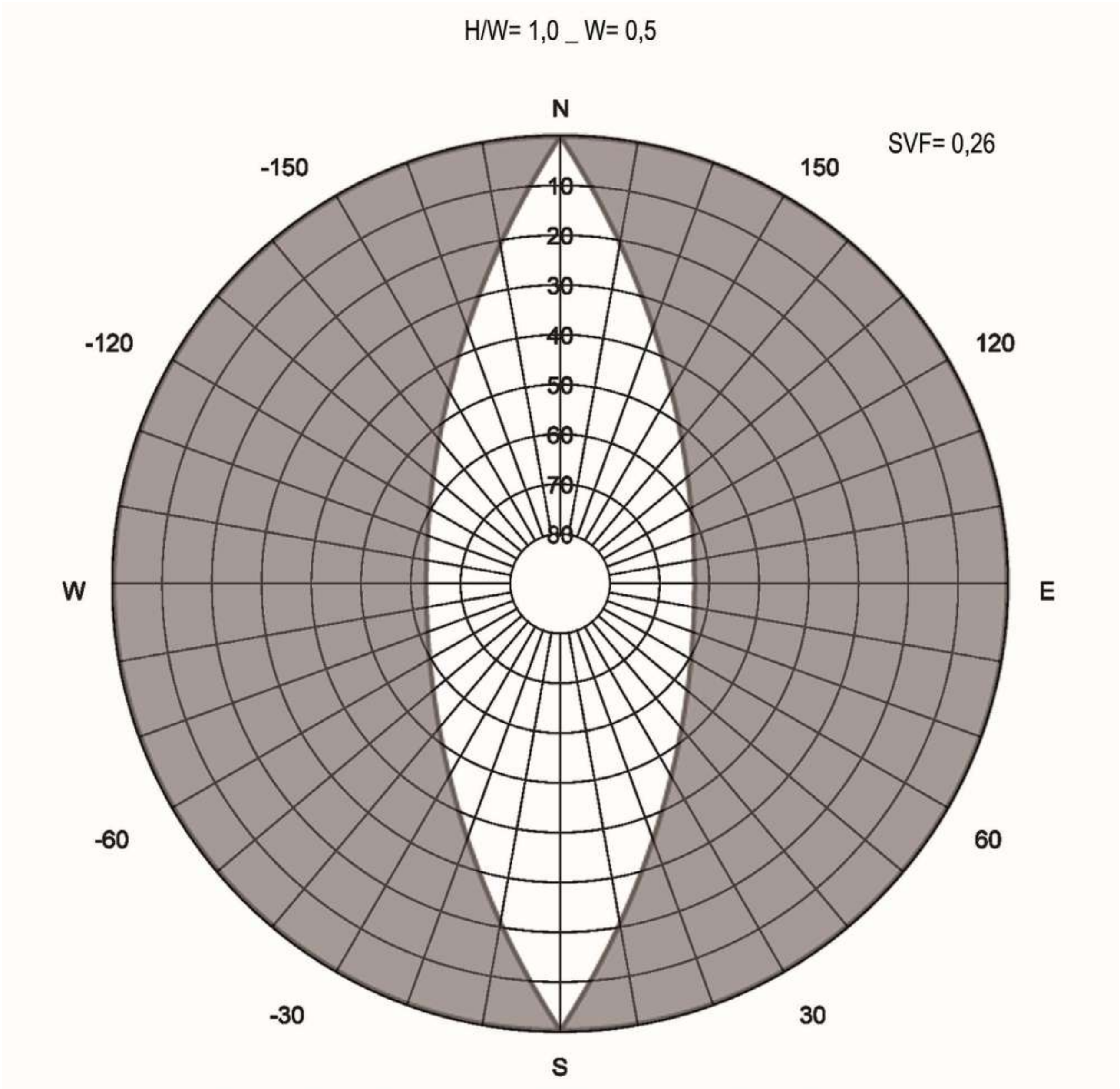
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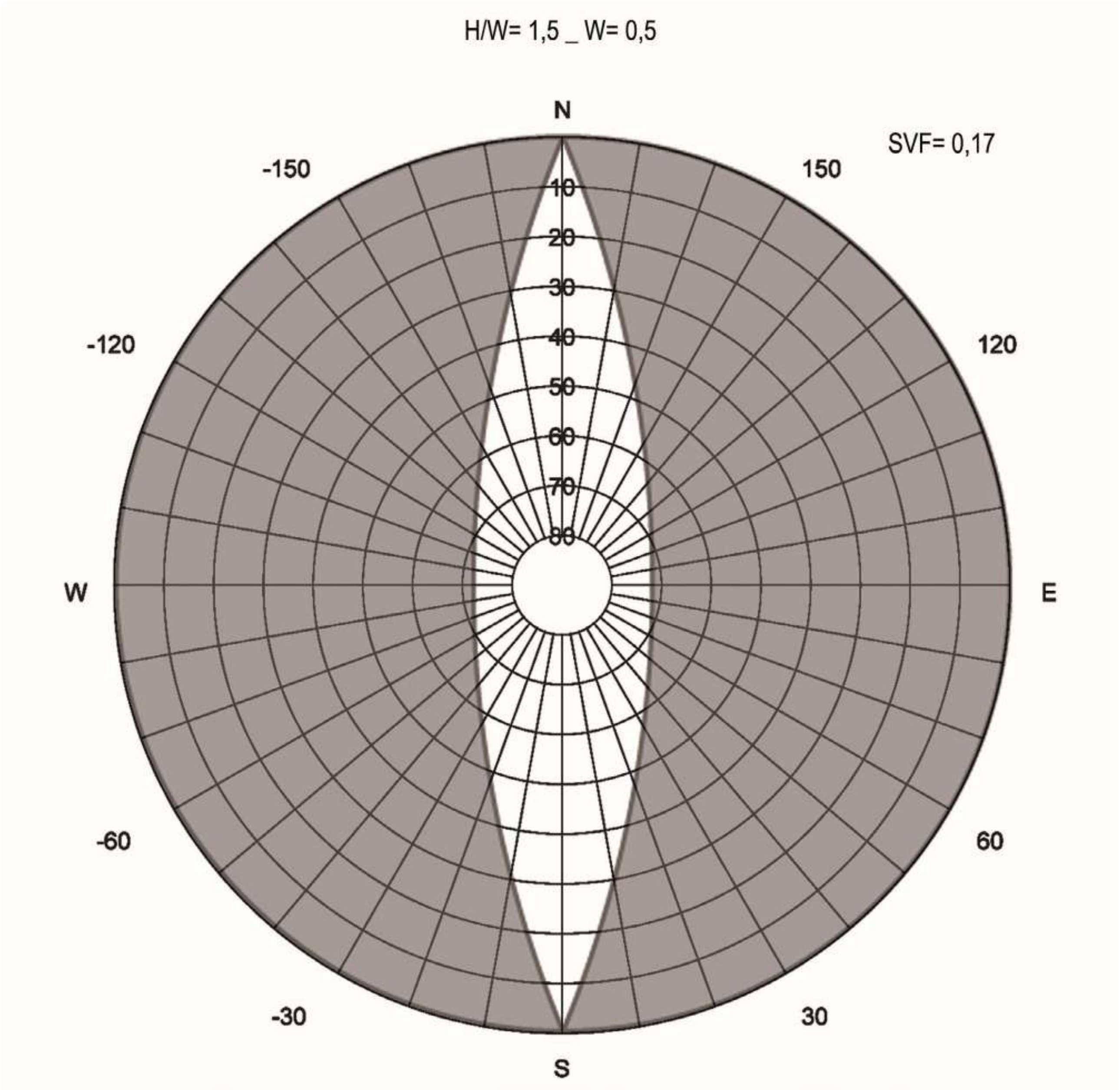
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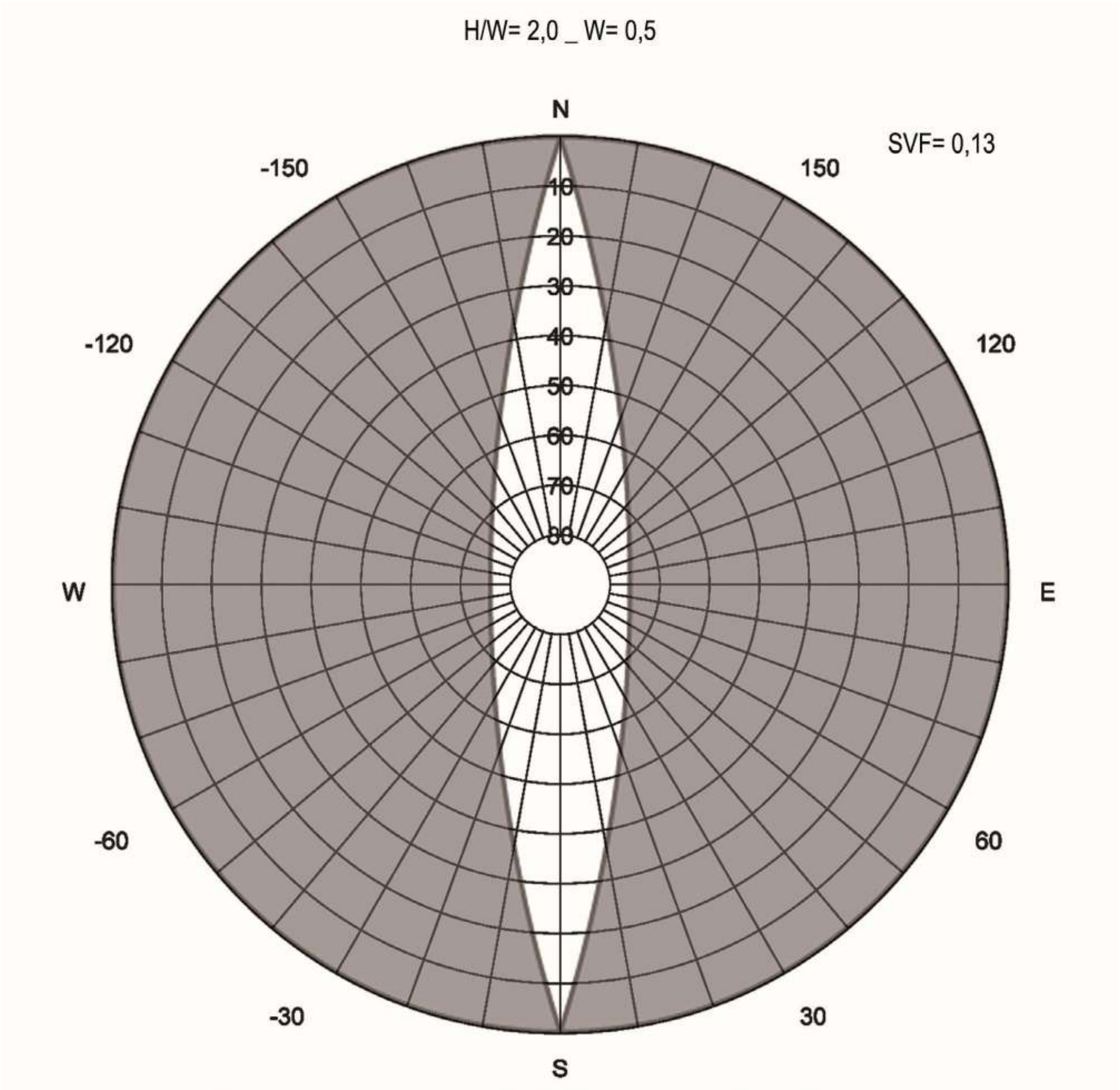
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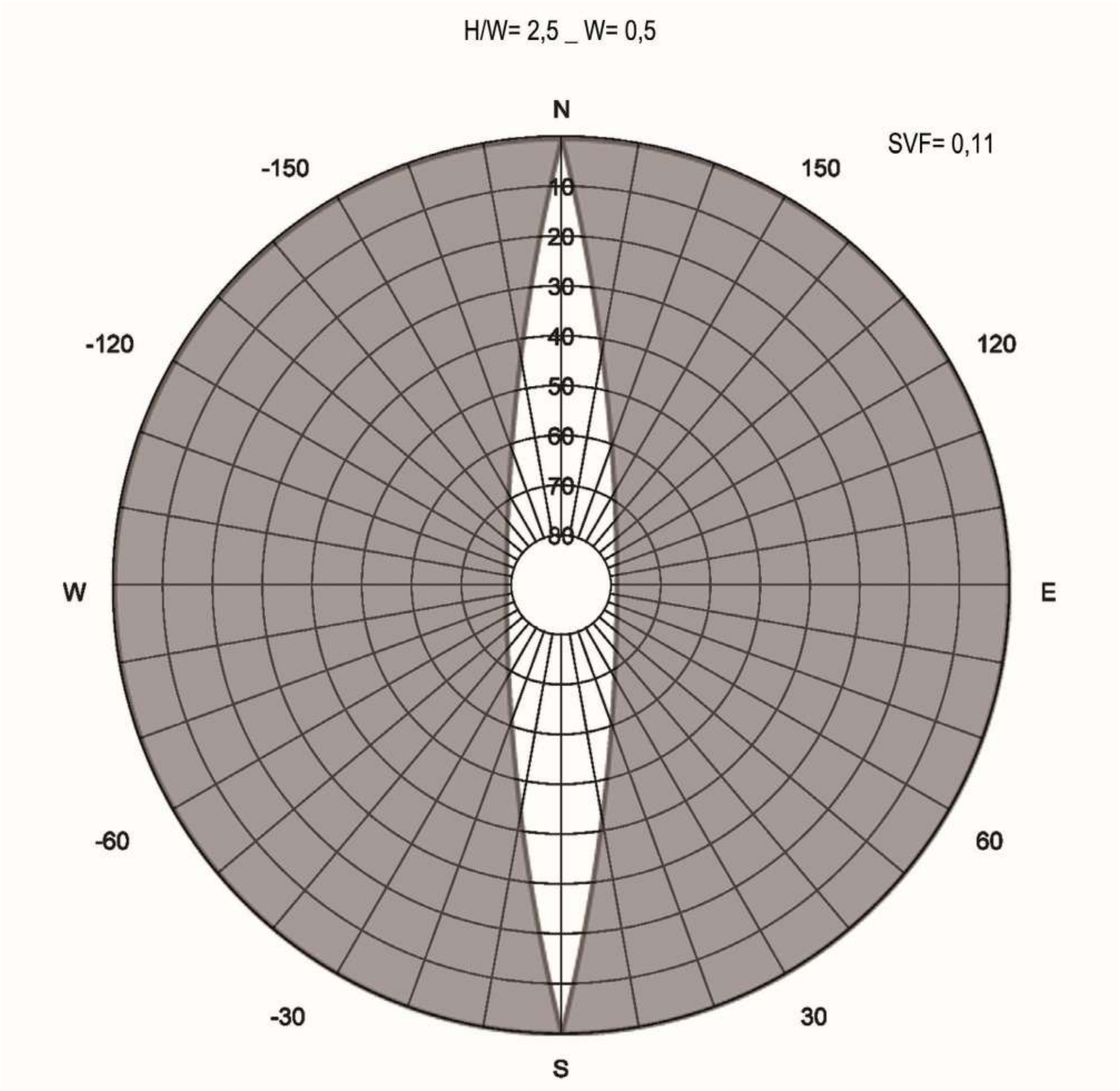
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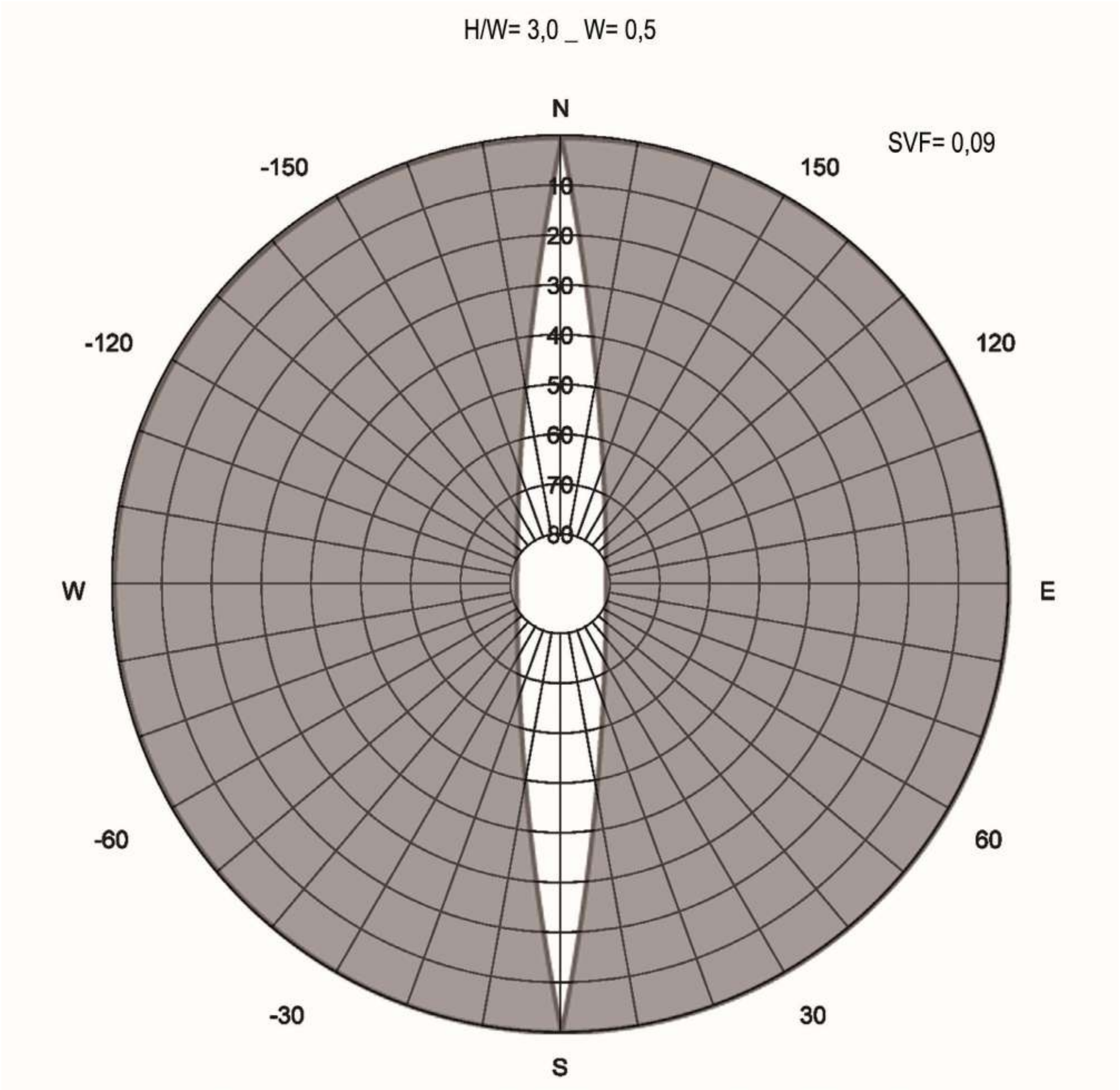
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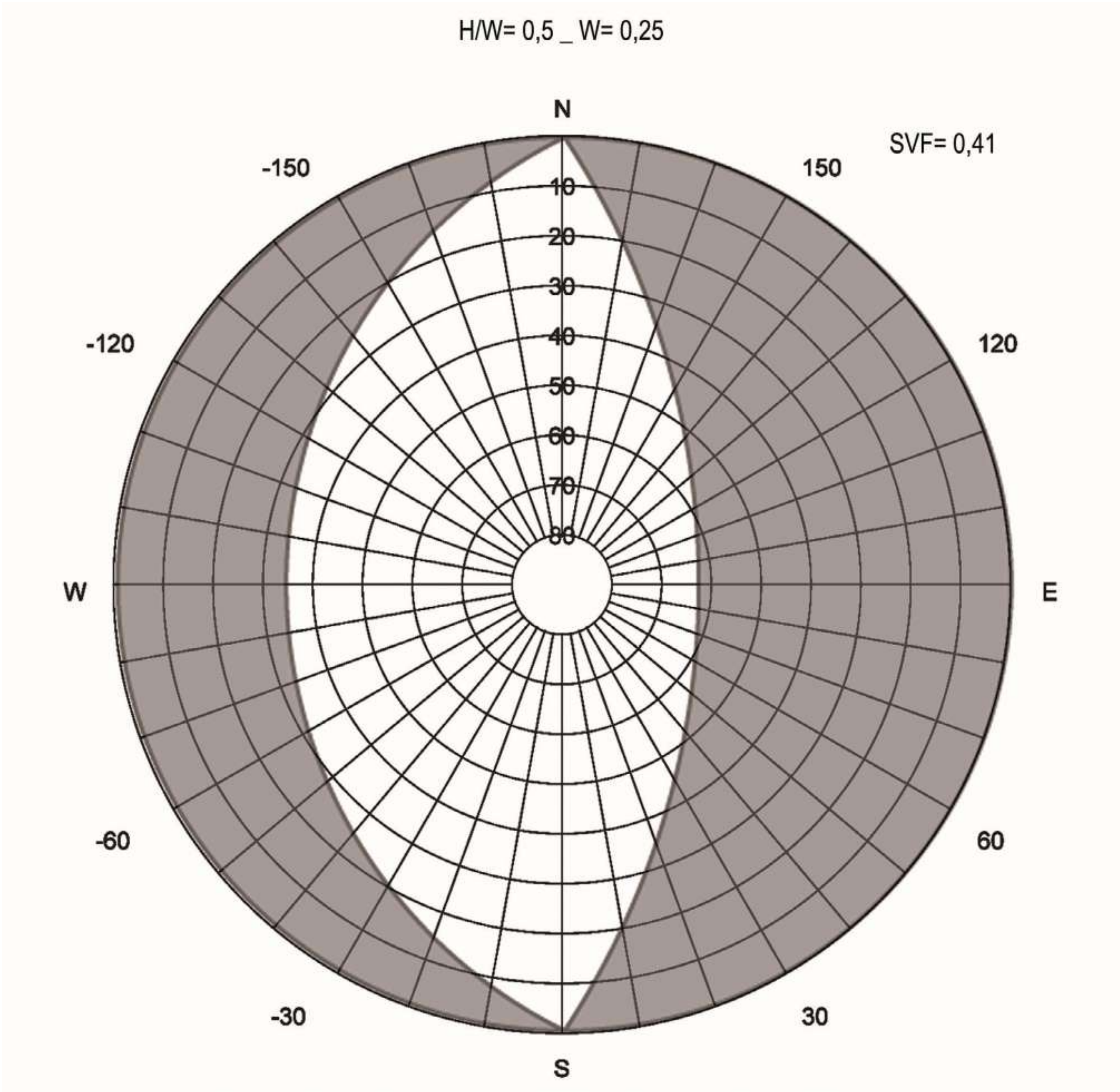
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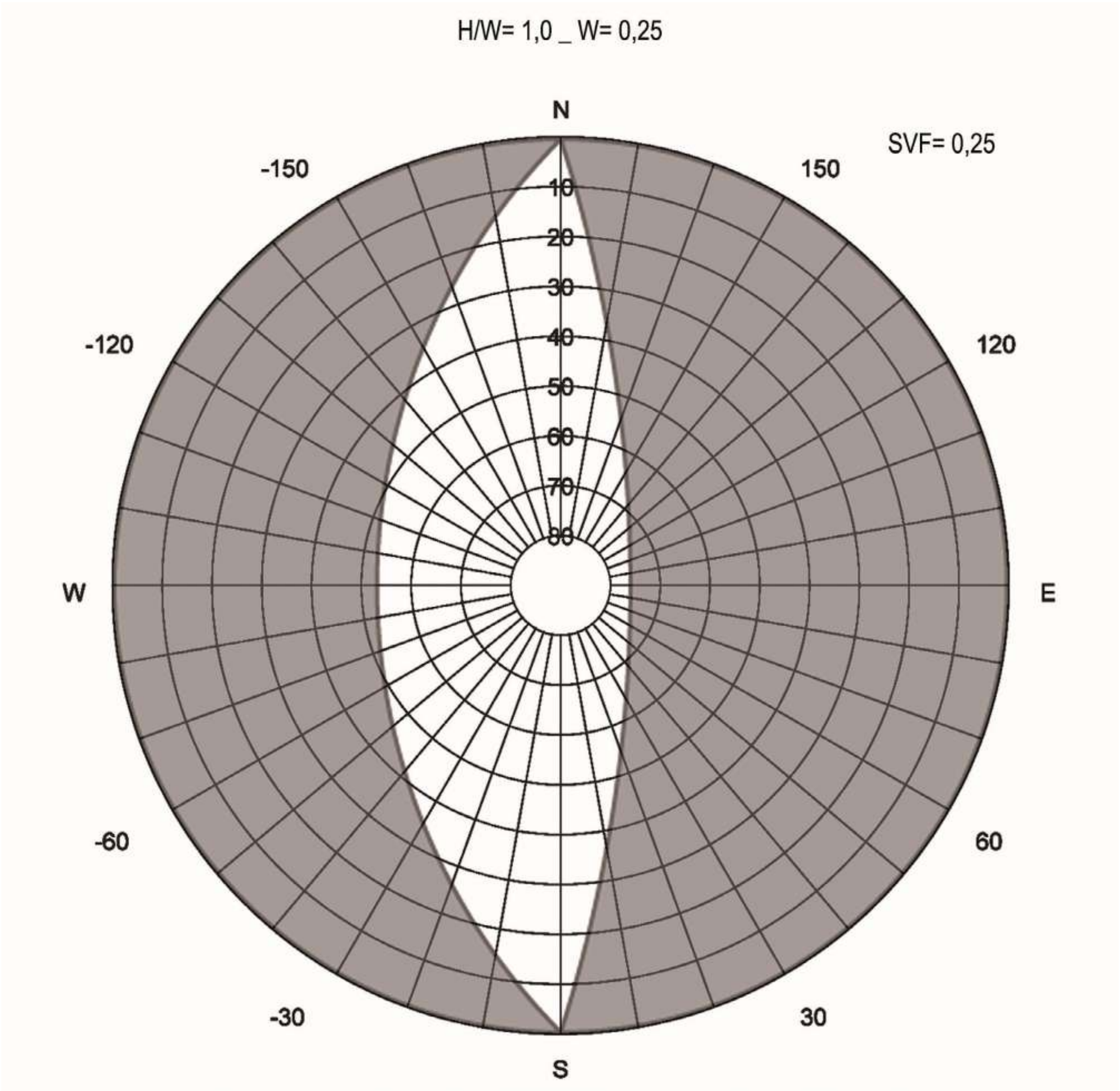
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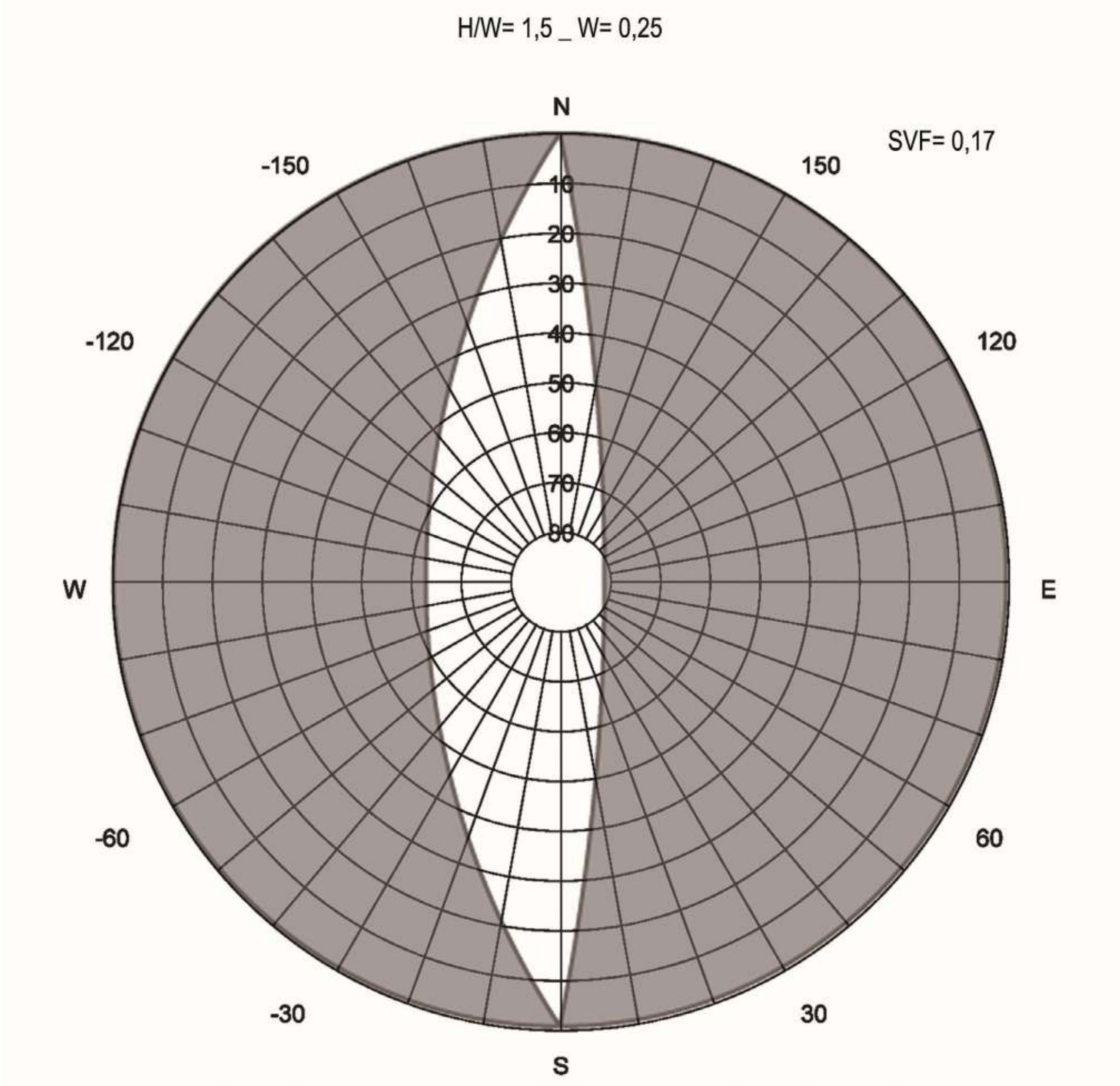
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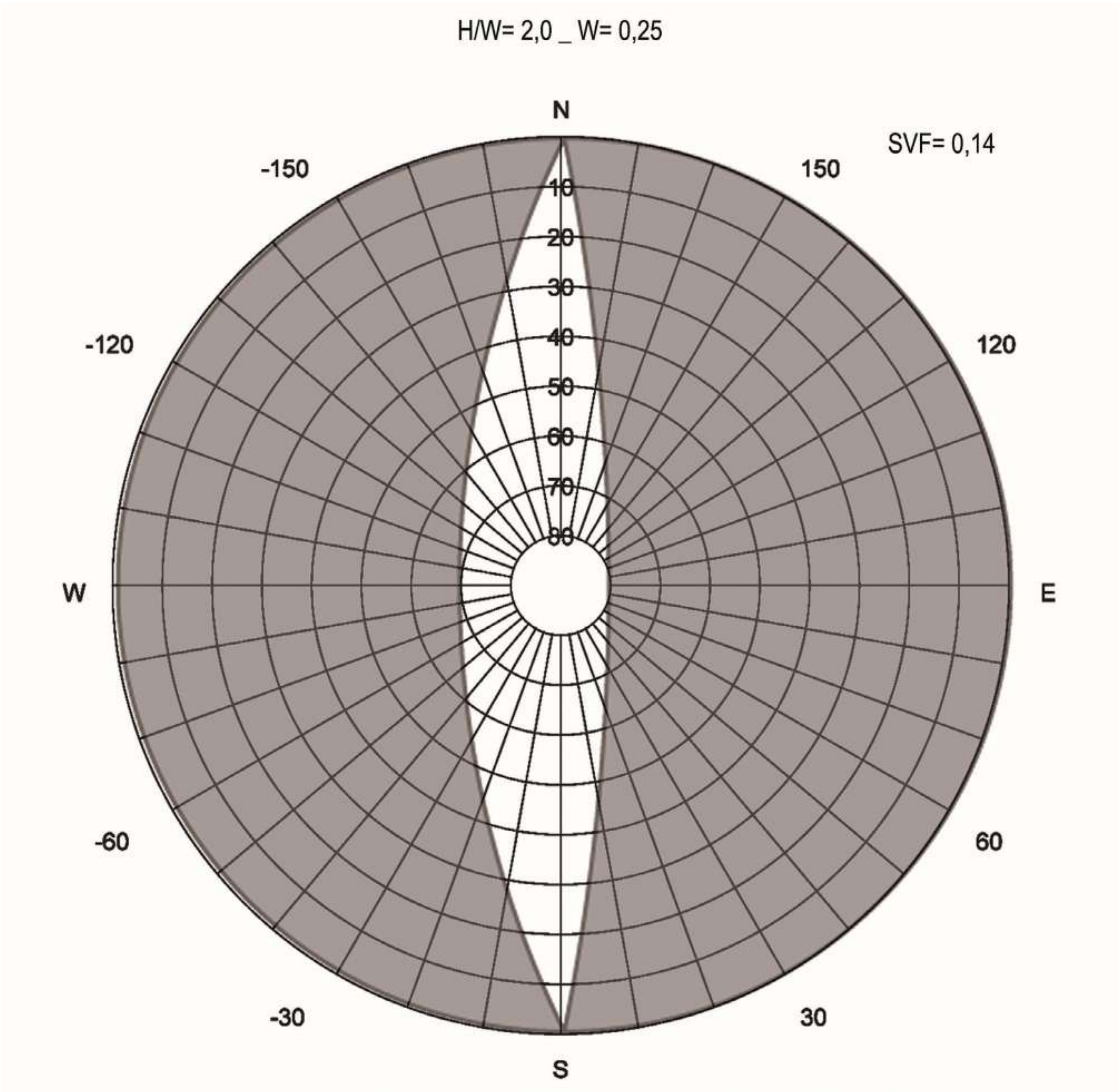
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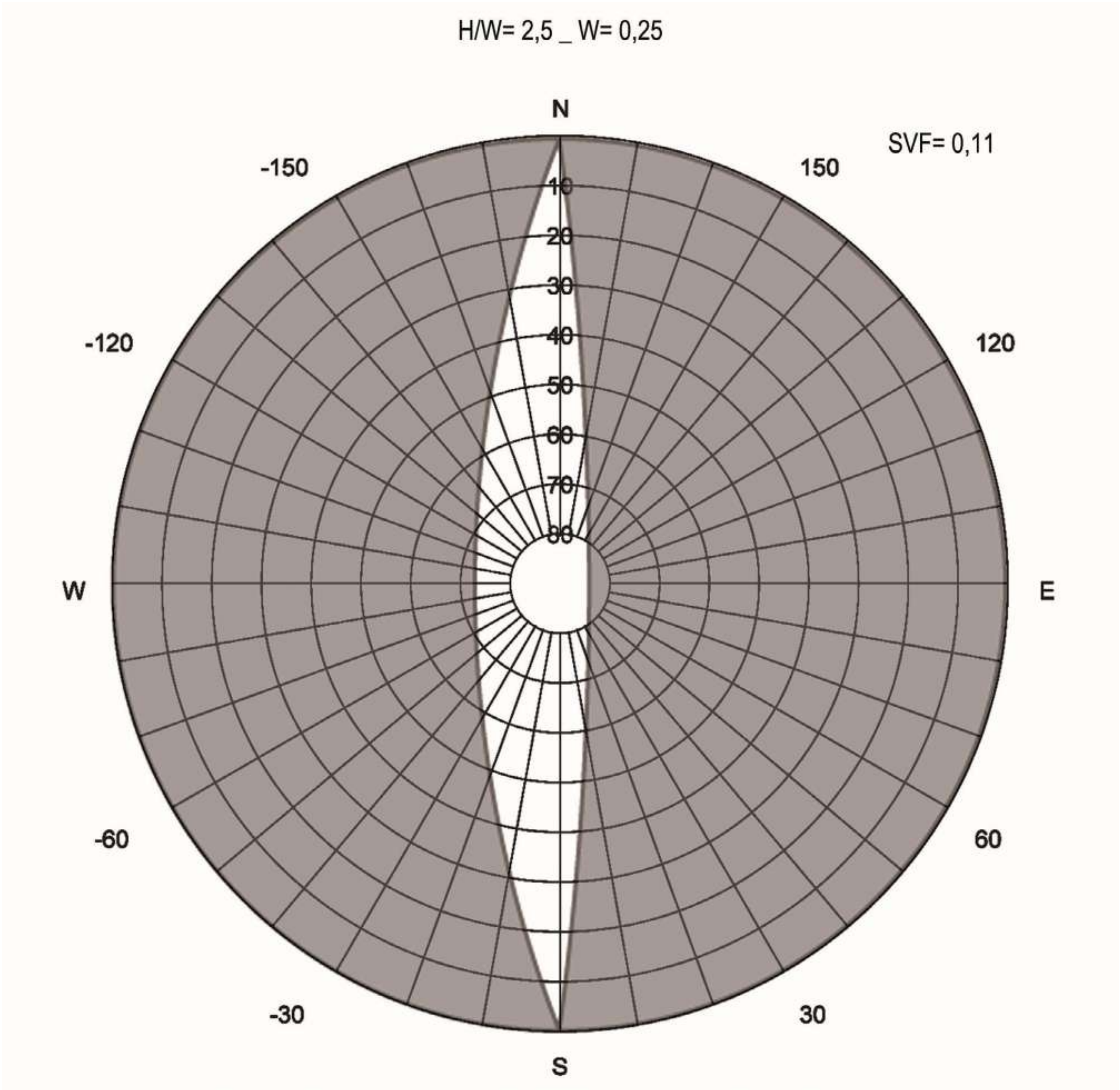
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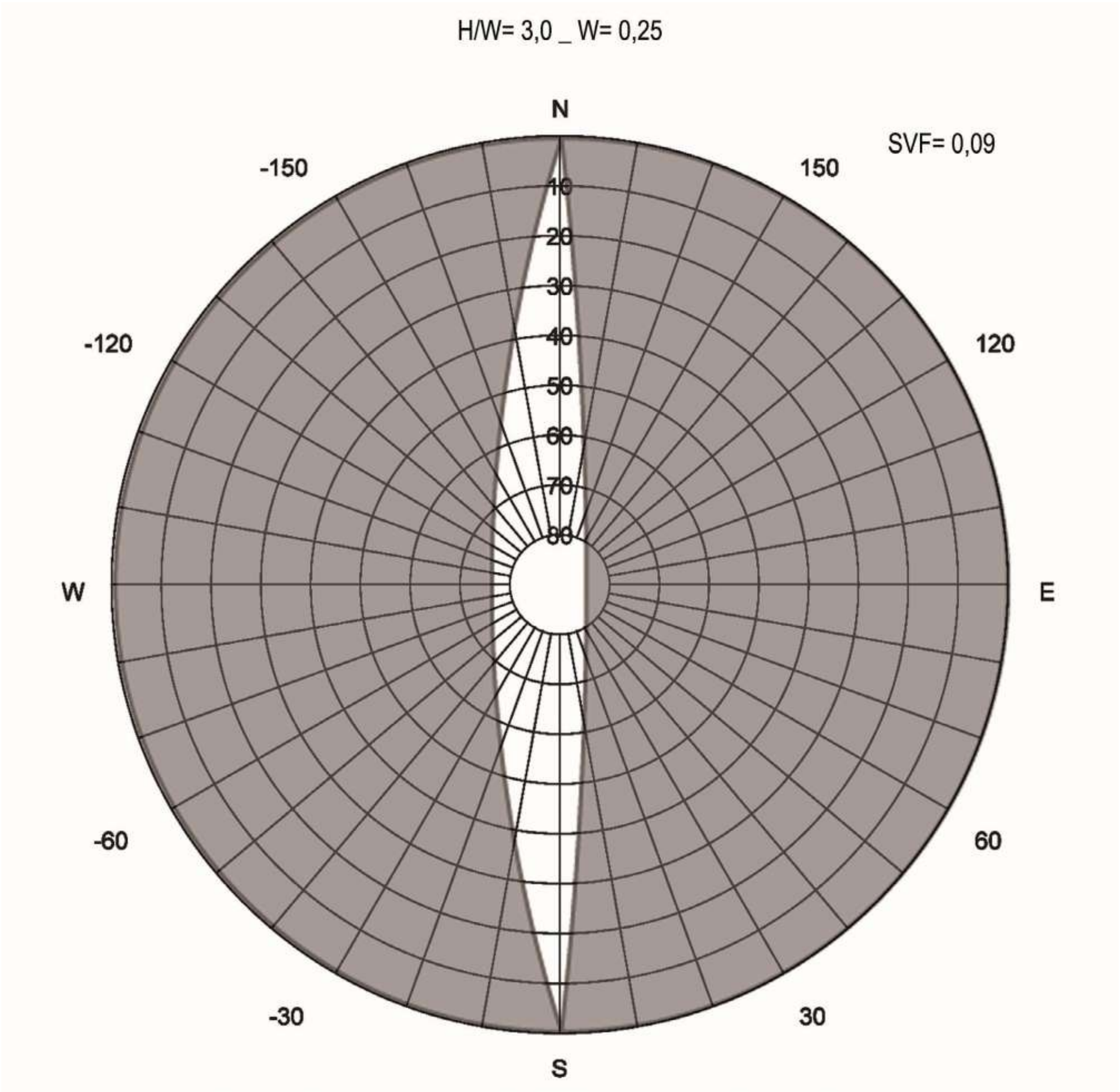
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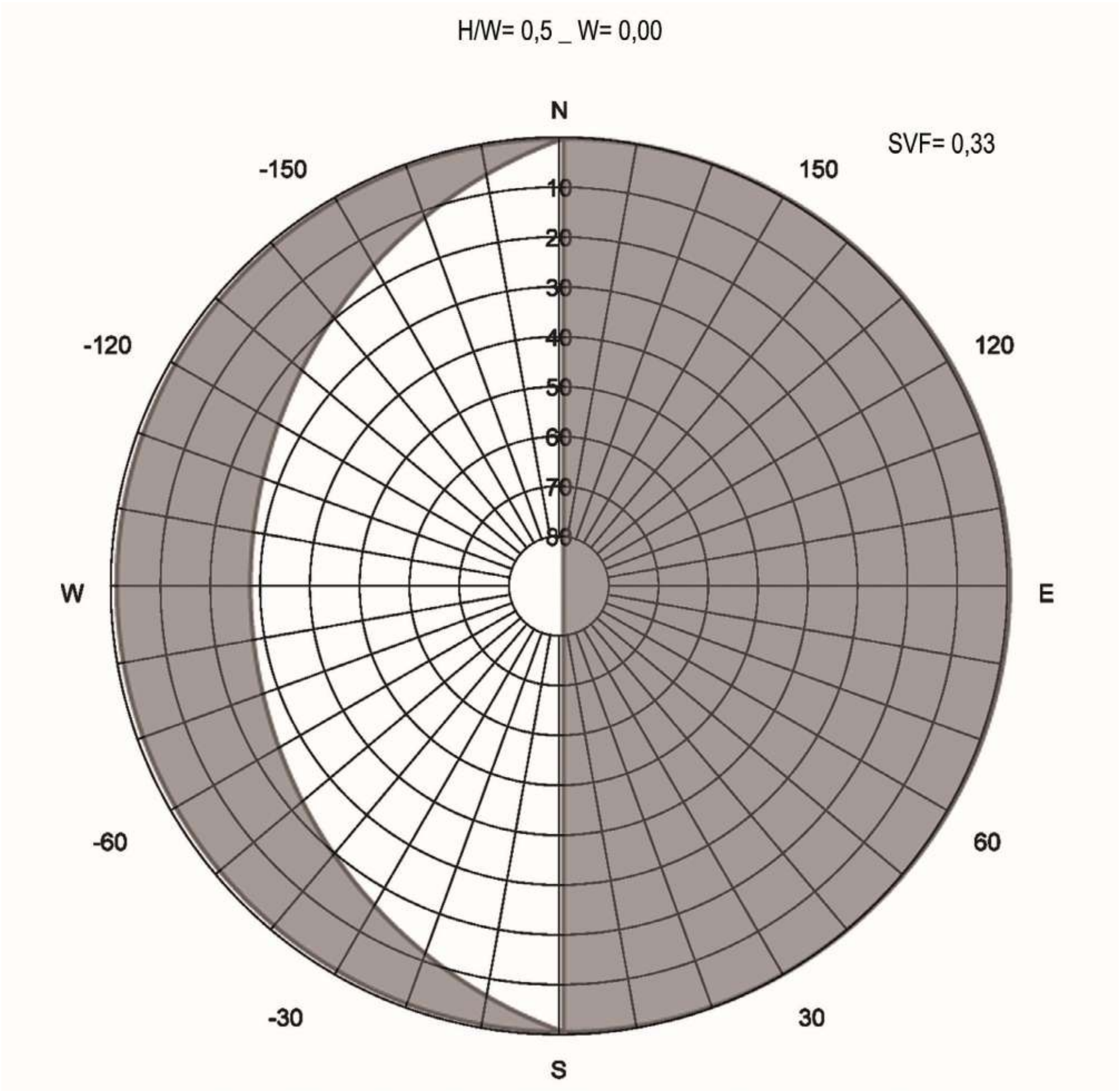
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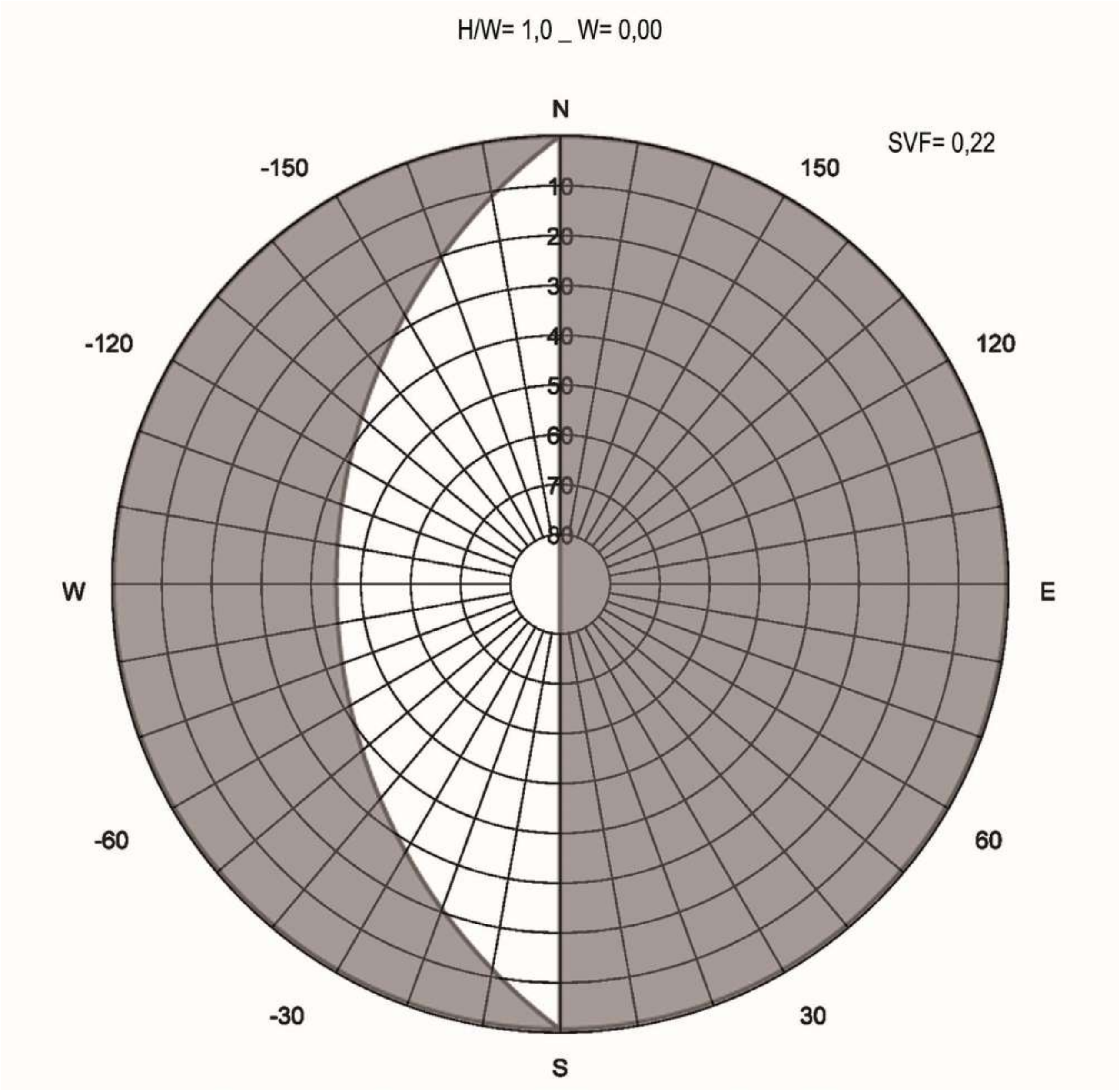
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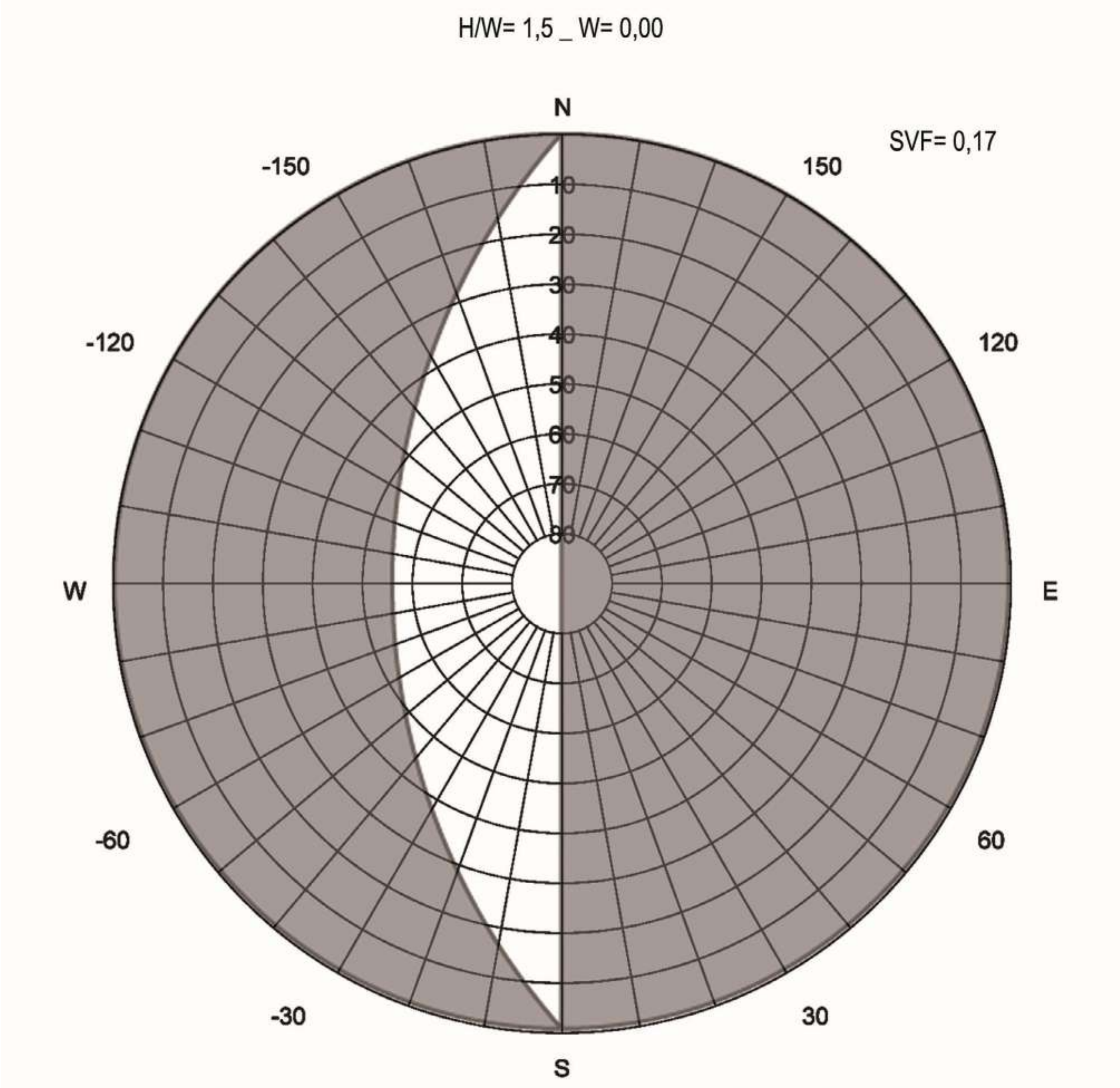
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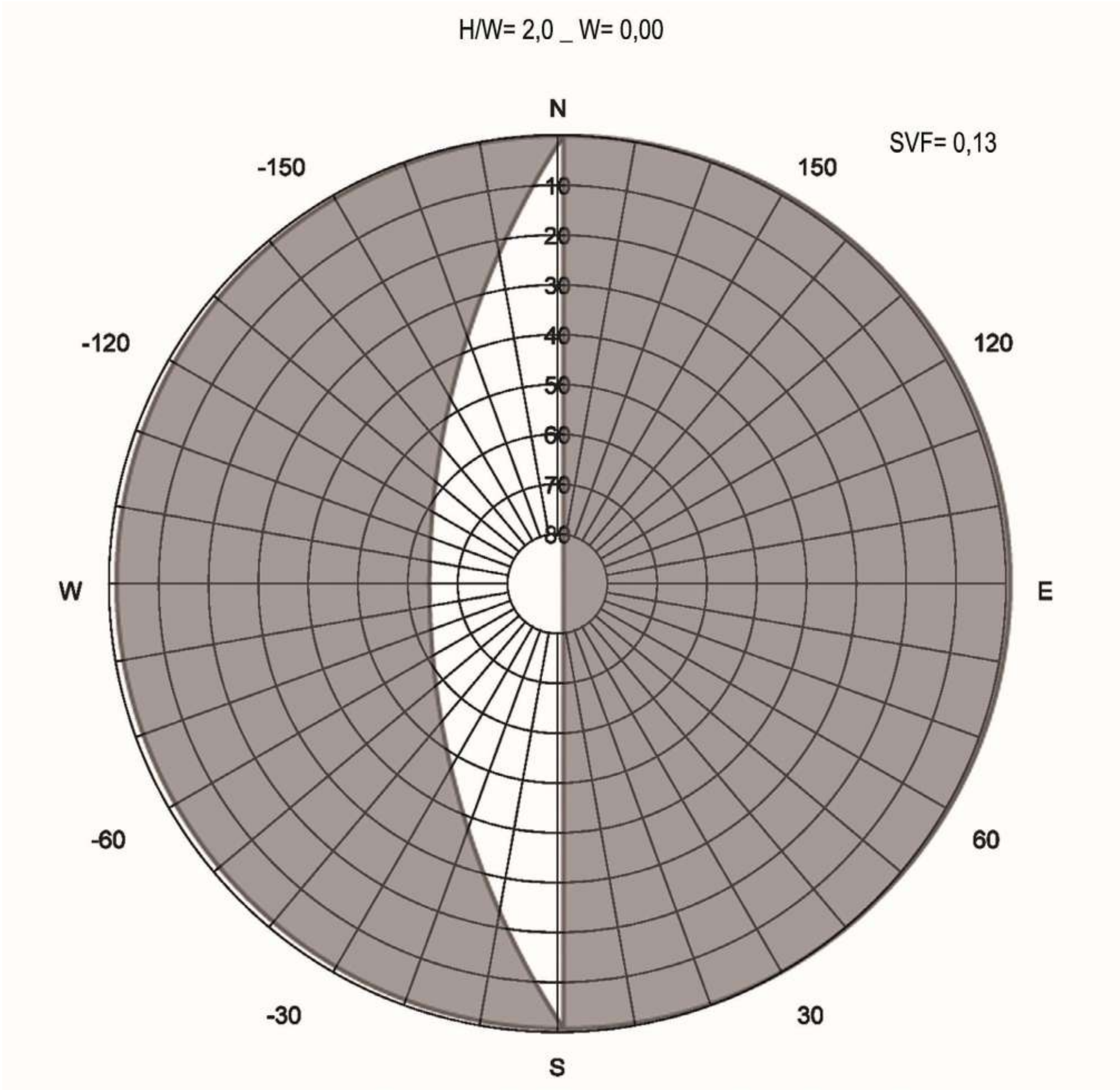
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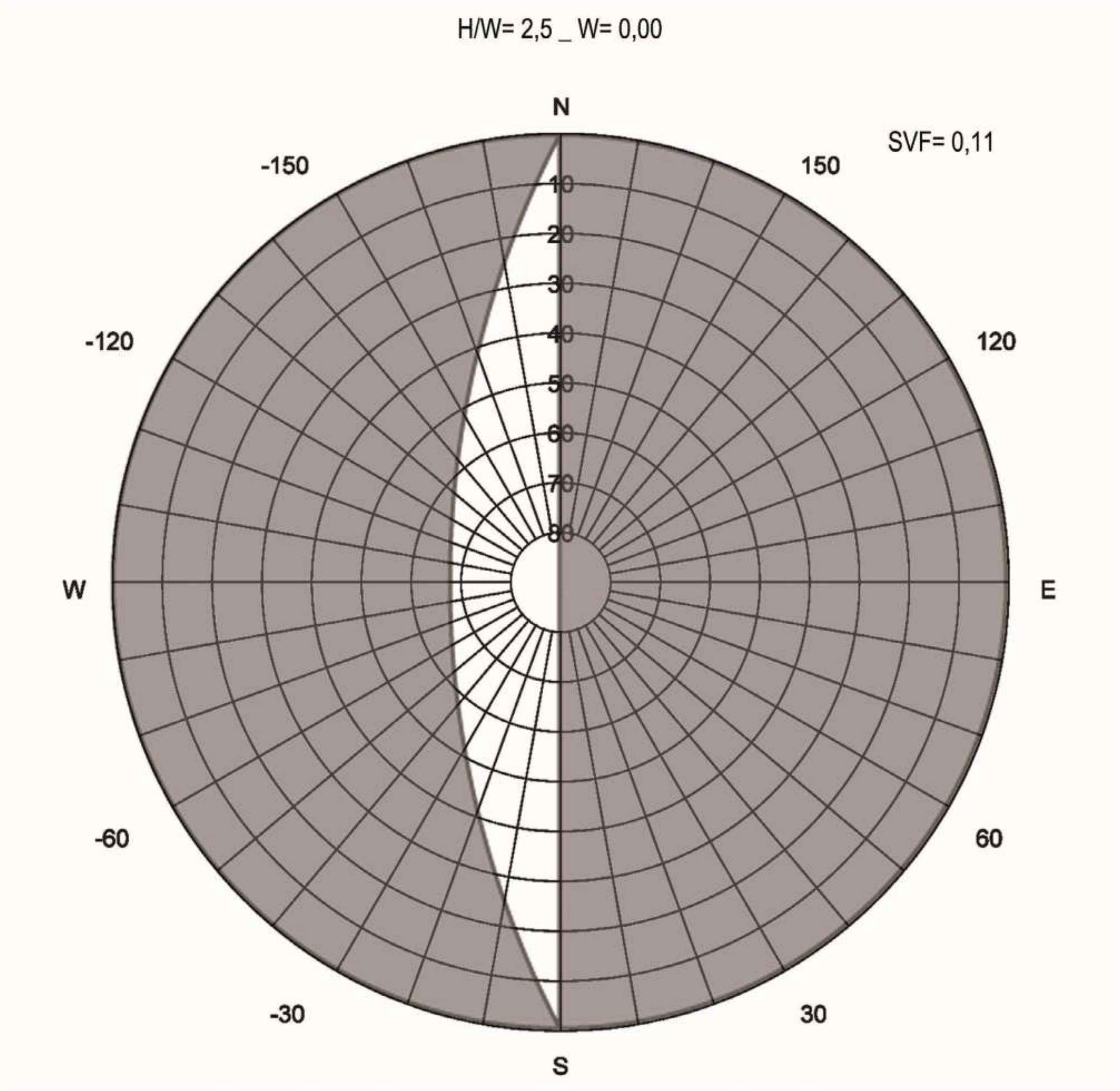
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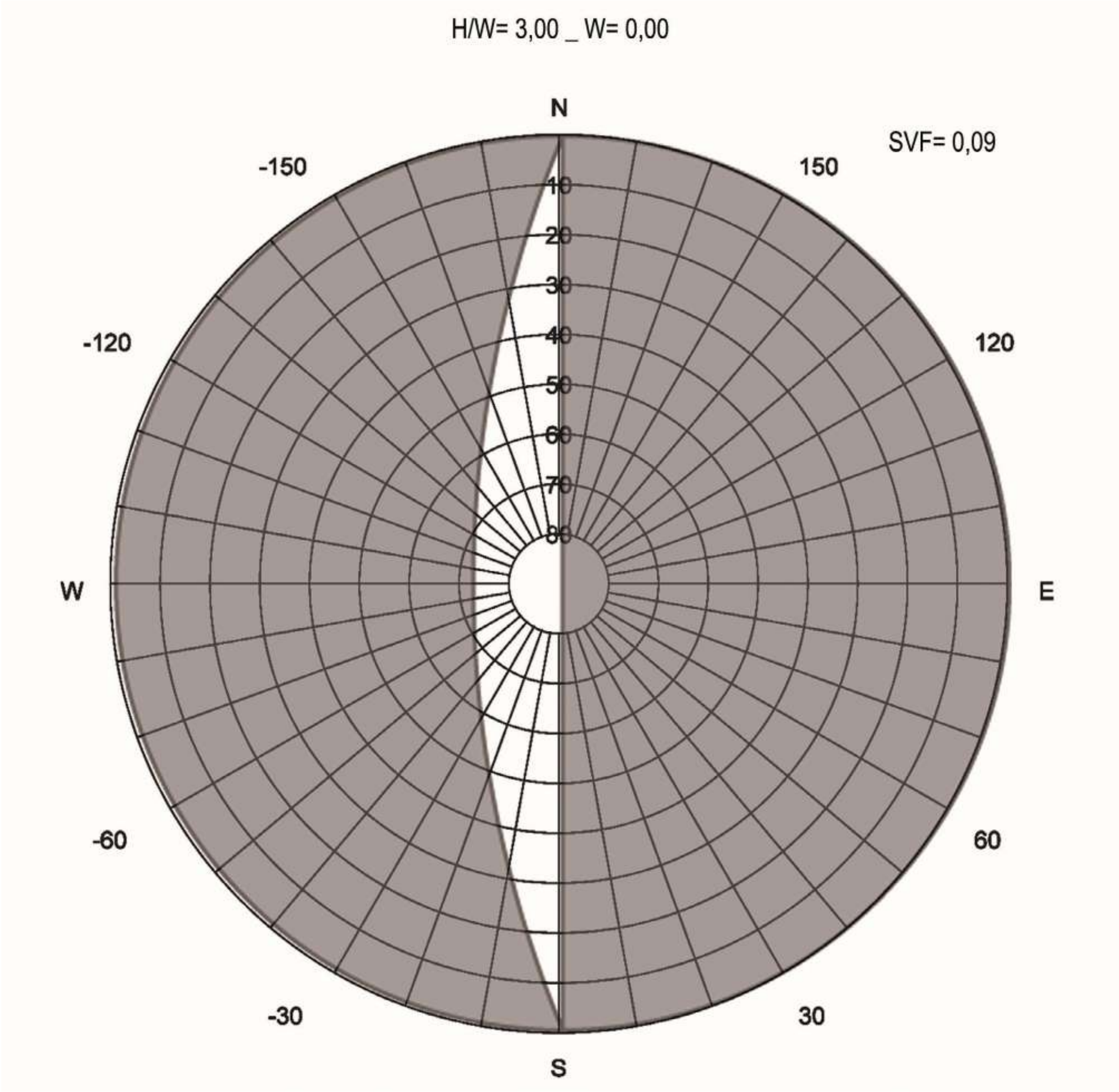
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# A4

# SHADOWING

## 1. EVALUATION OF SHADOWS

Solar exposure at a given point in an urban canyon can also be evaluated by overlapping the obstruction profiles and the polar sun chart of the location (diameters of the profile polar plot and of the polar sun chart must be the same).

The parts of the monthly sun paths that are inside the obstruction profiles correspond to the periods of the day in which the selected reference point is shaded (polar sun charts for latitudes between + 5 and - 11 are provided in Appendix 4a).

For example, overlapping the obstruction profile of the urban canyon examined in Figure A3.6, to the solar chart (Figure A4.1) of a location at 7° S latitude, it can be seen (Figure A4.2) that, in December, the centre canyon at ground level is in full sunshine from about 10:50 to about 13:40, and in all the other hours, in the morning and in the afternoon, is shaded.

In July the sunshine period is slightly different: from about 10:40 to about 13:30.

The sunshine and shadow hours for the same canyon for different orientations are obtained by rotating the canyon's obstruction profile accordingly, as shown in Figure A4.3, showing that for an orientation of 30° the full solar illumination hours of the middle canyon at ground level shift towards the morning between March and September and towards the afternoon between September and March; in an east-west oriented canyon, on the other hand, there is full solar illumination in all the hours of the day, except from May to July, when the middle of the canyon at ground level is always shaded.

A point in the middle of the asymmetric canyon whose obstruction profile is the one in Figure A3.7 will – in December – be in full sunshine only from about 11:40 to about 13:10 (Figure A4.4).

Different results will be found when overlapping the profile to polar sun charts of different latitudes.

The procedure is not limited to urban canyons, but can be applied to any urban scheme provided that an obstruction profile is available, as shown in Figure A4.5, which uses the profile of the courtyard in Figure A3.10.

It can be seen that, if the long axis of the courtyard is oriented N-S the centre point at ground level is fully illuminated by the sun from about 10:30 to about 13:30 in all months of the year; otherwise, if it is rotated 90° (long axis E-W), from the end of April to the beginning of August the point is fully shaded, while in all the other months it is fully illuminated form about 9:30 to about 14:40.

Applying the above described method to two locations in the EAC, Dar es Salaam in Tanzania (lat. 7°S) and Lodwar in Kenya (lat. 3°N), an analysis of the solar exposure of a canyon in relation to aspect ratio and orientation can be carried out quite easily, as shown in Figures A4.6 and A4.7.

## 2. SOLAR PROTECTION OF CANYON WALLS

Even if the contribution of the solar radiation reflected by the walls onto the canyon floor is smaller than that of direct radiation, it is advisable to reduce it as much as possible, as it influences outdoor comfort and heat flux towards the inside of the building because it also heats up the walls.

At low latitudes, facades can be protected from direct solar radiation quite easily by taking advantage of the fact that the angle of incidence of the sun's rays is always high, as it is for north-south deep and narrow canyons also, as the walls are fully exposed to the sun only in the hours close to noon.

In these conditions, horizontal overhangs, appropriately dimensioned and spaced along the height of the wall, can protect it very effectively from exposure to the sun.

The procedure for determining the dimensions of the overhangs is based on the same obstruction profile construction used for urban canyons (see above), as in the following example.

FIGURE A4.1 **POLAR SUN CHART FOR 7° S LATITUDE.**

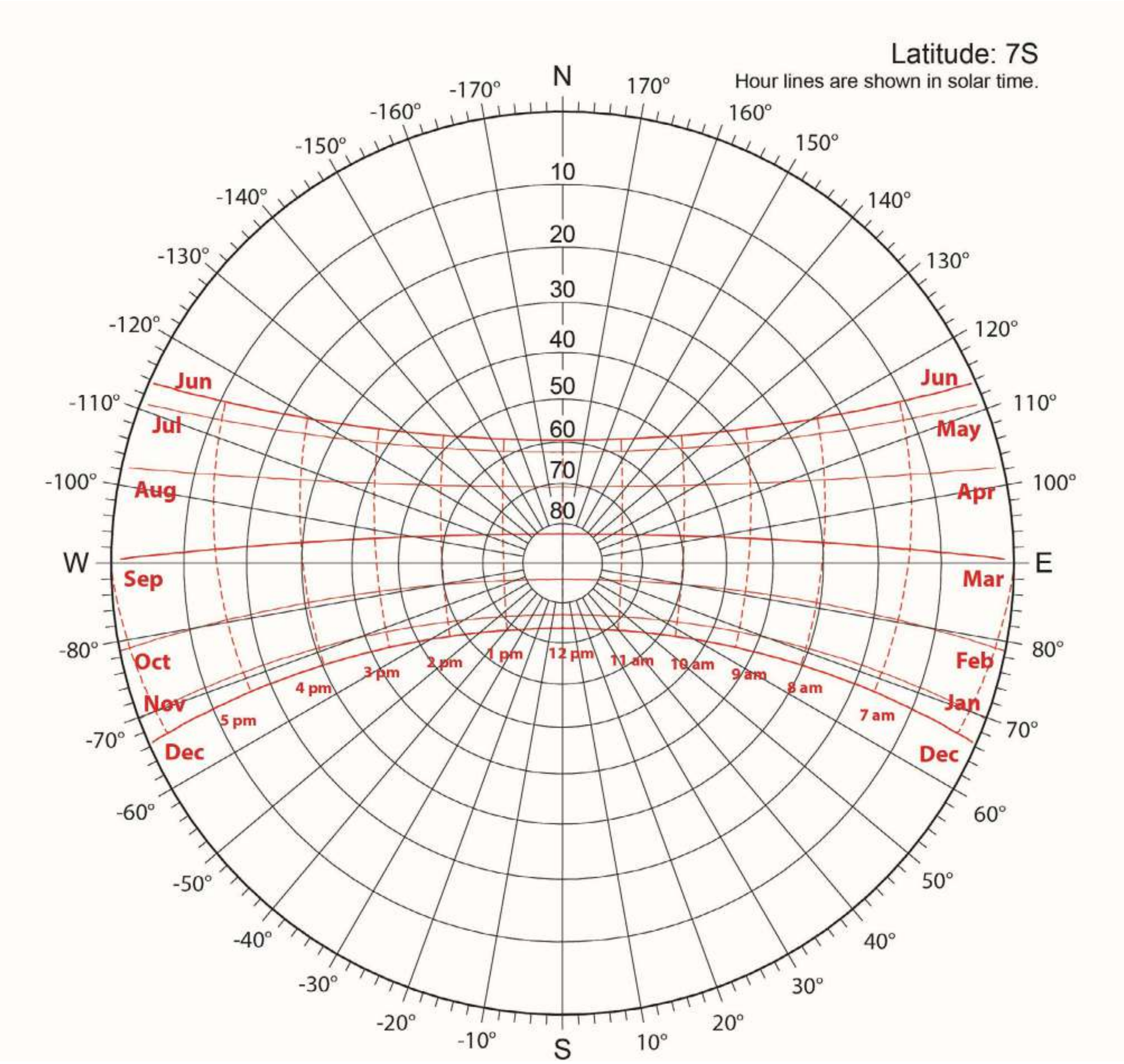


FIGURE A4.2 **SUNSHINE AND SHADOW HOURS AT A POINT AT GROUND LEVEL, IN THE MIDDLE OF THE SYMMETRICAL CANYON IN FIGURE A3.5.**

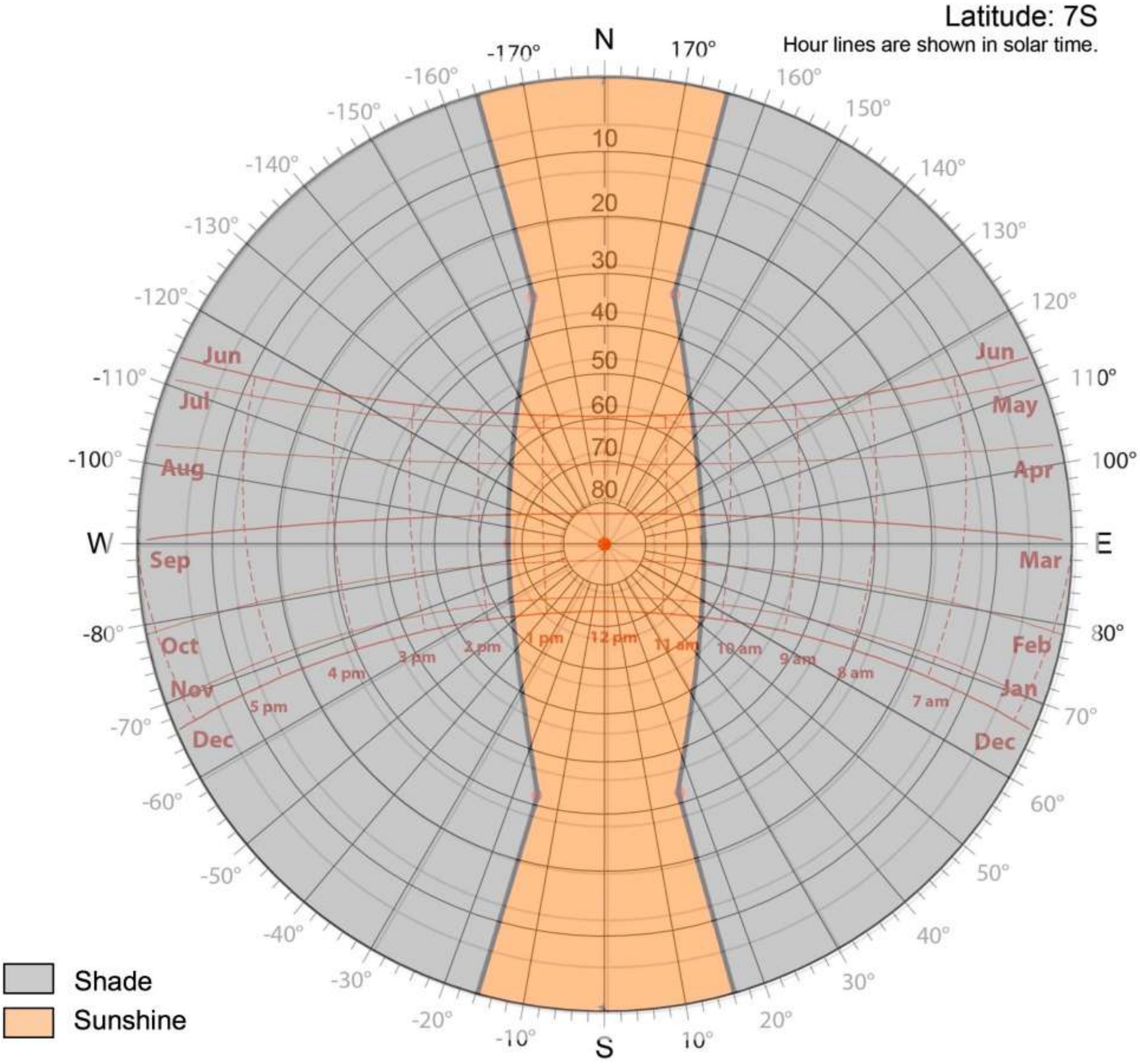


FIGURE A4.3 **SUNSHINE HOURS, AT A POINT AT GROUND LEVEL, IN THE MIDDLE OF THE NNE AND E-W ORIENTED SYMMETRICAL CANYON IN FIGURE A3.6.**

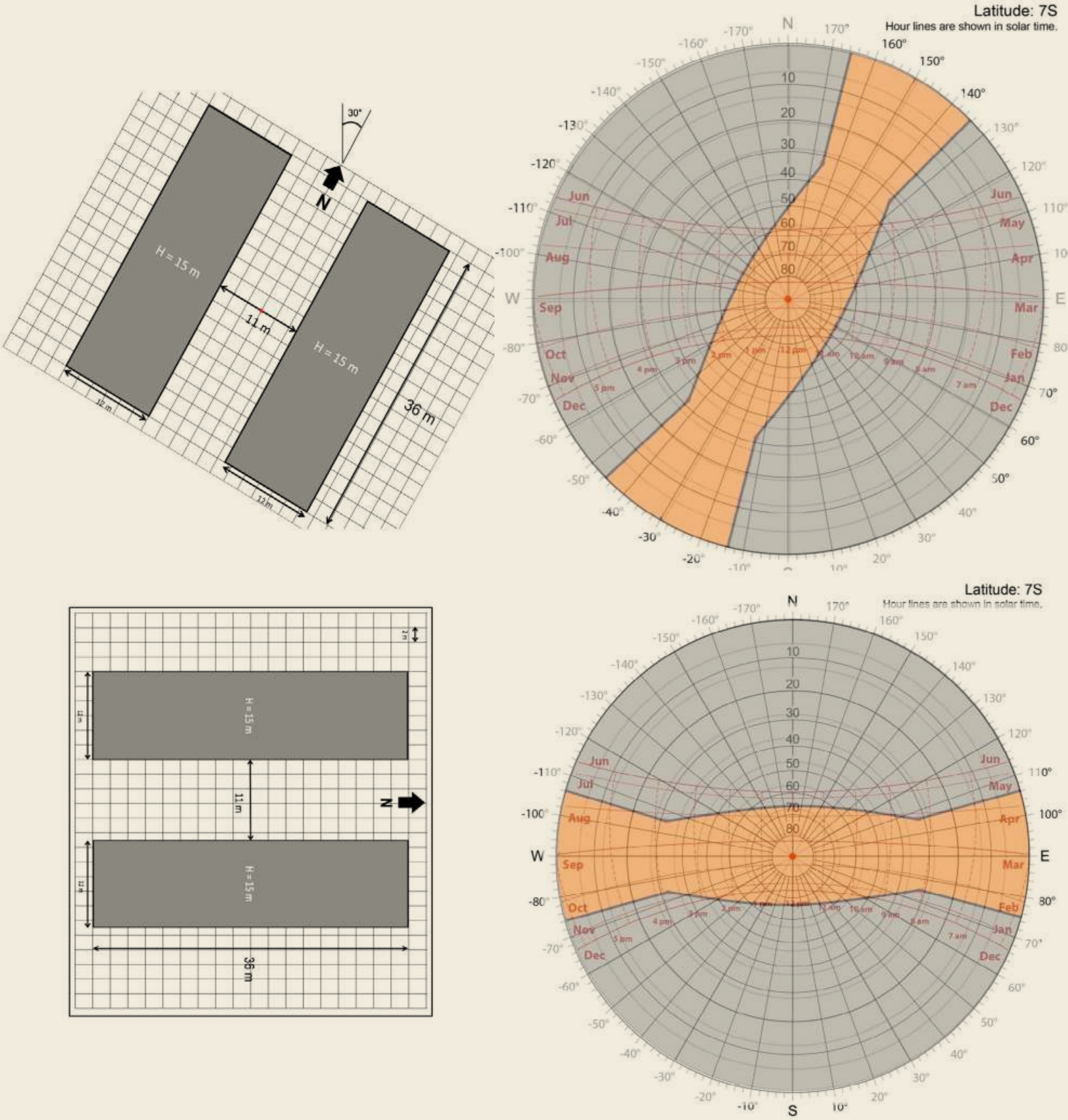


FIGURE A4.4 **SUNSHINE HOURS AT A POINT AT GROUND LEVEL, IN THE MIDDLE OF THE ASYMMETRICAL URBAN CANYON IN FIGURE A3.7.**

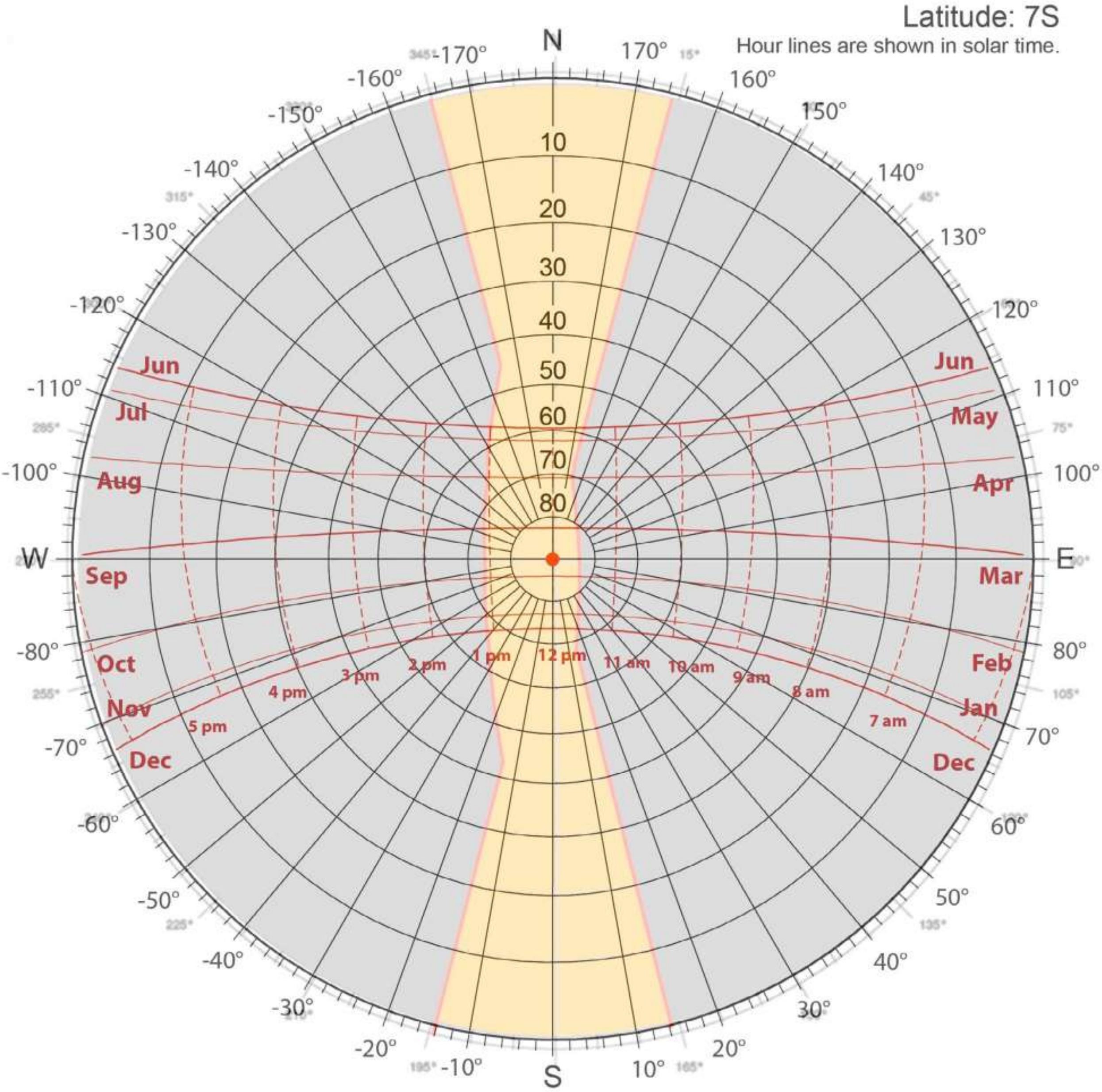


FIGURE A4.5 **OBSTRUCTION PROFILES OF THE COURTYARD IN FIGURE 3.10 OVERLAID ONTO THE SUN CHART, FOR TWO CASES: LONG AXIS N-S AND LONG AXIS E-W.**

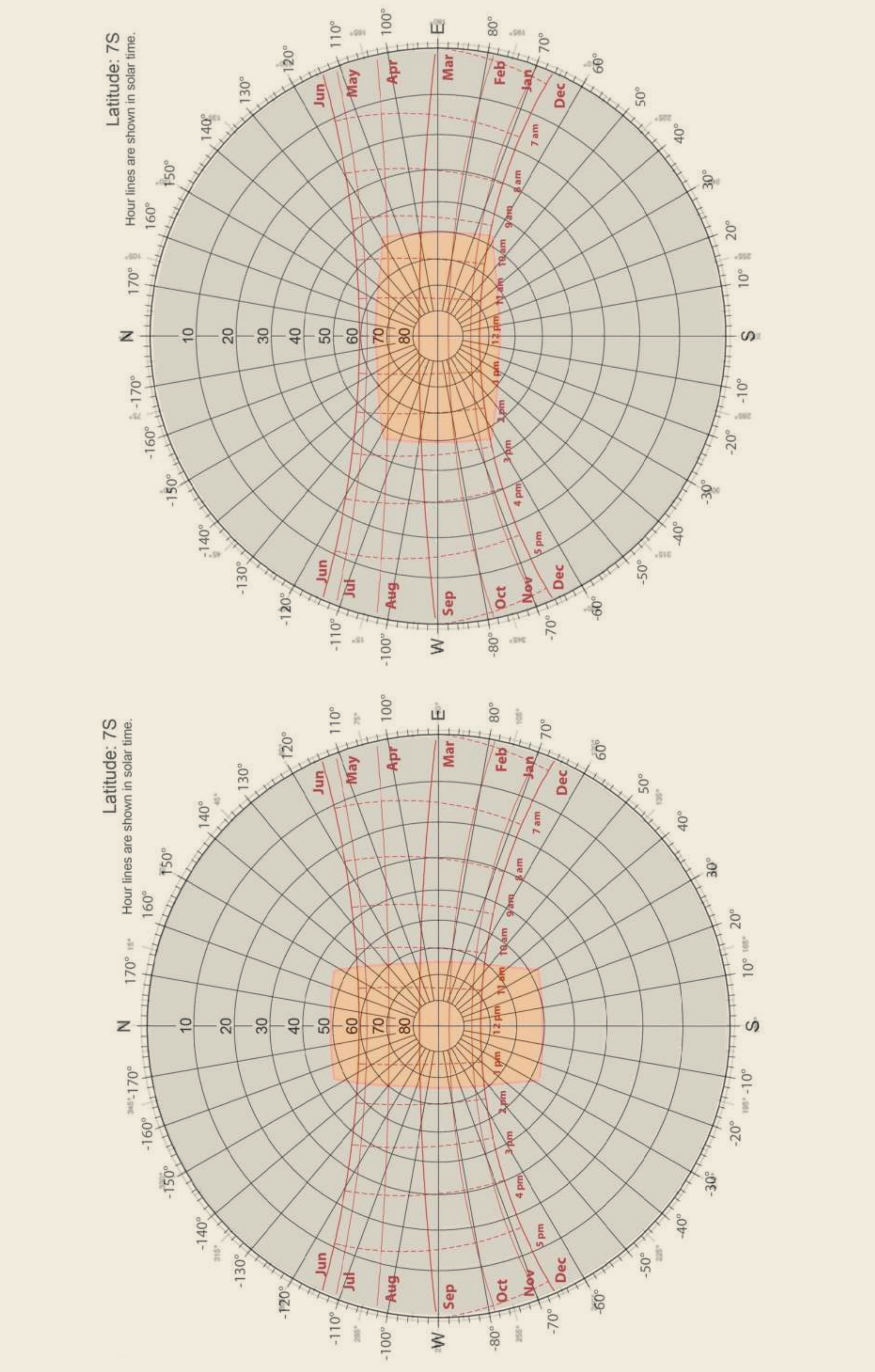


FIGURE A4.6 **SOLAR EXPOSURE OF A POINT ON THE FLOOR OF AN URBAN CANYON, IN THE CENTRE, AS A FUNCTION OF ITS ASPECT RATIO H/W AND ORIENTATION, AT THE LATITUDE OF DAR ES SALAAM, TANZANIA (≈ 7°S).**

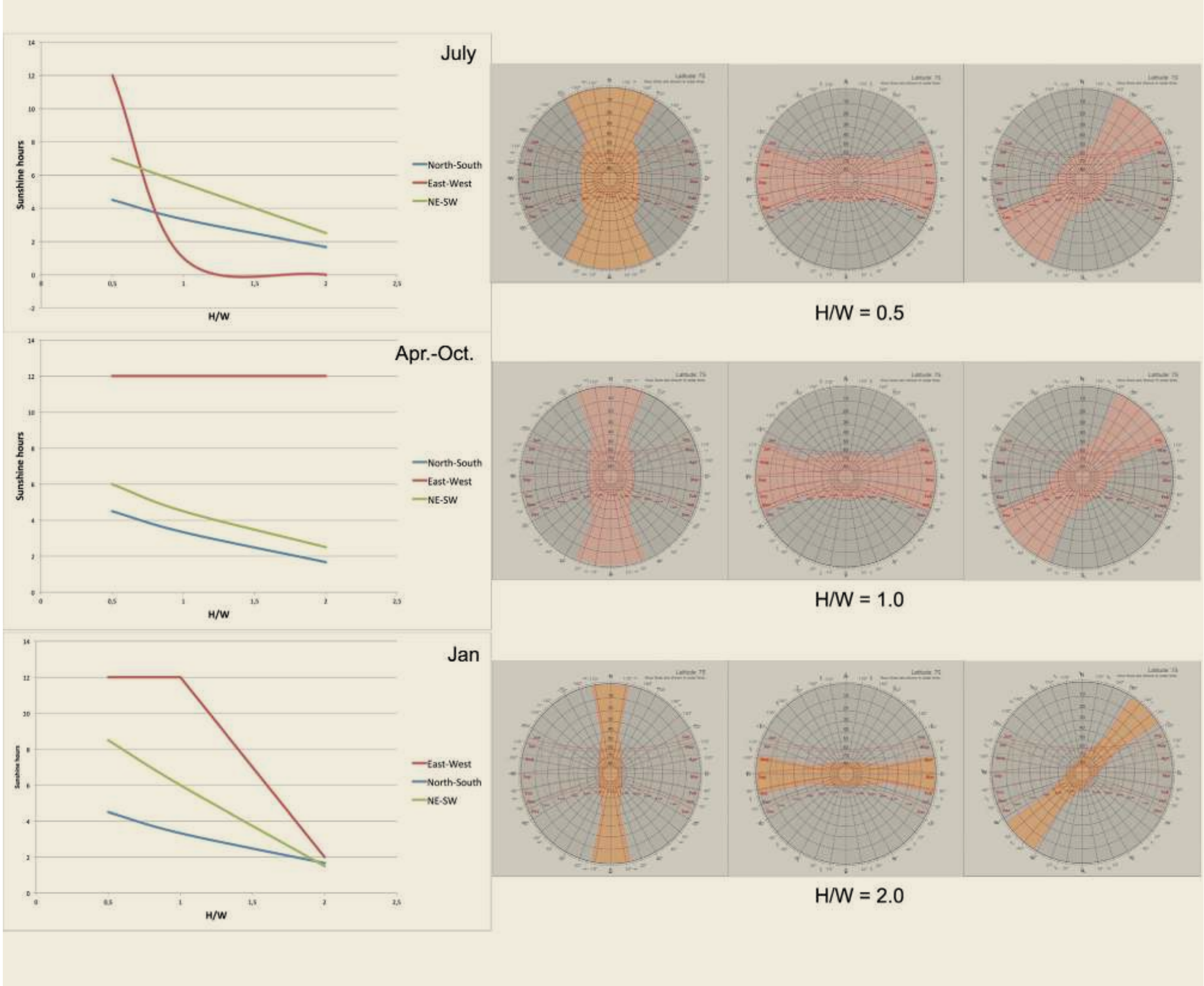
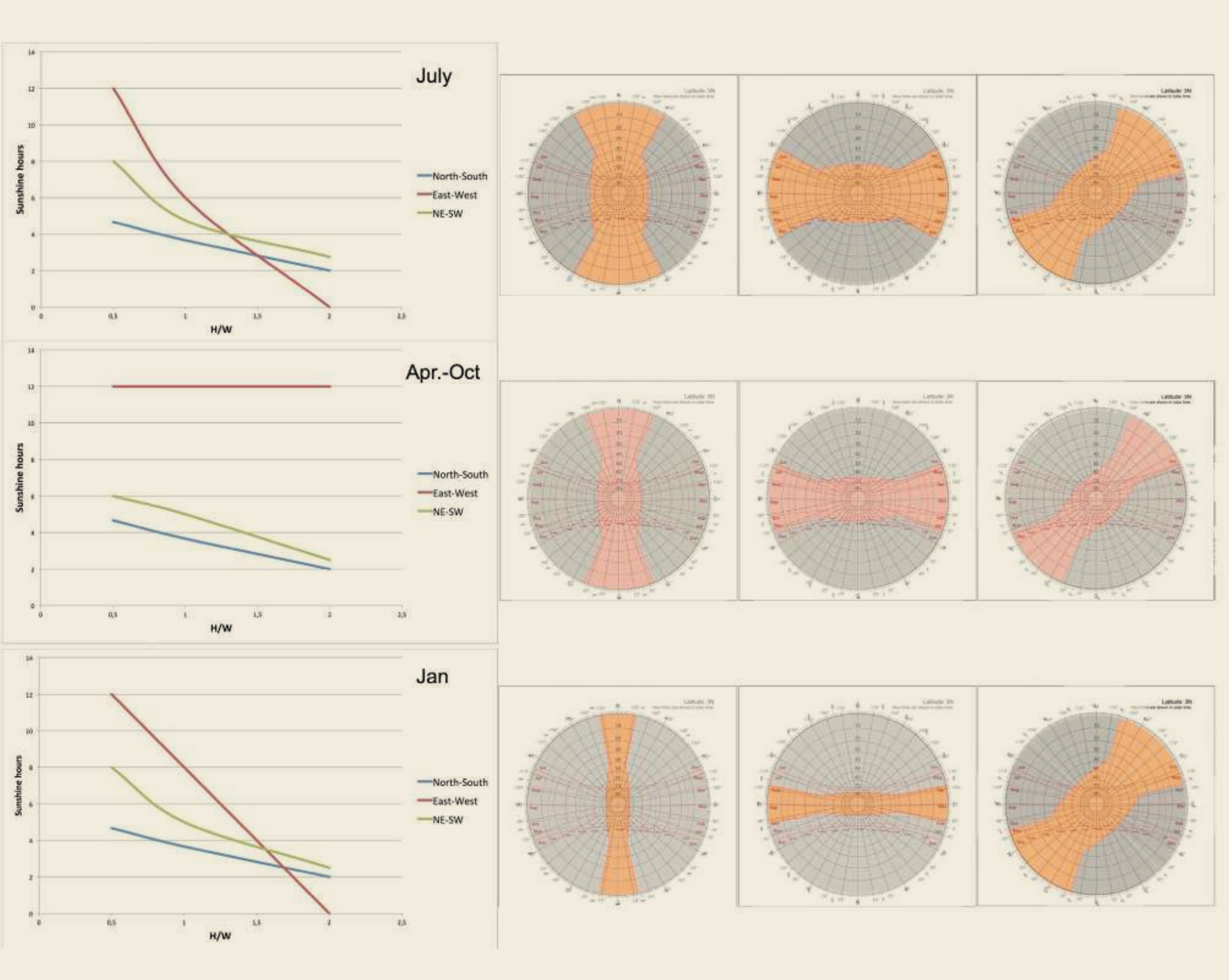


FIGURE A4.7 **SOLAR EXPOSURE OF A POINT ON THE FLOOR OF AN URBAN CANYON, IN THE CENTRE, AS A FUNCTION OF ITS ASPECT RATIO H/W AND ORIENTATION, AT THE LATITUDE OF LODWAR, KENYA (≈ 3°N)**



Let us suppose that we want the north facing wall of an east-west oriented canyon, H/W = 1.5, to be fully shaded at any time of the day and of the year, in a location at 7 S latitude, such as Dar es Salaam.

When we construct the obstruction profile from a point at the base of the north facing wall and superimpose it on the polar solar chart, it can be seen (Figure A4.8) that this point is shaded the whole day through from 21st September to 21st March (the sun is in behind it, in the southern quadrant) and it is exposed to the sun almost all day from 22nd March to 20th September.

To obtain complete[44] shadowing, the part of the sky seen from the selected point, represented in the polar plot by the area below the line β = 56.3° (Figure A4.9), should be obstructed. In this way the sun would always be behind the obstruction and, consequently, the point would be fully shaded. If this point is fully shaded, so are all the points above it, along the height of the wall.

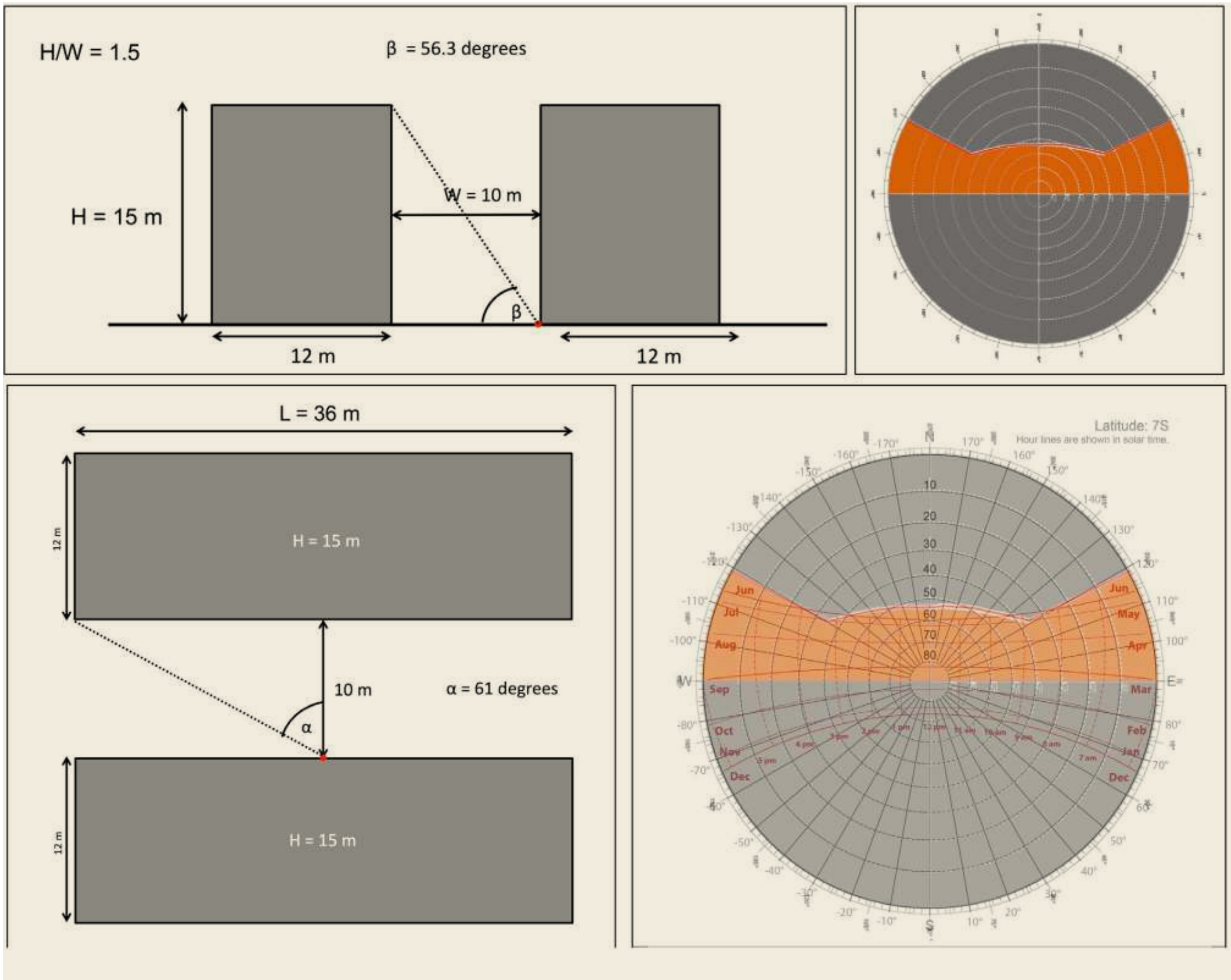
Such an obstruction can be obtained with a horizontal overhang, whose profile is the one shown in Figure A4.10 (top right), with a ratio h/w = 1.5. A single overhang should thus be 10 m, if the building height is 15 m, i.e. it should cover the entire canyon, which is obviously impractical; but the same full shadowing of the entire wall is obtainable with 2 m wide overhangs spaced 3 m apart or with 1 m wide overhangs spaced 1.5 m apart (Figure A4.10, below) these, are more reasonable propositions.

The final result of such an approach (see Figure A4.9) is the shadowing of the north facing wall of the canyon increasing from a minimum of five hours (9:30 - 14:30) in June to almost all day in March and September.

---

[44] *In fact, it will be more or less complete according to the ratio of the canyon length to its width*

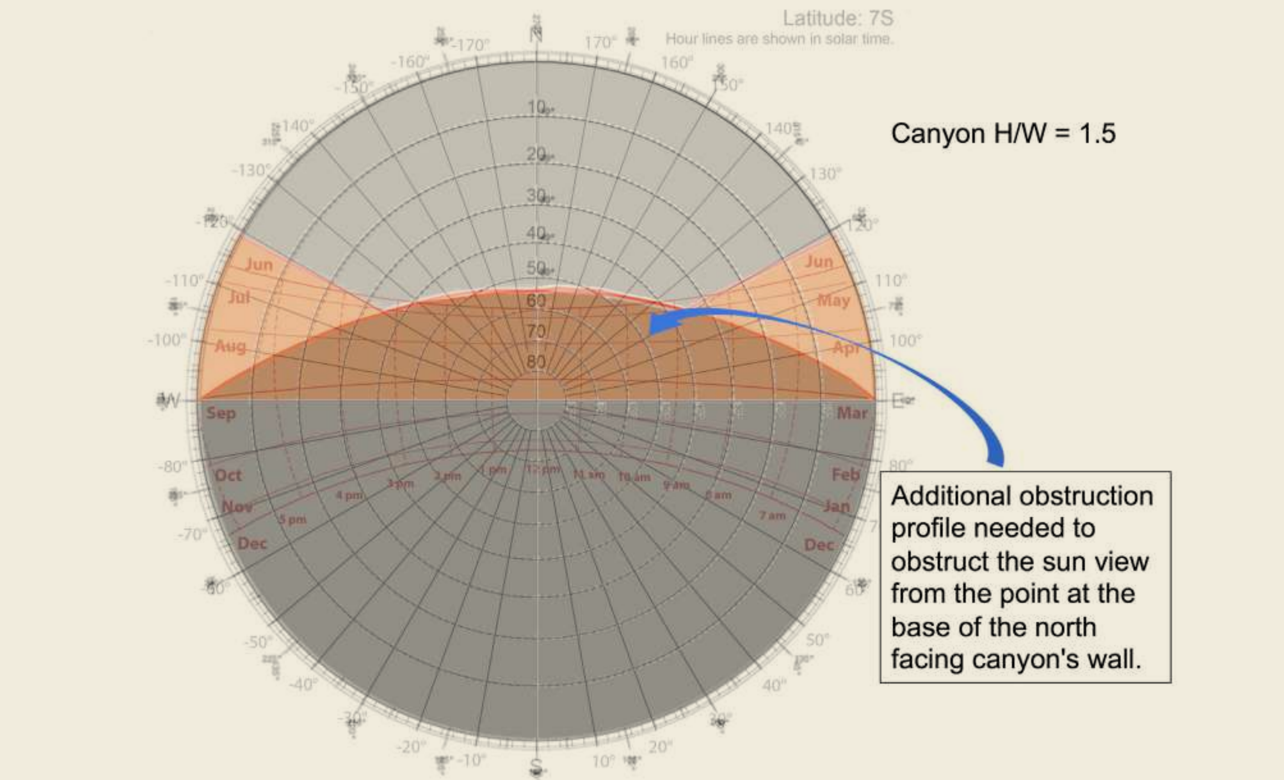
FIGURE A4.8 **OBSTRUCTION PROFILE OF THE NORTH WALL OF A H/W = 1.5 CANYON, AS SEEN FROM A POINT AT THE BASE OF THE OPPOSITE WALL, AT THE CENTRE OF THE CANYON LENGTH (TOP RIGHT), SUPERIMPOSED ON THE POLAR SUN CHART AT A LOCATION OF 7 S LATITUDE, SUCH AS DAR ES SALAAM.**



It can also be noted that:

1. The latter solution (1m wide overhang) would also have the advantage – compared with the 2m wide overhang – of a limited SVF reduction, thus only impairing the infrared emissions a little, but the former (2 m wide) has the advantage that the overhang can be used as a balcony floor.
2. At tropical latitudes the use of overhangs to shade the canyon walls would allow the use of largely glazed facades, as they would not reflect solar radiation, being protected most of the time.
3. The same approach can be used for the south-facing wall of the canyon; the overall solar protection effect on both sides is shown in Figure A4.11.

FIGURE A4.9 **MODIFICATION OF THE OBSTRUCTION PROFILE FOR OBTAINING FULL SHADING OF THE NORTH-FACING WALL OF AN EAST-WEST AXIS CANYON AT 7 S LATITUDE**



Additional obstruction profile needed to obstruct the sun view from the point at the base of the north facing canyon's wall.

FIGURE A4.10 **OVERHANG PROFILE CONSTRUCTION AND SIZING**

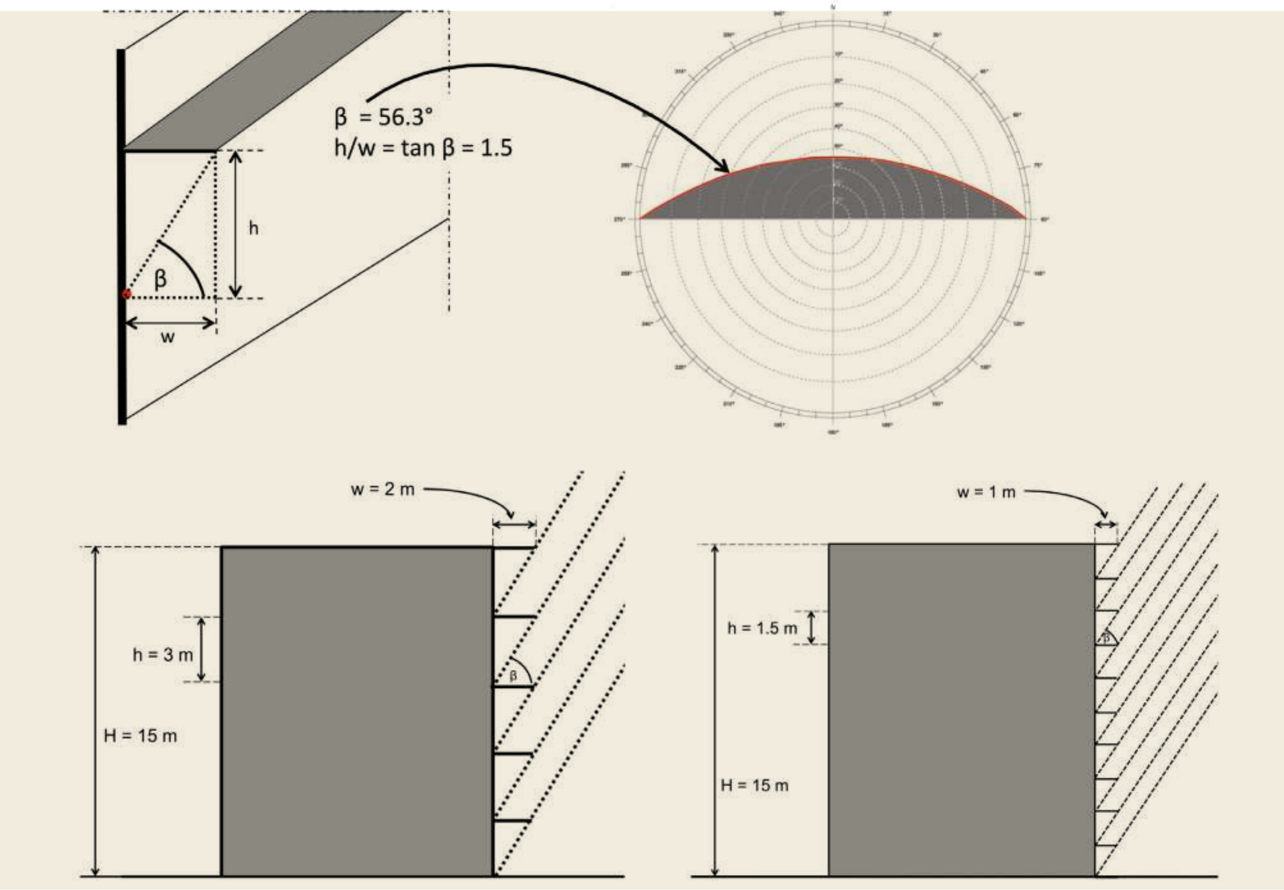
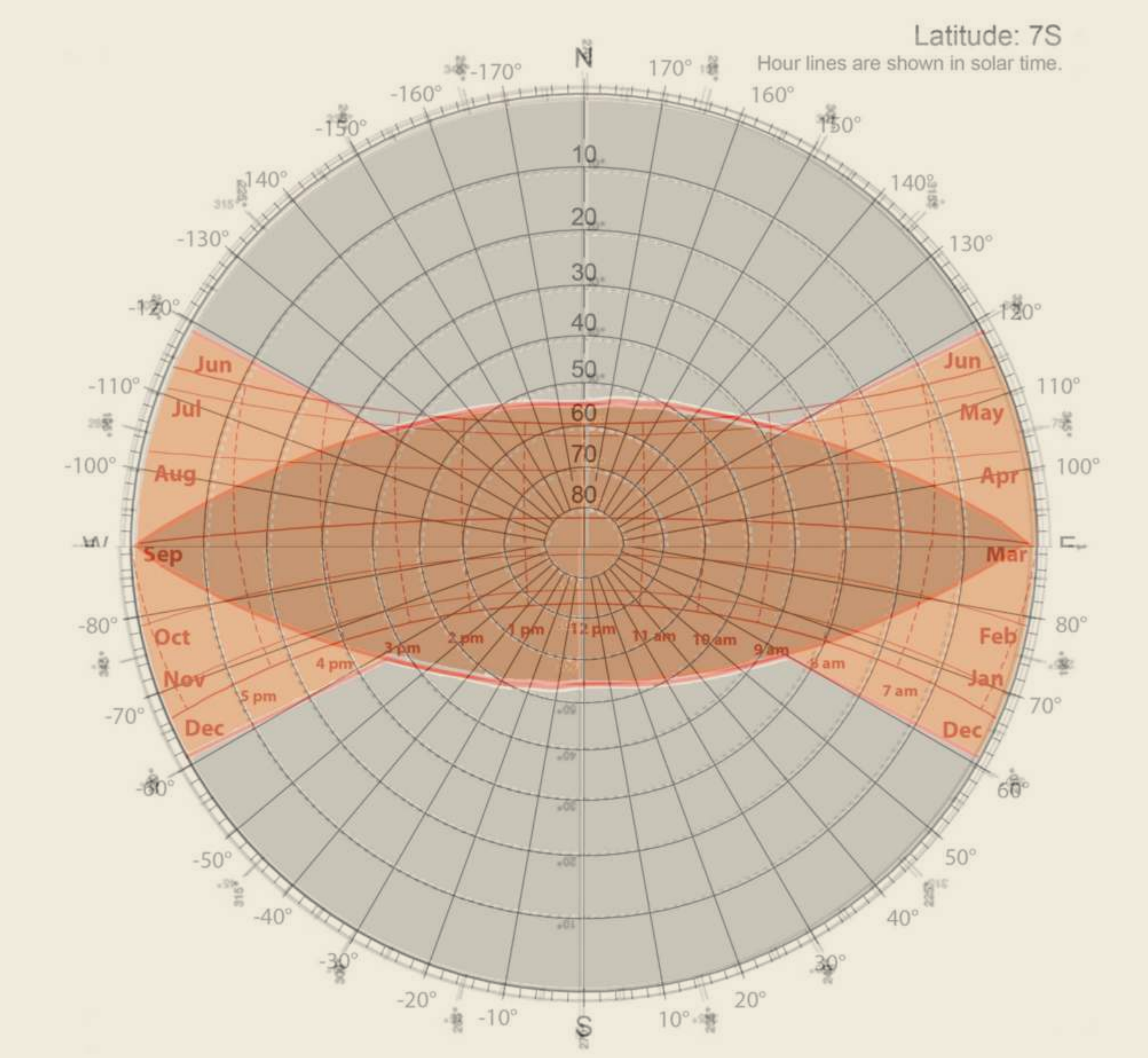


FIGURE A4.11 **SHADOWING EFFECT ON NORTH AND SOUTH FACING WALLS OF A H/W = 1.5 CANYON, EAST-WEST ORIENTED, OBTAINED WITH OVERHANGS 1 M WIDE, SPACED 1.5 METRES APART.**



## 3. SOLAR PROTECTION OF WALKWAYS

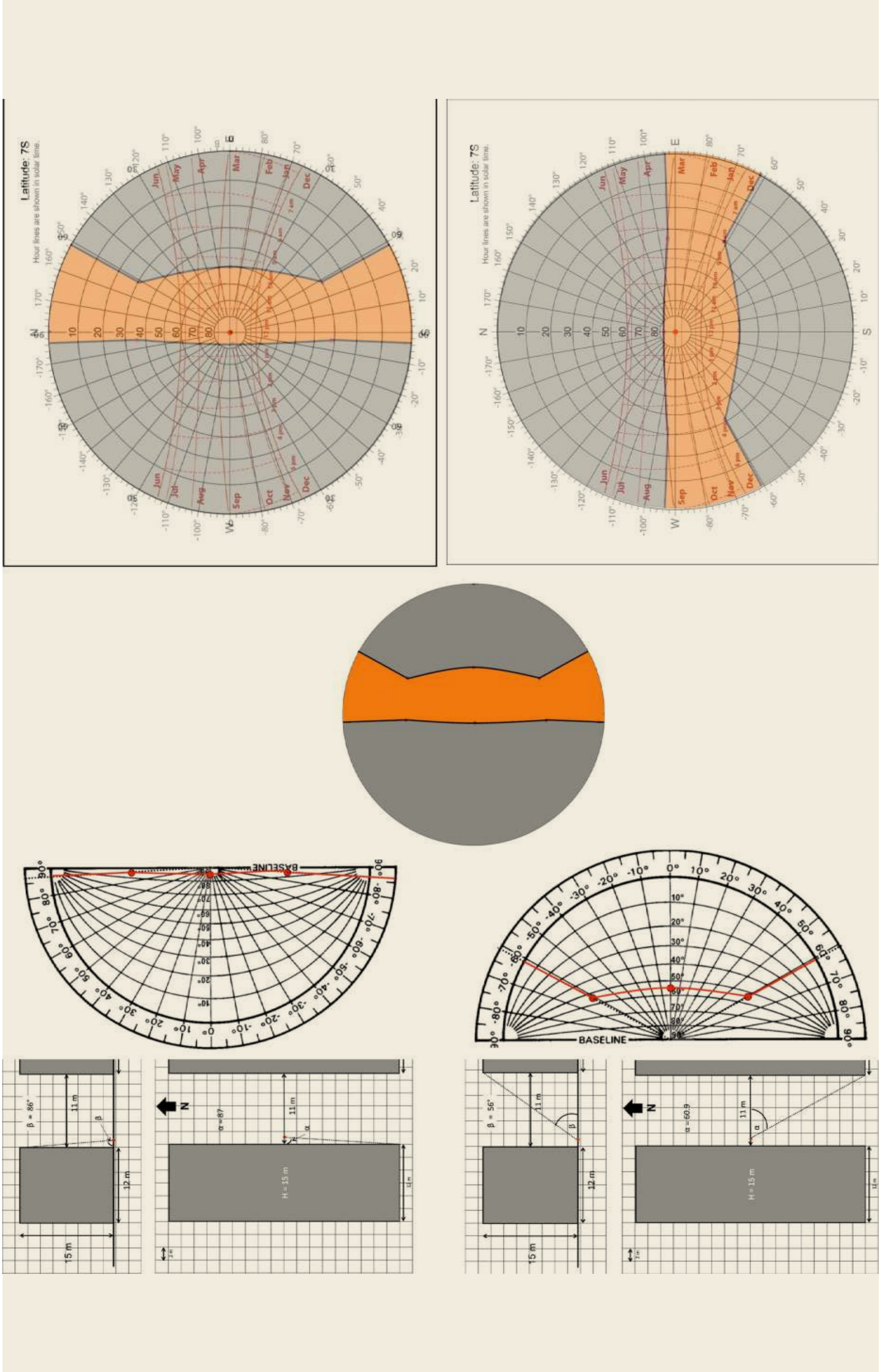
To check if the orientation and aspect ratio of a street canyon provide the required shade at a point along a walkway, the procedure of overlapping the obstruction profile and the sun chart can be followed. For example, a point 1 m from the east wall of a north-south axis canyon, at ground level, which is the obstruction profile shown in Figure A4.12 (centre), will be in full sun in December from about 09:20 to about 12:30 (Figure A4.12, top right); if the canyon is east-west oriented, the same point close to the south facing wall is shaded all day from March to September (Figure A4.12, bottom right).

Conversely, the same procedure can be used for finding the appropriate H/W and/or orientation to ensure that a given portion of the sidewalk is shaded in a given period of time, bearing in mind that north-south running streets could be treated as pedestrian links. By making north-south running streets narrow and thus shady, pedestrian movement within neighbourhoods can be encouraged.

## 4. ARCADE DESIGN FOR SHADOWING

Let us suppose that we want to evaluate the effectiveness of the arcade in Figure 4.1.38 (left) for creating an area, in an urban canyon, which is shaded as much as possible, at any time of year; the reference point chosen is at ground level, in the middle of the arcade width and length. The obstruction profile due to the opposite canyon wall, as seen from the selected reference point, is shown in Figure A4.13 (right).

FIGURE A4.12 **SYMMETRIC CANYON; H/W = 1.36. EXPOSURE TO SUN OF A POINT POSITIONED AT GROUND LEVEL, 1 M FROM THE WEST WALL (TOP RIGHT) AND AT 1 M FROM THE NORTH WALL AT A 7 S LATITUDE.**



The obstruction due to the arcade can be treated in the same way as the one produced by a horizontal overhang, as shown in Figure A4.14.

In Figure A4.15 the two obstructions and the polar solar chart at 7 S latitude are overlapped, showing that with the given arcade design, in a H/W = 1.36 canyon whose axis is oriented north-south, the pavement of the arcade, at its middle, would only be exposed to the sun for about one hour, between 9:00 and 10:00 hours, in any month of the year (Figure A4.15, left). However, if the canyon axis is east-west oriented, the south facing arcade would be exposed to the sun from 07:30 to 9:00 hours and from 15:00 to 16:30 hours in December, with the number of hours decreasing in the other months between September and March, and being zero from March to September (Figure A4.15, right).

If the results are judged unsatisfactory, a deeper arcade must be designed, following a procedure similar to that previously suggested for sizing the horizontal overhangs for protecting the canyon walls from solar radiation.

FIGURE A4.13 **ARCADE PLAN AND SECTION (LEFT). OPPOSITE CANYON WALL OBSTRUCTION PROFILE (RIGHT)**

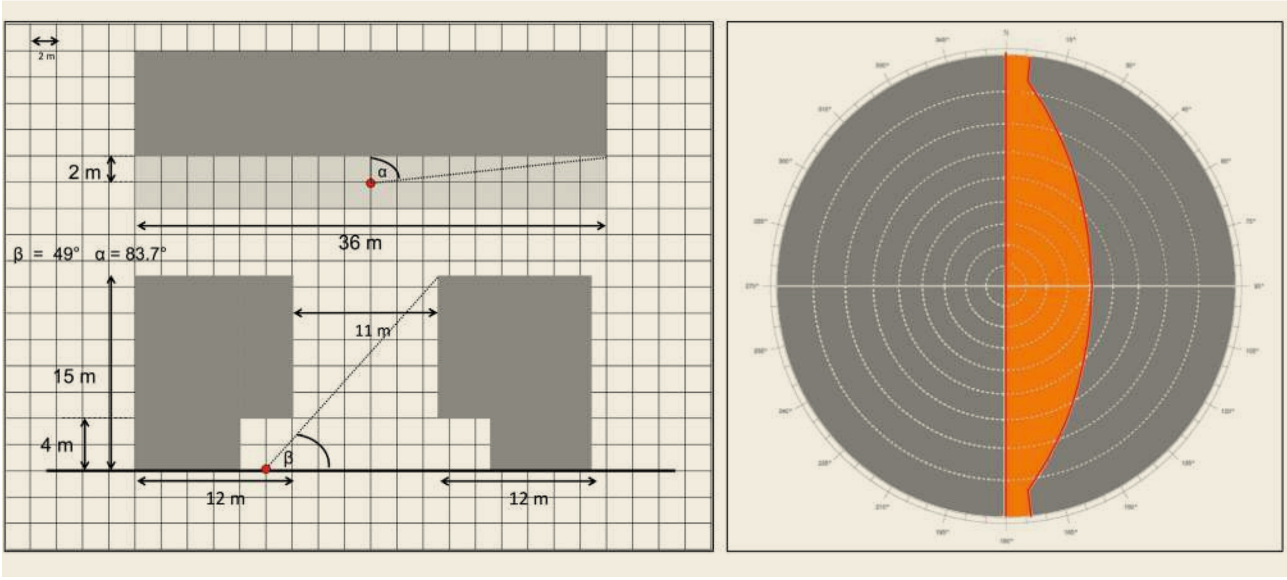


FIGURE A4.14 **ARCADE FRONT VIEW AND SECTION (LEFT); OBSTRUCTION PROFILE FROM THE SELECTED POINT (RIGHT).**

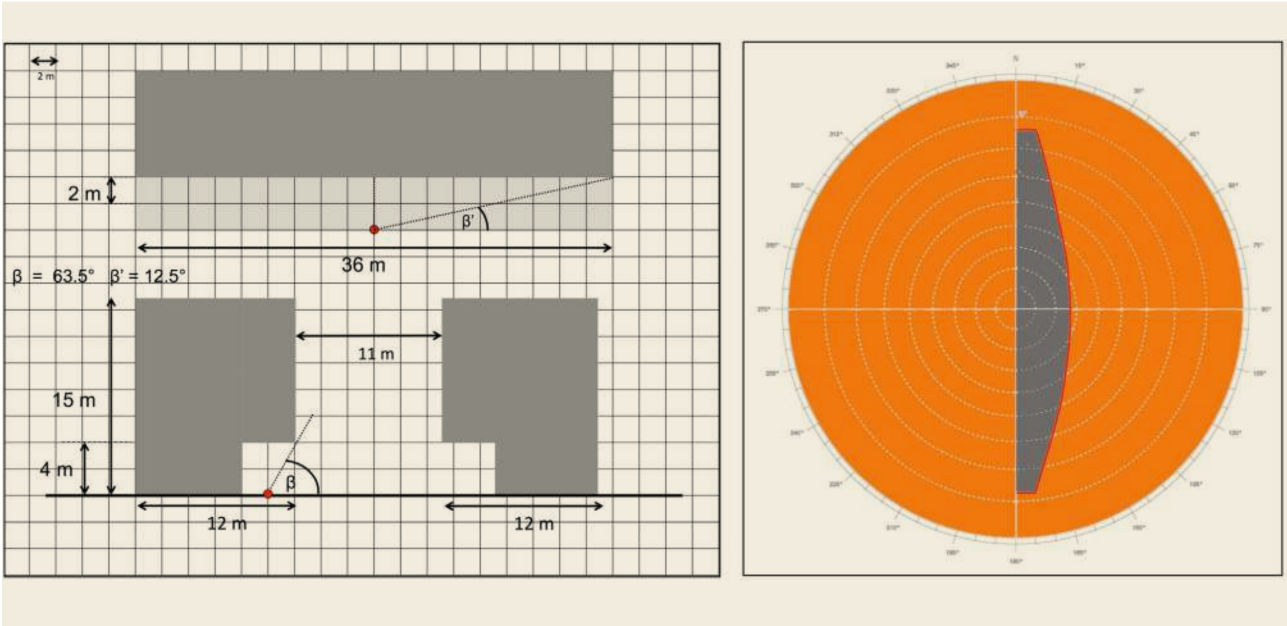
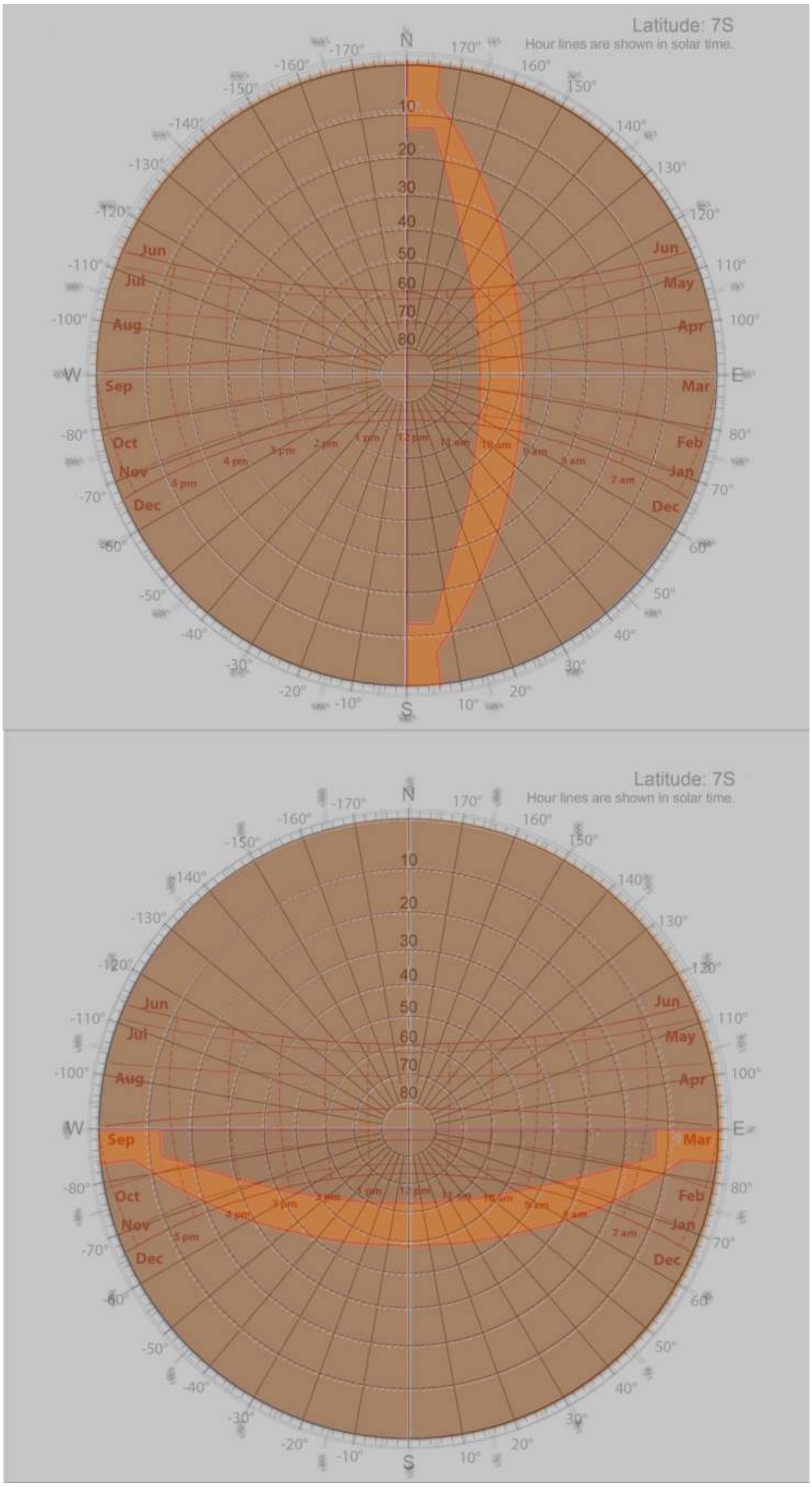


FIGURE A4.15 **SOLAR EXPOSURE OF THE PAVEMENT, IN THE MIDDLE OF THE ARCADE IN FIGURE 43, FOR AN ARCADE POSITIONED ON THE WEST WALL OF A NORTH-SOUTH RUNNING STREET (TOP) AND ON THE NORTH WALL OF AN EAST-WEST RUNNING STREET. H/W = 1.36**



## 5. SHADE FROM TREES

The shading effect of street trees can also be evaluated with the same method, as shown in Figure A4.16, showing that at ground level, under the trees, at the centre of the street, there will be shade from 9:00 to 17:00 hours; if the shading effect of the canyon walls is added, then the reference point will be shaded all the time in any month. The same effect is achieved if the street is east-west running.

The type and height of trees can be chosen according to the area to be shaded and the shading time required.

FIGURE A4.16 **SHADING EFFECT OF TREES AND CANYON WALLS AT THE CENTRE OF A H/W 1.36 NORTH-SOUTH RUNNING CANYON.**

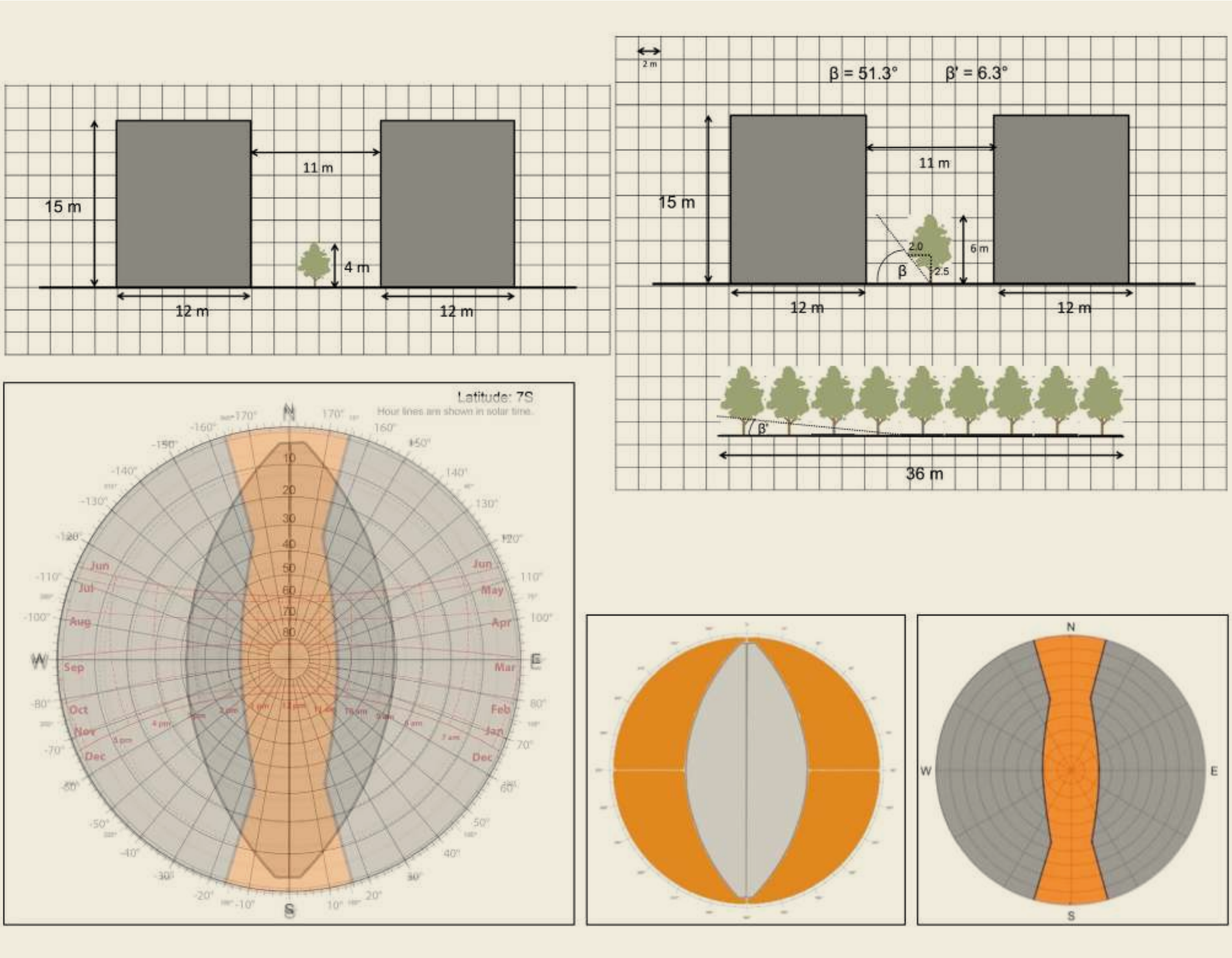
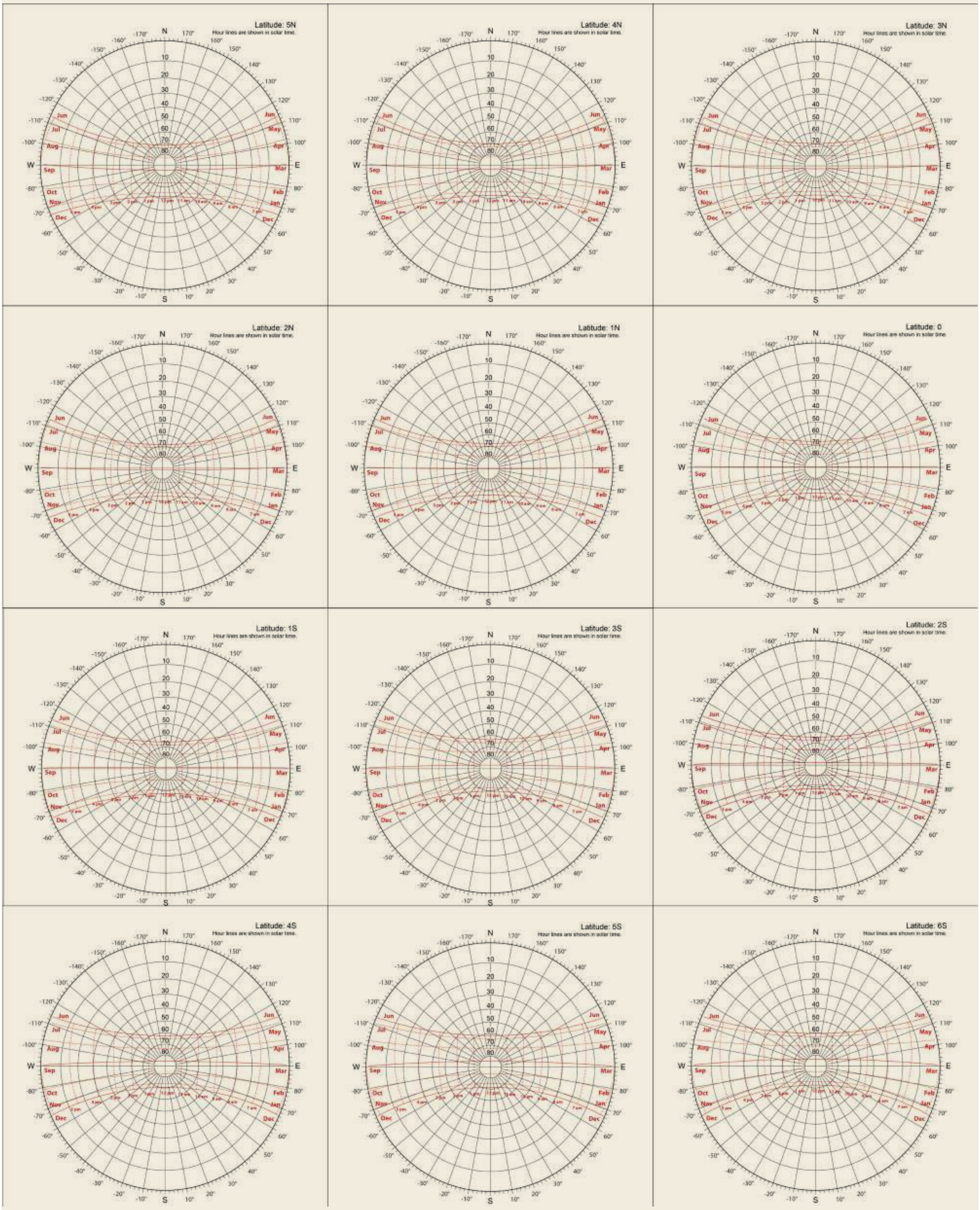
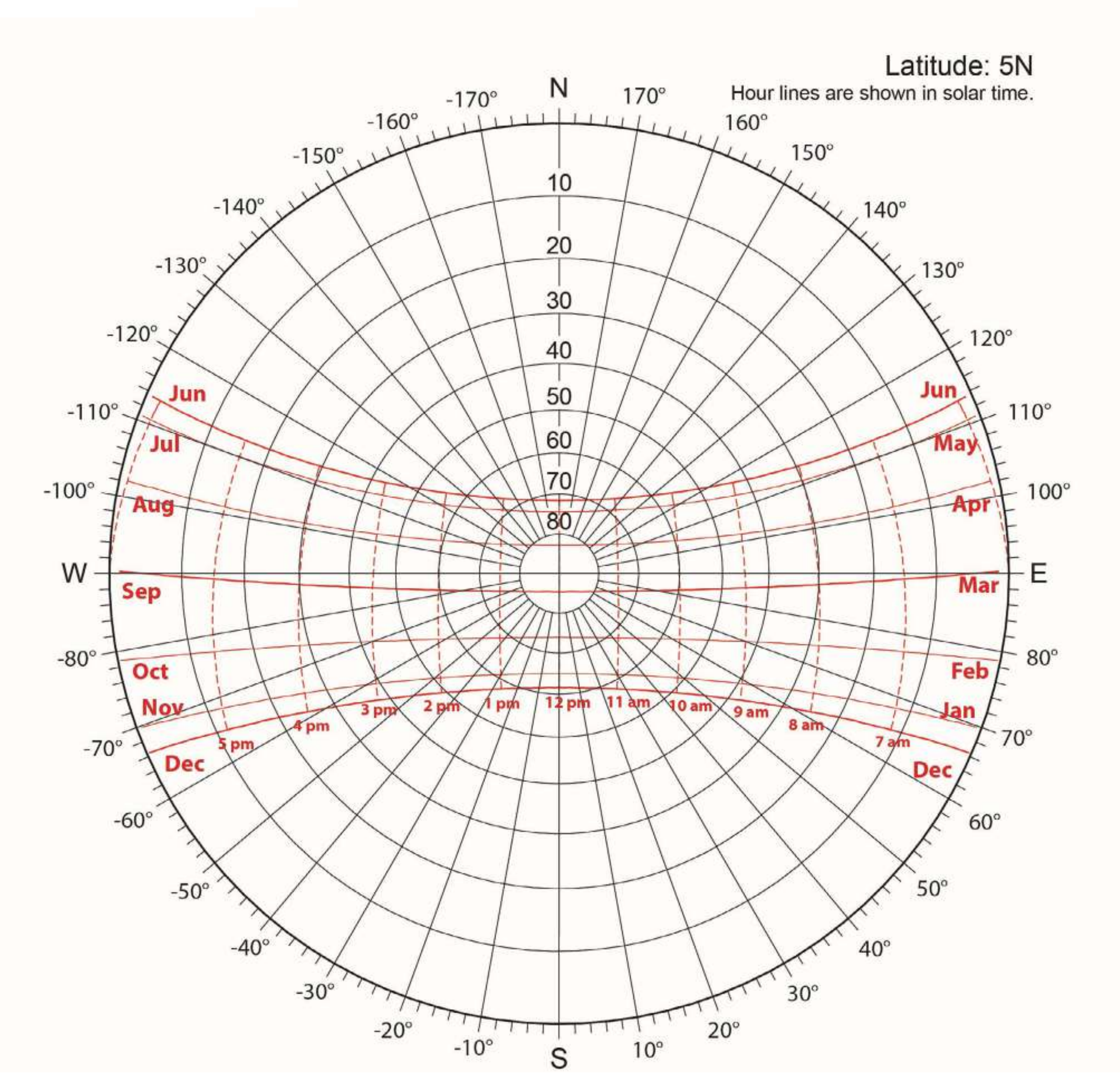
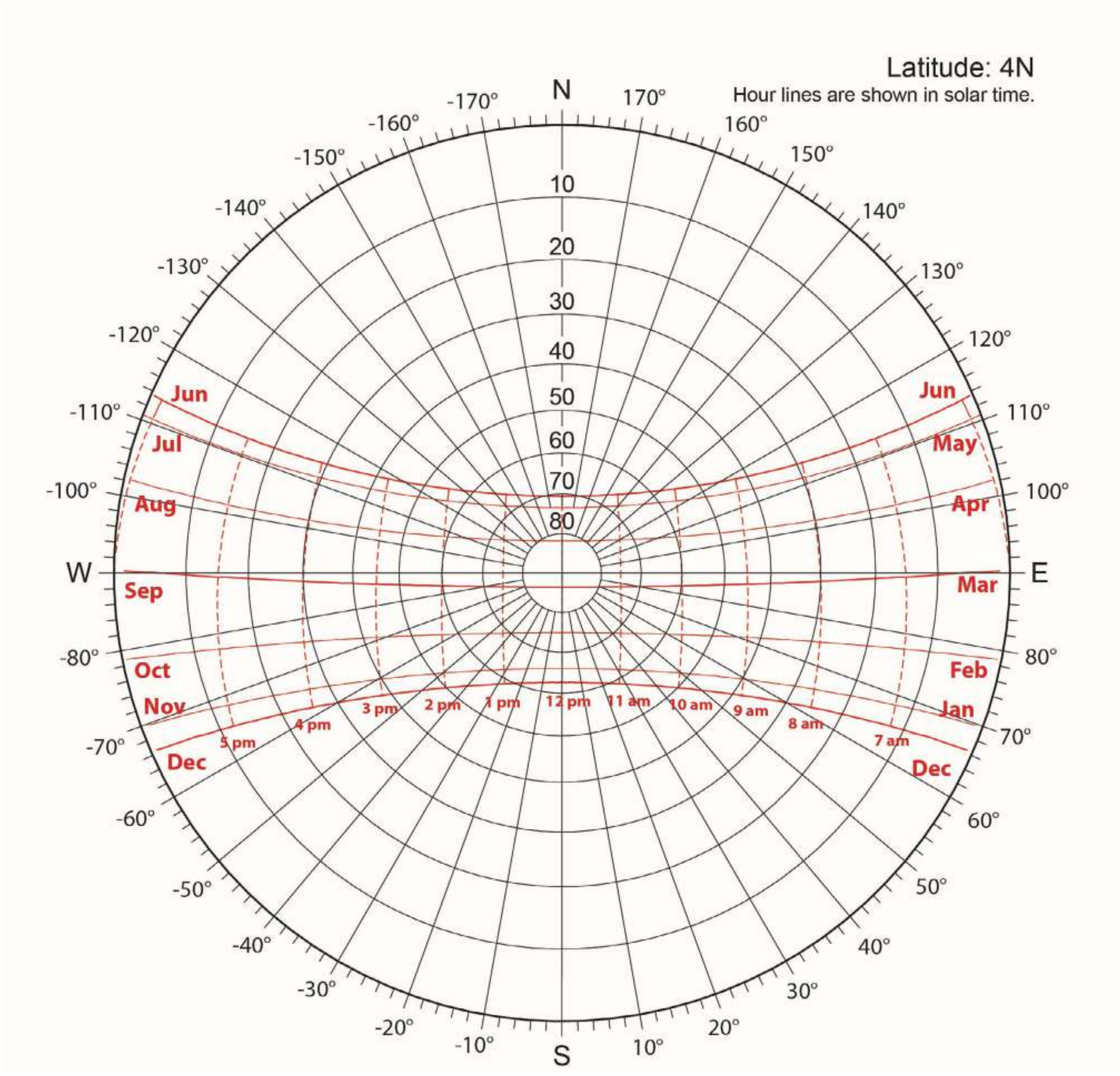


FIGURE A4.17 **SUN CHARTS FROM 5° N TO 6°S**



# A4a POLAR SUN CHARTS

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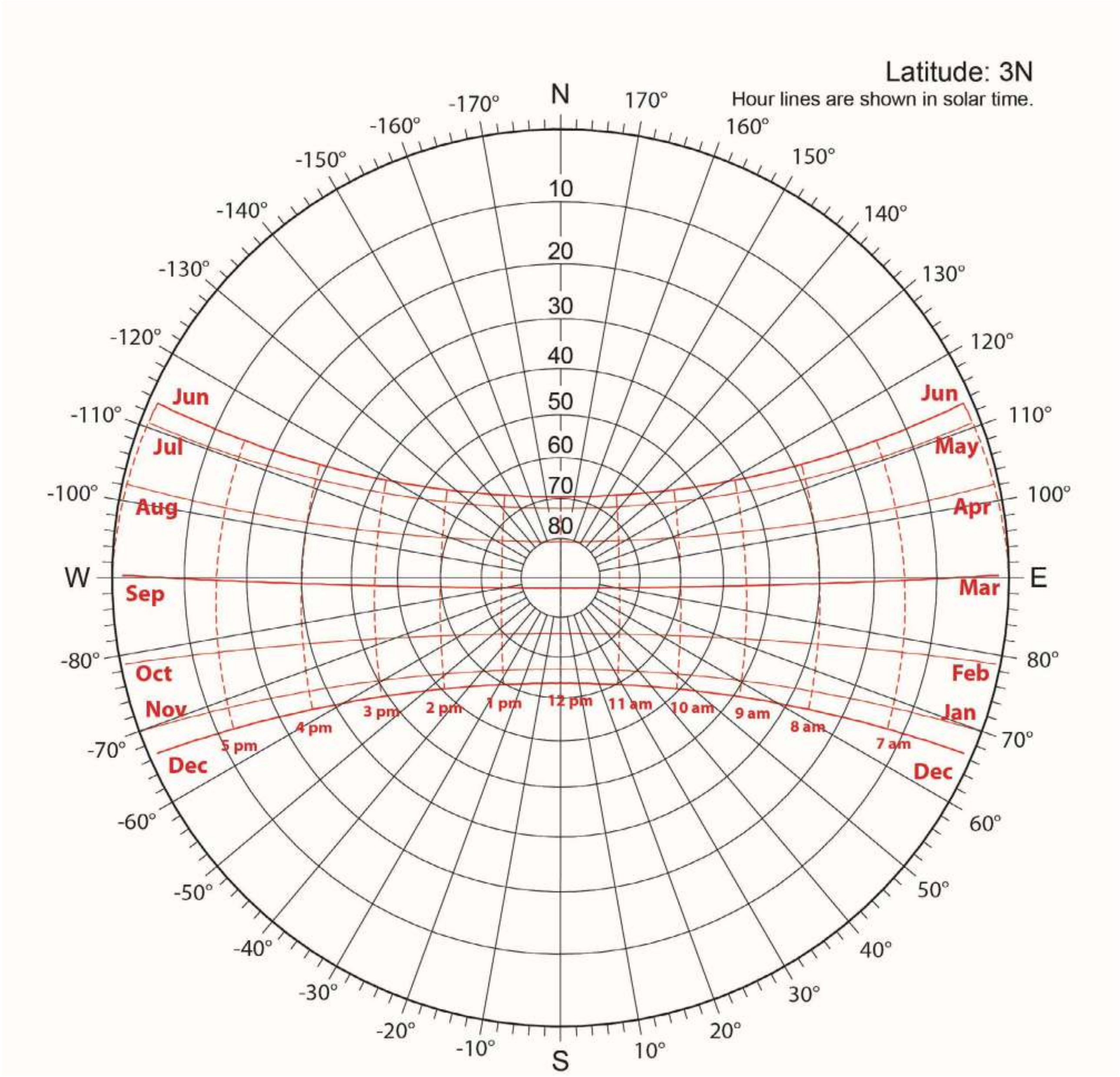
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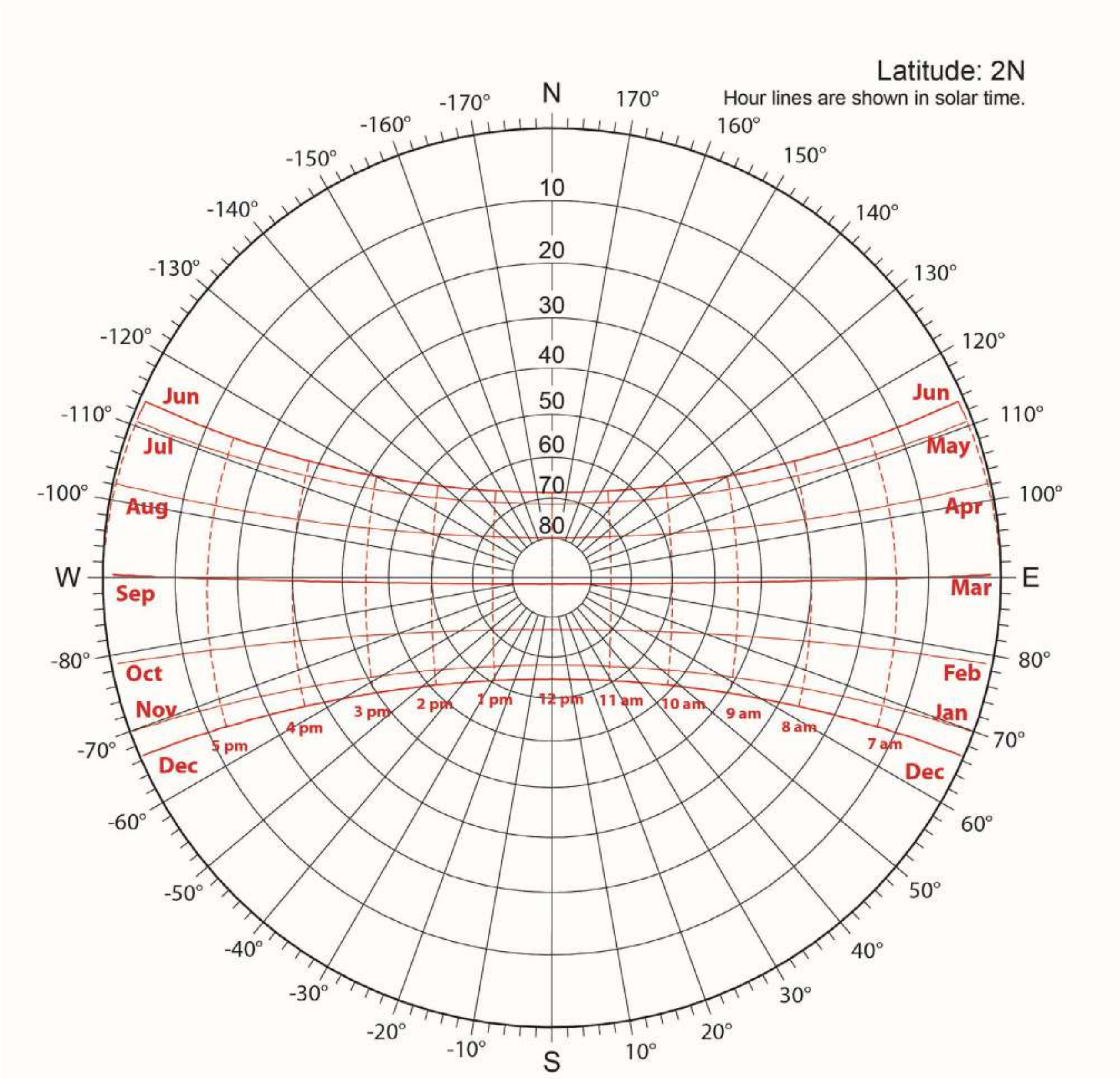
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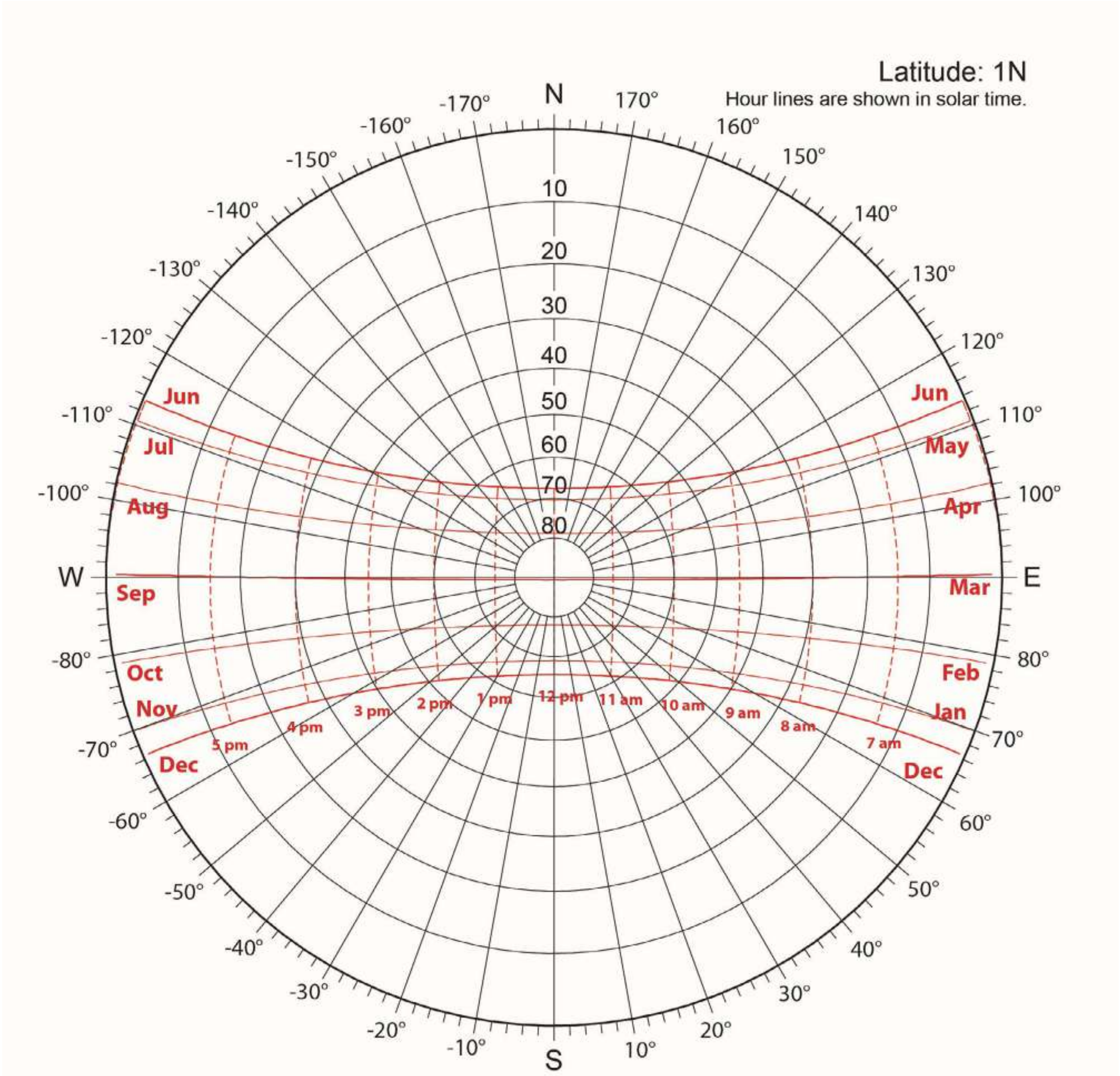
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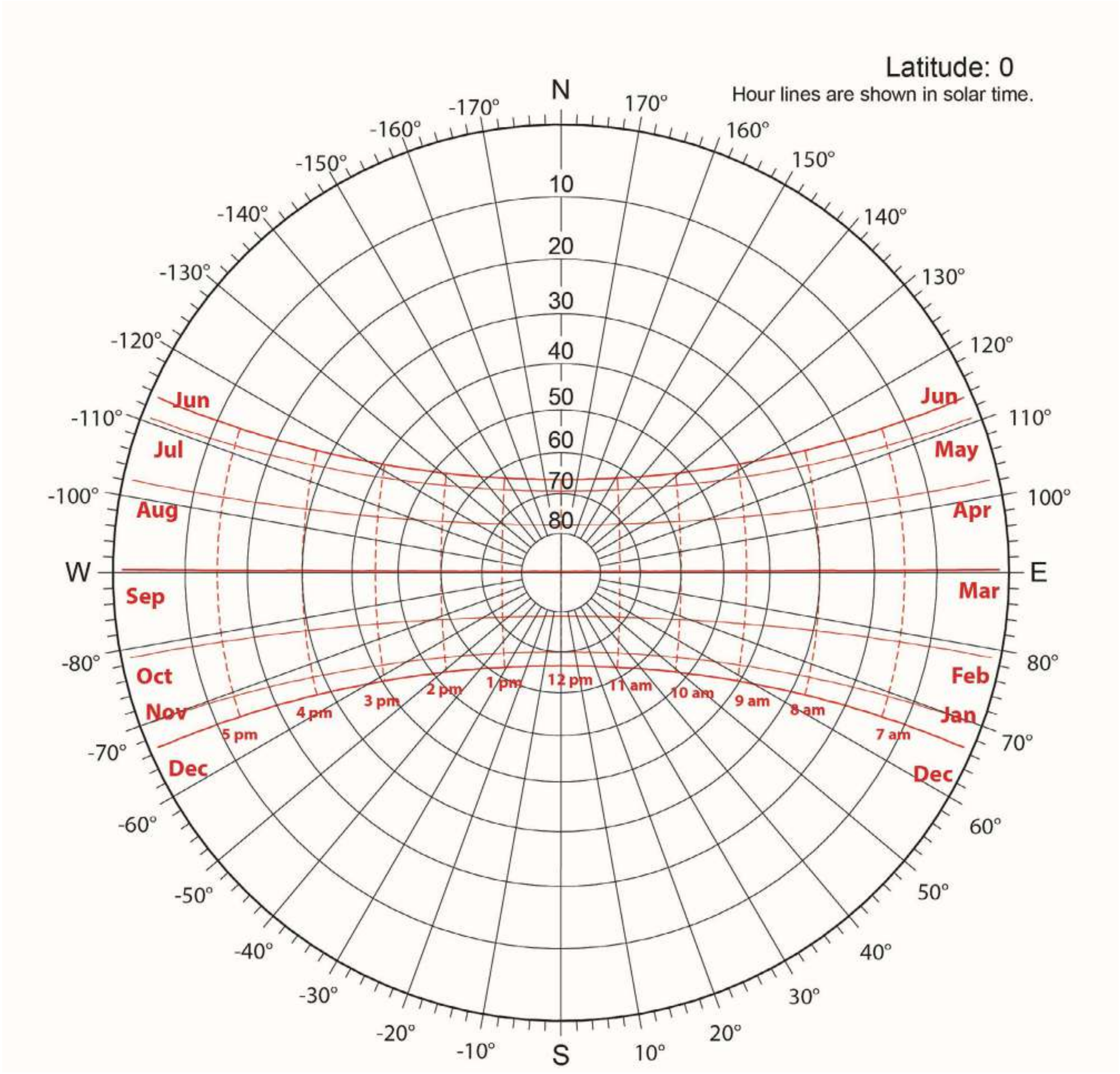

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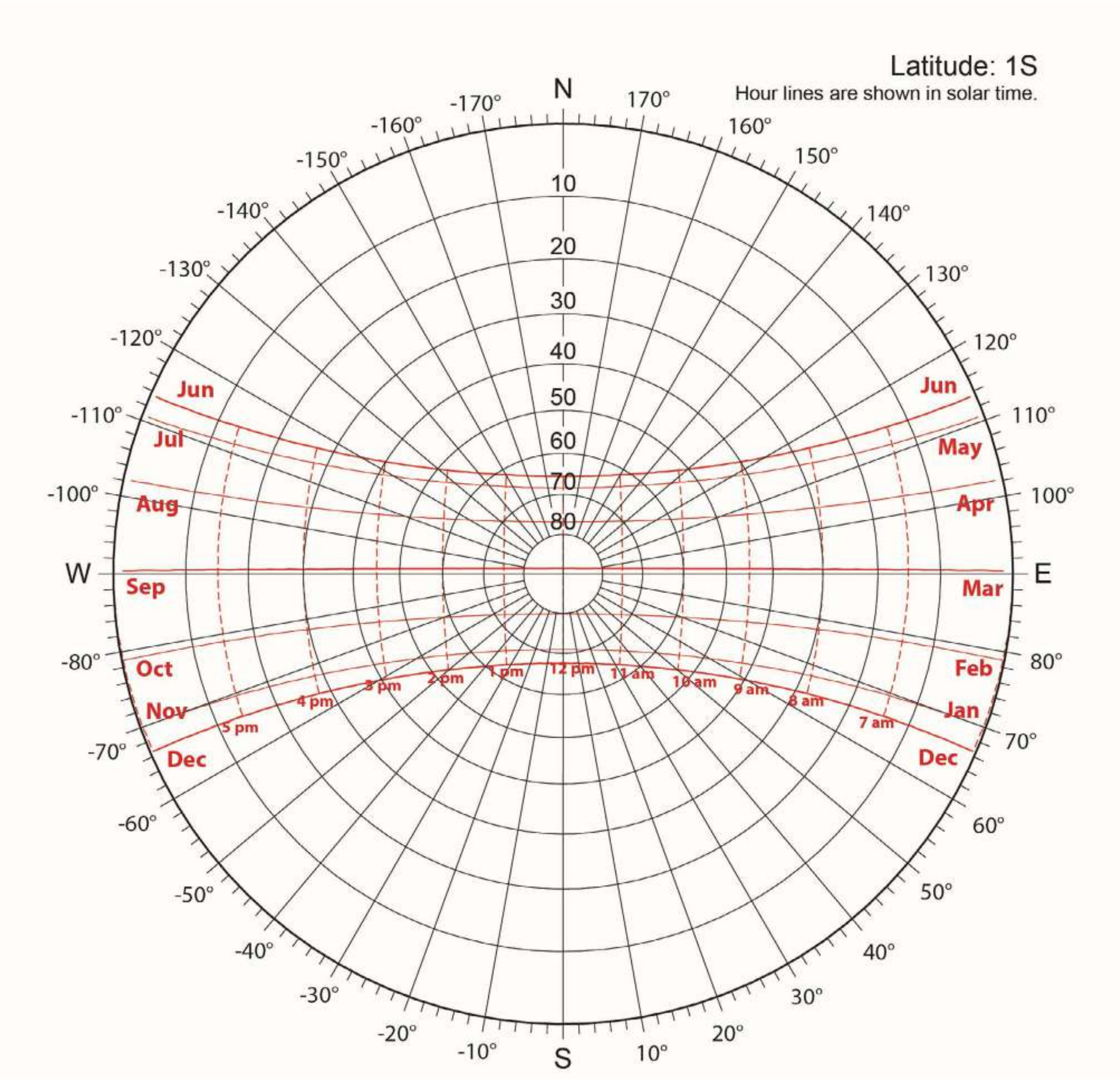
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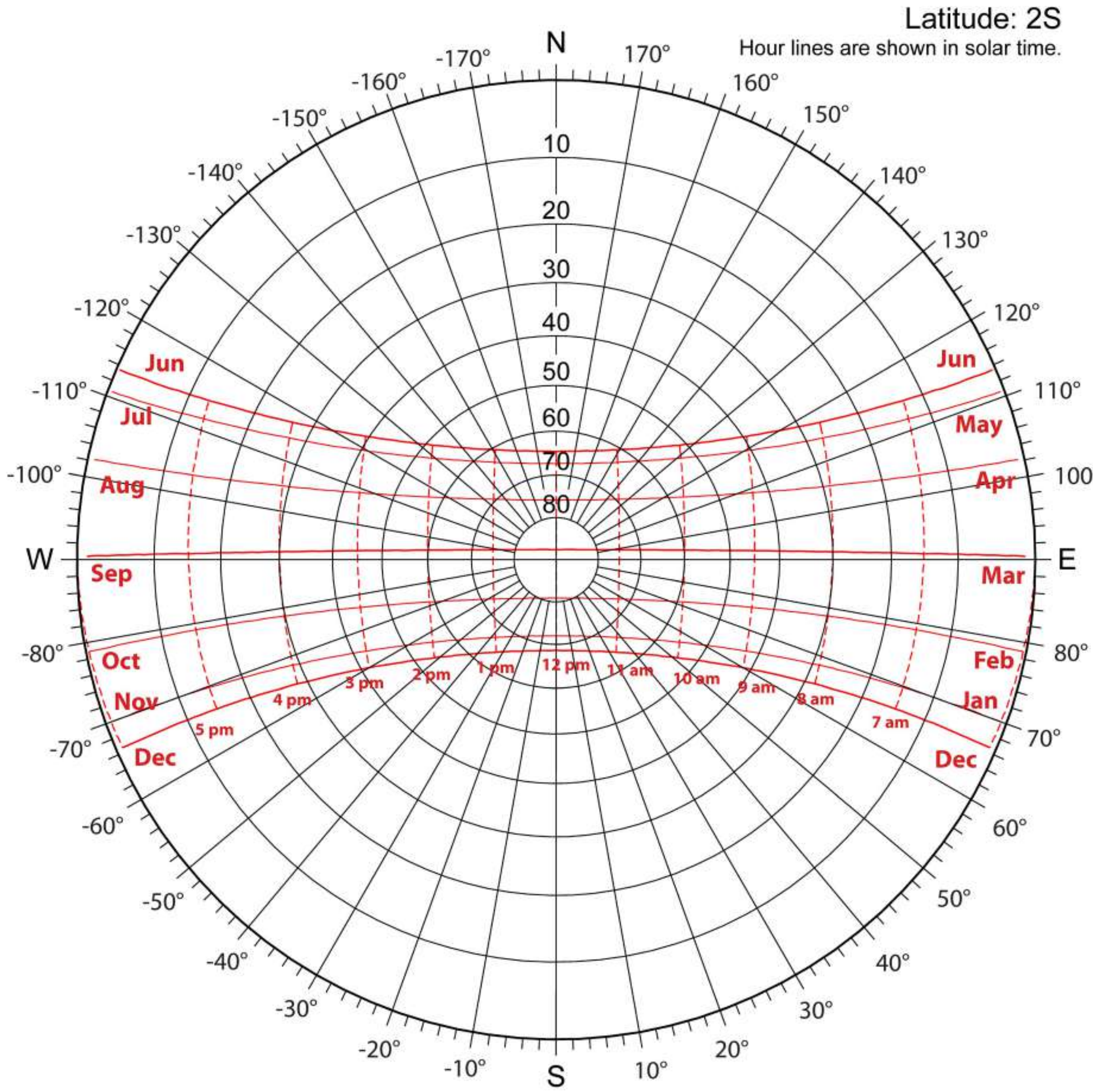
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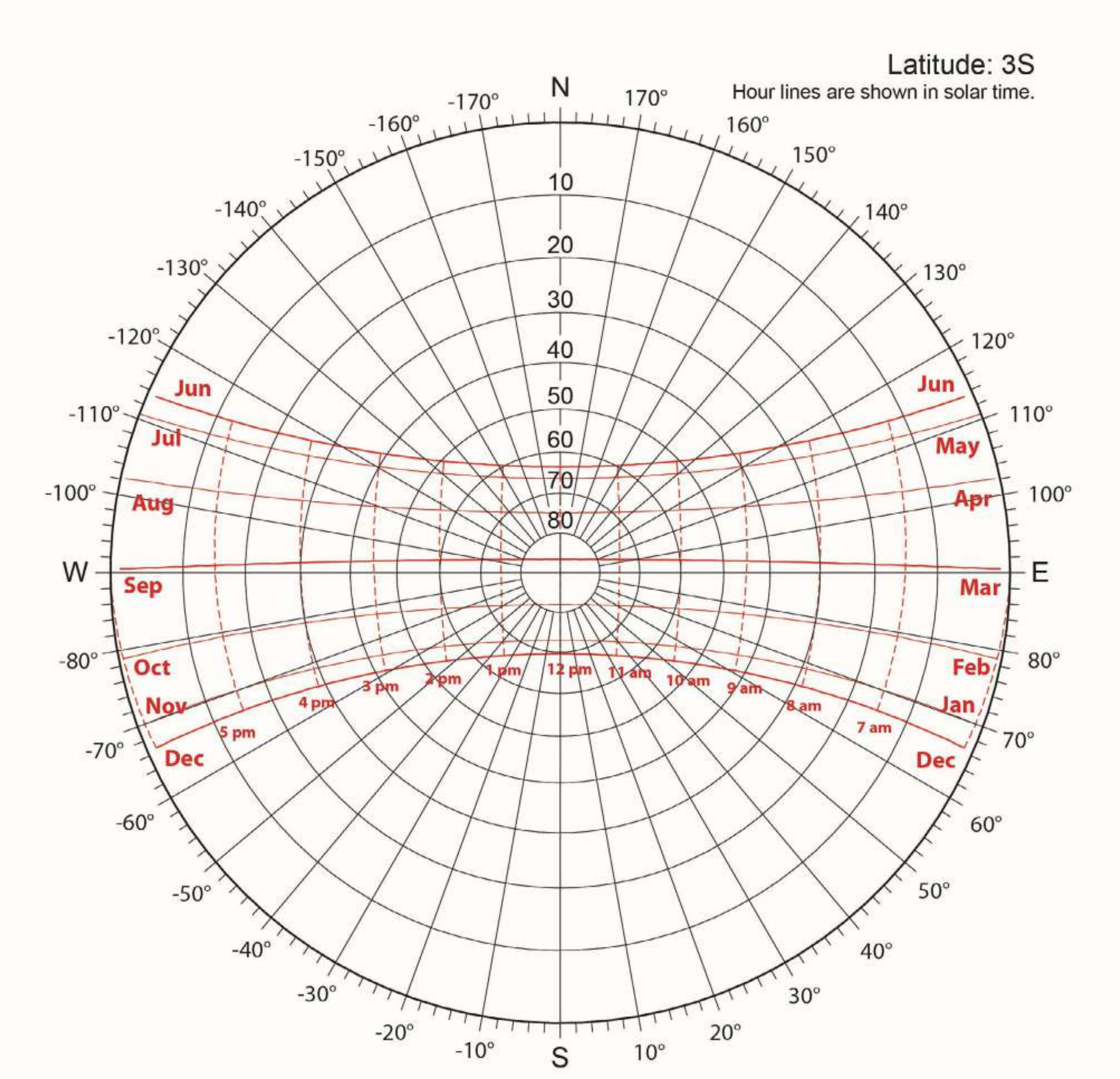
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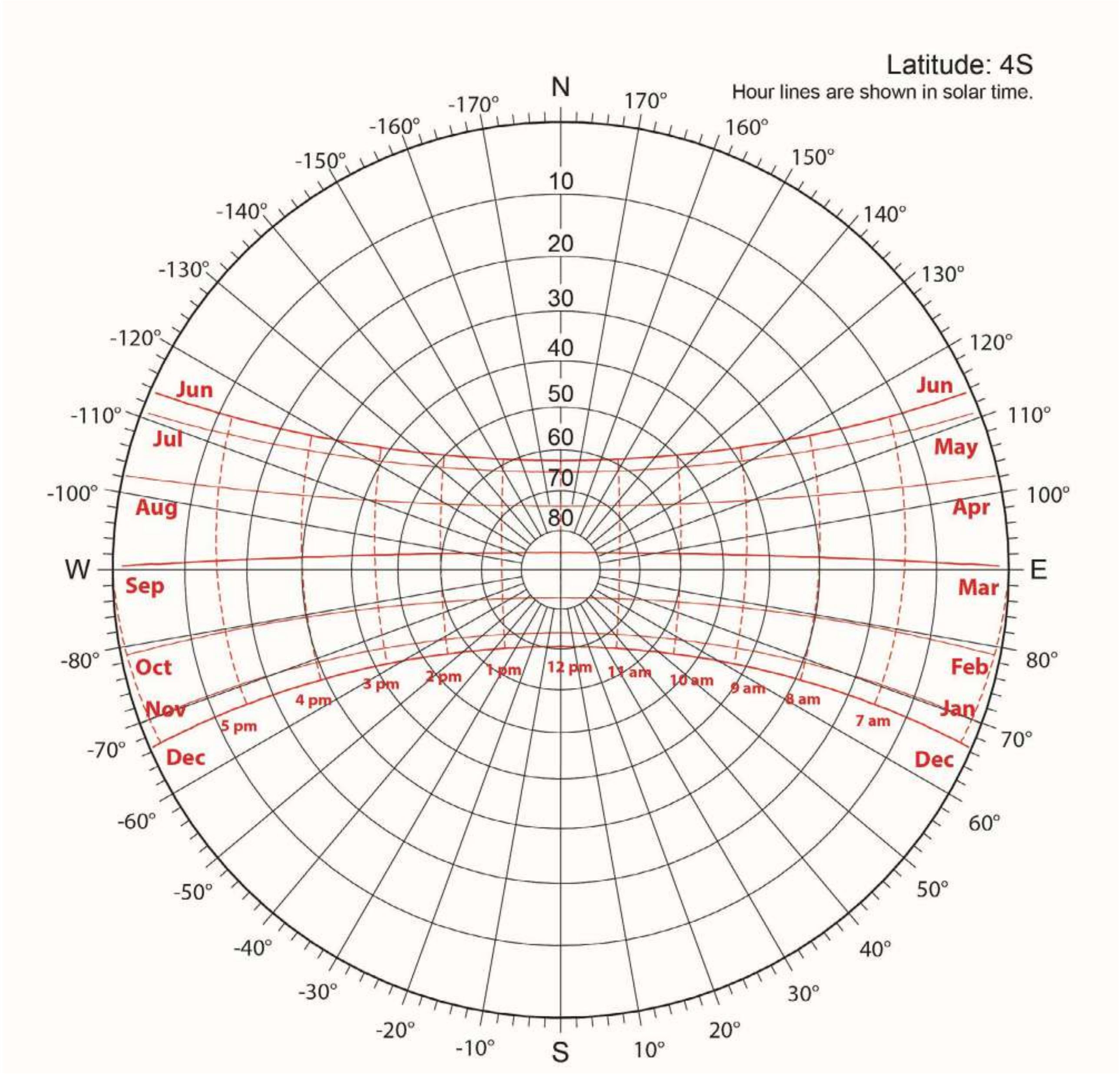
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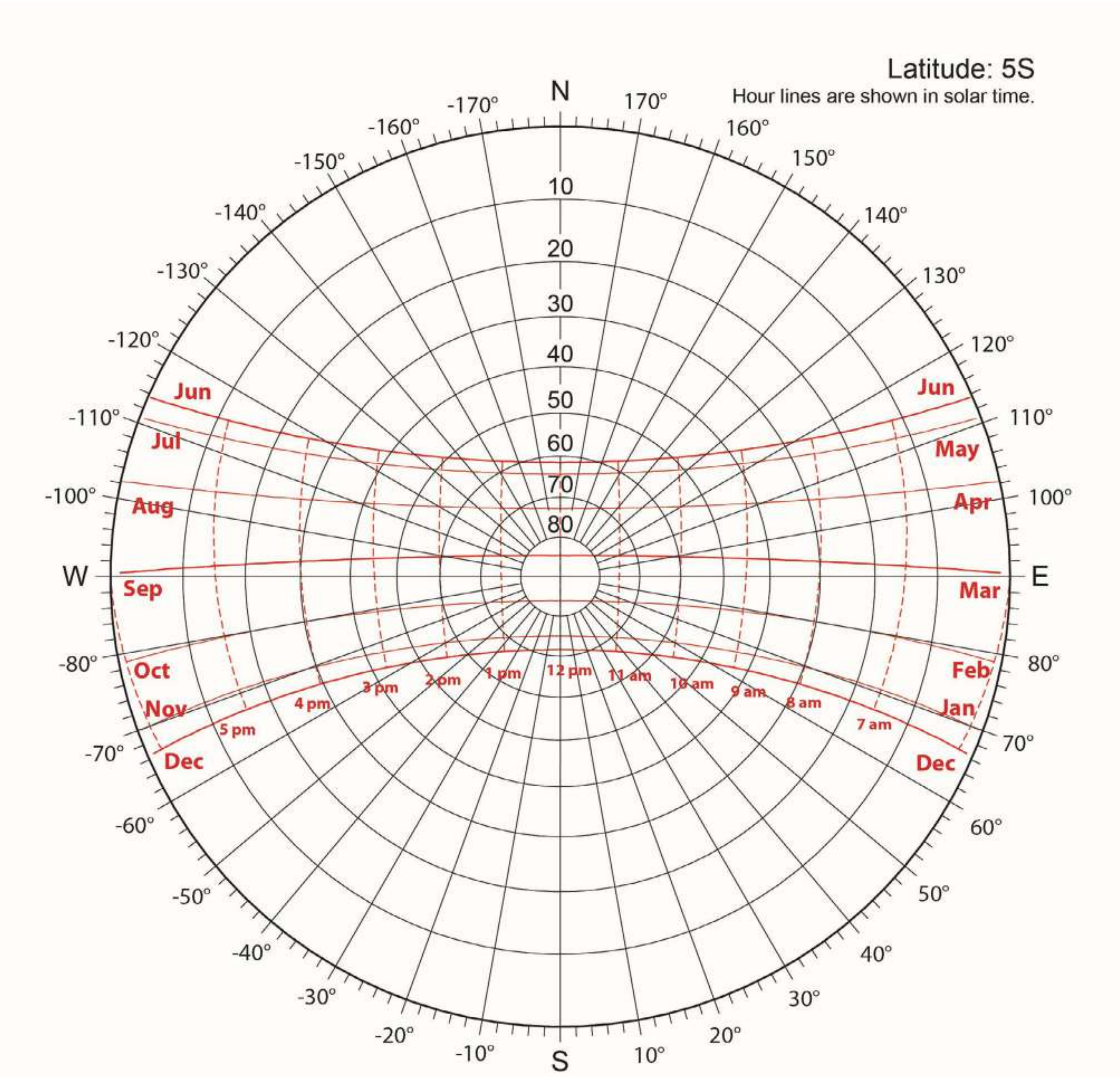
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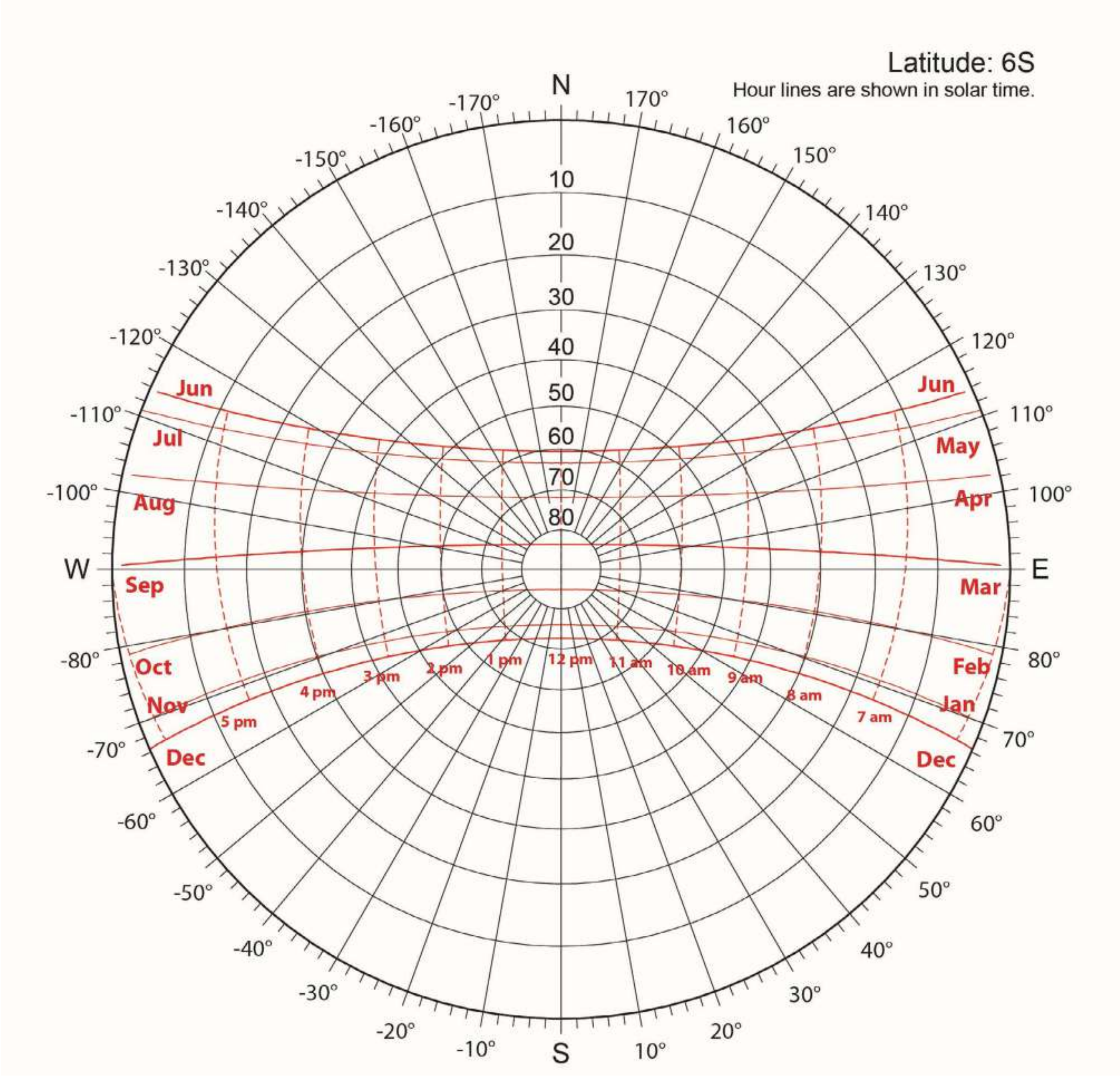
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# A5 RENEWABLE ENERGY TECHNOLOGIES AT NEIGHBOURHOOD SCALE

## 1. SOLAR THERMAL ENERGY

Solar thermal systems convert solar radiation into heat, transferring heat to a fluid. The fluid can be heated at low (< 100 °C) or high temperature. Low temperature heat is generally used for Domestic Hot Water (DHW) production, and less frequently for cooling. When heated at high temperature, mechanical power with a thermal engine is produced.

### 1.1 LOW TEMPERATURE SOLAR THERMAL ENERGY

The simplest solar thermal technology is the flat plate collector, for hot water production (Figure A5.1, left). However, the evacuated tubes solar collector (Figure A5.1, right) is more efficient. Even if the solar water heater includes a tank for hot water storage (Figure A5.2), there are periods of the year in which the solar energy falling on the collector is not sufficient to satisfy the demand for hot water, hence a back-up energy source is necessary. The easiest back-up is provided with an electric resistance. The use of a solar water heater, instead of a conventional electric water heater, allows an annual energy saving up to 70%. The collector area required for a family of four people, in a tropical climate, is only about 2 $m^2$.

The decreasing cost of photovoltaic (PV) panels and of heat pump water heaters is progressively reducing the cost gap between the solar thermal water heater and the combination PV + heat pump, and in most cases the latter system is already more cost effective.

As with the evacuated solar collectors it is possible to reach temperatures above 85 °C, solar thermal systems can be used also for cooling, coupling them with an absorption chiller (Figure A5.3) or a desiccant cooling (DEC) unit (Figure A5.4).

Both need a back-up source of energy to cope with successions of cloudy days. Flat plate or evacuated solar collectors can also be used for water desalination or for the final treatment of wastewater to make it potable.

FIGURE A5.1 **FLAT (LEFT) AND EVACUATED (RIGHT) SOLAR COLLECTOR**

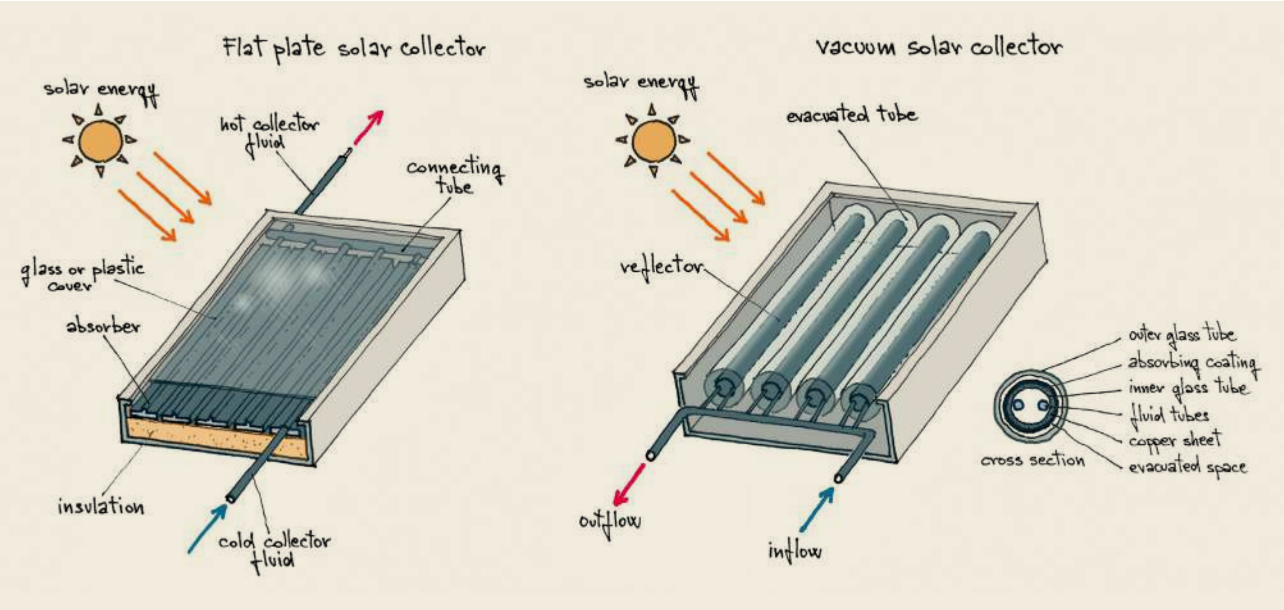

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FIGURE A5.2 **INTEGRATED STORAGE SOLAR DHW SYSTEM**

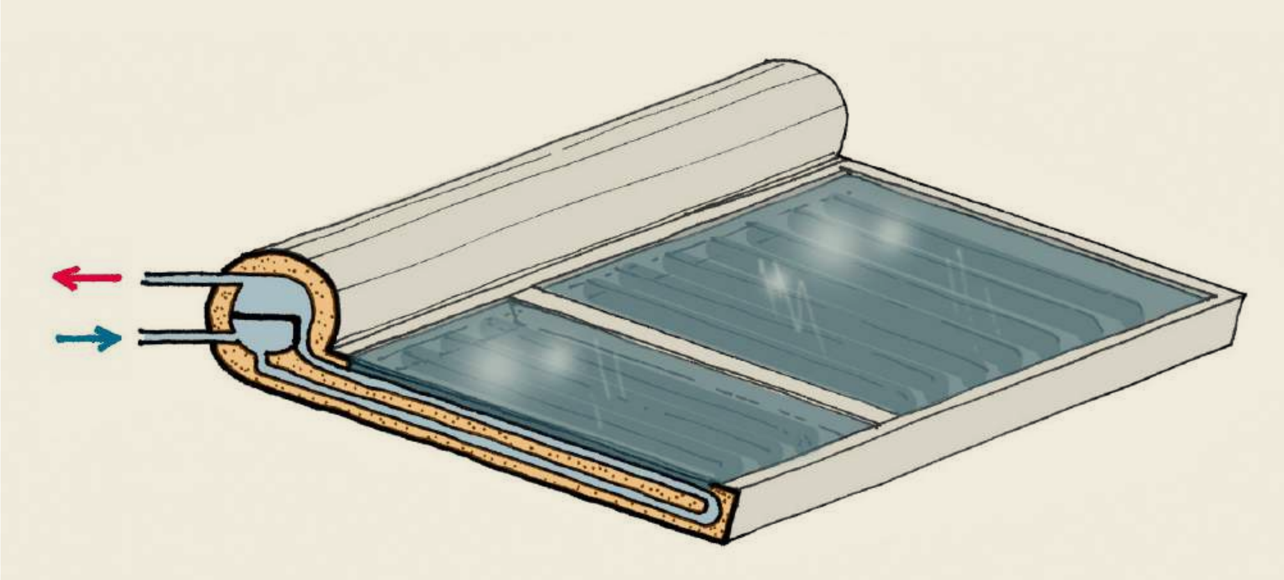


FIGURE A5.3 **SOLAR POWERED AIR CONDITIONING SYSTEM**

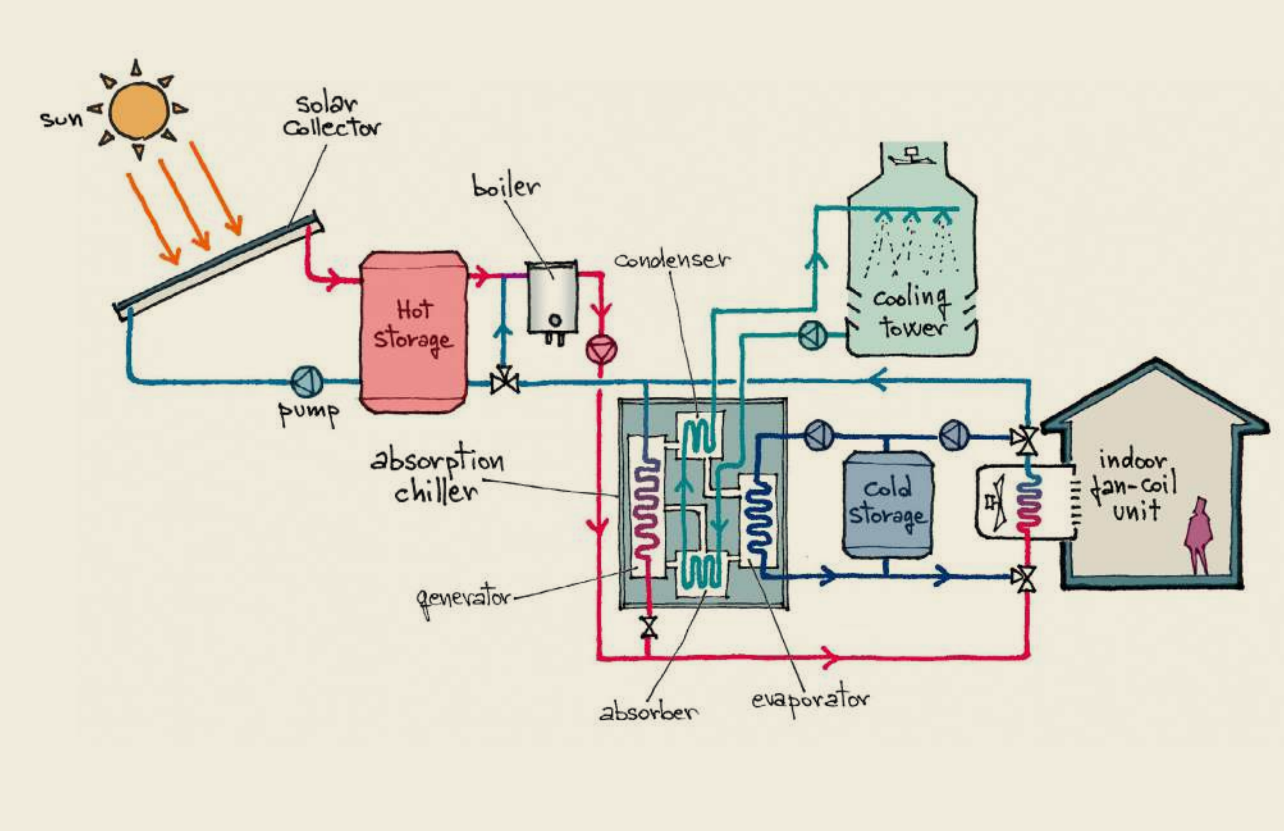
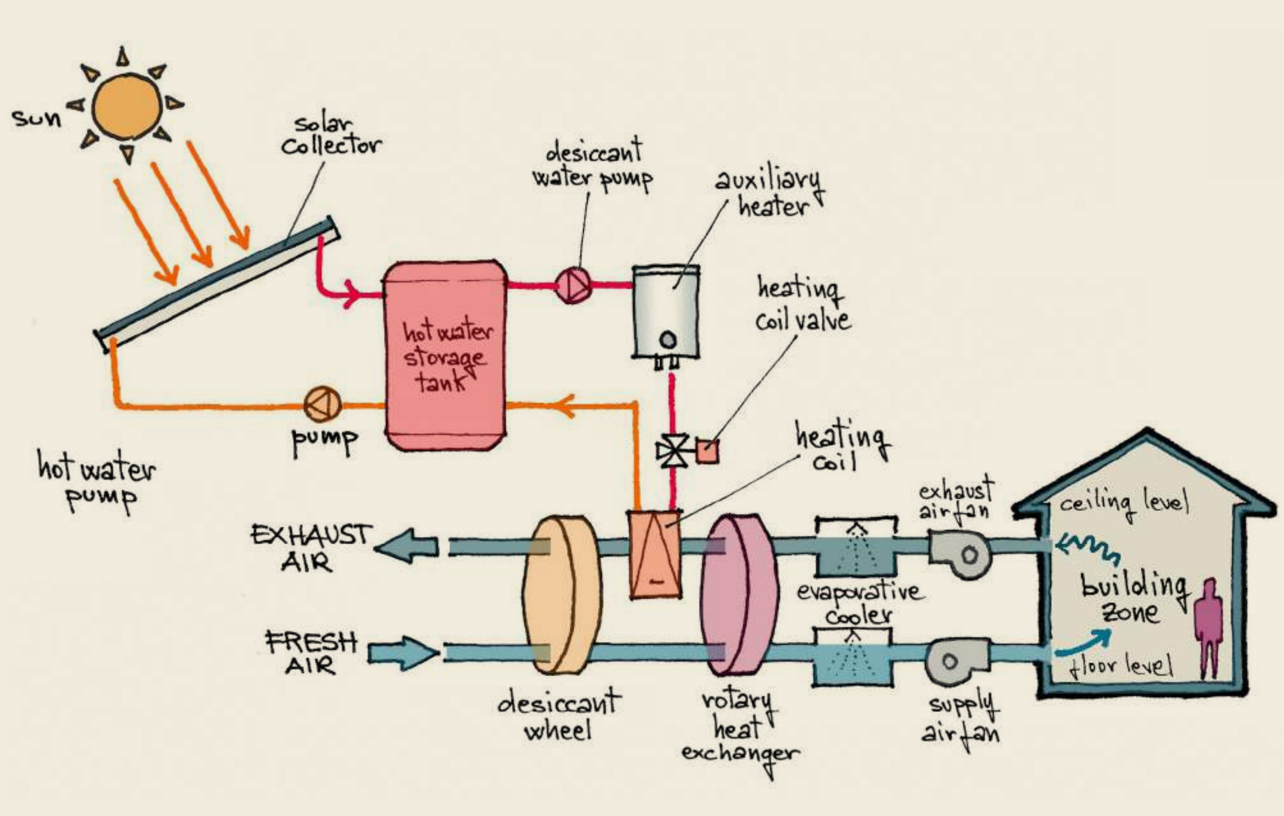


FIGURE A5.4 **MAIN COMPONENTS OF A SOLAR-POWERED DESICCANT COOLING SYSTEM**



## 1.2 SOLAR THERMODYNAMIC POWER STATIONS

Solar energy, converted into heat, can also be used for electricity production, provided that high temperatures are reached, which is possible by concentrating solar rays (Figure A5.5).

The most suitable technologies for neighbourhood scale are the parabolic through, the linear Fresnel and the dish/engine. A solar power plant with parabolic through concentrators (Figure A5.6) is a technology that, after a short period of success in the early eighties, sank into oblivion, but nowadays many new plants are being built.

Based on parabolic through concentrators producing steam supplied to a turbine, solar power plants are not suitable in hot humid climates, because of the low amount of direct solar radiation, but they are very effective in hot dry climates, where they could become part of the landscape around or within the settlement.

Depending on the distance, their waste heat could be used for chilled water production and injected into a nearby district cooling network or for supplying a desalination or a wastewater purification plant.

Depending on the size and on other parameters, the linear Fresnel concentrator may be more appropriate than the parabolic through.

Dish concentrating collector power plants (Figure A5.7) are made up of modular units comprising the concentrator and the engine/generator unit, and thus are more easily scalable.

FIGURE A5.5 **CONCENTRATING SOLAR TECHNOLOGIES: BASIC LAYOUT SCHEMES**

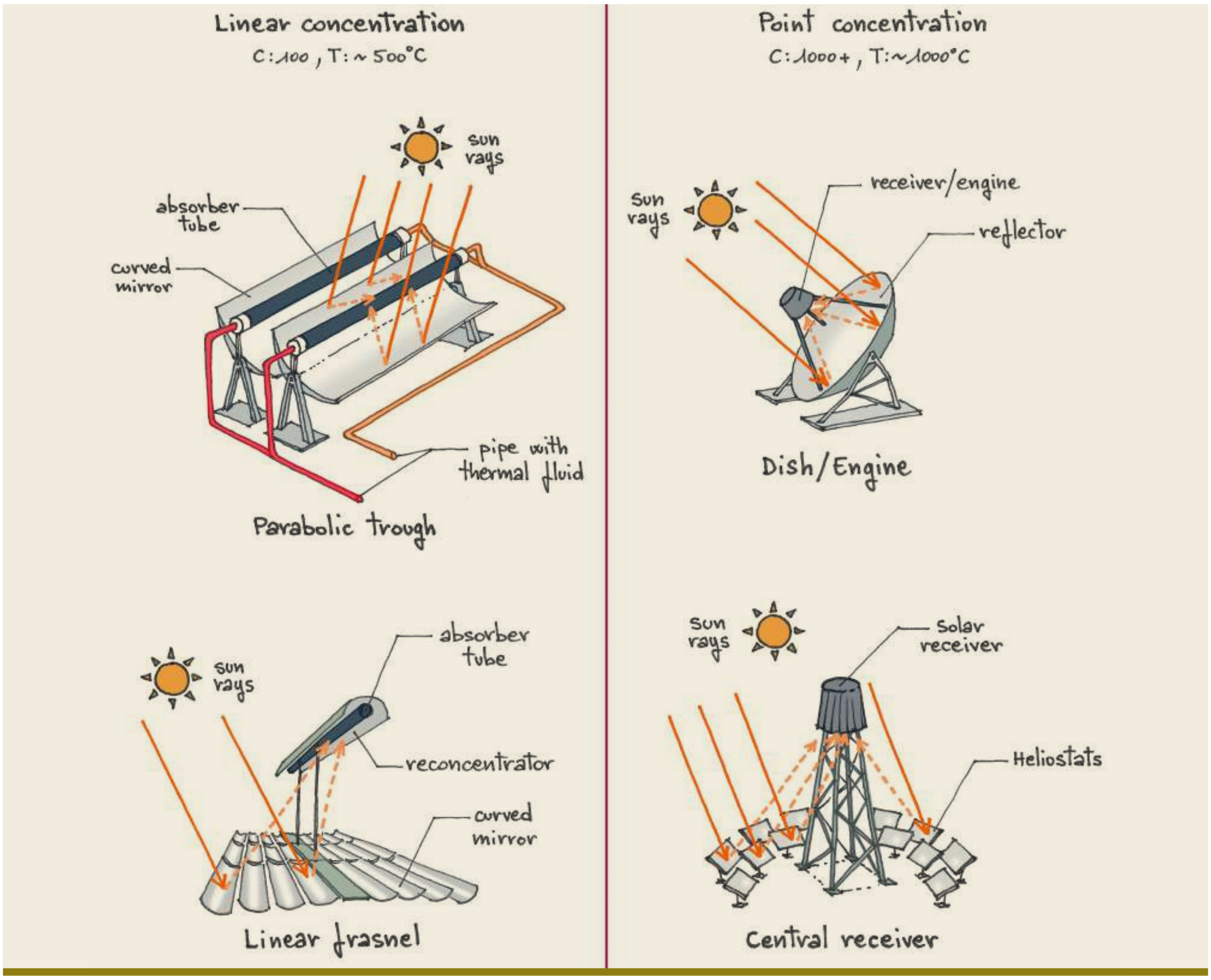


FIGURE A5.6 **PARABOLIC THROUGH SOLAR POWER PLANT**

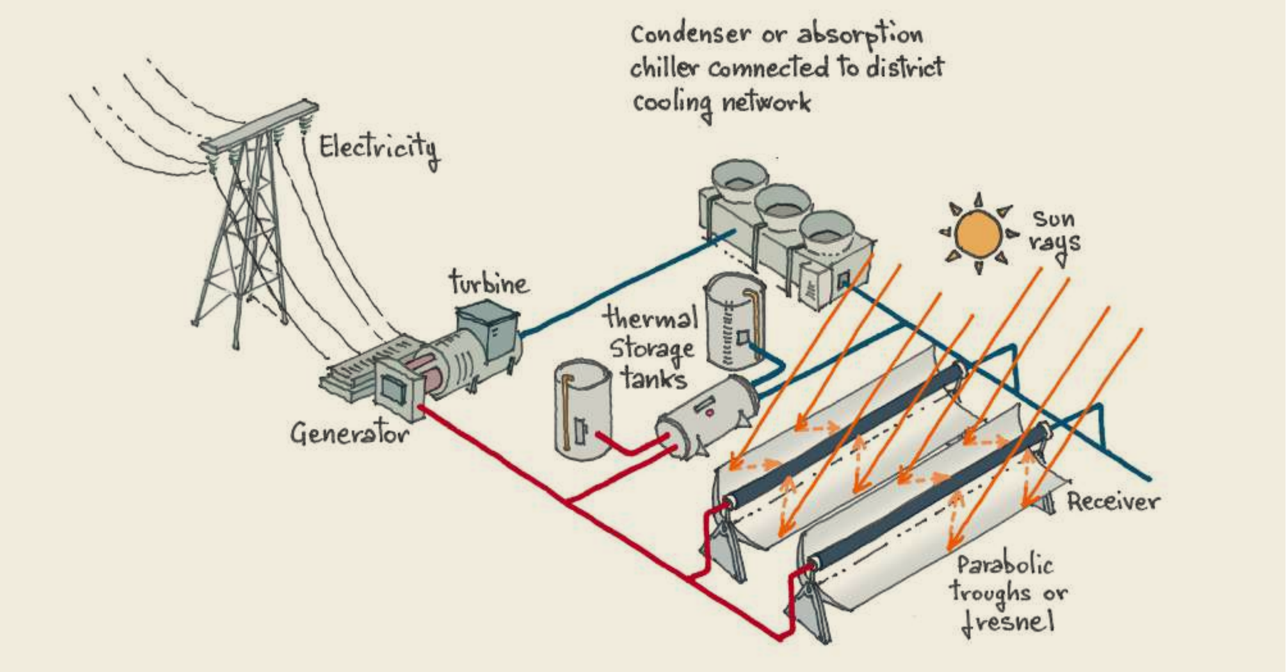
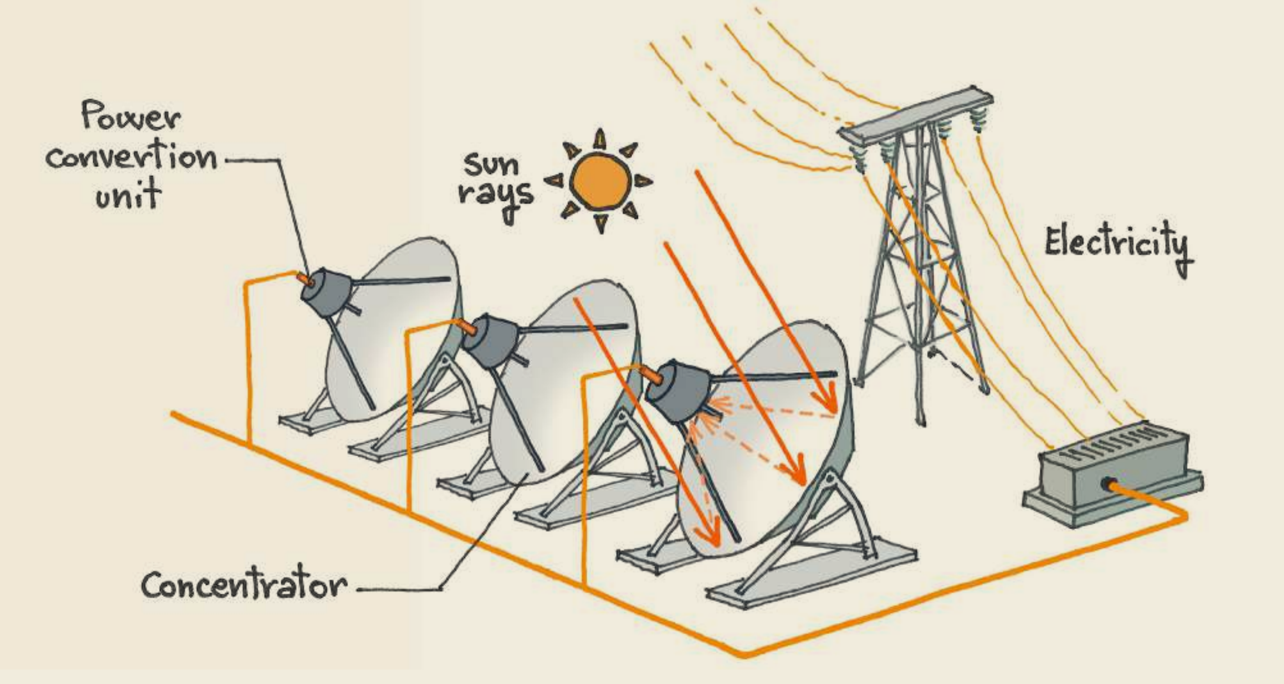


FIGURE A5.7 **ILLUSTRATION OF A DISH/ENGINE POWER PLANT**



## 2. PHOTOVOLTAIC SYSTEMS

Photovoltaic panels are capable of converting solar energy into DC current directly, without any moving parts or circulating fluid. They can be grid connected (Figure A5.8, left) or stand alone (Figure A5.8, right), or a combination of the two, with the electric storage providing, entirely or partially, electricity when the sun is not shining or when demand exceeds production, together with the grid. Grid-connected systems use the grid as storage, in the sense that the DC current is first transformed into AC, and then delivered to the grid (partially or totally). The electricity required by the user comes partially or totally from the grid. The amount of solar electricity used is given by the difference between the energy delivered to the grid and that received. If the grid is a mini-grid, it can be provided with a storage system, which is a substitute for the individual storage.

In many cases, such as the ones commonly found in new settlements in developing countries, PV systems are competitive with centralised electricity production with fossil fuels; they are the main actors of the decentralised energy system of a low energy urban settlement, integrated by storage systems.

The productivity of a photovoltaic system is highly dependent on the climatic context in which the system is located. The amount of electricity production, in fact, is directly proportional to the availability of solar radiation and, to a much lesser extent, inversely proportional to the working temperature of the cells. It is therefore extremely important to define the correct inclination and orientation of the modules, in order to maximize the incident radiation and favour the heat loss. At the latitudes of tropical countries, the optimum tilt angle is 0° (horizontal), but up to 15° there is no significant decrease in production. Hence, contrary to what is generally proposed for higher latitudes, it is not appropriate to put PV panels on the walls, or as overhangs for window shading in the south or north facades, since they would be shaded for half the year.

As an indicative figure, in the EAC a 1 kWp well-designed photovoltaic system can produce between 1500 and 1650 kWh electricity annually, depending on the site of the installation, and thus the amount of solar radiation available, with a required area of about 7.5 m$^2$. This figure, however, could diminish in the near future, as the efficiency of PV cells is improving.

Architectural integration represents a privileged sector for PV systems, with very promising prospects for growth, even in strictly economic terms. In fact, the installation of the modules on the building envelope provides a variety of opportunities, such as the use of the land surface already occupied by buildings, the savings on support structures, the replacement (with the same performance) of materials and components such as traditional roof elements, the possibility of using the energy produced on site according to the logic of distributed generation.

Being the easiest and the most reliable way to produce renewable electricity, PV roofs are the natural candidates for supplying all the energy necessary for the operation of residential buildings: lighting, air conditioning, domestic appliances, even cooking if induction stoves are used[45].

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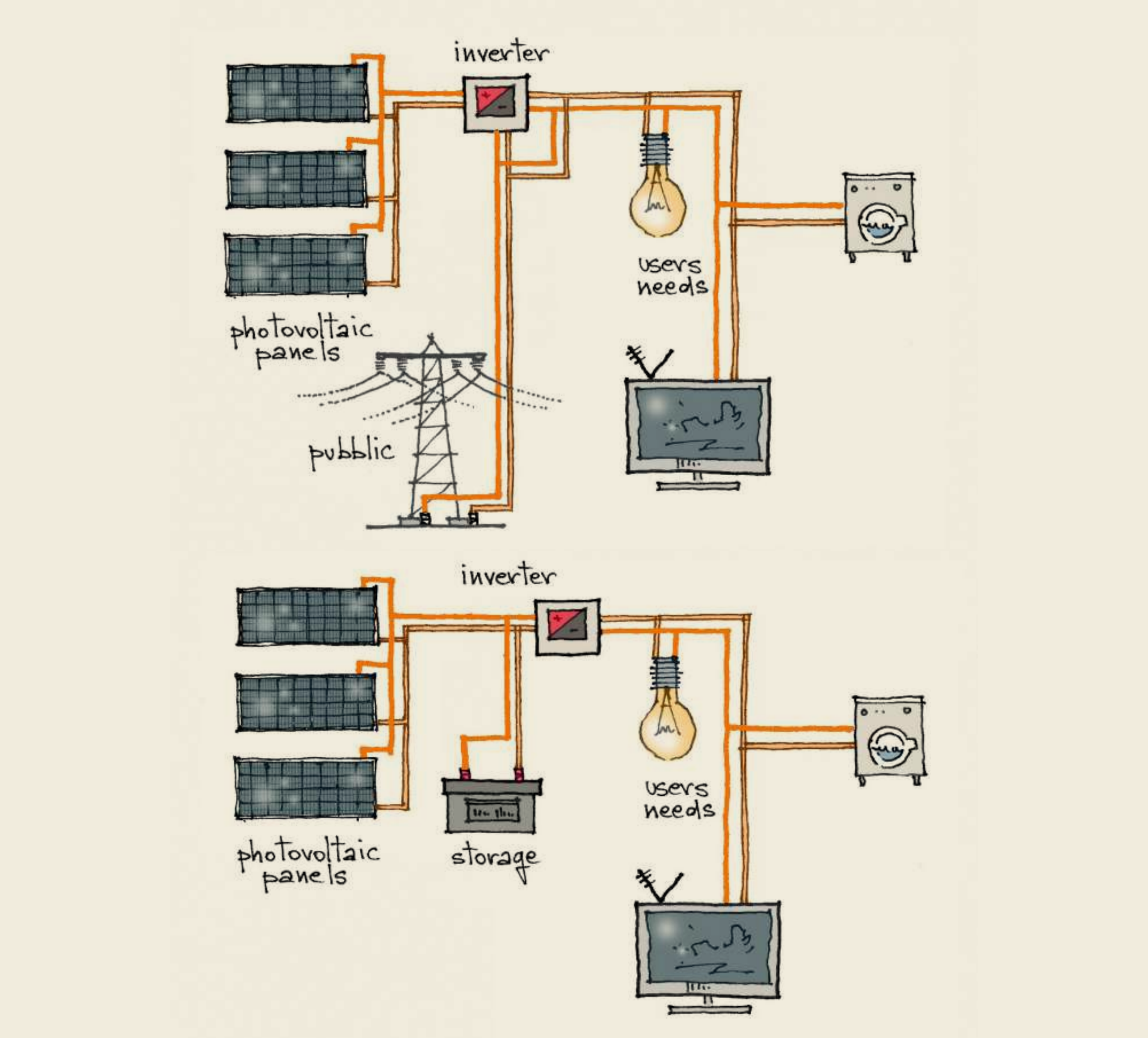
[45] *Conventional electric cooking stoves, based on electric resistances are very inefficient in terms of primary energy consumed. Induction cookers, instead are comparable to gas stoves.*

FIGURE A5.8 **STAND ALONE (BOTTOM) AND GRID CONNECTED (TOP) PV SYSTEMS**



For this reason, there is a limiting factor, in a sustainable neighbourhood, to the maximum height of a residential building, the constraint being the number of apartments that can be supplied from a given roof, i.e. PV, surface. For example, if the average annual electricity consumption of each 100 m$^2$ apartment into which the building is subdivided is 3,000 kWh, then – with a PV production of 1,500 kWh/kW (see figures given above) – the roof area needed by each apartment is 3,000/1,500 x 7,5 = 15 m$^2$. Thus, the maximum height of the building, in order to provide the required energy, is 100/15 ≈ 6-7 floors. The PV area required is larger and the maximum building height lower if the roof of the building has to supply all or part of the electricity needed for common services in the building, such as lighting, elevator, water pumping, etc., or for other uses, such as commercial buildings, street lighting, car battery charging, etc.

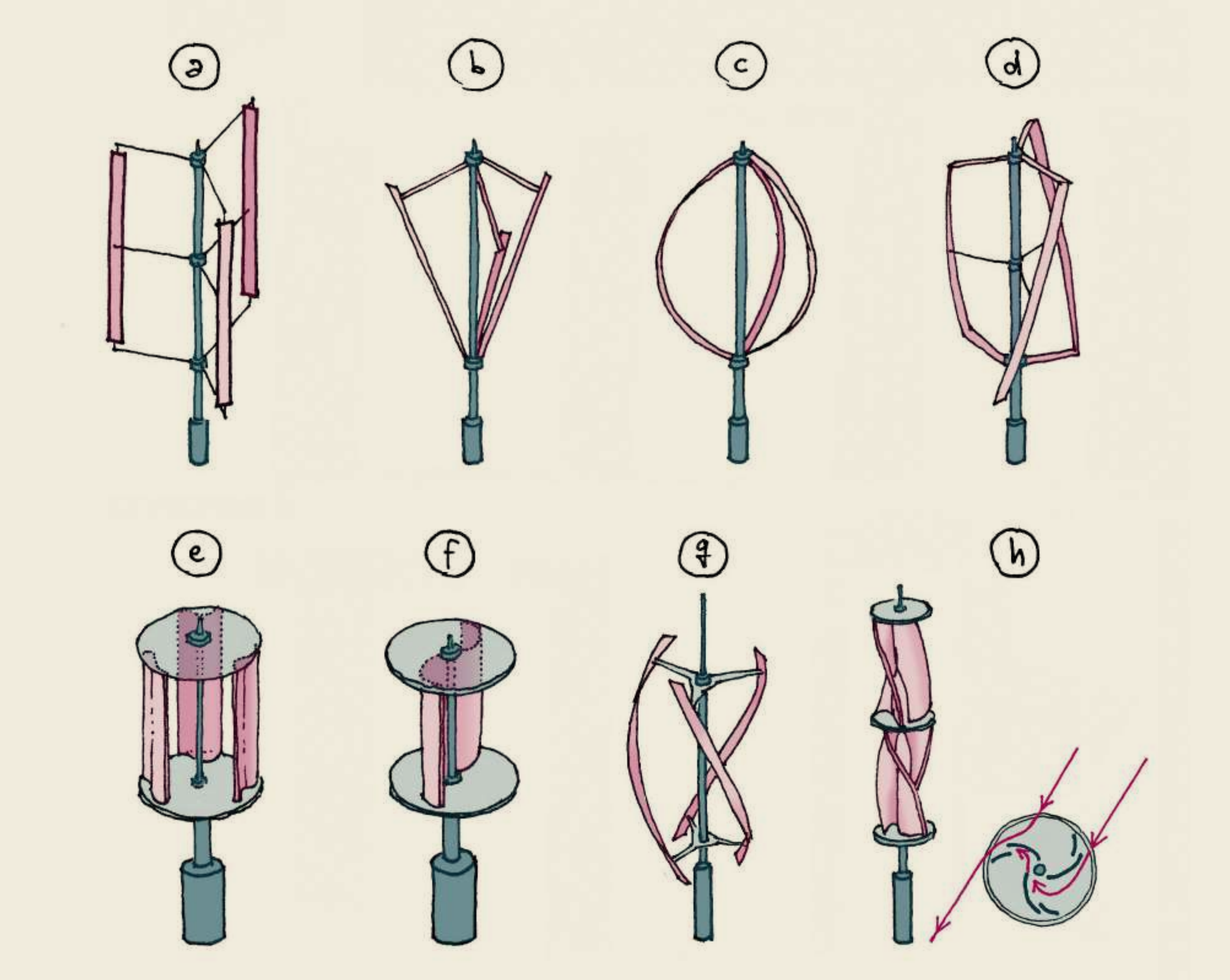
## 3. WIND ENERGY

Nowadays wind turbines are a well-established and cost-effective technology in windy areas. Wind farms are often part of the landscape of peri-urban areas, especially in Northern Europe.

Wind power is not available everywhere, but in many areas, it is often significant enough to make the installation of wind turbines cost effective.

Large wind turbines are not the only possibility to take into consideration in windy areas, because small wind generators (Figure A5.9), with either horizontal or vertical axis, are also an option. Even if their cost-effectiveness is less than that of the large turbines, they are a valuable option and could make a considerable contribution to the energy balance of the settlement, due to the large number that could be installed on the roofs of the buildings and to

FIGURE A5.9 **VERTICAL AXIS WIND TURBINES. (a), (b), (c) DARREIUS TYPE; (d) GORLOV TYPE; (e) SQUIRREL CAGE DARREIUS; (f) SAVONIUS TYPE; (g) AND (h): INNOVATIVE TURBINE DESIGN**



the fact that their production is not linked to the presence of sun, thus complementing or substituting the PV production and reducing the amount of back-up power needed to match demand and supply.

The power generated by wind turbines installed on the roofs of buildings' usually ranges between 0.5 and 4 kW. More powerful turbines, from 20 to 50 kW (10 – 15 m rotor diameter) can be installed in open spaces, such as parking areas, urban parks or constructed wetlands.

## 4. BIOMASS

Biomass represents a valuable resource and an alternative to fossil fuels, for many reasons: availability, different typologies, programmability and storage, and technological maturity.

Many technologies are available depending on the type of biomass to be processed, on the final use and on the economic conditions.

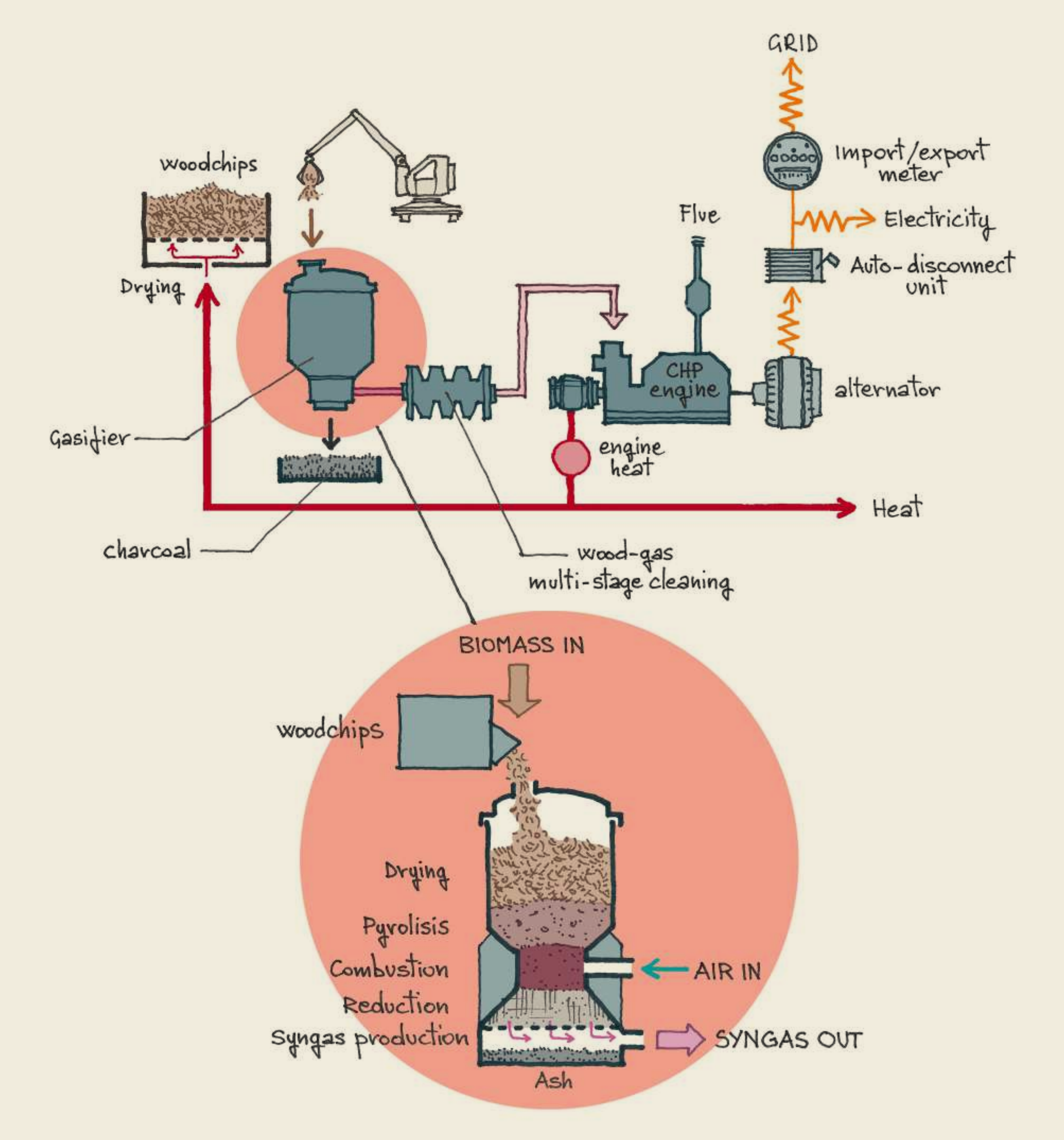
Biomass available at neighbourhood scale derives from urban agriculture, residues from parks and gardens, the organic fraction of solid waste and sewage sludge. Biomass from agriculture, and parks and gardens can be used directly (as direct combustion of pellets or wood-chips) or after gasification. The organic fraction of solid waste and sewage sludge can be used to produce biogas.

### 4.1 GASIFICATION

Gasification is a process that converts biomass into carbon monoxide and hydrogen by the reaction of the raw material at high temperatures with a controlled amount of oxygen (Figure A5.10).

The resulting gas mixture is called synthesis gas or syngas and is itself a fuel. Gasification is a very efficient method for extracting energy from many different types of organic materials, and also has applications as a clean waste disposal technique.

FIGURE A5.10 **PRODUCTION OF ELECTRICITY VIA GASIFICATION OF WOODCHIPS**



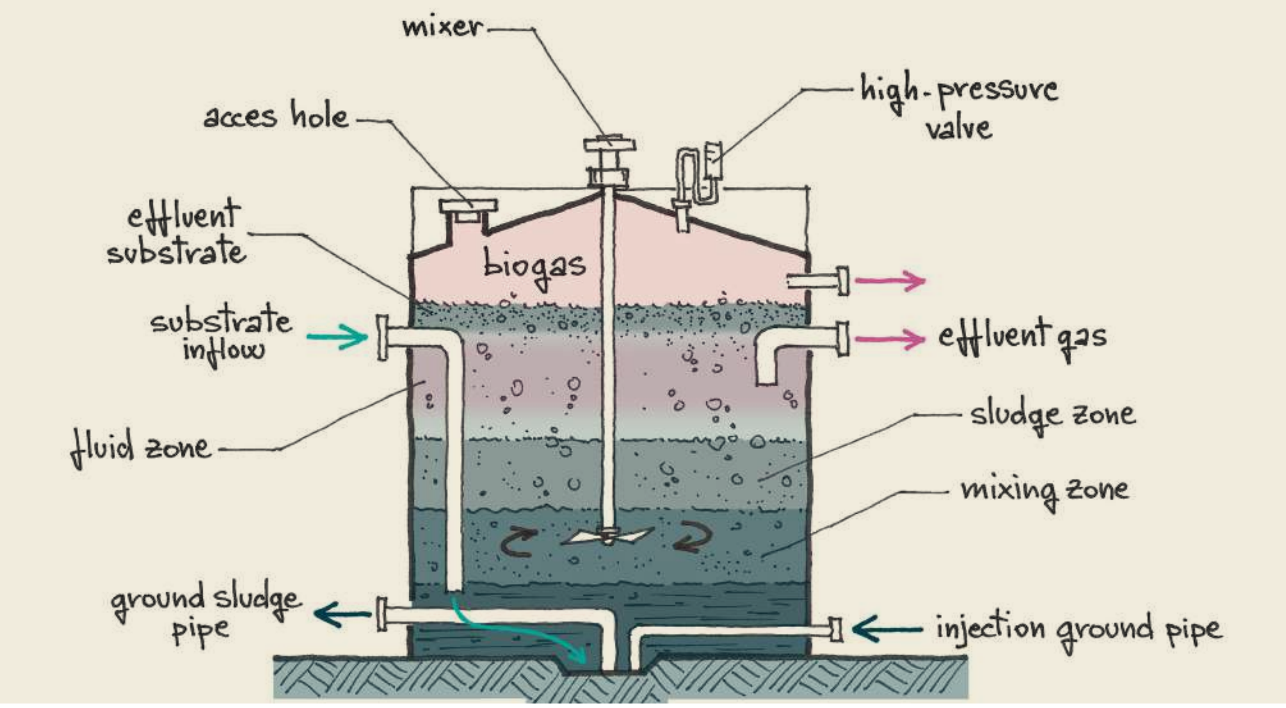
CHP units based on internal combustion engines can be fuelled by syngas. Biomass fuelled CHP is a renewable energy efficient technology which is very useful for integration into a distributed generation system, because of its programmability.

A biomass fuelled CHP unit requires space not only for the gasifier, the engine and – if used – the absorption chiller, but also for storage of both biomass and gas.

## 4.2 BIOGAS PRODUCTION

Organic residues and sewage sludge can be used as renewable energy sources if fermented in the absence of oxigen in anaerobic digesters (Figure A5.11). Anaerobic digestion is the process of conversion of organic matter to biogas by microbial action in the absence of air. The bacteria decompose the organic wastes to produce a mixture of methane and carbon dioxide (biogas). After digestion, the sludge is passed to a sedimentation tank where it is thickened. The thickened sludge needs to be treated further prior to reuse or disposal. The process has two benefits: it yields biogas, which can replace

FIGURE A5.11 **DIAGRAM OF A BIOGAS DIGESTER.**



conventional fuels and it provides digested sludge, which can be used as a high nutrient fertilizer.

Anaerobic digestion takes place in biogas reactors, gastight chambers whose input is organic waste, such as black water, sewage sludge, cooked food waste and vegetable waste; the outputs are gas and sludge.

Based on available experiences in the EU and on technical literature, the output from wastewater management can be assumed to be 18-26 litres of biogas produced by anaerobic digestion of sludge per person per day (Bachmann 2005) and a low heating value (LHV) of 6.5 kWh/m$^3$. At household scale, including kitchen wastes, the production may reach 30-60 litres per person per day (Nembrini 2006).

The Upflow Anaerobic Sludge Blanket Reactor (UASB), Figure A5.12 is a biogas digester specifically designed for wastewater treatment.

Biogas production has many advantages (Figure A5.13) but also some disadvantages.

**Advantages**

- Generation of biogas and fertiliser
- Reduction of greenhouse gas emissions through methane recovery
- Combined treatment of different organic waste and wastewaters
- Reduction of solids to be handled (e.g. less excess sludge)
- Good pathogen removal depending on temperature
- Process stability (high loads can be treated but anaerobic sludge can also be preserved for prolonged periods without any feeding)

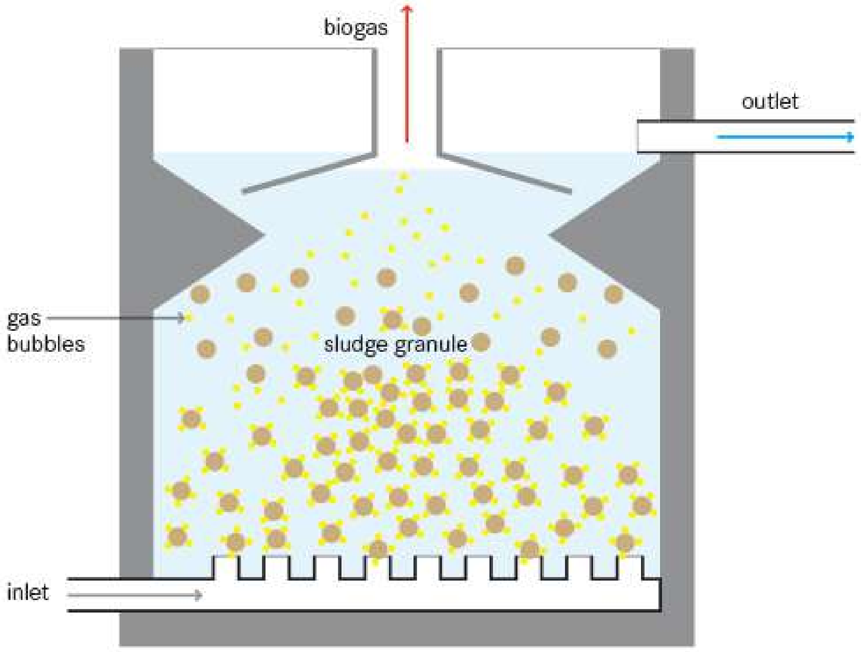
**Disadvantages**

- Small and medium-scale anaerobic technology for the treatment of solid waste in middle- and low-income countries is still relatively new
- Experts are required for the design and construction; depending on scale they may also be required for operation and maintenance
- High sensitivity of methanogenic bacteria to a large number of chemical compounds
- Sulphurous compounds can lead to odour
- Requires seeding (start-up can be long due to the low growth yield of anaerobic bacteria)

The most common heat engines used for biogas energy conversion are gas turbines and combustion engines. Combustion engines can be either internal combustion engines (e.g. reciprocating engine) or external combustion engines (e.g. Stirling engine).

In Figure A5.14 an example of a market-ready biogas production-utilisation system at neighbourhood scale is shown (Kompogas).

FIGURE A5.12 **UASB REACTOR (SSWM 2016)**



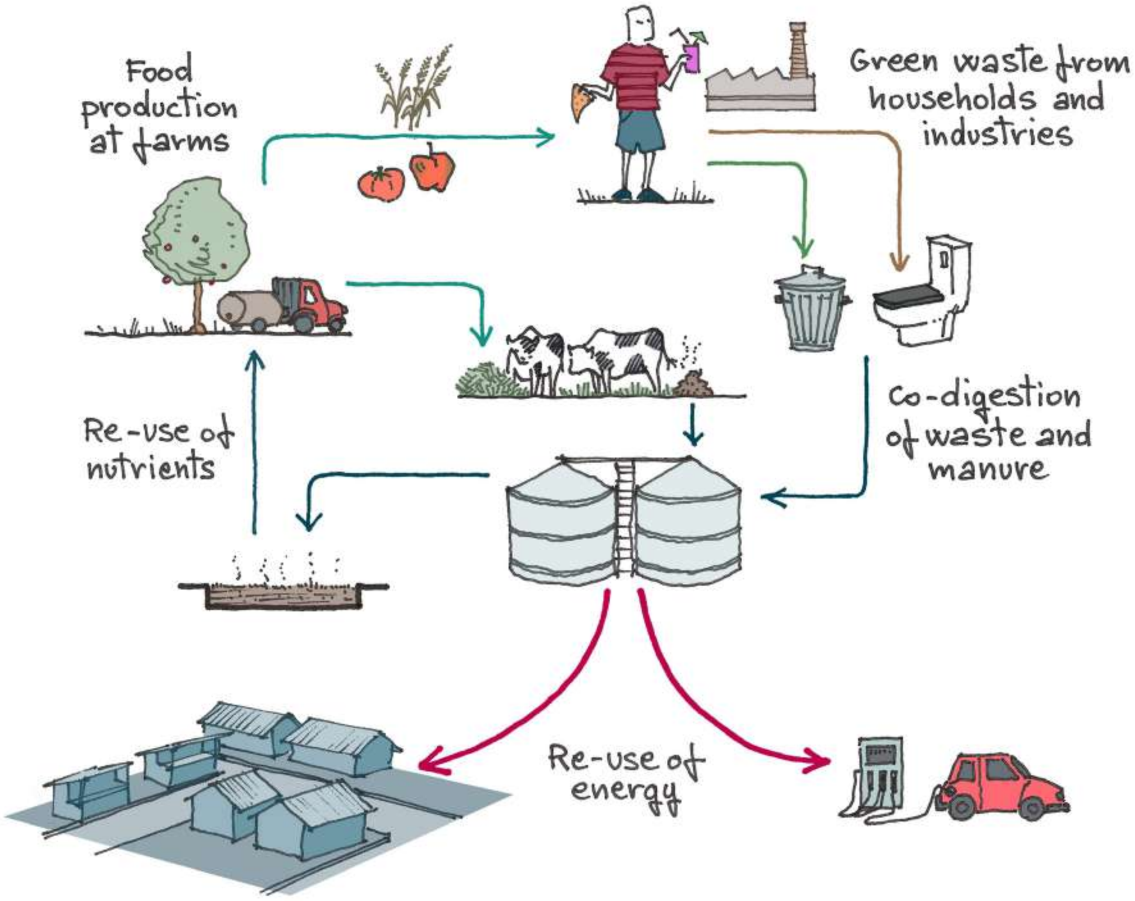
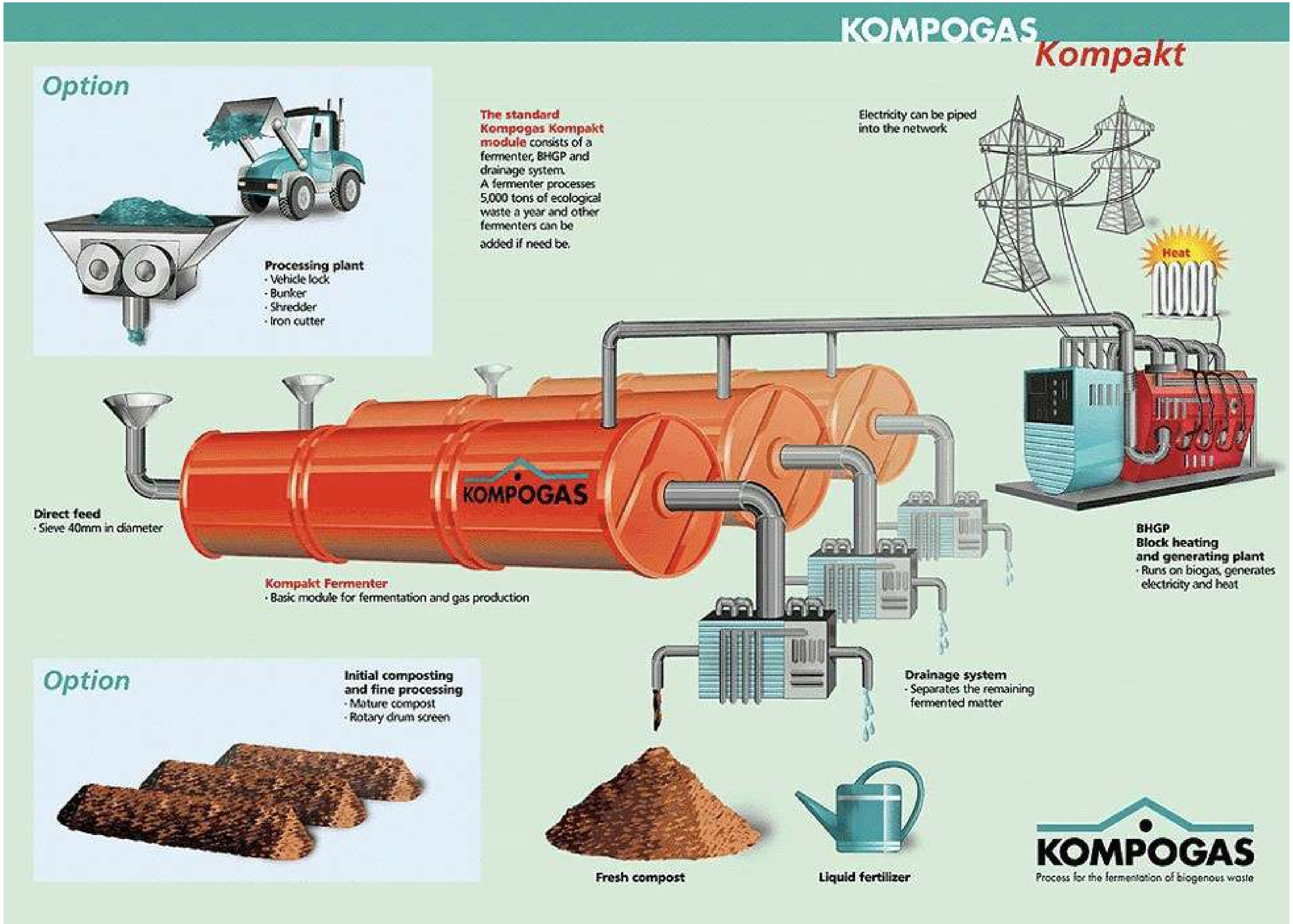


FIGURE A5.14 **MARKET READY BIOGAS FUELLED ELECTRICITY, HEAT AND FERTILISER PRODUCTION AT NEIGHBOURHOOD SCALE. THE INPUT IS ORGANIC WASTE DERIVED FROM SEPARATED MUNICIPAL WASTE COLLECTION.**



## REFERENCES

Bachmann N., (2005), Sustainable biogas production in municipal wastewater treatment plants, IEA Bioenergy - http://task37.ieabioenergy.com/files/daten-redaktion/download/Technical%20Brochures/Wastewater_biogas_grey_web-1.pdf

Nembrini, G. P., Kimaro, A., (2006) Using Biogas Plants for Treatment of Urban Community Wastes to Supply Energy and Improve Sanitation, presented at the Expert Group Meeting on "Energy Access for the Urban Poor", Nairobi

SSWM (2016), UASB Reactor - http://www.sswm.info/category/implementation-tools/wastewater-treatment/hardware/semi-centralised-wastewater-treatments/u

# A6 THE HYDROLOGIC CYCLE

Water, like energy, cannot be created or destroyed. Water is constantly being recycled in a process known as the water cycle, or hydrologic cycle. The sun's energy powers this cycle. This energy causes water to evaporate and rise in the form of water vapour. Once the vapour begins to cool it condenses into water droplets. Gravity pulls the water back down to earth as precipitation. After the water has returned to the earth's surface, energy from the sun causes it to evaporate, thus completing the cycle (Figure A6.1).

Precipitation that falls to Earth is distributed in four main ways: some is returned to the atmosphere by evaporation, some may be intercepted by vegetation and then evaporated from the surface of leaves, some percolates into the soil by infiltration, and the remainder flows directly as surface runoff into rivers, lakes and finally into the sea (Figure A6.2). Most groundwater is derived from precipitation that has percolated through the soil (Britannica online Encyclopedia, n.d.).

As precipitation infiltrates into the subsurface soil, it generally forms an unsaturated zone and a saturated zone (Figure A6.3). In the unsaturated zone, the voids - that is, the spaces between grains of gravel, sand, silt, clay, and cracks within rocks - contain both air and water. Although a lot of water can be present in the unsaturated zone, this water cannot be pumped by wells. Below the unsaturated zone is a saturated zone where water completely fills the voids between rock and soil particles.

FIGURE A6.1 **SIMPLIFIED SCHEMATIC OF THE WATER CYCLE**

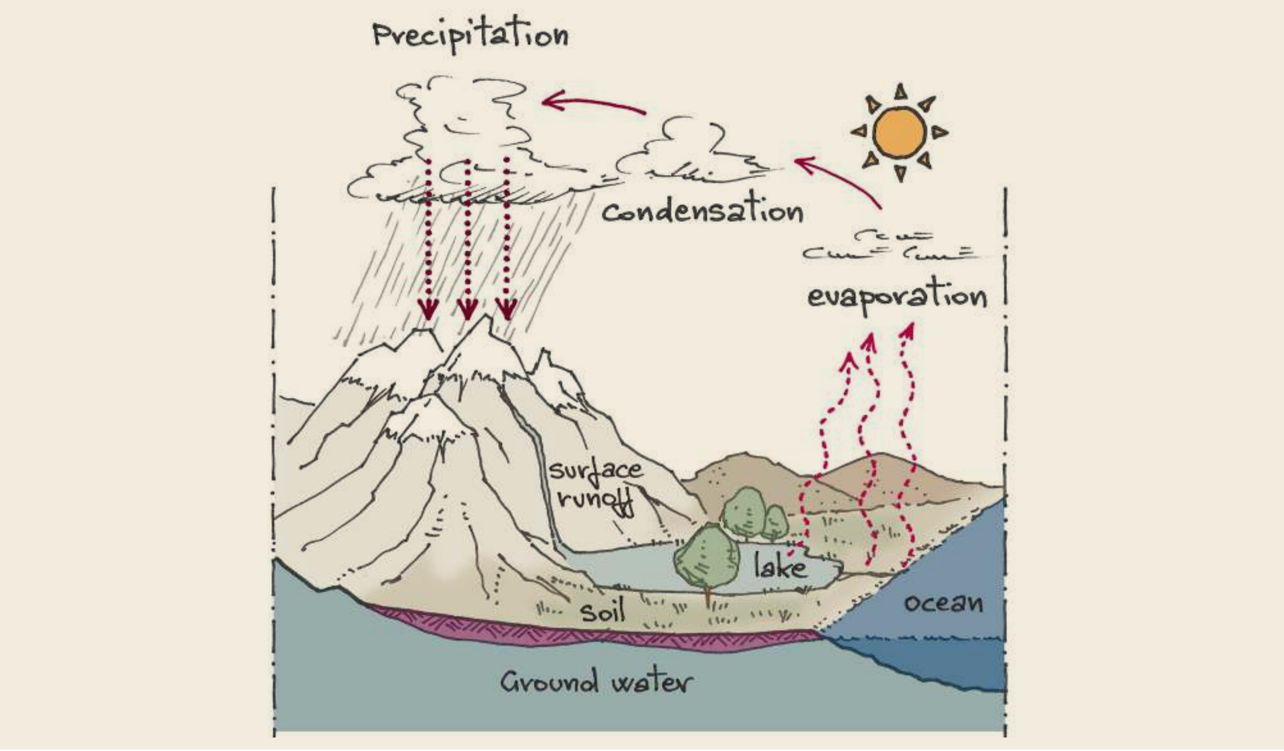


FIGURE A6.2 **THE WATER CYCLE IN MORE DETAIL.**

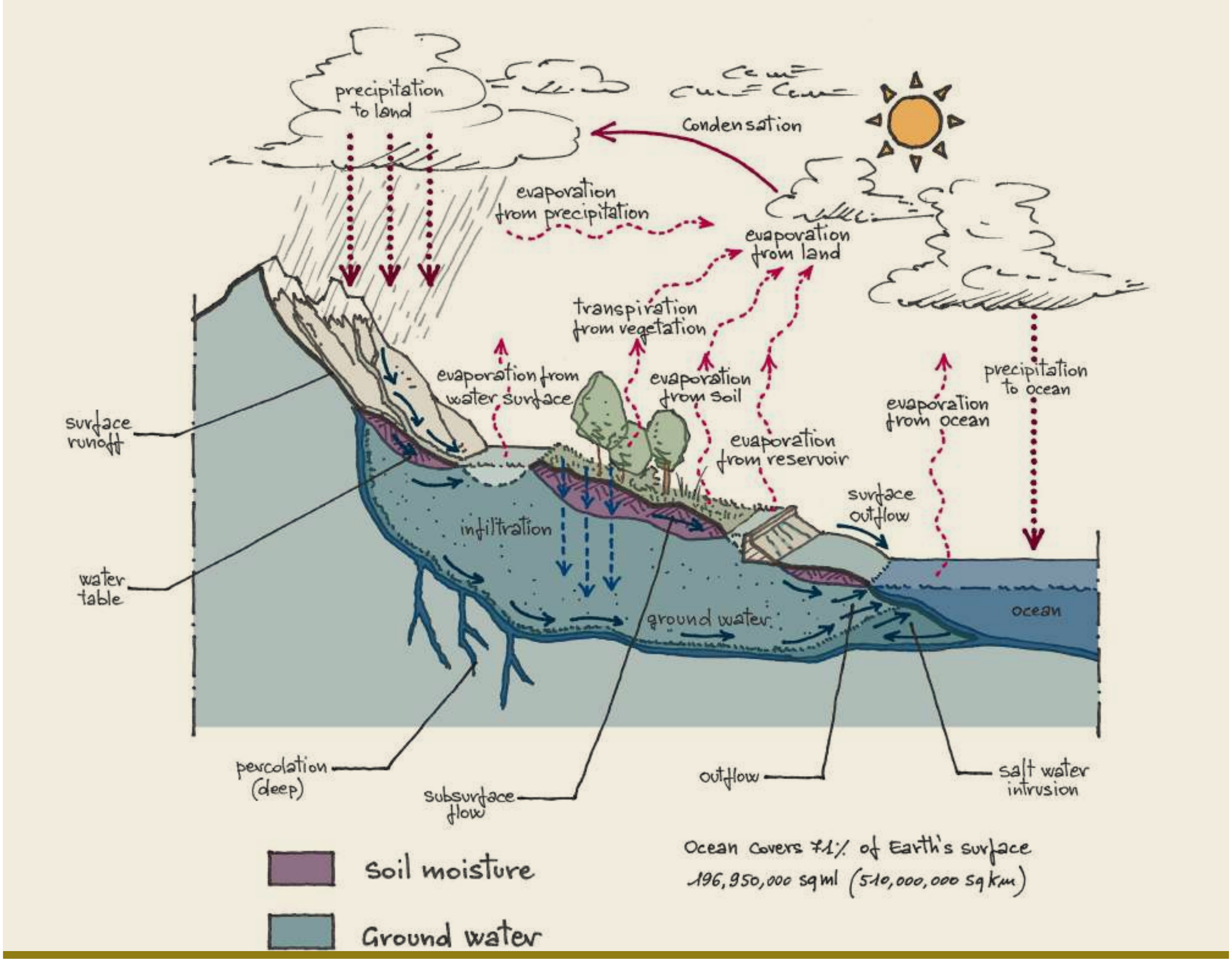


FIGURE A6.3 **SUBSURFACE WATER (ADAPTED FROM: USGS WATER SCIENCE SCHOOL, n.d. - a)**

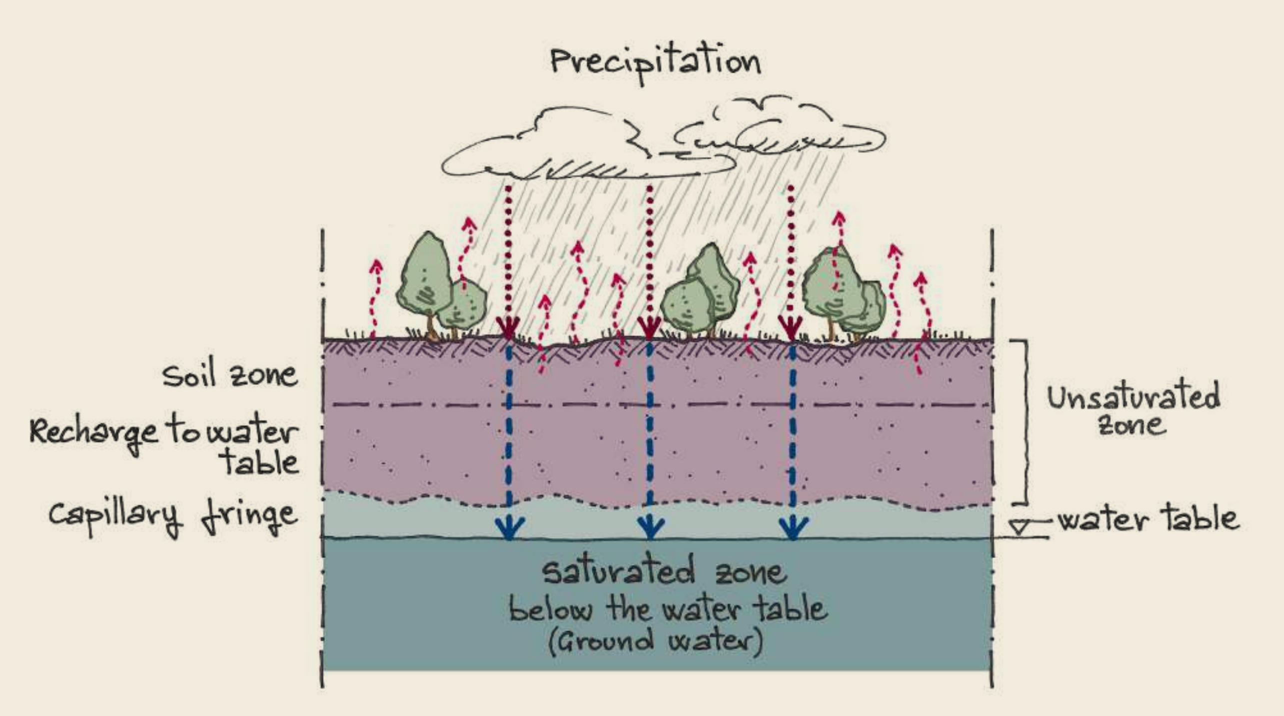


FIGURE A6.4 **INFILTRATION REPLENISHES AQUIFERS (ADAPTED FROM: USGS WATER SCIENCE SCHOOL, n.d. - b)**

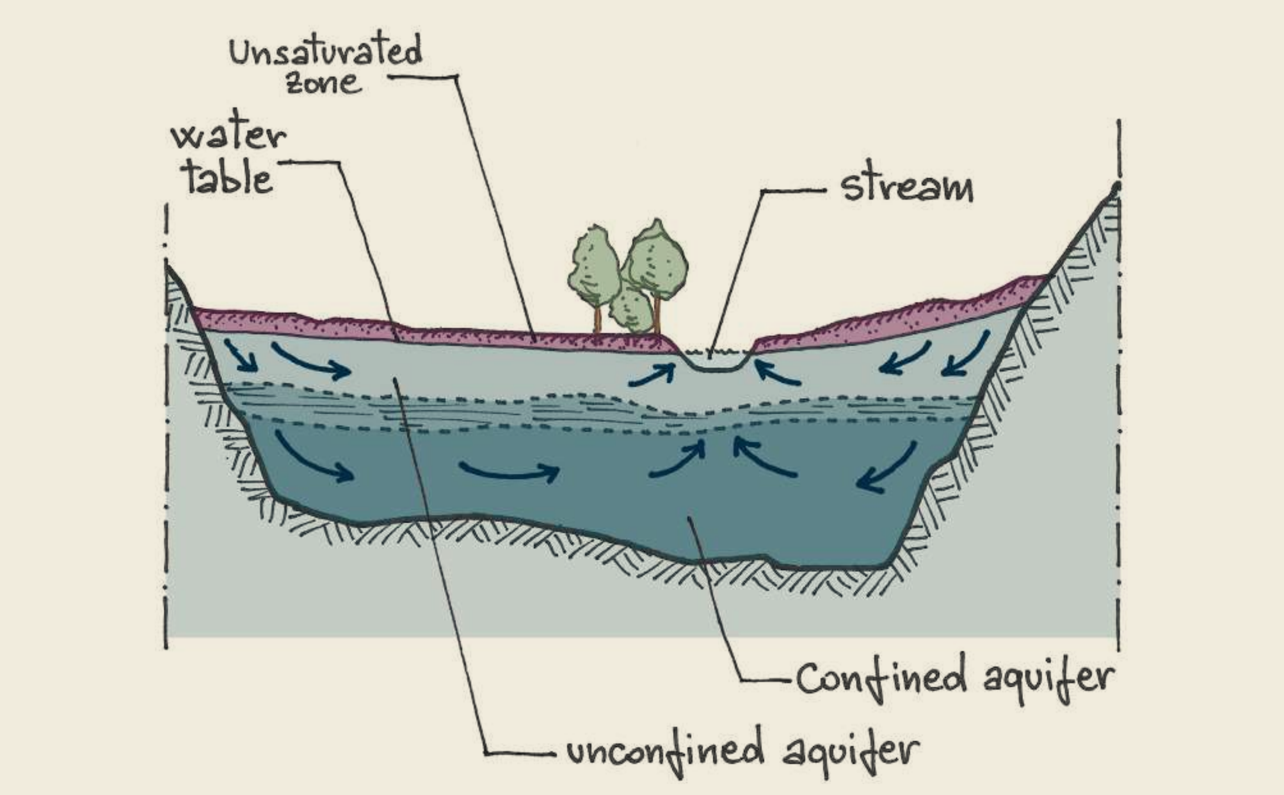
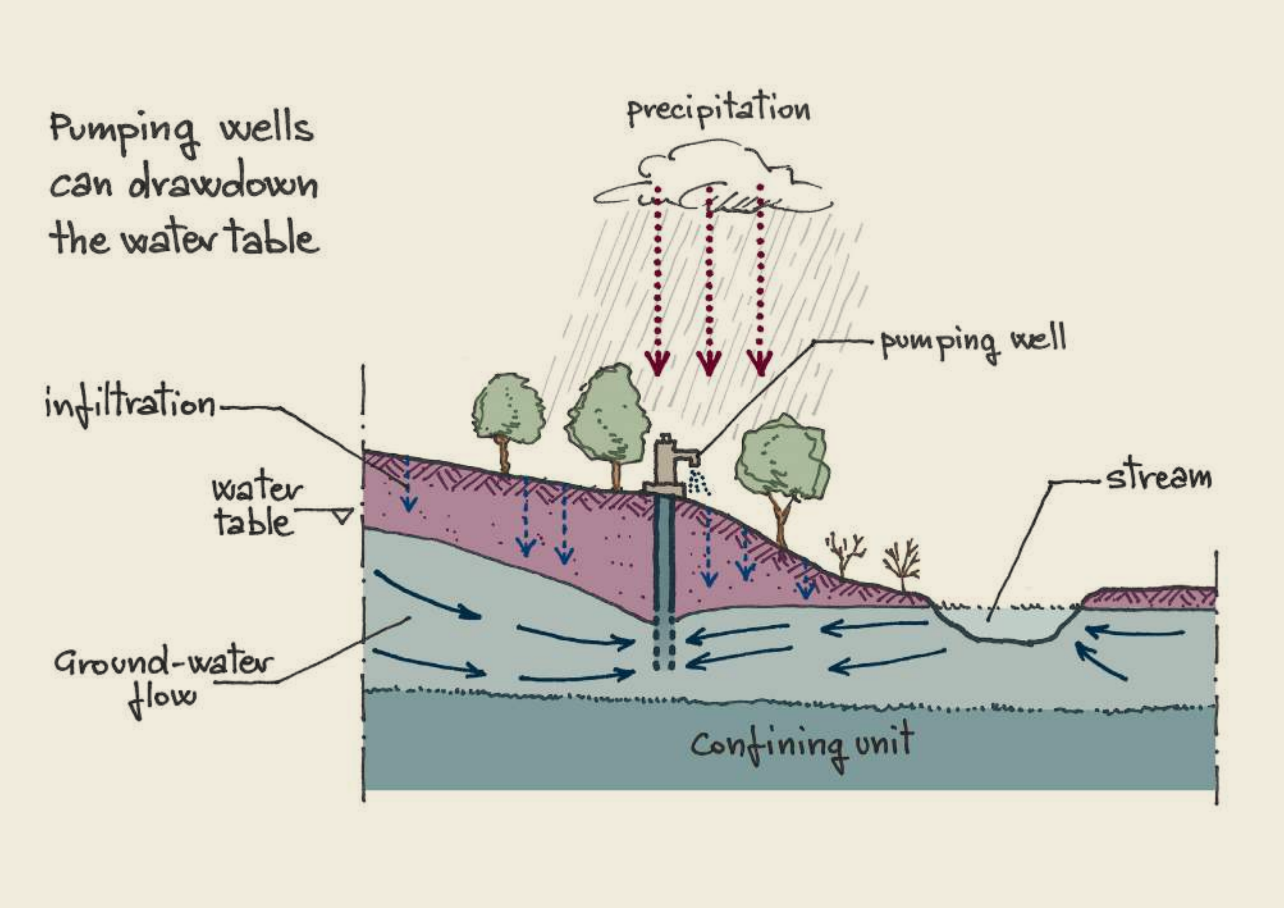


FIGURE A6.5 **EXCESSIVE WATER PUMPING CAN DRY OUT WELLS**



The boundary between the unsaturated and saturated zones is called the water table. The level of the water table can change naturally over time due to changes in weather cycles and precipitation patterns, stream flow and geological changes, and even human-induced changes, such as an increase in impervious surfaces, such as roads and paved areas, in the landscape.

Some of the water that infiltrates will remain in the shallow soil layer, where it will gradually move vertically and horizontally through the soil and subsurface material. Some of the water may infiltrate deeper, recharging groundwater aquifers. If the aquifer is porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their various purposes (USGS Water Science School, n.d - a) (Figure A6.4).

Natural refilling of deep aquifers is a slow process because groundwater moves slowly through the unsaturated zone and the aquifer.

Pumping can have a great deal of influence on water levels below ground, especially in the vicinity of a well, as shown in Figure A6.5. Excessive pumping can lower the water table so much that the wells no longer supply water.

## REFERENCES

Britannica online Encyclopedia (n.d), Water Cycle - http://www.britannica.com/science/water-cycle

USGS Water Science School (n.d -a) - Infiltration - http://water.usgs.gov/edu/watercycleinfiltration.html

USGS Water Science School (n.d -b) - The Water Cycle - http://water.usgs.gov/edu/watercyclegwstorage.html

# A7 DEWATS COMPONENTS

## 1. PRIMARY TREATMENT

The simplest and cheapest primary treatment device is the Septic Tank (Figure A7.1), a watertight chamber made of concrete, fibreglass, PVC or plastic, for the storage and treatment of blackwater and greywater. Settling and anaerobic processes reduce solids and organics, but the treatment is only moderate. The septic tank is the most common small-scale decentralised treatment unit for grey water and blackwater.

**Pros**: simple, durable, little space required because it is underground

**Cons:** low treatment efficiency, effluent not odourless

An alternative to the septic tank is the Imhoff tank (Figure A7.2), a primary treatment technology for raw wastewater, designed for solid-liquid separation and digestion of the settled sludge. It consists of a V-shaped settling compartment above a tapering sludge digestion chamber with gas vents. In the digestion chamber, the settled solids are anaerobically digested generating biogas.

**Pros:** durable, little space required because it is underground, odourless effluent.

**Cons:** less simple than septic tank, needs very regular de-sludging.

FIGURE A7.1 **SEPTIC TANK - SCHEMATIC CROSS SECTION (ADAPTED FROM: TILLEY 2008)**

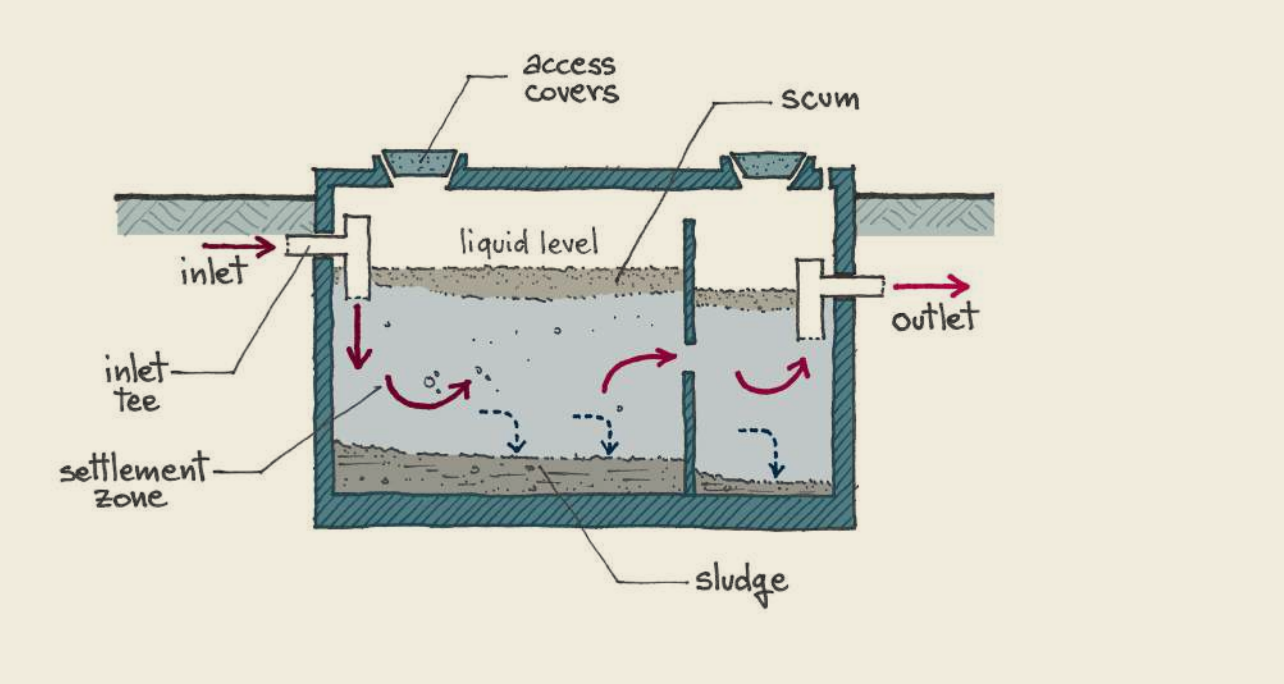
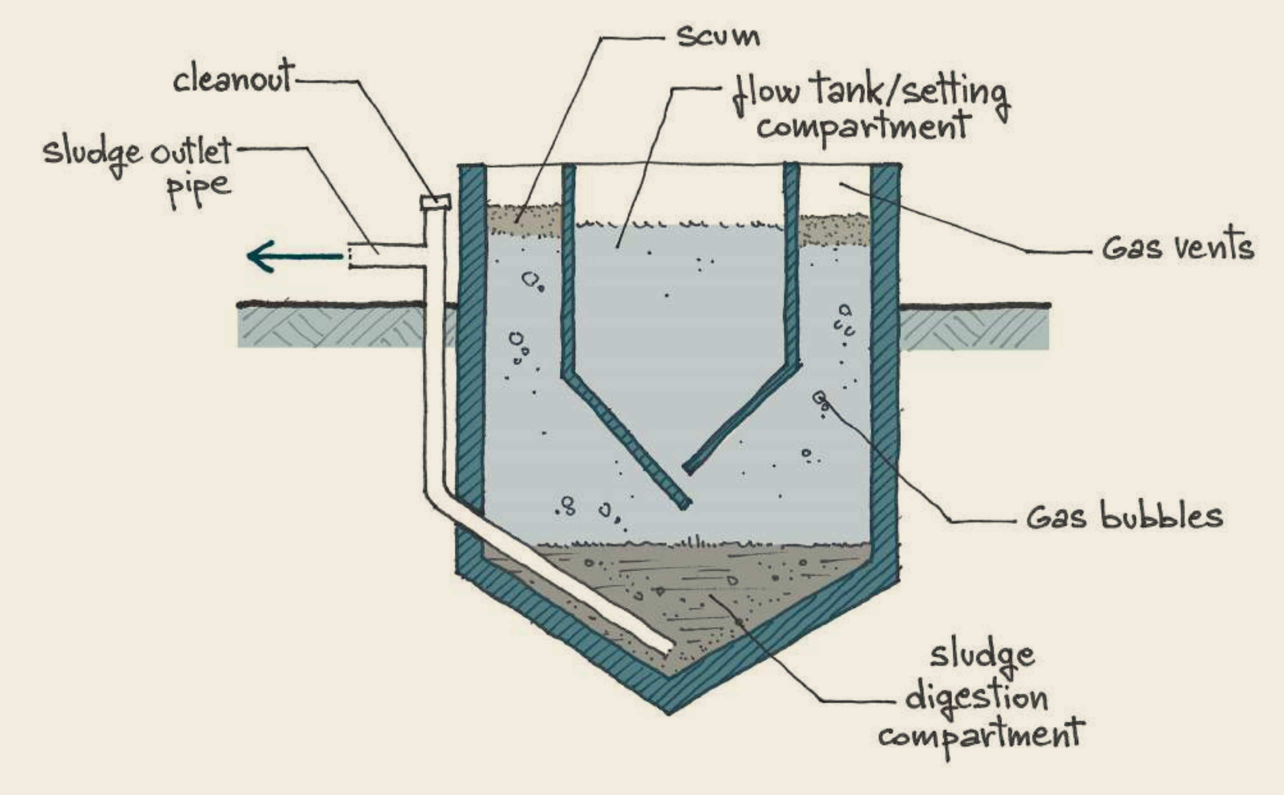


FIGURE A7.2 **IMHOFF TANK - SCHEMATIC CROSS SECTION (ADAPTED FROM: TILLEY 2008)**



A third alternative to the septic tank is the anaerobic biogas reactor (see Appendix 5). Among the advantages of the anaerobic biogas reactor is that, besides wastewater, other kinds of organic inputs can also be used, such as food wastes, increasing both the amount of gas produced[46] and the digested slurry. The disadvantage is that its operation is less simple than that of both septic and Imhoff tanks.

Furthermore, the entering wastewater should not be too diluted; thus, the best solution would be to feed it only with black water, using separate piping for grey water, which can be sent directly to the secondary treatment unit, or even to the tertiary.

**Pros:** access to renewable source of energy (biogas)

**Cons:** less simple than septic tank; special skills needed for gas-tight dome construction.

## 2. SECONDARY TREATMENT

In anaerobic baffled reactors (ABR), a number of mechanical and anaerobic cleansing processes are applied in sequence (Figure A7.3). The reactor consists of different chambers (connected in series) in which the wastewater flows up-stream. Activated sludge is located on the bottom of each chamber. During inflow into the chamber wastewater is thoroughly mixed up with the sludge and wastewater pollutants are decomposed. In the first chambers the easily degradable substances are removed. In the following chambers, substances which are more difficult to degrade are removed: the more chambers applied the higher the performance.

**Pros:** simple and durable, high treatment efficiency, little permanent space required because it is underground, hardly any blockage, relatively cheap compared to anaerobic filter: ideal for DEWATS.

**Cons:** requires larger space for construction, less efficient with weak wastewater, longer start-up phase than anaerobic filter.

Anaerobic filter reactors are fixed bed reactors (Figure A7.4). Biological cleansing processes rely on anaerobic organisms that settle on the surface of filter material and degrade inflowing organic wastewater pollutants.

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[46] *The minimum amount of biogas for a household requires for cooking is approximately 2m3/d. Approximately 20 to 30m3 of domestic wastewater is required daily to produce the minimum amount of gas. This implies that community biogas production deriving only from wastewater treatment cannot fulfil the cooking energy needs of the community by itself (Source: Decentralised Wastewater Treatment Systems and sanitation in developing countries (DEWATS): a practical guide, Water, Engineering and Development Centre (WEDC), Loughborough University, Leicestershire, UK https://wedc-knowledge.lboro.ac.uk/details.html?id=10409).*

FIGURE A7.3 **BAFFLED REACTOR – SCHEMATIC SECTION AND VIEW (ADAPTED FROM: SANIMAS n.d.)**

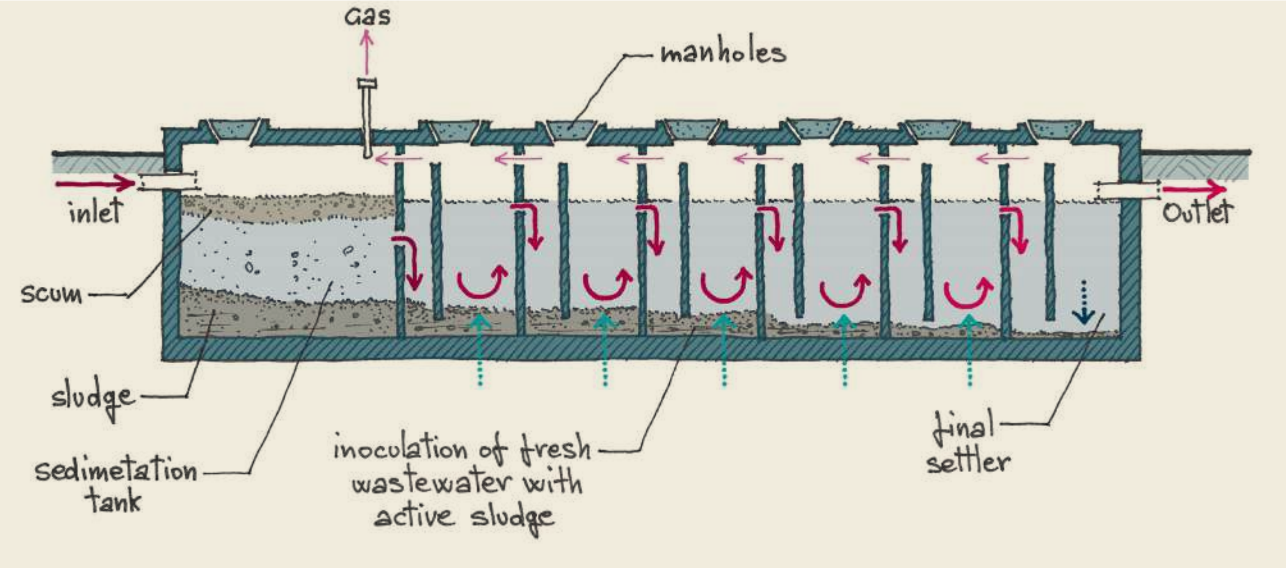
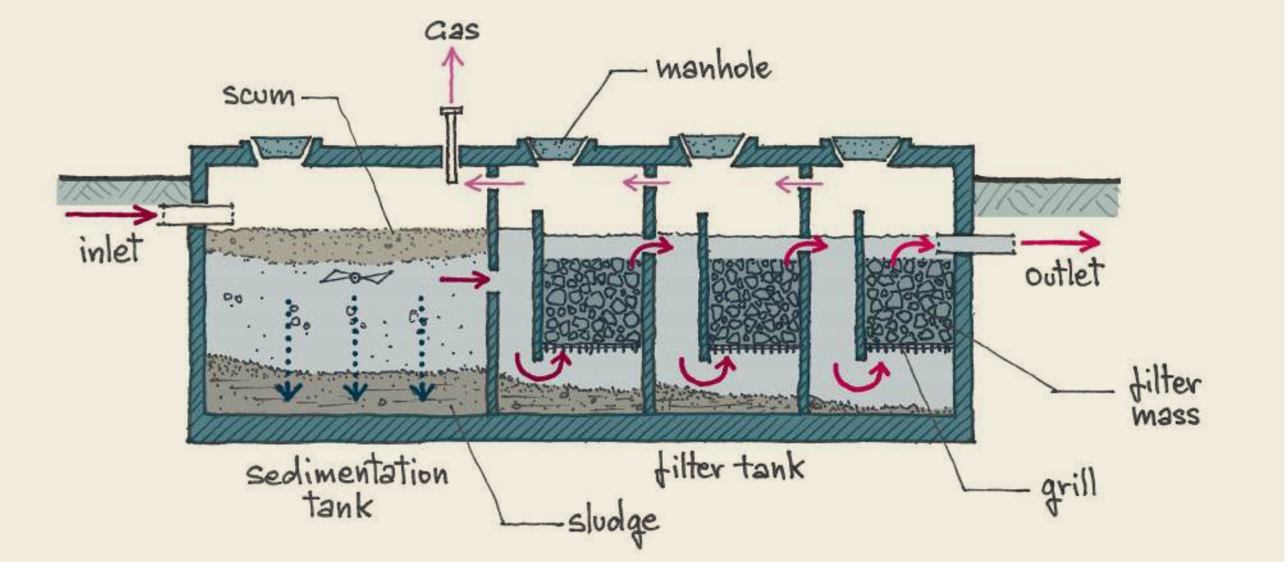


FIGURE A7.4 **ANAEROBIC FILTER REACTOR – SCHEMATIC CROSS SECTION AND VIEW (ADAPTED FROM: SANIMAS n.d.)**



The system is operated continuously via upstream and downstream processes. Rocks, gravel, slag or plastic contact beds can be used as filter materials.

**Pros:** simple and fairly durable if well-constructed and waste-water has been properly pre-treated; high treatment efficiency, little permanent space required because it is underground

**Cons:** costly to construct because of special filter material, blockage of filter possible, effluent smells slightly despite high treatment efficiency.

## 3. SECONDARY AND TERTIARY TREATMENT

A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. It is used for secondary or tertiary treatment of wastewater or as single treatment for grey water. Pre-treated wastewater flows continuously and horizontally through a planted filter bed (Figure A7.5).

Plants provide appropriate environments for microbiological attachment, growth and transfer of oxygen to the root zone. Organic matter and suspended solids are removed by filtration and microbiological degradation. The effluent of a well-functioning constructed wetland can be used for irrigation and aquaculture, contributing to the optimisation of the local water and nutrient cycle.

FIGURE A7.5 **SCHEMATIC CROSS-SECTION OF A SUBSURFACE HORIZONTAL FLOW CONSTRUCTED WETLAND (ADAPTED FORM: WATER AND SANITATION PROGRAM 2008)**

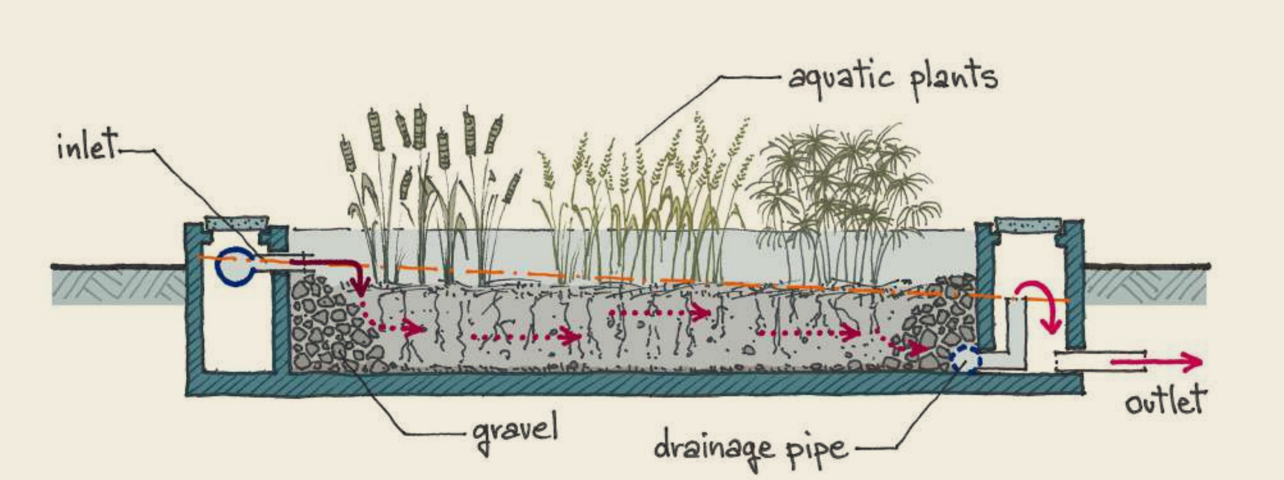
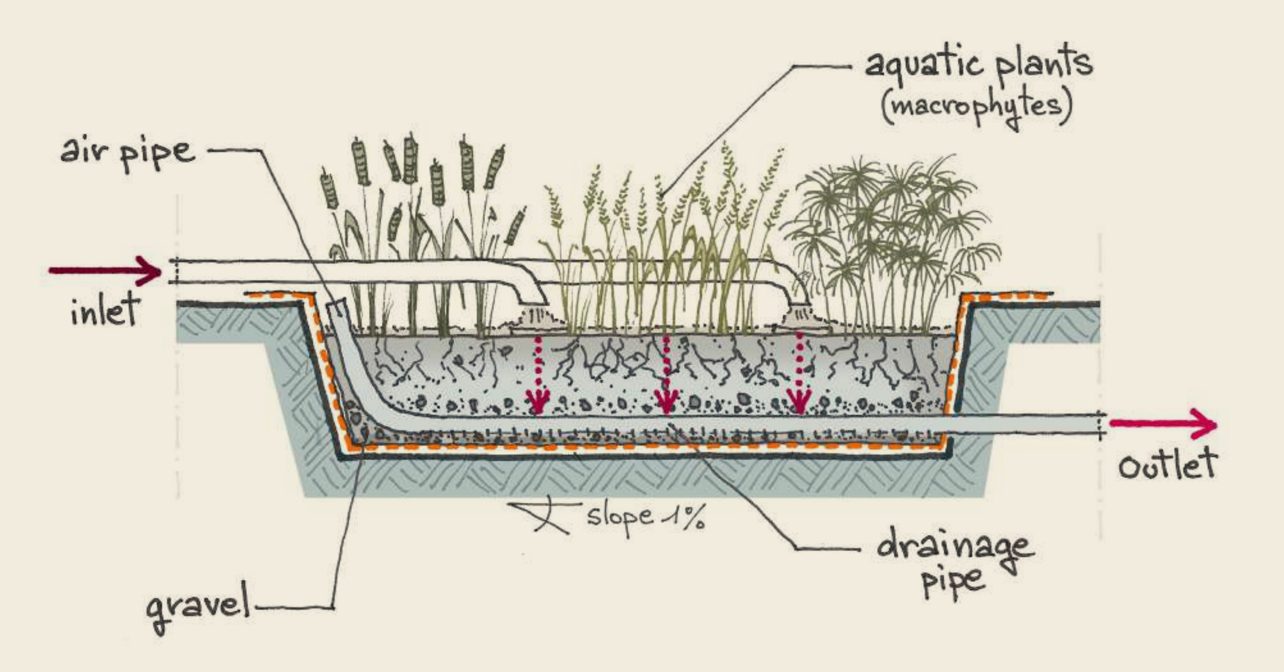


FIGURE A7.6 **SCHEMATIC CROSS-SECTION OF THE VERTICAL FLOW CONSTRUCTED WETLAND**



**Pros:** relatively inexpensive to build where land is affordable, if filter material is available at site; it can be maintained by the local community as no high-tech spare parts, electrical energy or chemicals are required. High treatment efficiency when properly constructed, pleasant landscaping possible, no wastewater above ground, no nuisance of odour. The risk of mosquito breeding is low. The plants grown in the wetland may be used for composting or biogas production.

**Cons:** design and implementation require expert knowledge. High space requirement, as an area of 1 – 2 $m^2$/person equivalent is required (UN-Habitat 2008); costly if right quality of gravel not available at site; intensive maintenance and supervision during first 1-2 years.

Similar characteristics are seen in a vertical flow constructed wetland (Figure A7.6), which is a filter bed that is planted with aquatic plants where wastewater is poured or dosed onto the wetland surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix.

The filter medium acts as a filter for removing solids, a fixed surface which bacteria can attach to and as a base for vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter medium. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics.

FIGURE A7.7 **SCHEMATIC CROSS-SECTION OF THE POLISHING POND**

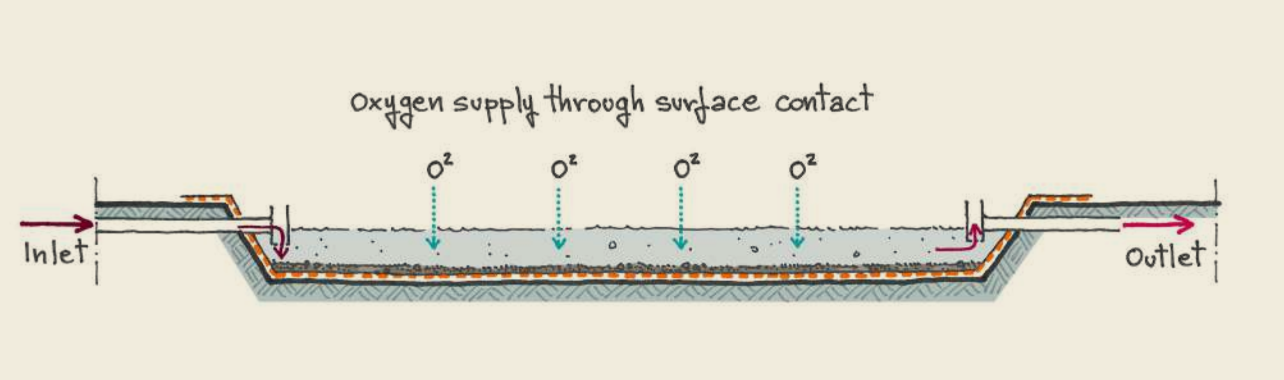
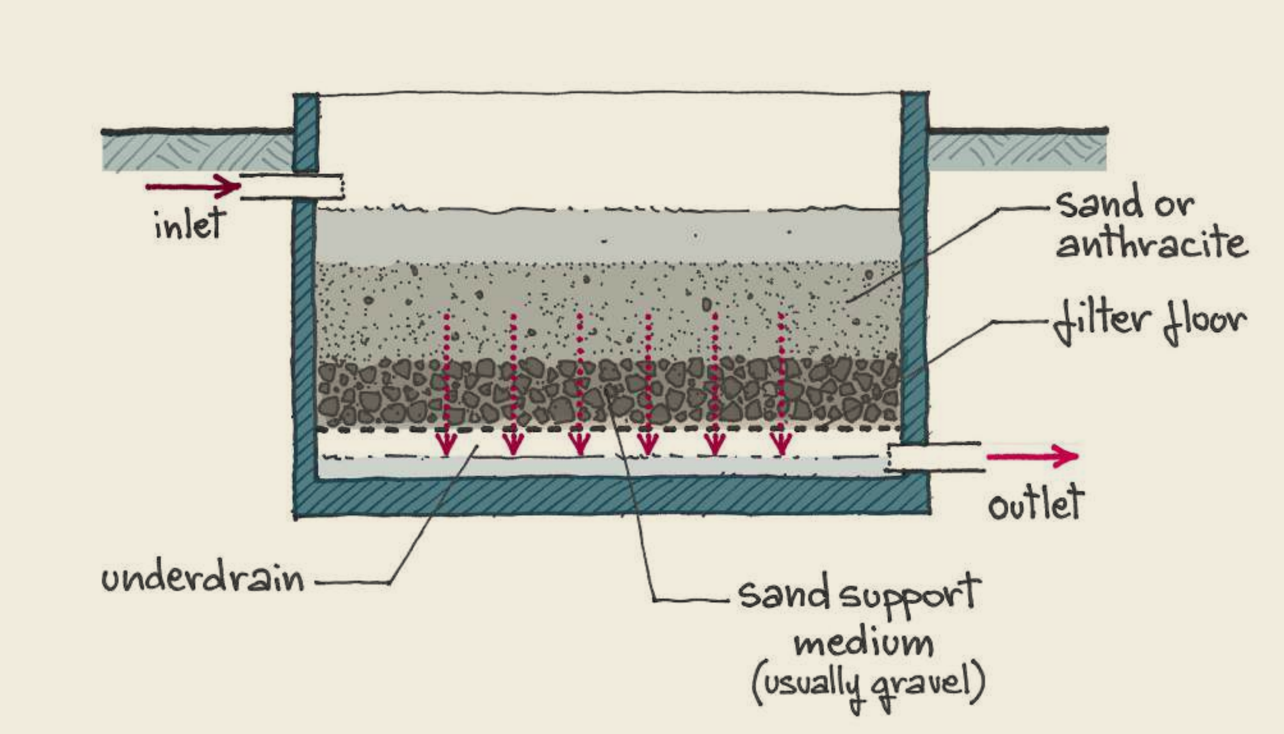


FIGURE A7.8 **DEPTH FILTRATION PRINCIPLE (ADAPTED FROM: TILLEY 2008)**



A smaller area than the horizontal flow is required: 0.8 – 1.5 m²/person equivalent (UN-Habitat 2008).

**Pros and cons:** the same as the horizontal flow constructed wetland, except for clogging, which is a more common problem.

In polishing ponds (Figure A7.7) both aerobic degradation and pathogen removal take place, and the effluent may be suitable for discharge to natural receiving waters or for reuse (not potable water).

**Pros:** they are simple in construction, reliable in performance if properly designed, and can be used to create an almost natural environment.

**Cons:** they may be the ideal breeding environment for mosquitos, thus should be located far from urbanised areas or careful control measures should be put into action. The water and vegetation components can be manipulated to regulate mosquito development, and chemical and biological agents, such as larvivorous fish, can be used to reduce otherwise uncontrollable populations.

Depending on the end-use of the effluent or national standards for discharge in water bodies or aquifer recharge, a post-treatment step may be required to remove pathogens, residual suspended solids and/or dissolved constituents. Tertiary filtration and disinfection processes are most commonly used to achieve this.

Tertiary Filtration processes can be classified as either depth (or packed-bed) filtration or surface filtration processes. Depth filtration involves the removal of residual suspended solids by passing the liquid through a filter bed comprised of a granular-filter medium (e.g., sand), Figure A7.8. If activated carbon is used as a filter medium, not only are a variety of organic and inorganic compounds removed but any unpleasant taste and odour are also eliminated. Surface filtration involves the removal of particulate material by mechanical sieving as the liquid passes through a thin septum (i.e., filter layer).

Due to its low cost, ready availability and easy operation, chlorine has historically been the disinfectant of choice for treating wastewater. Concerns about harmful disinfection by-products and chemical safety, however, have increasingly led to chlorination being replaced by alternative disinfection systems, such as ultraviolet (UV) radiation and ozonation (O3). UV radiation is found in sunlight and kills viruses and bacteria. Thus, disinfection naturally takes place in shallow ponds (such as polishing ponds). UV radiation can also be generated through special lamps, which can be installed in a channel or pipe.

An alternative approach uses Membrane BioReactors (MBRs). MBRs can filter out viruses, pharmaceuticals and even metals. However, as the size of the particle to be filtered out diminishes, the amount of energy needed to process the wastewater increases (Elmer 2011).

## REFERENCES

Elmer, V., & Fraker, H. (2011). Water, neighborhoods and urban design: Micro-utilities and the fifth infrastructure, Working Paper 2011-4, Institute of Urban and Regional Development, University of California, Berkeley.

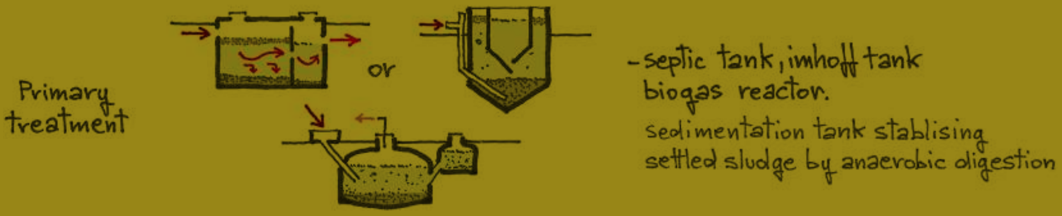
Gauss, M., and S. Ledent, (2008). "Constructed wetlands: a promising wastewater treatment system for small localities." Word Bank Office, Lima, Peru - http://www.wsp.org/sites/wsp.org/files/publications/ConstructedWetlands.pdf

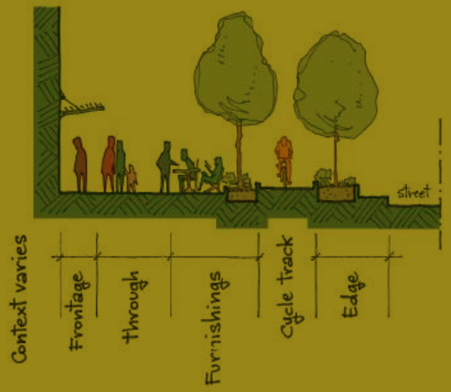
Sanimas, n.d., Informed Choice Catalogue, http://www.sswm.info/sites/default/files/reference_attachments/SANIMAS%202005%20Informed%20Choice%20Catalogue.pdf

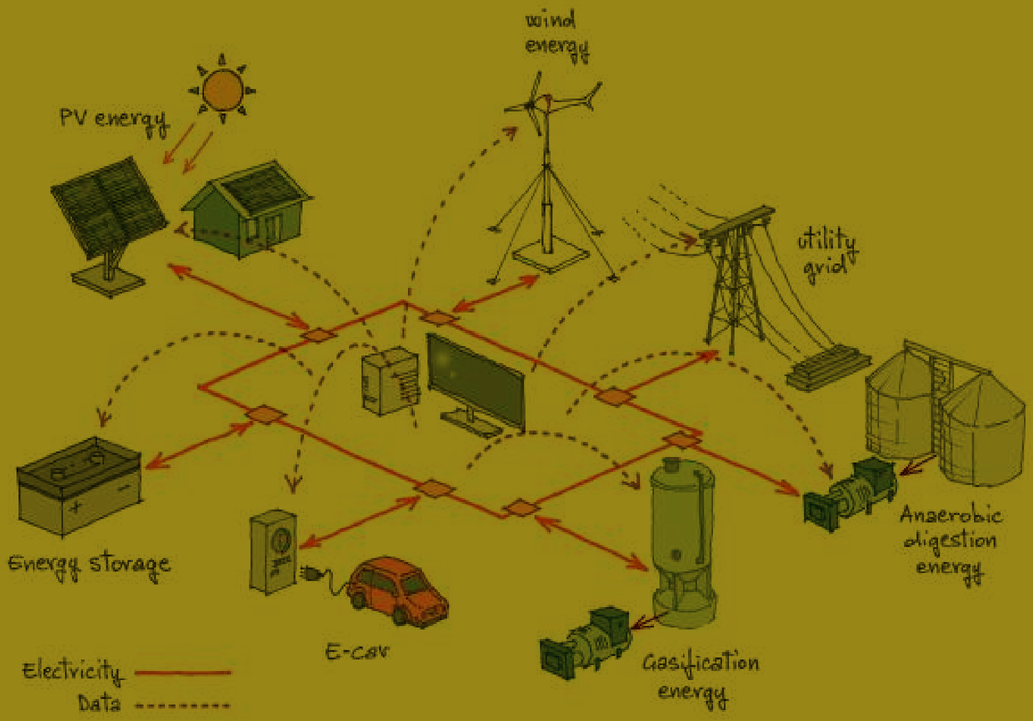
Tilley, E. (2008). Compendium of sanitation systems and technologies. Swiss Federal Institute of Aquatic Science and Technology (Eawag) - http://star-tides.net/sites/default/files/documents/files/Compendium%20of%20Sanitation%20Systems%20and%20Technologies.pdf

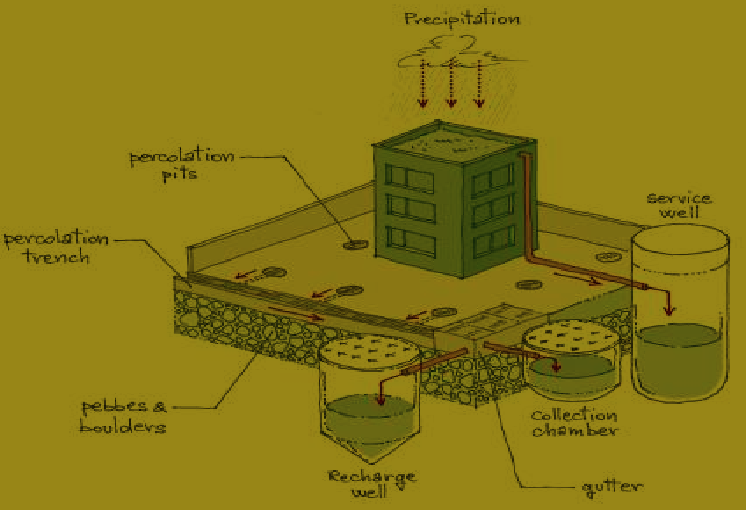
UN-Habitat 2008, Constructed wetlands manual - http://unhabitat.org/books/constructed-wetlands-manual/

Water and Sanitation Program (2008), Constructed Wetlands: A promising wastewater treatment system for small localities, http://www.wsp.org/sites/wsp.org/files/publications/ConstructedWetlands.pdf









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