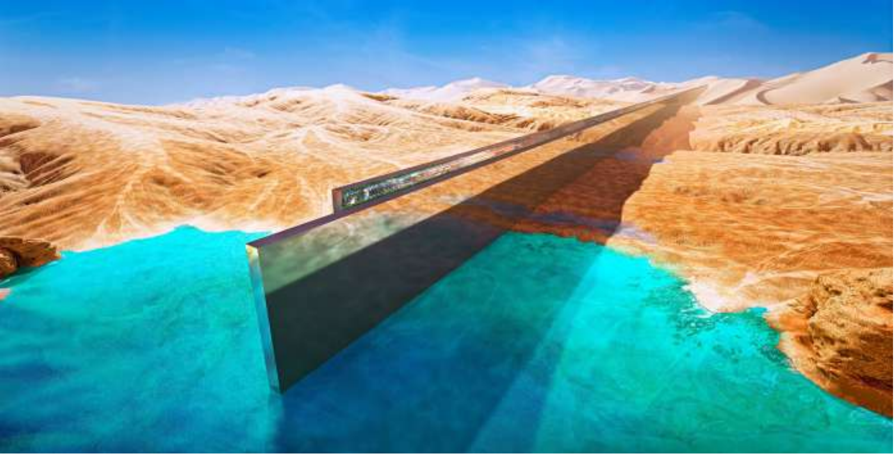

Update to the Sustainable Planning Guidelines for Urban Growth in KSA

المركز السعودي لكفاءة الطاقة
Saudi Energy Efficiency Center

KAPSARC
مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

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About KAPSARC

KAPSARC is an advisory think tank within global energy economics and sustainability providing advisory services to entities and authorities in the Saudi energy sector to advance Saudi Arabia's energy sector and inform global policies through evidence-based advice and applied research.

This publication is also available in Arabic.

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Introduction

In 2021, the share of the urban population in the Kingdom of Saudi Arabia (KSA) was reported at 84.5% (World Bank, 2022), and urbanization is expected to continue to increase up to 97.6% by the year 2030 (UN-Habitat, 2016), making cities the center for energy consumption. In addition, the Kingdom's population is expected to reach 50 to 60 million by 2030 (Fitaihi, 2023; Alyusuf, 2022), introducing a vast quantity of new development accompanied by rapid resource consumption.

A sustainable urban planning principle aligned with Vision 2030 targets and initiatives is essential for efficient energy use. An overarching goal of Saudi Vision 2030 is to have three Saudi cities within the top-ranked 100 cities in the world. This will be achieved in part by providing a good quality of life and an attractive living environment, developing the cities, and achieving environmental sustainability.

The Kingdom of Saudi Arabia (KSA) Government has a role in planning for, and delivering, an urban Saudi that is more energy efficient, sustainable, and livable. The development and management of the cities affects national prosperity and the wellbeing of all Saudis, no matter where they live. Currently, Saudi cities face the challenge of population concentration in urban areas. According to UN-Habitat (2019), the share of urban population is about 83% by 2015, and this trend is expected to continue, with 9 out of 10 people living in urban areas by 2050 (Fig. 1). In addition, cities face several long-term challenges: the need to improve the growth of productivity; provide affordable and accessible housing; create safe community spaces; meet the needs of a growing and ageing population; ensure an inclusive and cohesive society; and address the consequences of climate change.

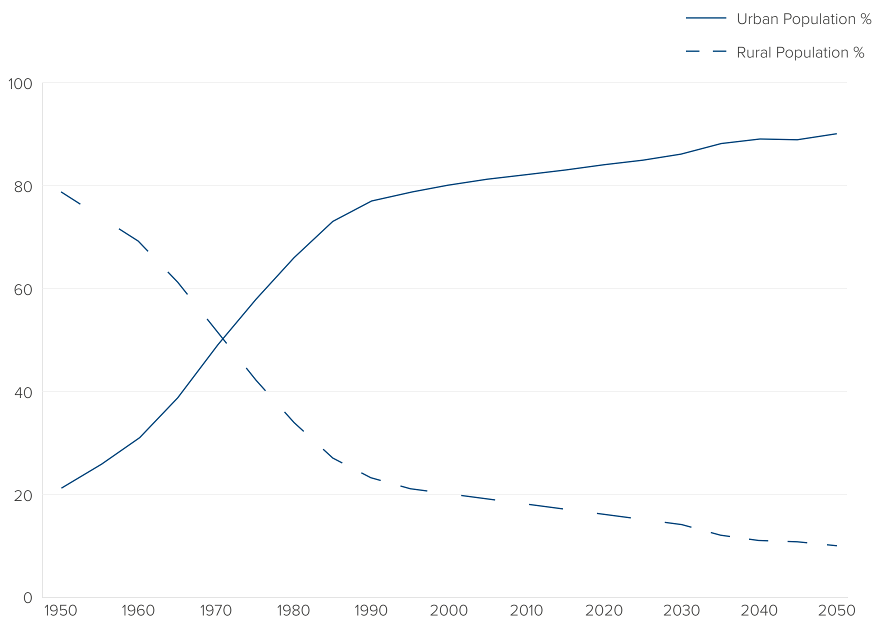


Fig. 1. Growth of urban and rural populations in Saudi Arabia during, 1950–2050 (Saudi Cities Report- UN-Habitat, 2019)

Saudis expect their cities to provide a variety of social and economic opportunities and protect valuable environmental and cultural resources. Policy objectives should ensure that investments in, and management of, urban systems will create more energy efficient, sustainable and livable outcomes for the Saudi cities. Diversity of lifestyle choices, improved accessibility and affordability, and less carbon dependent ways of living, need to be adopted. This includes enabling the citizen through education and training and matching people to jobs; by facilitating an adequate supply of appropriate housing; by lessening dependency on private motor vehicle use and carbon fuels; and by re-thinking the way our cities and communities are planned.

In cities the challenges and opportunities of energy efficiency, sustainability and livability are part of an interrelated and dynamic system. Addressing one goal can have an impact, either positively or negatively, on the others. For example, efficient public transport can address congestion and improve environment and opportunity (energy efficient); it can also reduce greenhouse gas emissions (sustainability); and enable affordable access to education, health and recreational facilities (livability). Likewise, adoption of technologies like 5G and artificial intelligence / intelligent transport system will speed up business model (energy efficient); reduce the need for physical movement and transportation of people and documents (sustainability); and enable enhanced social, cultural and participatory education (livability).

This Sustainable Planning Guidelines for Urban Growth in KSA ('Guidelines') establishes the first long-term national framework to guide the site selection, urban transport planning, district cooling framework, building and water management, public realm design in cities. In establishing the framework, the Saudi Government aims to improve the energy use in efficient manner, sustainability, and livability of the major urban centers.

Why We Need the Guidelines

Urban issues have emerged as key features of national policy agendas. The importance of cities and their metropolitan areas to the national economy as well as their strategic role as global nodes in international markets has led governments to renew their support for cities. The concept of the Guidelines goes beyond the boundaries of inadequate definitions given by other relevant policies that directly or indirectly affect urban development. Resilient solutions to global warming require a national approach to cities. The Saudi Government, as a key player in the future of the urban systems, must provide leadership on this issue. The decisions that government, business and individuals make have a significant impact on the cities. It is necessary that we know what effect our decisions are likely to have on the cities, and to set clear aspirations and directions that guide actions and interventions for the long-term basis.

National, Regional/Provincial and Local Governments

Given that the Kingdom has 13 regions with diverse identities, cultures, and climates, this guideline provides high-level and generic guidance applicable for a national outlook. Generally, planning guidelines should be managed by three levels of government—local, regional/provincial, and national (Fig. 2). These three levels are key players in shaping and managing cities and each level should have its own policies, strategies, and regulations that align with a range of international benchmarks and goals, including the United Nations Sustainable Development Goals. The different levels of government provide most of the facilities and services that maintain communities' wellbeing such as health, education, and safety. They invest in infrastructure, such as roads and railways, as well as investing in or regulating other utilities like power and water. Together, these levels of government have the primary responsibility for planning for urban growth and change and the responsibility for statutory land use planning development approvals.

To ensure infrastructure and services best meet the needs of communities, it is important that they are delivered by the closest level of government equipped for the task. This is the principle of subsidiarity. The KSA Government considers that its role complements but should not duplicate the roles played by other levels of government.

National/Kingdom level

- The national-level strategy planning provides a broad strategic direction for the Kingdom.

Regional/provincial level

- The highest-level regional spatial framework and strategic plan guides planning policy to accommodate and manage population growth, employment targets, and housing within the region for the short, medium, and long term.
- Plans must be approved by the relevant department or ministry.

Local/city level

- The local plans and policies provide comprehensive structure plans plot by plot in different domains.
- Plans must be approved by the relevant department or ministry.

The local sphere of government should consist of local authorities (e.g., municipality), which must be established considering local characteristics such as population size and areas across the Kingdom. A local government authority (LGA) should have the right to govern, on its own initiative, the local government affairs of its community, subject to national-level legislation(s). The national and provincial government may not compromise or impede an LGA's ability or right to exercise its powers or perform its functions, but it must be accountable to the relevant department or ministry.

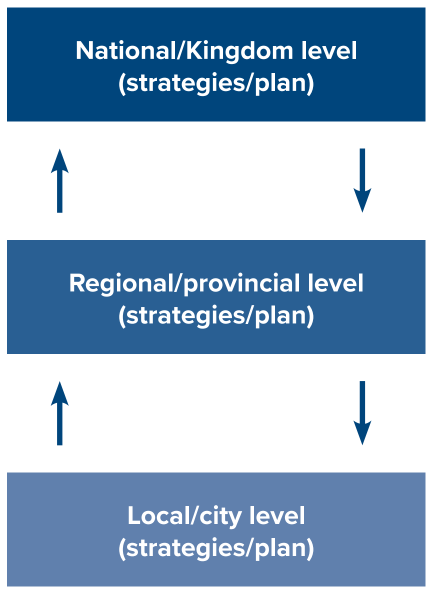


Fig. 2. Strategic planning toolkit

Introduction cont.

Industry (i.e., Private Sector) and the Community

The private sector is a powerful shaper of cities. Through multiple individual decisions and investments, market forces have a strong impact on the economic, environmental, and social fabric of the cities. Increasingly, the private sector is providing critical infrastructure in cities, such as power, gas, telecommunications and transport infrastructure. Individuals and households, as consumers of goods and services, and as employees and citizens, interact with governments and businesses to influence how cities are planned and operate. Continued engagement with the community and industry/private sector is essential for the successful planning and operation of the cities.

Undertakings

Daily, over 800,000 barrels of oil equivalent are consumed by light-duty and heavy-duty vehicles, accounting for approximately 19% of primary energy consumption in Saudi Arabia. Over the past 10 years, the SEEC has collaborated with different transport stakeholders to save approximately 75,000 barrels of oil equivalent per day compared to BAU in the road transport sector. Maximizing energy efficiency is achieved by exploring new focus areas, including initiatives to provide energy efficiency in building design, urban planning, and district cooling framework. The guidelines focus on energy efficiency aspects toward energy-efficient cities. In late 1960, Saudi planning regulations were developed to cover city-wide master plans, as the supergrid and superblock had adapted to accommodate the rapid urban development. Since then, Saudi urbanization has been rapidly growing, with unprecedented population growth, economic development, and industrialization, ranking Saudi Arabia in the top 10 oil-consumption countries worldwide. The visionary leadership of Saudi Arabia has responded to the increasing energy-consumption growth with a course of conservative strategies to create an energy-efficient country.

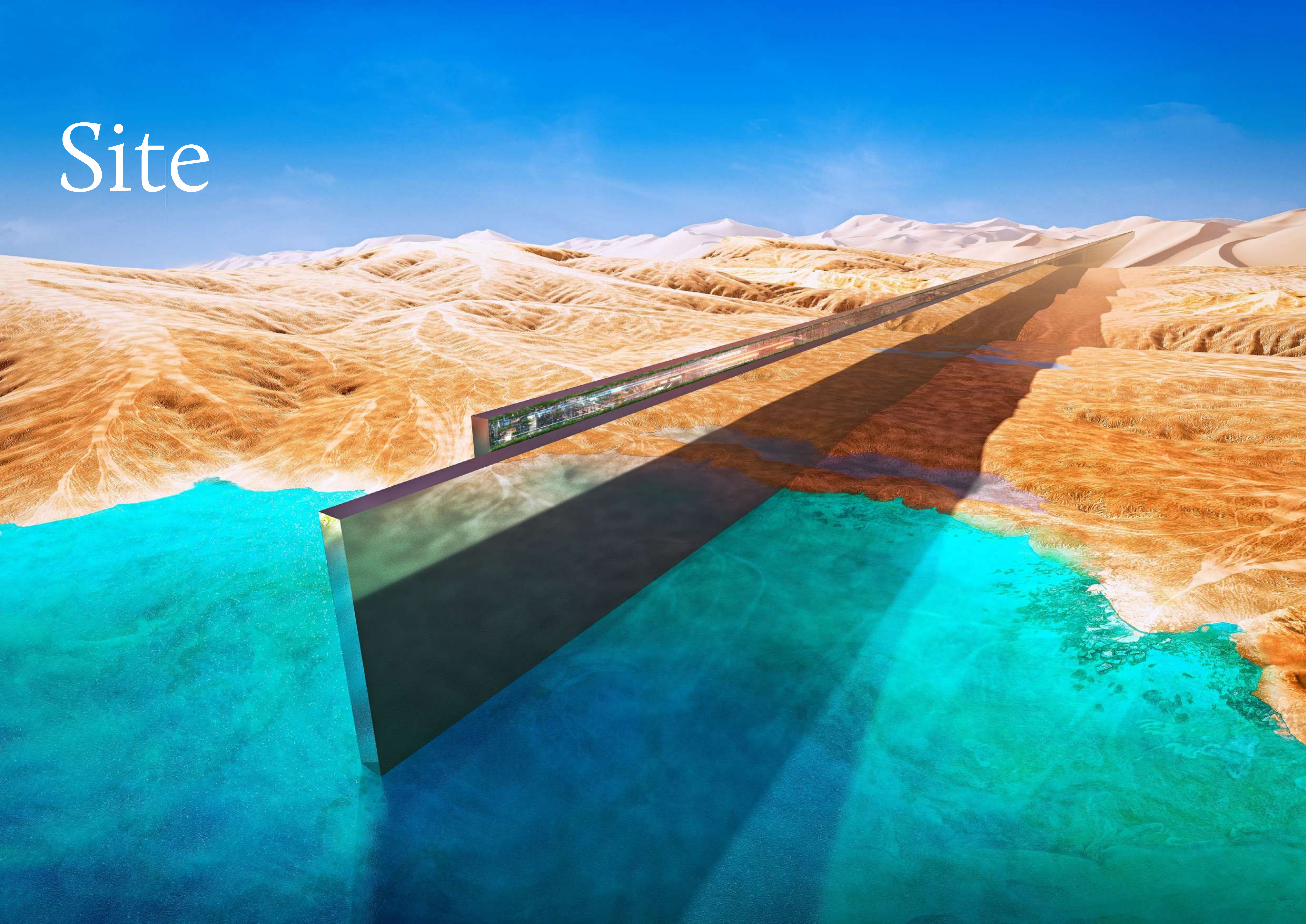
Therefore, with the increasing domestic energy consumption, officials and policymakers of Saudi Arabia's major cities are pursuing different initiatives to improve citizens' urban life and make cities resilient and more sustainable. These guidelines are focused on reducing energy consumption through sustainable urban planning and community design. The Sustainable Urban Planning Guidelines are comprised of two major undertakings:

- Reduction in transportation-related fuel consumption through the development of planning and implementation guidance for smart growth, density, mixed-use, and transit-oriented development (TOD).
- Reduction in energy consumption on a municipal scale through the development of design and implementation guidance for district cooling (DC), water conservation, and building energy efficiency.

Feedback and reviewing document(s)

A series of workshops that entailed stakeholders' discussions and feedback were conducted. Also, multiple official regulations and guidelines' documents were reviewed to ensure alignment and consistency along different levels of regulations from national, regional, and local levels in addition to a benchmark analysis that was performed for each section to identify best practices and standards. This effort helped to produce revised sustainable urban planning guidelines for the Kingdom that are outlined on the basis of being generic and high-level focused on energy sustainability efforts. Furthermore, these guidelines follow existing policies and regulations that have the desire to achieve national initiatives within the framework of the 2030 Saudi Vision.

Site



Site

Introduction

In recent years, rapid urbanization in Saudi Arabia has created many challenges related to extensive sprawl, unsustainable consumption of natural resources, and rising demand for infrastructure and services. Nonetheless, despite the rapid population growth rate in many cities, the physical extent of urban areas is expanding faster, resulting in inefficient land-use patterns, a surplus of vacant serviced land, high housing costs, and environmental pollution.

Actions toward meeting a well-planned and managed urbanization resulted in the formulation of the National Spatial Strategy (NSS), which focuses on improving infrastructure efficiency and service sustainability in urban and rural areas and achieving a sustainable urban system while preserving natural resources as part of its key objectives. The Future Saudi Cities Program also intends to reduce urban sprawl and address urbanization through thoughtful and appropriate planning principles.

More information regarding the cost of sprawl and recommendations to stop its increase can be found in the guidelines for assessing the sustainability of local plans developed by the Saudi Energy Efficiency Center (SEEC) in collaboration with the Ministry of Municipal and Rural Affairs and Housing (MoMRAH) in 2023.

In the opposite tables, they show the proportion of vacant land within the boundaries of Saudi cities and Historical urban growth in Jeddah.

Riyadh

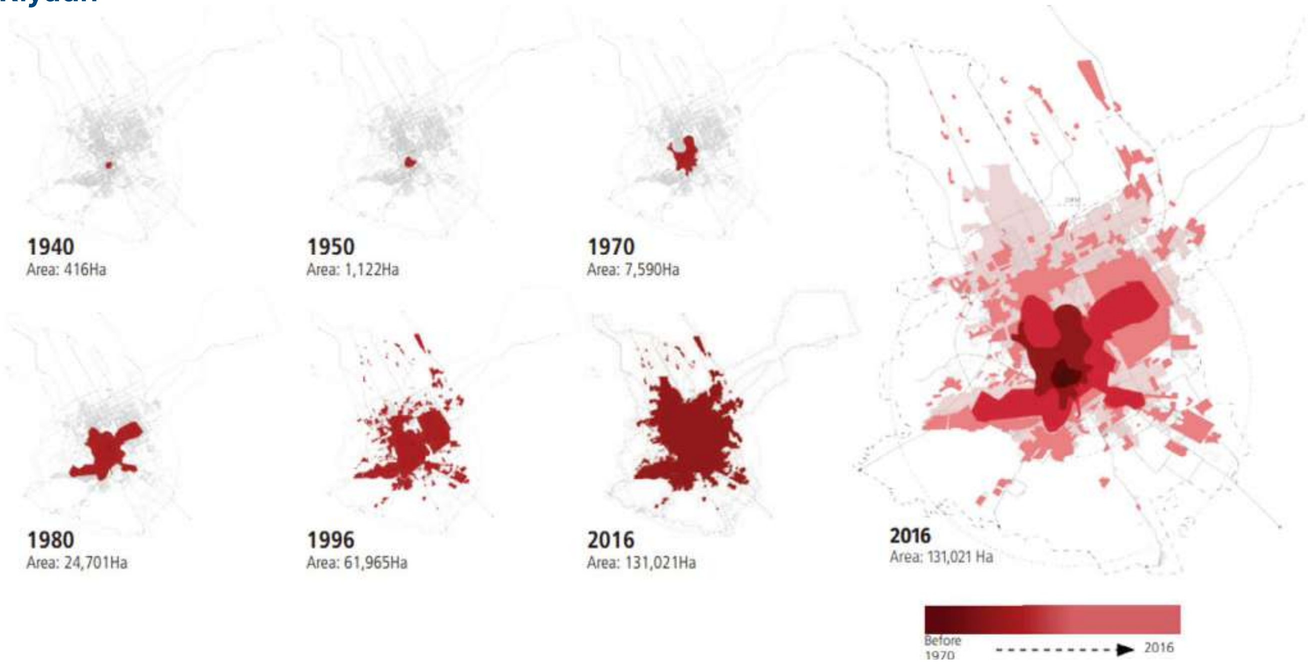


Fig. 3. Spatial expansion of Riyadh (City Profiles, Future Saudi Cities Program, 2019)

"The extent of urban areas in Saudi cities is expanding rapidly, resulting in inefficient land-use patterns, a surplus of vacant serviced land, high housing costs, and environmental pollution.

City	Vacant Land (%)	
	Within urban growth boundaries	Within the build-up area
Arar	65%	31%
Buraydah	68%	37%
Dammam	46%	48%
Ha'il	90%	55%
Madinah	41%	12%
Tabuk	71%	36%

Source: City Profiles, Future Saudi Cities Program (2019)

Year	Area (hectares)	Population
1947	300	35,000
1961	1,460	150,000
1971	1,700	404,650
1976	6,650	-
1978	-	1,312,000
1980	11,415	-
1987	36,700	-
1995	39,173	1,790,000
2005	74,647	-
2010	105,000	-
2016	-	3,456,259
2019	176,500	4,470,705

Source: Governmental Census (2016); Jeddah Municipality (2020)

1.0

Site Selection

One of the most critical decisions that can be made to protect the vision of a sustainable Kingdom is the location of future developments. When construction occurs in disparate locations across the Kingdom landscape without respect to transportation, infrastructure, or redevelopment plans, it can exacerbate sprawl issues and increase the overall fuel consumption of the Kingdom, not just per capita but nationally, as the population increases. Considering the following criteria helps city planners choose the preferred site for development.

Criteria	Description
Site suitability	The location's characteristics, including topography, geology, hydrology, natural resources, and heritage values, should minimize the risk of adverse impacts occurring.
Connectivity	The location's proximity to existing infrastructure, including urban areas, transport, electricity, water, and sewers, should minimize any adverse economic and environmental impacts.
Zoning	The location should be zoned appropriately under the relevant planning ordinance or be capable of being rezoned.

For industrial development site guidelines, please refer to the MODON Development Standards document (MOD-STD-111-03) and Jubail Industrial City Development Code (T08-T10-G65-20TV-GA-008-0).

2.0

Underdeveloped Urban Land

The development or redevelopment of land that has been bypassed, remained vacant, or is underutilized within an urban area plays a critical role in achieving community revitalization and resource and land conservation and reducing vehicle kilometers travelled (VKT) from sprawl-pattern development. A series of incentives and disincentives may be imposed to encourage the development of these undeveloped parcels, and municipalities should determine which are best suited to their governance styles and enforcement capabilities.

Use Case

Between 1990 and 2013, Riyadh witnessed a decline in infill as a means of urban expansion and an increase in the expansion of contiguous physical growth at the edges, with an approximately 23% growth rate. This has made sprawl increasingly prevalent, often resulting in declining density and more wasteful, less efficient, and unsustainable land use patterns. Infill, which consists of development in urbanized open space within the urban extent on unbuilt parcels adjacent to existing developments, is Riyadh's second main type of urban expansion. This accounts for 36% and 25% of the built-up area added to the Riyadh urban extent during 1990–2000 and 2000–2013, respectively. Additionally, inclusion consisting of the annexation of rural or urban settlements outside the urban extent, then reclassifying them from rural to urban use, accounts for 21% and 9% of the urban expansion occurring in Riyadh in the two periods under consideration. The below shows the Composition of the added area in Riyadh

Forms of Urban Expansion (%)	1990-2000	2000-2013
Edge	43%	66%
Infill	36%	25%
Inclusion	21%	9%

Source: UN-Habitat Urban Expansion Database

> *This accounts for 36% and 25% of the built-up area added to the Riyadh urban extent during 1990–2000 and 2000–2013, respectively.*

Encouraging Infill Development on Underdeveloped Urban Land

Priority development zone: Municipalities must establish priority zones for development in areas that can achieve the density and diversity recommended in these guidelines with consideration of existing or planned transit infrastructure. The municipality can help create demand for properties by only leasing or building within priority development areas (i.e., schools, government administrative buildings, housing). By leveraging its purchasing power, the municipality can create a significant incentive for landowners to initiate development.

Expedited permitting: A landowner seeking a permit for development in a designated priority development zone may receive expedited permitting to facilitate the development.

Infrastructure investment: The municipality can encourage more rapid development by investing in the infrastructure in priority development zones and prioritizing capital improvement projects that expand infrastructure and services near the identified zones.

Incentives: Land in a designated priority development zone should see property values rise as the municipality focuses on TOD and infill. In addition to higher property values, the municipality may offer development grants or rebates to support the financial feasibility of development or offer density bonuses to encourage development.

Public amenity option: Municipalities can encourage landowners in a designated city center or priority development zone that is left vacant to temporarily transform it into an urban park or other public amenity space. The landowner would be responsible for building, maintaining, and operating the public park or amenity space until the municipality approves a development permit.

Vacancy fine: Land in a designated city center or priority development zone that is left vacant will incur a monetary fine based on the square meters of undeveloped land until such time as the landowner instigates development through permitting (related to the Law of White Land Tax).

> *Municipalities can encourage landowners in a designated city center or priority development zone that is left vacant to temporarily transform it into an urban park or other public amenity space.*

3.0

Transit-Oriented Development

Transit-oriented development (TOD) can occur at a wide range of scales and involve various uses within a well-connected street network, including safe accessibility and a balanced mix of land uses. It brings higher density and more compact, mixed-use development within easy walking distance from public transit, which supports long-term efficiency and sustainability plans. As an urban planning tool, TOD combines elements of land use and transport planning, urban design, urban regeneration, real estate development, financing, land value capture, and infrastructure implementation to achieve more sustainable urban development. More details about TOD principles will be discussed in the Urban and Public Transport section.

TOD Influence Zone

The area of influence where the TOD should be implemented is near a transit station or along transit corridors. Generally, influence zones extend to a catchment radius of 400–800 m around a transit station.

> *"It brings higher density and more compact, mixed-use development within easy walking distance from public transit, which supports long-term efficiency and sustainability plans.*

Credit: The World Resources Institute

Fig. 4. Transit-oriented development (TOD) strategy

Sustainability Through Transit-Oriented Development

Energy Efficiency

Transit-oriented development stimulates sustainable land use planning and has the potential to reduce energy consumption rates and lower greenhouse gas (GHG) emissions by decreasing VKT and facilitating walking and biking. Land consumption directly caused by sprawl also reduces natural habitat that acts as a carbon sink.

Infrastructure Efficiency

Car-oriented development requires more resources and land, which causes the degradation of natural resources and puts more pressure on roads and parking infrastructure. More compact, connected, and coordinated urban growth can significantly reduce the cost of infrastructure development and increase urban infrastructure efficiency.

Economic Sustainability

Cities' infrastructure capital could be reduced with a compact strategy for urban growth. Compact neighborhoods provide more accessible job opportunities and diverse activities and enhance the quality of life.

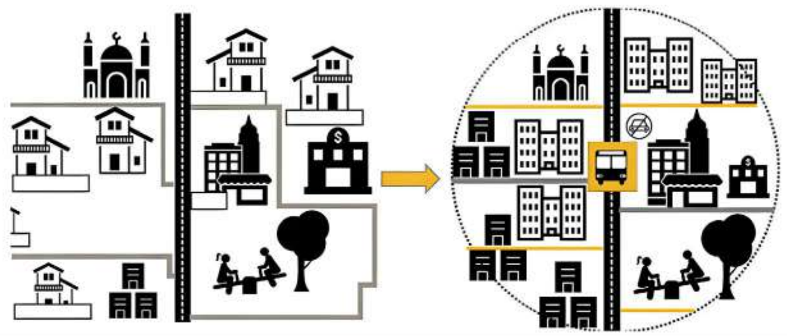
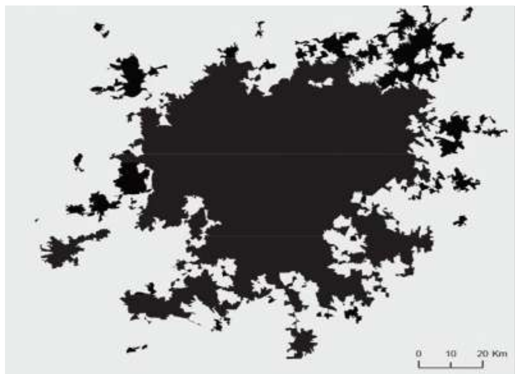


Fig. 5. Transit-oriented development influence zone

Atlanta



Atlanta	Barcelona
Population (million)	
5.3	5
Urban area (km²)	
7,692 km²	648 km²
Transport carbon emissions (tons)	
6.9	1.16

Barcelona

Fig. 6. Transport carbon emissions of a compact vs. a sprawl city (LSE Cities, 2014)

4.0

Key Terms

Infill development: New development occurring within unused and underutilized lands within existing development patterns, typically (but not exclusively) in urban areas. This type of development is meant to encourage density and accommodate environmentally sustainable urban growth by using existing utility and transportation infrastructure.

Edge development: A form of expansion where land use is a development directly adjacent to existing land uses. New infrastructure, such as streets and utilities, is expanded from the existing network.

Inclusion development: Developing in rural or urban settlements outside the urban extent and then reclassifying from one category of urban place to another.

Density bonus: An incentive-based tool that permits developers to increase the maximum allowable development on a site.

Transit corridor: Walkable areas around all the stations along a transit line.

5.0

Compliance Checklist

Site Selection	Yes	No	N/A
The proposed site is suitable in terms of topography, geology, and hydrology and is not on reserved land.			
The proposed site is within acceptable proximity to the needed infrastructure.			
The proposed site is aligned with the current zoning ordinance.			
The site selection process is aligned with the sustainable urban planning guidelines within NSS 2030.			

TOD	Yes	No	N/A
The TOD zone is within 400–800 m of a transit station or per the TOD strategy in the city if it exists.			
The TOD zone allows safe pedestrian movement between transit, mixed land uses, and surrounding areas.			
The TOD zone allows for the intensification of density over time.			

Urban Planning and Transportation

Urban Planning and Transportation

Introduction

Like many cities worldwide, Saudi Arabian cities are facing a rapid increase in the demand for transport energy. Although vehicle efficiency improvements can moderate energy demand growth, VKT per capita is growing, and VKT reductions will be essential in the long run to achieve sustainable energy goals.

Research shows a clear relationship between a city's urban and transport infrastructure form and the amount of vehicle travel. The primary characteristics that affect VKT are the density of jobs and housing, the neighborhood ratio of residential to other uses, access to alternate modes of transport, the distance to regional centers, and the urban design of the public space. A holistic effect on travel behavior results from combining origin/destination accessibility, human-scale place-making, and varied modes of transport. When all are present, VKT tends to be much lower than when one or more characteristics are missing. The land use and transportation guidelines recommended here aim to balance these factors, leading to lower energy use through decreased VKT.

The new cities outside the congested cores of fast-growing metropolitan areas can be built or planned to better accommodate the pursuit of a lower VKT concept. These new cities often boast modern infrastructure and aspirational themes and are tangible representations of a city's, government's, or culture's vision for the future; they are inherently wrapped up in local and national political economy dynamics. These guidelines and strategic recommendations are intended to support new urban growth sustainably.

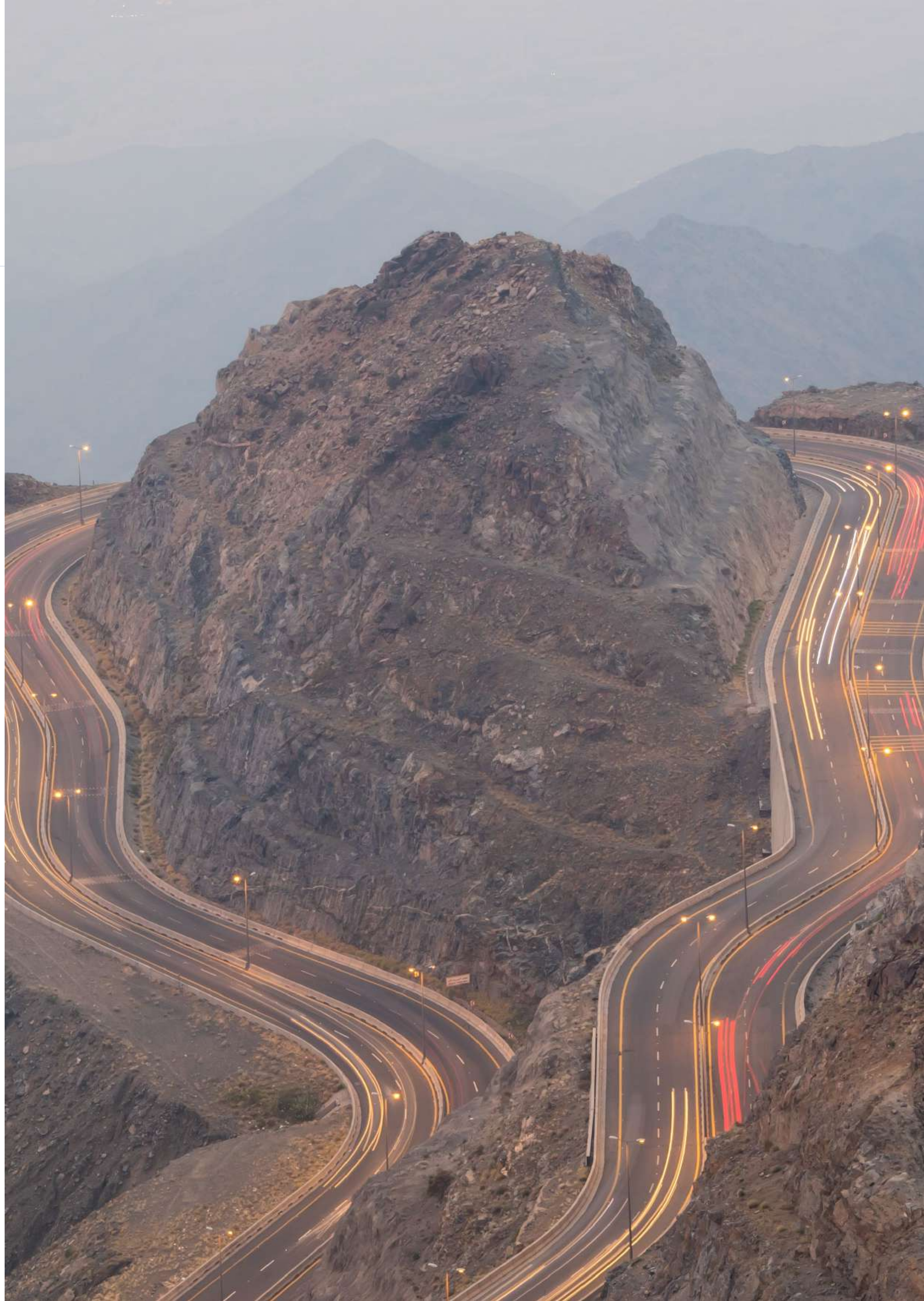
The guidelines for urban planning and transportation (UPT) target reducing energy consumption through sustainable urban transport planning and design. The UPT section is comprised of the following key undertaking:

- Reduction in transportation-related fuel consumption through the development of planning and implementation guidance for smart growth, density, transit-oriented, and mixed-use development.

Through this undertaking, one of the largest impacts in energy savings can be seen in reduced VKT per person. This shift in transportation-related energy consumption relies on synergistic strategies encouraging alternative transportation activities, such as transit access, TOD, density, and mixed land use. For example, transit would not be highly successful without density, and density would not be highly successful without transit. This can be conducted by effectively integrating transportation and land use planning. It is well understood that total transportation fuel use savings depend on the development intensity and amount of sustainable transportation investment in a new development. The investment degree depends on community type—a smaller-scale community will not require the same degree of transit infrastructure as a larger city.

> *"Like many cities worldwide, Saudi Arabian cities are facing a rapid increase in the demand for transport energy.*

In 2021, the transport sector accounted for around 28% of the total energy consumption in Saudi Arabia (IEA, 2021), transportation and land use interventions in new developments can significantly reduce auto dependency and, thus, fuel consumption. These results highlight the impact that intensifying and diversifying the urban form and properly locating new development can have on total VKT. Based on the set criteria in this guideline, the energy savings can approximately go up to 34% compared to the business-as-usual (BAU) scenario.



1.0

Density

The question of density is closely connected to urbanization and how cities may evolve. Density and compactness are two closely related but different criteria, both relevant for sustainable urban development and the transformation of cities. While a high degree of compactness is desirable, too much density can be detrimental to livability, health, and urban well-being. A crucial question is: What is optimal density, and what sort of urban form (e.g., compact vs. dispersed, formal vs. informal) and process (e.g., top-down vs. participatory) can be utilized to realize it? However, it needs to be balanced through good design solutions.

Best Practices

We use density to describe the average number of people, households (HHs), floor space, or housing units on one unit of land, usually expressed in dwellings per hectare. There are different ways of measuring the density of urban areas.

- **Floor area ratio (FAR)**: The total floor area of buildings divided by the land area of the plot upon which the buildings are built. For instance, a FAR of 3 indicates that the total floor area of a building is three times the gross area of the plot on which it is built, as would be found in a multi-story building (Figure 7).
- **Residential density**: The number of dwelling units in any given area.
- **Population density**: The number of persons living in any given area.

Hence, there are three clearly identifiable city typologies with specific characteristics, density profiles, and historical evolutions:

- The North American and Australian low-rise and low-density city typology (e.g., Los Angeles, Phoenix, Melbourne, and Perth) has only 1,000 to 2,500 people per km^2 (typically low density).
- The European compact and polycentric mid-rise city (e.g., Barcelona, Paris, Berlin, and Athens) has 3,000 to 6,000 people per km^2 (typically medium density).
- The Asian high-rise city with a distribution of individual towers (e.g., Shanghai, Beijing, Tokyo, and Bangkok) has around 10,000 people per km^2 (typically high density).

The different cases reveal different planning approaches and offer some pointers worth consideration. Singapore has followed a top-down approach, involving multiple design and development companies to create urban diversity with various typologies. In Hong Kong, the uniformity of the overall scale and high-rise apartment tower typology remains, while in Sydney, multi-actor participation is only served through designing ndividual buildings, and the outcome is more piecemeal, with high- and low-density neighborhoods next to each other. Singapore and Hong Kong both apply a top-down planning hierarchy, where planning decisions result from the government's strict development controls. In contrast, Vancouver and Sydney have been successful in their participatory process and community engagement.

> *"A crucial question is: What is optimal density, and what sort of urban form (e.g., compact vs. dispersed, formal vs. informal) and process (e.g., top-down vs. participatory) can be utilized to realize it?*

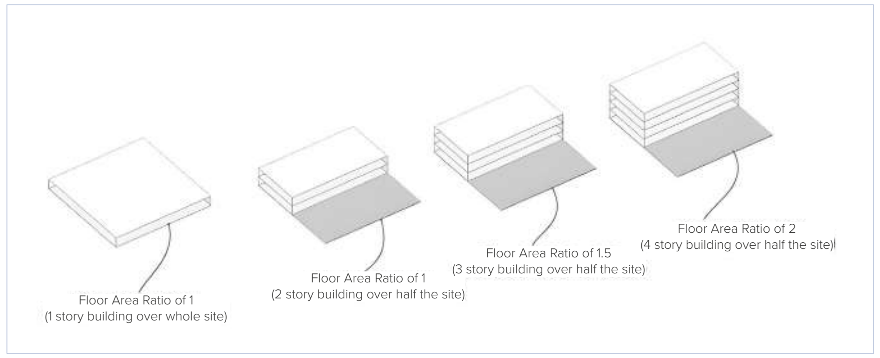


Fig. 7. Example floor area ratio

Credit: https://www.propertyhunt.sg/pinnacle-duxton/

Fig. 8. Housing development the Pinnacle at Duston in Singapore West

Credit: Frasers Property, 2023 https://www.frasersproperty.com.au/

Fig. 9. The new Central Park development in Sydney, a high-density inner-city mixed-use development close to the Central railway station and in walking distance to three universities

1.0

Density cont.

Guidelines

Very dense high-rise cities are not necessarily the best option; medium-density, compact infill developments of 4–8-story perimeter blocks are the much-preferred option and a very useful model for achieving a compact, green, mixed-use, and walkable city. Density types vary widely, ranging from 1,000 to 10,000 people per 100 hectares.

Low-density guidelines

Low density includes mostly single-family detached housing consisting of homes on individual lots in an auto-oriented transport design. It involves segregated land uses with <4,000 persons/km^2.

Neighborhood Type	Density, Diversity, Location
• Mostly single-family detached housing • Semi-detached homes and duplexes	• 4–8 HHs/hectare • 1,000–3,999 people/100 hectare • Local mosque, local retail, local park within 500m • Juma mosque, schools, commercial, municipal offices within 1,500m • Infill or adjacent

Mid-density guidelines

Mid-density includes suburban or urban edge developments of 3–4-story housing, either multi-family or zero–lot-line single-family housing. It includes public transit and pedestrian-friendly design with some mixed land use at a density of 4,000–6,999 persons/100 hectares.

Neighborhood Type	Density, Diversity, Location
• Townhouses, low-rise apartments • Mid-density suburban or urban edge development	• 9–14 HHs/hectare • 4,000–6,999 people/100 hectares • 500–600m^2 lot sizes • Local mosque, local retail, local park within 400m • Juma mosque, schools, commercial, municipal offices within 1,300m • 15–20% mixed-use by land area • Infill or adjacent and within 2km of a downtown-type place

> *"Mid-density includes suburban or urban edge developments of 3–4-story housing, either multi-family or zero–lot-line single-family housing.*

High-density guidelines

High-density neighborhoods with higher housing and commercial buildings over five stories are generally developed as nodes around fixed guideway transit stations. They include pedestrian-friendly street design with many mixed-use parcels, ground-floor retail, and a density of 7,000–9,999 persons/100 hectares.

Neighborhood Type	Density, Diversity, Location
• High-rise apartments • Mixed-use urban neighborhoods near the city center	• 15–20 HHs/hectare • 7,000–9,999 people/100 hectares • FAR 2–5 min • Local mosque, local retail, local park within 300m • Juma mosque, schools, commercial, municipal offices within 1,000m • 35–40% mixed use by land area • Infill or adjacent to a larger urban area

> *"High-density neighborhoods with higher housing and commercial buildings over five stories are generally developed as nodes around fixed guideway transit stations.*

Urban City Center Guidelines

Urban city centers have many high-rise buildings closely spaced around extensive fixed guideway transit or subways. Most buildings are mixed use with ground-floor retail and a density exceeding 10,000 persons/100 hectares.

Neighborhood Type	Density, Diversity, Location
• High-density mixed-use, transit-oriented urban city center	• 21+ HHs/hectare • 10,000+ people/100 hectares • FAR 5 min • Local mosque, local retail, local park within 250m • Juma mosque, schools, commercial, municipal offices within 800m • >40% mixed use by land area • Infill, core of the city

1.0

Density cont.

Each neighborhood type that is part of a new community should be built to meet the performance standards specified for that neighborhood type. The following image (Figure 10) is an example of the different densities in urban formation.

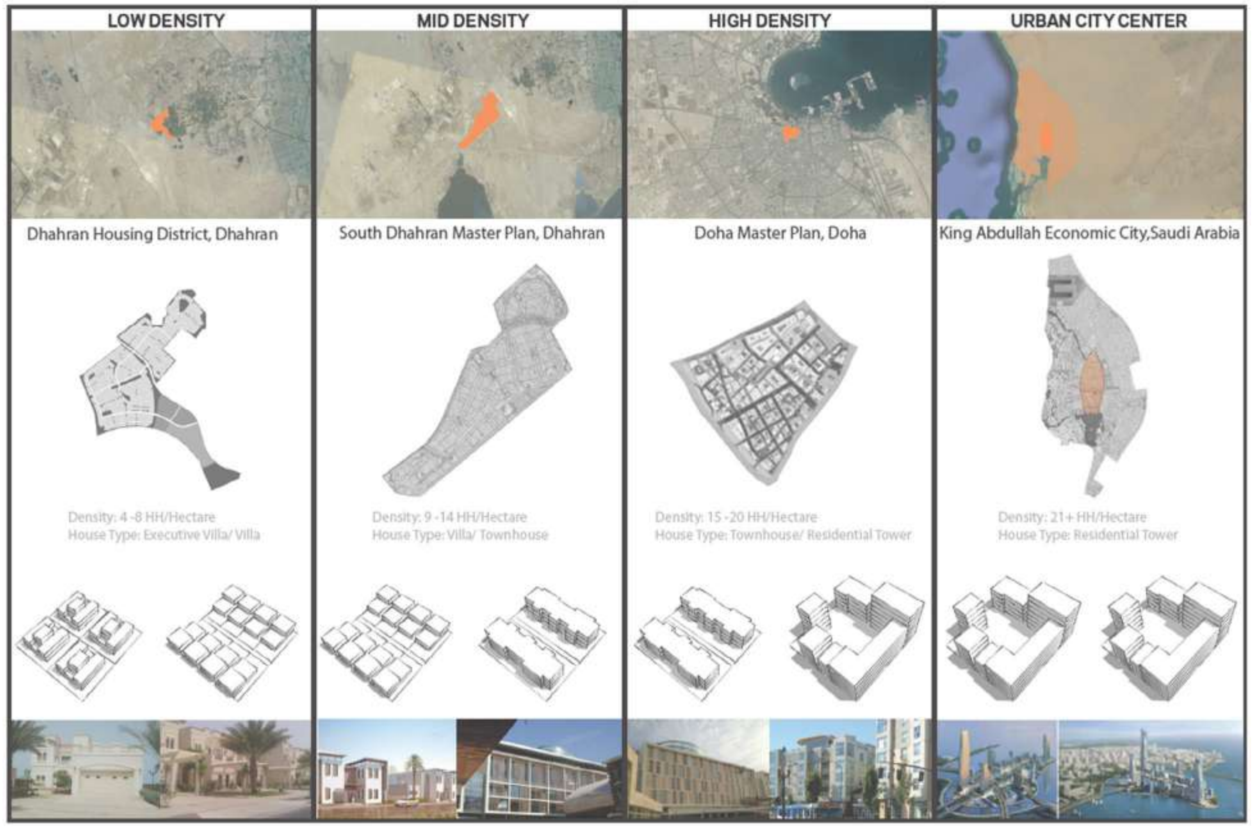


Fig. 10. Examples of neighborhood and housing type by density

The guidelines for community size by neighborhood types are below, with suggestions for applications:

Hypothetical Community Size	% Low Density	% Mid Density	% High Density	% City Center
5,000–50,000	4%	63%	33%	0%
50,000–100,000	4%	48%	45%	3%
100,000–300,000	4%	26%	42%	28%
Over 300,000	7%	20%	39%	34%

2.0

Land Use and Best Practices

It is necessary to plan for future land use and development in a manner consistent with community goals and objectives (Behrend, 2017). New land use and community character challenges arise as cities continue to mature: competition for desirable land use from surrounding communities will increase; redevelopment of aging sites will increase in importance; management of traffic on an existing roadway network will continue to be a priority; greater transit support will require greater supportive densities; and public infrastructure systems will continue to age. As a result, the development strategy has shifted toward focusing on vacant or underutilized property, called "infill," to provide for quality redevelopment, and then "brownfield" and "greenfield."

Over time, zoning decisions should produce changes that gradually establish greater conformity between the zoning, plans, and places/sites. The place/site plans should be carefully considered to ensure consistency when making planning and development decisions. The community changes that may directly conflict with the place/site plans could undermine the city's long-term objectives and should be avoided.

Guidelines

The following directions should be prioritized for local and regional-level land use planning:

- Develop compact and mixed-use neighborhoods with walkable access to jobs, amenities, education, services, and transit.
- Focus new development on infill first and then brownfield and greenfield areas.
- Utilize new development models that provide a broad mix of housing and neighborhood types to accommodate residents with varied incomes and different life stages.
- Improve the quality of districts and neighborhoods to promote an authentic, vibrant sense of place.
- Preserve and reuse historic structures and sites.
- Conserve and enhance, for current and future generations, the ecological integrity, environmental heritage, and environmental significance of cities across the Kingdom.
- Reduce resource/energy consumption by planning and controlling land use and development.
- Maintain harmony with identified local entities and characteristics in the new developments.

Factors Considered

The land use planning approach should incorporate inputs from the public participation process, acknowledge existing land use patterns, and reflect planning best practices. More specifically, the following factors should be taken into consideration in preparing the land use planning:

Existing Land Use

Residential neighborhoods may not be expected to change. The changes can be considered by meeting the defined goals, aims, and zoning options.

Existing Zoning

Zoning practices are expected to condense over time to a more streamlined set of land use–based zoning districts. The current zoning should be utilized to develop the propensity for change tool, which guides the future transition to the land use approach.

> *"It is necessary to plan for future land use and development in a manner consistent with community goals and objectives (Behrend, 2017).*

Land Use Patterns in the Region

Land use patterns for surrounding communities and the region should also be considered and aligned with plans.

Community Engagement as Input: Keep-Improve-Change

Having comments and opinions about land use patterns and related community planning issues through community engagement can facilitate effective land use planning direction. The Keep-Improve-Change mapping tool, which guides conversations during the planning process, helps shape to what extent different areas of the city are expected to change. Some features must be kept or improved to promote the city's best assets. Other less-desirable characteristics have a different impact on community perceptions and economic vitality. These areas or characteristics must be either significantly changed or completely transformed. Change areas are the focus to accommodate forecasted growth, support transit, and meet the guiding principles and are mixed-use types that need short-term zoning changes to achieve the city plan's vision.

Land use plan categories:

- **Agricultural vacant land**
  The agricultural areas have primarily agricultural uses and are located outside the city. Residential uses are found in these areas but are primarily limited to residences associated with agricultural production in the zone. Vacant land may also be found outside the built-up areas. Agricultural and vacant land areas define most of the area outside the city's priority growth and urban expansion areas.
- **Agricultural vacant land/residential transition**: The agriculture/residential transition category identifies lands outside the current city limits that have or may soon experience residential development pressures. In the case of residential transition, the proximity of the city-limit boundary should be applied to utilize the current utility and transportation systems. The area should be considered for development only after existing residential developments outside the city are annexed and served by municipal services.
- **Residential:**
  - **Low density**: The low-density residential category encompasses traditional single-family neighborhoods in the city. This category accounts for most of the city's land acreage. The predominant housing type is single-family detached homes, although attached single-family units are allowed in certain areas. Density in the low-density residential category traditionally allows up to eight HHs per hectare.
  - **Medium density**: Medium-density residential land uses include attached housing such as townhouses, condominiums, and low-rise apartments. The density range should be 9–14 HHs per hectare. Medium-density areas are typically adjacent to lower-intensity commercial uses and schools and along movement corridors. These uses can also serve as buffers between lower-density residential uses and higher-intensity land uses and will inherently produce a higher number of vehicle trips on a per-hectare basis than low-density residential housing areas. Characteristics of medium-density residential developments can be different from typical single-family neighborhoods.
  - **High density**: High-density residential land uses include multi-story high-rise apartments and condominium complexes. The density should be 15–20 HHs or more per hectare. Land use plan identifies areas of the community where these uses are appropriate. High-density residential areas are not typically adjacent to single-family housing, although newly developing areas may be an exception when planned comprehensively. Similar to medium-density uses, high-density uses are typically adjacent to higher-intensity commercial and industrial uses and schools and along movement corridors. These uses will inherently produce more vehicle trips per hectare than low-density residential housing areas.

> *"Medium-density areas are typically adjacent to lower-intensity commercial uses and schools and along movement corridors. These uses can also serve as buffers between lower-density residential uses and higher-intensity land uses and will inherently produce a higher number of vehicle trips on a per-hectare basis than low-density residential housing areas.*

2.0

Land Use and Best Practices cont.

- **Commercial**
  - **Urban business**: The urban business commercial category accommodates retail sales and services along collector and arterial roadways serving the community. This category allows for uses such as banks, restaurants, grocery stores, gas stations and convenience stores, hardware stores, professional offices, and other businesses selling merchandise or services. The nature of urban business operations may dictate their location along major commercial corridors to generate business.
  - **Highway commercial**: Highway commercial uses include high-intensity businesses that require a large amount of land for their operations. Uses like auto and recreational vehicle sales, motels, nurseries and other outdoor sales, gas stations, restaurants, and "big chain shop" retailers would be typical in these areas. Due to the potential for these uses to generate high traffic volumes, their location is typically limited to arterial roadways and interchange areas.
  - **Downtown**: The downtown core provides areas for a mix of office, retail, service, residential, and public uses. The downtown will continue to be a community activity hub by providing places for financial and civic activities, specialty shops, and restaurants when buildings and sites are designed in the context of their environment. Residential uses are allowed and encouraged to be located above commercial establishments.
- **Industrial**: Industrial uses include the established manufacturing and industrial areas in the city core and along railroad or movement corridors. These areas provide an important employment and economic base for the community and will continue to do so for the foreseeable future. Building expansions are permitted to accommodate changing operations when impacts to adjacent residential neighborhoods or commercial development can be addressed.
- **Parks and open space**: Parks and open spaces are a very important component of both community living and overall community design, as they provide various outdoor recreational opportunities. Parks and open spaces should be at least 3–4 m^2 per capita.
- **Community facilities/public buildings**: This category includes public schools, city and county governmental buildings, publicly operated institutions, and religious institutions.

A land use map (LUM) should be produced to provide a layout of the proposed location of various land uses within the community and the urban expansion area. The "investigation areas" process may be applied for incorporating the new land use areas, which can be found in Book 2: Arriyadh Metropolitan Structure Plan 2030. Investigation areas require detailed planning before definite new land uses or development in LUMs within the urban boundary. The LUM should be used as a guide when considering future growth and development. This map is intended to be a general guideline, which may change as growth occurs. Changes to the proposed use of land should be considered in the context of their impact on the overall land use plan for the community. All changes should be made through a formal amendment process.

> “
> *Parks and open spaces are a very important component of both community living and overall community design, as they provide various outdoor recreational opportunities.*

3.0

Transportation

Designing streets friendlier to pedestrians and cyclists than they are to four-wheeled vehicles will encourage more people to leave their cars at home. Integrating public transport into a seamless system that enables passengers to switch effortlessly from bus to tram, train, or metro will attract more users (NSW Government, 2018a).

Urban planning is an important civic function that can help cut energy use in urban transport significantly. Cities can retain their focus and sense of place if they plan for "densification" instead of a Los Angeles-style sprawl. By planning mixed functions in neighborhoods, commuting can be minimized. This can save GHG emissions because energy consumption in cities is directly linked to the number of inhabitants per km^2 and, thus, the amount of energy used. Figure 11 clearly shows that a high-density city (e.g., a compact city) consumes less transport-related energy because a mixed and compact city can reduce VKT significantly. Therefore, land use planning and transport policies will guide cities toward lower transport energy use, triggering lower carbon emissions.

However, a significant relationship exists between a city's population density and metro ridership. Figure 12 shows that low-density cities have fewer metro-passenger miles per year than high-density cities, and high-density cities have higher metro ridership (e.g., Seoul).

Transit-Oriented Development

Transit-oriented development is a moderate- to higher-density development located within an easy walk of a major transit stop, with a mix of residential, employment, and shopping opportunities designed for pedestrians without excluding automotive transport. It encourages transit-supportive land use to provide more balanced transportation choices so that travel by transit or active transportation (e.g., walking, cycling) can be as viable an option as driving. Citizens should have barrier-free access to and within TOD zones and areas.

Key Elements

- Optimize land use allocation:
  - Ensure transit-supportive uses.
  - Discourage non-transit–supportive uses.
  - Encourage a mix of uses.
  - Locate the uses as close to the transit station as possible.
- Promote density.
- Create convenient pedestrian and cycling connections:
  - Short.
  - Continuous.
  - Direct.
  - Convenient.
- Ensure good urban design.
- Create compact development patterns.
- Manage parking.
- Make each station a "place".

> *"Urban planning is an important civic function that can help cut energy use in urban transport significantly. Cities can retain their focus and sense of place if they plan for "densification" instead of a Los Angeles-style sprawl.*

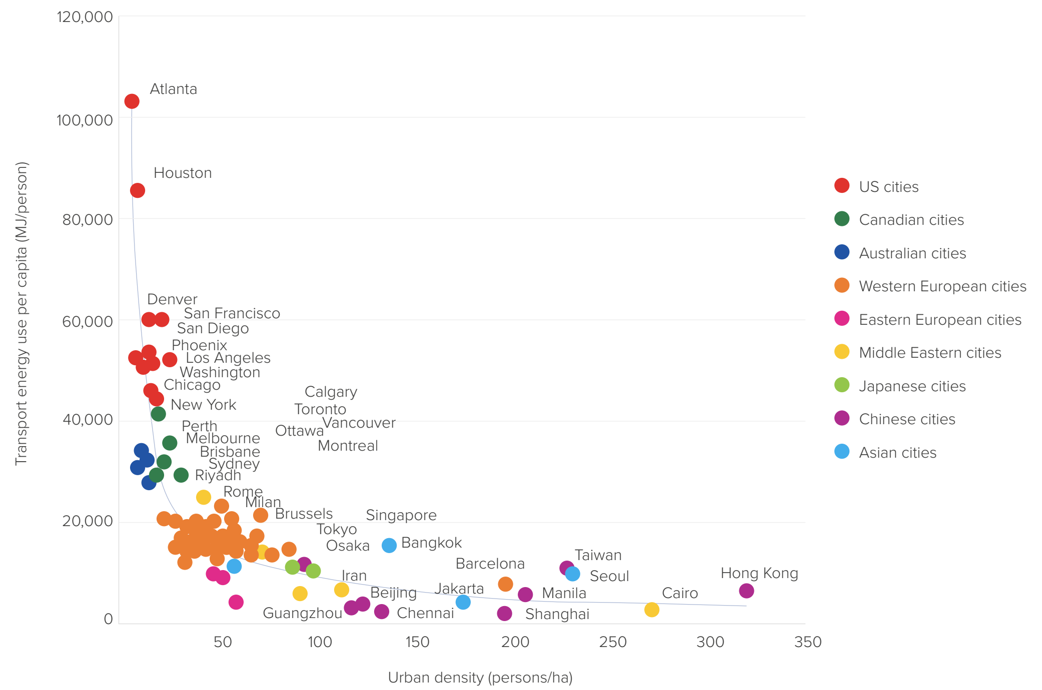


Fig. 11. Urban density and transport-related energy consumption (WHO, 2011)

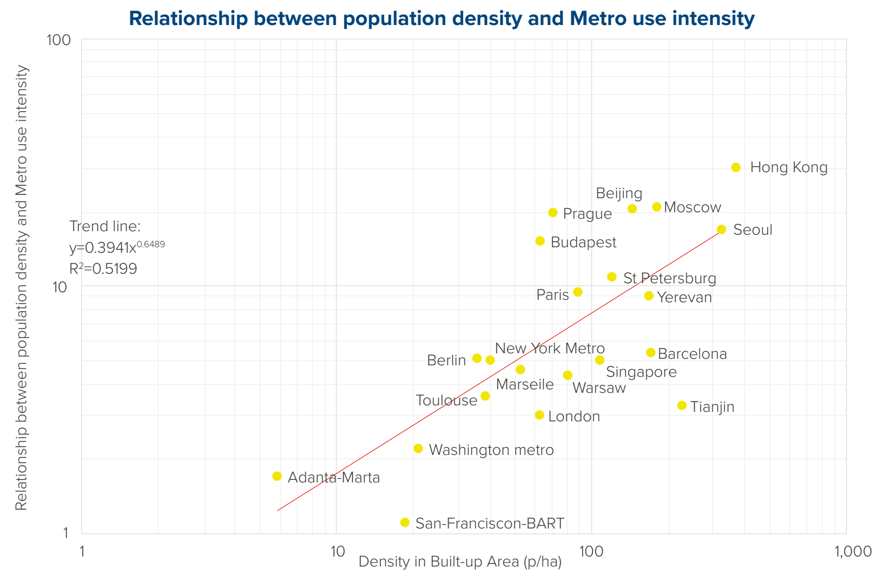


Fig. 12 Population density and metro use intensity (Bertaud and Richardson, 2004)

3.0

Transportation cont.

Best Practices

The TOD principles are:

- Walk: develop neighborhoods that promote walking, e.g., Broadway Boulevard, Times Square, Herald and Greely Squares, and Madison Square Park, New York.
- Cycle: prioritize non-motorized transport networks, e.g., Copenhagen, Denmark.
- Connect: create dense networks of streets and paths, e.g., Singapore
- Transit: locate development near high-quality public transport, e.g., Hammarby Sjostad, Southern Stockholm.
- Mix: plan for mixed use, e.g., Olympic Village in Vancouver.
- Densify: optimize density and transit capacity, e.g., Central Saint Giles, London.
- Compact: create regions/suburbs with short commutes, e.g., Paris Rive Gauche, Paris.

Guidelines

The TOD principles should be applied to all types of TOD, from major transit areas to local neighborhood transit areas. The difference in application will be a matter of scale, intensity, and approach and must be consistent with the function and objectives of different areas. Higher-level TOD areas include key nodes and corridors planned for rapid transit lines. The TOD areas across the city can be classified into four main types of TOD areas: urban areas, suburban areas, greenfield areas, and other, as shown below.

Transit-oriented development typology	Characteristics
Urban areas	• Node areas around a corridor • Employment and residential functions and civic uses varying by node scale • Different service levels for different node types • Area with potential development along a transit corridor
Suburban areas	• Mixed-use area • Good potential area for economically obsolete area intensification • Potential to facilitate bus travel
Greenfield areas	• Underdeveloped area identified as a community node • New areas to be built around transit • Will evolve over time to have the same characteristics and similar functions as an urban node • A node in the neighborhood context incorporating residential and local-scale commercial developments supported by local transit
Other	• High level of institutional uses, with significant transit ridership

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The TOD principles should be applied to all types of TOD, from major transit areas to local neighborhood transit areas.

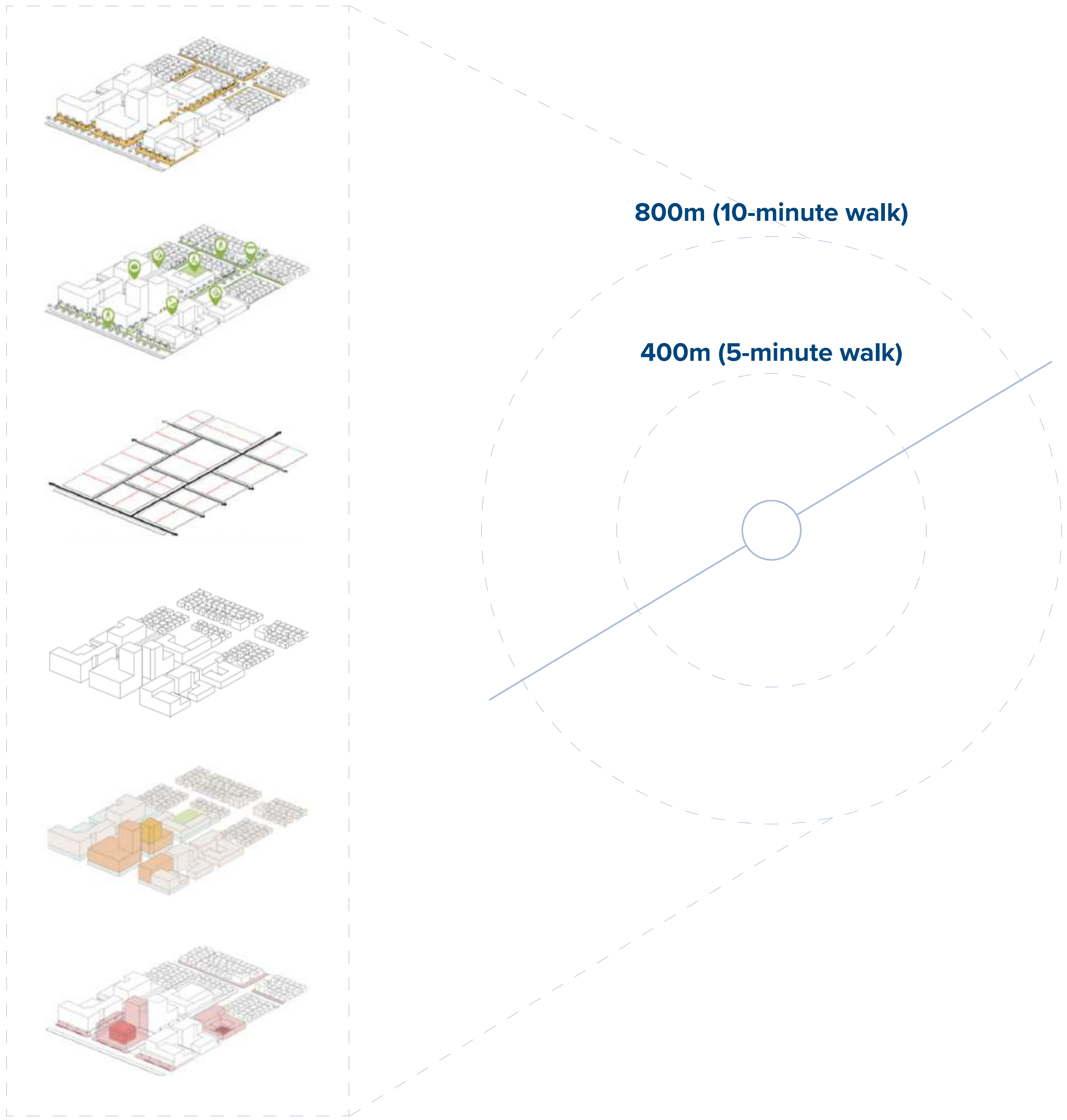


Fig. 13. Concept and key elements of TOD as an example

3.0
Transportation cont.

The distance a person is willing to walk to use transit defines the primary area in which TOD should occur. This distance is equivalent to roughly a 5–10-minute walk, or 400–800 m. At these radii around a station, there is potential for 300–400 acres of land for TOD.

Urban areas: The urban areas include some urban corridors and nodes identified in the local level area's master plan. The primary corridor will have the highest-order transit in the city and should be the focus of the largest-scale TOD. The peripheral node areas will be among the highest-order transit stations (as a multi-modal location) and will likely attract the most development outside the downtown area. Various station areas may also be potential development/redevelopment sites along the corridor, although it is unlikely that every station area will have a high demand for new development. It is essential that TOD principles are applied at the appropriate scale to ensure these nodes develop to support local transit and achieve their planned function in the urban structure. The TOD guidelines applied to urban areas will be of the highest scale.

Typical design elements:

- A high degree of focus on creating a sense of place by locating unique and visually appealing buildings, public art, etc., within the TOD area.
- Lot coverage of 50–70%.
- Wide sidewalk: 1.8–2.5 m min to 4.5m maximum in high-traffic areas (3.5m or larger is ideal); planting shade trees.
- FAR: 2–5 minimum.
- Scale of development: 3–10 stories, subject to the approval of the relevant authority/ministry.
- Highest-density uses (mixed use, retail, residential, institutional) clustered within 800 m of the transit station.
- "Transit village" created: developing the entire node as a village focused on transit.
- Given the location as a transit hub, this may be an appropriate area to enter a partnership for park-n-ride facilities, etc.
- Appropriate parking management guidelines.
- Higher-order cycling facilities (secured bike storage, etc.).
- Transit stops located to create optimal walking distance of 250–400m to access work and 500–800m for residential areas, where feasible.

Suburban areas: The suburban areas include areas along transit routes. Non-transit routes are also grouped into this type of TOD area. The design of the suburban TOD will be similar to that of the urban TOD but on a lesser scale. The long-term goal is to use TOD principles to bring suburban transit corridors up to a similar scale. Suburban-area transit corridors can benefit from TOD at key locations, such as where two transit routes intersect. TODs along suburban corridors will be the primary access point for transit for the surrounding neighborhoods. As a primary corridor, higher scales of development and intensification are appropriate. The density and intensity of uses near TOD areas in suburban corridor areas should increase over time.

Typical design elements:

- Medium-level scale and intensity of buildings.

> *Transit stops located to create optimal walking distance of 250–400m to access work and 500–800m for residential areas, where feasible.*

- Wider sidewalks placed within 800m of the station area.
- FAR: 1–5 minimum.
- Scale of development: 3–8 stories, subject to the approval of the relevant authority/ministry.
- Cycling facilities required at transit stations—secured facilities preferable.
- Creating a positive pedestrian environment, utilizing a wider right of way (ROW) to expand sidewalks and planting shade trees.
- Design and land use should be realistic to the existing uses, but it is important to also plan for more intensity in the future giving access to higher-order transit on the corridor.
- Discouraging new auto-related uses within 800m of a transit station area
- Promoting sidewalks with a minimum 1.8m width.
- Appropriate parking management guidelines.
- Promoting connections to other modes, such as cycling, with bicycle locking areas or other cycling facilities, such as bike ramps at stairs, where appropriate.
- Ensuring bus signs and stops are clearly marked and highly visible.

Greenfield areas: Greenfield areas such as new nodes or new undeveloped areas have the potential to be planned, designed, and developed according to TOD principles from the start. Applying TOD principles early in the planning and development of greenfield areas may help transit services and use become established sooner. With TOD principles/elements applied, new greenfield areas can develop around transit; thus, transit services are more feasible as the population and density needed to support transit become established over time. Greenfield areas (as with all TOD areas) should have an overall mixture of densities, which may include low density. Greenfield areas include new neighborhoods, such as the planned greenfield community node. The greenfield community node will benefit from being planned according to TOD principles.

Typical design elements:

- Planning for clustering of uses and buildings from the beginning.
- FAR: 1–5 minimum.
- Scale of development: 3–8 stories, subject to the approval of the development authority.
- Creating a focal point for new communities near the center, with good transit access.
- Planning for walkways and pedestrian paths early in the process to improve long-term connections.
- Appropriate parking management guidelines.
- Ensuring good pedestrian connections between buildings and bus stops.
- Thinking of transit from the beginning of planning for and assigning new land use designations and zoning.

Other areas: The final category where TOD may be applied is in nodes that include major activity centers indicated in the local-level master plan. Major activity centers have many potential transit riders due to the presence of airports, health centers, colleges, and universities. Thus, TOD principles should be applied in these areas like other urban or suburban nodes. Each activity area is unique and must apply TOD principles according to its specific

> *Applying TOD principles early in the planning and development of greenfield areas may help transit services and use become established sooner.*

3.0

Transportation cont.

function and needs. Specific TOD principles can be applied as these areas evolve. Similarly, other city areas may become prominent activity areas where TOD will be desirable.

Typical design elements:

- Medium to high-level scale and intensity of buildings.
- FAR: 2–5 minimum.
- Scale of development: 3–10 stories, subject to the approval of the development authority.
- Wider sidewalks placed within 800m of the station area.
- A high degree of pedestrian amenities.
- Cycling facilities required at transit stations, with secured facilities preferable.
- Creating a positive pedestrian environment by utilizing the ROW to expand sidewalks and plant shade trees.
- Design and land use should be realistic to the existing uses, but it is important to also plan for more intensity in the future, giving access to higher-order transit on the corridor.
- Discouraging new auto-related uses within 800 m of a transit station area.
- Connections to other modes of transit should be clearly marked and have easy-to-read/understand signs.

As the transport section focuses on TOD, the following image shows how the new development should form along the transit corridor. Each buffer contains three types of density: high density in the center (including the city center), mid density, and low density.

Mobility-as-a-Service—Customer at the Center

Mobility-as-a-Service (MaaS) integrates various forms of transport services into a single mobility service accessible on demand (Signor, 2019). These digital platforms integrate and analyze data from multiple modes of transport, such as rail, bus, taxi, and cycle hire, to offer choices in journey planning to consumers. This requires, for example, the ability for MaaS platform providers to access service timetabling data and purchase tickets digitally. Potential benefits of MaaS include the following:

- Reduction in carbon dioxide (CO_2) emissions.
- Reduction in road congestion
- Improvement in air quality because of decreased car use and road congestion.
- Improvement in users' physical health by encouraging increased use of active modes of travel.
- Improvement in passenger travel experience by offering a simplified ticketing system.
- Facilitating better management of travel demand and transport infrastructure by utilizing aggregated customer and travel data from the MaaS app.

In order to obtain the above benefits, authorities must have a clear vision and strategy to provide the public with greater flexibility and the correct suite of public and on-demand transport services. Any MaaS deployment should reflect this strategy, and all stakeholders (local authorities, MaaS operators, and transport operators) should understand their role in this integrated approach. Holistically addressing

> *Mobility-as-a-Service (MaaS) integrates various forms of transport services into a single mobility service accessible on demand.*

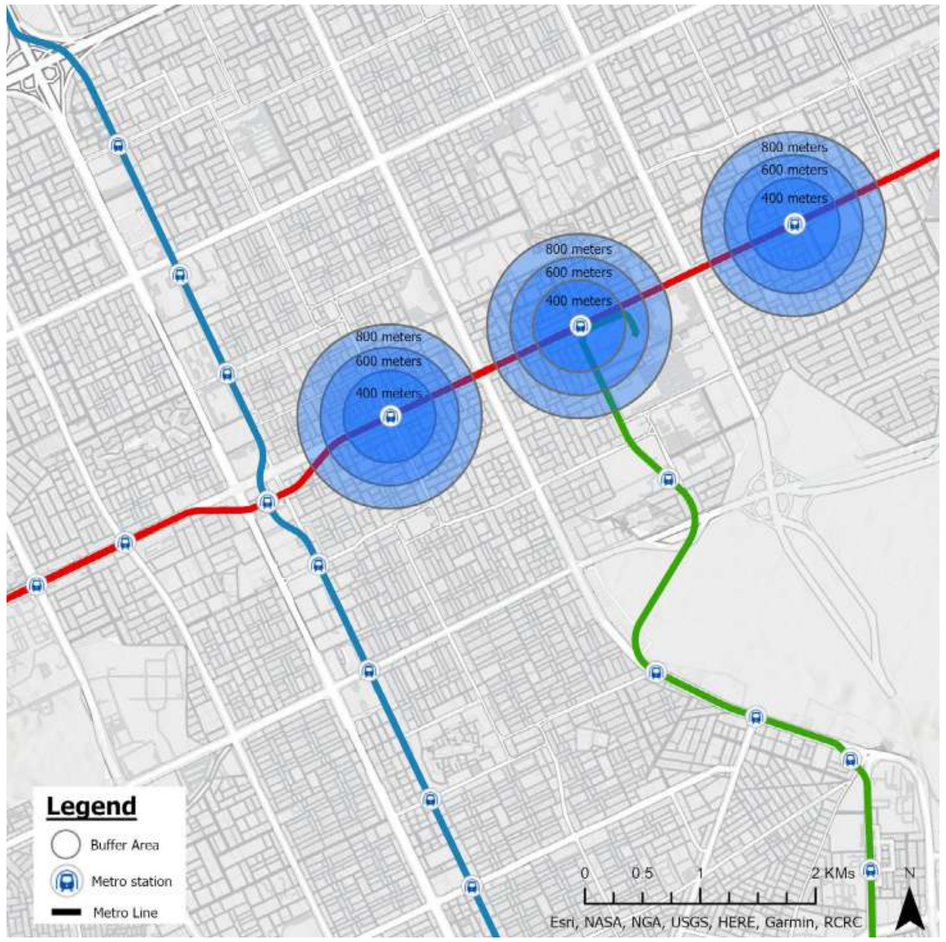


Fig. 14. Example of new developments along the transit corridor

> *In order to obtain the above benefits, authorities must have a clear vision and strategy to provide the public with greater flexibility and the correct suite of public and on-demand transport services.*

3.0
Transportation cont.

the transport needs of consumers is essential to fulfilling the full potential of MaaS and ensures the delivery of its environmental, social, economic, and health benefits.

Best Practices

Whim: Finland (Turku, Helsinki), Antwerp, Vienna, and Japan

Wien Mobil: Austria

Mobility Shop: Germany (Hanover)

UbiGo: Stockholm, Sweden

Guidelines

The requirements for a functioning MaaS ecosystem relate to demography, the level of "app and digital maturity" of expected customers, the availability of data, the existence of transportation services, and a sufficient level of technological development, both in terms of digital infrastructure and application-specific technologies (Transit, 2021.) In terms of population and demography, a MaaS solution should have an adequate base of potential users. This means creating useful and feasible MaaS services in densely populated areas is easier. In non-urban areas, MaaS can also be an option, but it must take a different form. City centers are the obvious areas where MaaS has potential, whereas the potential is smaller in the countryside.

The backbone of many MaaS initiatives is the public transportation system. In addition, many existing private transportation services, such as taxis, can be integrated into a MaaS offer. Some transportation modes can also be completely novel, such as e-scooters. However, constructing a MaaS ecosystem is primarily dependent on the availability of existing transportation modes that can be harnessed to provide the physical transportation services required for MaaS.

In order to plan or implement effective MaaS, the local authority should work together with the service providers and transport operators to:

- Prepare a plan/strategy to explicitly support the development of MaaS in the local context.
- Develop MaaS systematically.
- Expand MaaS at the regional level to enhance MaaS further.
- Design parking and street-use policies to explicitly support the shared use of vehicles.
- Support a new business model by adapting parking standards for (new) residential developments, reducing the area of parking spaces, allocating parking spaces for shared cars, and enabling new mobility services for residents.

Combined Ticketing System

The aim of MaaS is to offer a harmonized public transportation authority ticketing system. The MaaS data interface and platform, into which the public transport ticketing system is incorporated, enables the integration of local service providers into the system and offers a variety of combination tickets. For example, a transit ticket can also be included when buying an event ticket. When buying a bus/train ticket, the same ticket is valid in the entire province. One ticket can be used for four trips (each direction) on the day, which also applies to the combined tickets.

"
Support a new business model by adapting parking standards for (new) residential developments, reducing the area of parking spaces, allocating parking spaces for shared cars, and enabling new mobility services for residents.

Credit: Good Design Award (G-Mark) https://www.g-mark.org/award/describe/49069?locale=en

Fig. 15. Concept of Maas, example of "Whim"

"
The backbone of many MaaS initiatives is the public transportation system. In addition, many existing private transportation services, such as taxis, can be integrated into a MaaS offer. Some transportation modes can also be completely novel, such as e-scooters.

3.0

Transportation cont.

Basic Infrastructure

First, digital infrastructure, specifically the regional infrastructure (mobile data networks), must be high enough to support the seamless data flows necessary for MaaS. Second, alternative mode options must be available; if the basic network for walking, biking, public transit, car hire, etc., is unavailable, MaaS will not solve the challenges. Third, mobility hubs encourage seamless integration into public and shared mobility offers. These are modular in approach and scaled to local needs. Shared and on-demand services operating from mobility hubs can include:

- **Demand-responsive transport**: providing on-demand service systems supporting accessibility in towns and urban centers.
- **Vehicle hire**: accessing extensive branch networks to provide vehicles on demand as an option for users to access cars when longer trips are required.
- **Car clubs**: the provision of on-street car/van-share services with potential for Low Carbon Emission Vehicles (LCEVs) and Hybrid vehicles as they become commercially viable for such applications.
- **Bike share**: providing users with on-demand access to dock or undock (pedal and electric) bicycles at a variety of pick-up and drop-off locations for one-way (point-to-point) or roundtrip travel.
- **E-scooters**: e-scooter service provision on private campus-style developments, potentially expanding to other areas.
- **Ridesharing**: ridesharing services with charging stations for Low Carbon Emission Vehicles (LCEVs) and Hybrid vehicles

Movement and Place

The movement and place (M&P) approach recognizes that transport links perform two functions: movement of people and goods and serving as a place (a destination) (NSW Government, 2022b). This way of thinking ensures that while planning for and developing our network, we are simultaneously considering the needs for movement and placemaking. An important element of successful M&P development is integration with the surrounding area. The future M&P plan should be synchronized with the Street & Mobility strategy stated in the Saudi National Urban Design Guidelines developed by MoMRAH in 2022.

Best Practices

In Australia, place-based planning policy has been applied at the federal, state, and local levels of government through various community and planning agencies over the last few decades. In New South Wales, the Movement and Place Framework describes a collaborative method for project planning, design, implementation, and operation across multiple scales of development. The United States Department of Agriculture has applied place-based planning approaches within the context of national parks and forests. In Scotland, a place-based framework has also been developed. Case studies can be found across the global north, including France, Poland, Italy, Spain, Portugal, etc.

Guidelines

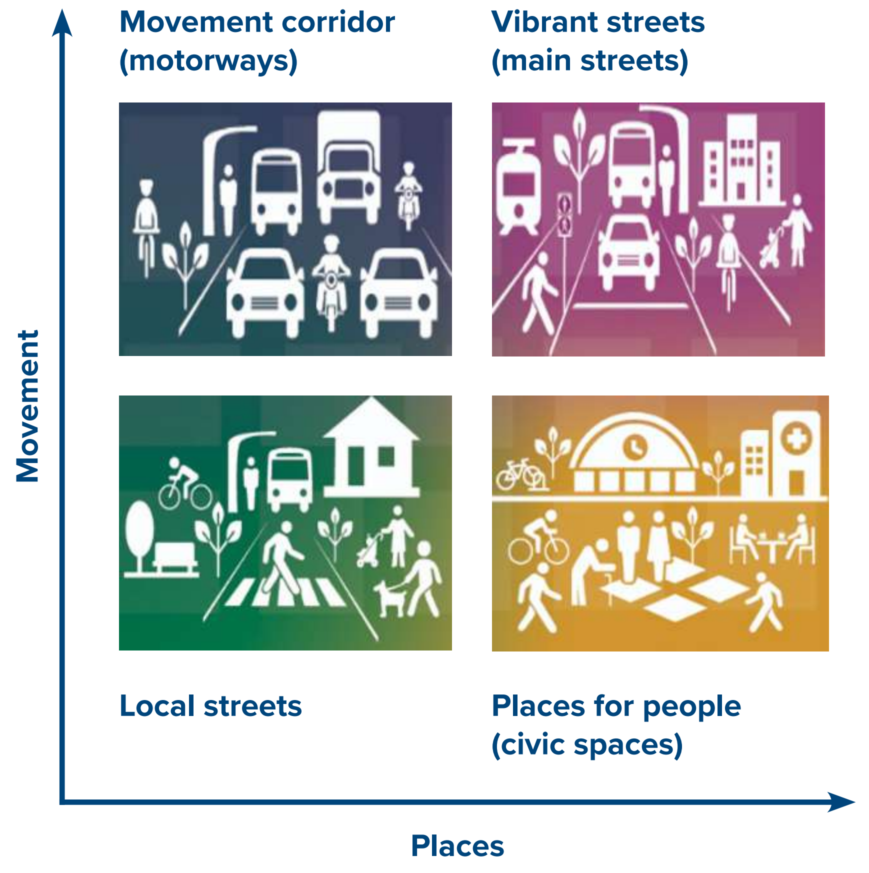
When planning a new development, whether infill or urban extension, a primary consideration is the relationship between place and movement. For example, in differing circumstances, a different emphasis is placed on the provision of schemes that prioritize the movements within the development and its surroundings and on the place's quality, design, and aesthetic. This is detailed simply in the diagram below.

> *When planning a new development, whether infill or urban extension, a primary consideration is the relationship between place and movement.*

It is commonly perceived that a motorway does not prioritize a sense of place, but there is a greater emphasis on providing fast, unimpeded traffic movement. This obviously differs considerably from a small village/rural area, for example, which may be said to have a lesser emphasis placed on movement but a high value given to the sense of place and character. Many developments fall somewhere between the two, such as a new district center, with a potential need for both high levels of movement and high quality of place.

Consideration of the M&P concept should inform pre-planning discussion, which will help prepare short- and long-term strategic plans for the site.

> *It is commonly perceived that a motorway does not prioritize a sense of place.*



Credit: Movement and Place framework, NSW Government, Australia, https://www.movementandplace.nsw.gov.au/

Fig. 16. Concept of Movement and Place framework

4.0

Key Terms

Bicycle lanes: Bicycle or bike lanes are separated portions of the roadways exclusively designated for bicycle-only travel. Bicycle lanes follow the same direction as automobile travel and often include painted signals and signs to designate the bike-lane area clearly. Innovative bike-lane designs include colored pavements, lanes separated from vehicle travel, and urban bike trails. Cars do not belong there, and drivers stay clear of the lane when the line is solid, crossing or turning when the line is dashed.

Bike share: A bike-sharing system is a service in which bicycles are available for individuals who do not own them. Users hire daily, annual, or even per-use memberships. The major advantages of a bike-sharing system are that it provides free or low-cost access to bicycles for short-distance trips in an urban area as an alternative to transit or use of private vehicles, reducing traffic congestion, noise, and local air pollution.

Brownfield development: Brownfield land is any previously developed land not currently in use. These sites may have existing structures where updates could occur or new infrastructure may be constructed to work with existing development. Therefore, brownfield redevelopment comprises rehabilitating a particular piece of land for a new use after the former use has been discontinued. Brownfield redevelopment is a complex process involving numerous players. Landowners, citizens, investors, urban and spatial planners, and politicians are involved and have a broad range of interests.

Credit: Shutterstock

Fig. 17. Bike lane

Credit: Getty

Fig. 18 Bikeshare

Credit: Water Baords, California

Fig. 19. Brownfield development

Bus rapid transit: Also called busways, this transit system implements buses to provide a more efficient and high-speed bus transportation method. Higher efficiency is often gained by providing dedicated bus lanes, a higher frequency service, or new technology.

Car sharing: Car sharing is a type of short-term car rental where you only pay for what you use, resulting in access to vehicles without the high costs of car ownership, such as the cost of fuel, maintenance, registration, taxes, toll fares, insurance, and cleaning. This is useful for drivers who only need a vehicle occasionally, live in areas of limited parking, and may want to access different types of cars for varied uses.

Greenfield development: Greenfield land is undeveloped land in an urban or rural area that land developers typically desire for new development.

Infill development: Infill development is new development that occurs within the boundaries of existing development. Benefits include the ability to tie into existing infrastructure, such as water, sewer, stormwater, electric, telecommunications, transit, and roadway networks, with no extension required, which may reduce infrastructure costs.

Local authority: A local authority (also known as a local planning authority) is the local government body empowered by law to exercise urban planning functions for a particular area and control development.

Mobility-as-a-Service: MaaS is the integration of various forms of transport services into a single mobility service accessible on demand. In other words, MaaS is a type of service that enables users to plan, book, and pay for multiple types of mobility services through a joint digital channel.

Credit: Wolfram Burner on Flickr

Fig. 20. Bus rapid transit

Credit: The Canadian press/Larry MacDougal

Fig. 21. Car share

4.0

Key Terms cont.

Mobility hubs: Mobility hubs are places in a community bringing together public transit, bike share, car share, and other ways for people to get where they want to go without a private vehicle.

Mixed use: Mixed-use development is characterized as pedestrian-friendly development that blends two or more residential, commercial, office, cultural, institutional, and/or industrial uses. Mixed use is an important element of smart growth, a planning strategy that seeks to foster community design and development that serves the economy, community, public health, and the environment.

Mode share: Mode share, also known as modal share or mode split, is the distribution of travelers using a particular transportation type. Walking and cycling are two examples of non-motorized travel modes, while private automobiles, public transportation, private buses, and taxis are examples of motorized modes of transportation.

Movement and place: M&P is a cross-disciplinary, place-based approach to planning, designing, delivering, and operating transport networks. It recognizes and seeks to optimize the network of public spaces formed by roads and streets and the spaces they adjoin and impact.

Multimodal transportation: Multimodal transportation involves transportation networks that rely on multiple and connecting modes of transit and transportation, e.g., bus lines that connect to metro rail, which connect to bike sharing, which connect to streetcars, which connect to carpool drop-off areas.

Shared lane (sharrow): This marker indicates that a cyclist has the same rights to the lane as a car. Drivers share these lanes carefully with cyclists, giving cyclists 3 ft when passing and not following too closely. The placement of the "sharrow" on the road indicates a reasonable space for the cyclist to ride. Sharrows are sometimes closer to the center of the lane or are not always consistently placed within a lane. Regardless of where sharrows are placed, cyclists are generally allowed full use of the lane by law.

Smart growth: Smart growth is an urban planning approach focusing on growth in compact, walkable areas to limit sprawl and its associated traffic congestion. Smart growth encourages bicycle-friendly, dense, transit-oriented, mixed-use development with diverse housing options and amenities.

Transit corridor: A transit corridor is defined as the walkable areas around all the stations along a transit line. Different transit technologies will define different areas of influence.

Transit station: A transit station is a passenger station for vehicular and/or rail mass-transit systems. Terminal facilities provide maintenance and services for vehicles operated in the transit system, including buses, taxis, railways, etc.

Urban sprawl: Urban sprawl refers to the poorly planned, low-density, auto-dependent development that expands over large amounts of land. This type of development places long distances between homes, stores, and workplaces, leading to high segregation between residential and commercial uses. This generally comes with adverse environmental and social impacts, including traffic congestion, air pollution, and loss of forest and agricultural lands and communities.

Vehicle kilometers traveled: VKT measures the number of kilometers traveled by motor vehicles over a given time and area.

Credit: Oxford Properties Group Inc

Fig. 22. Mixed use development

Credit: NACTO

Fig. 23. Shared lane

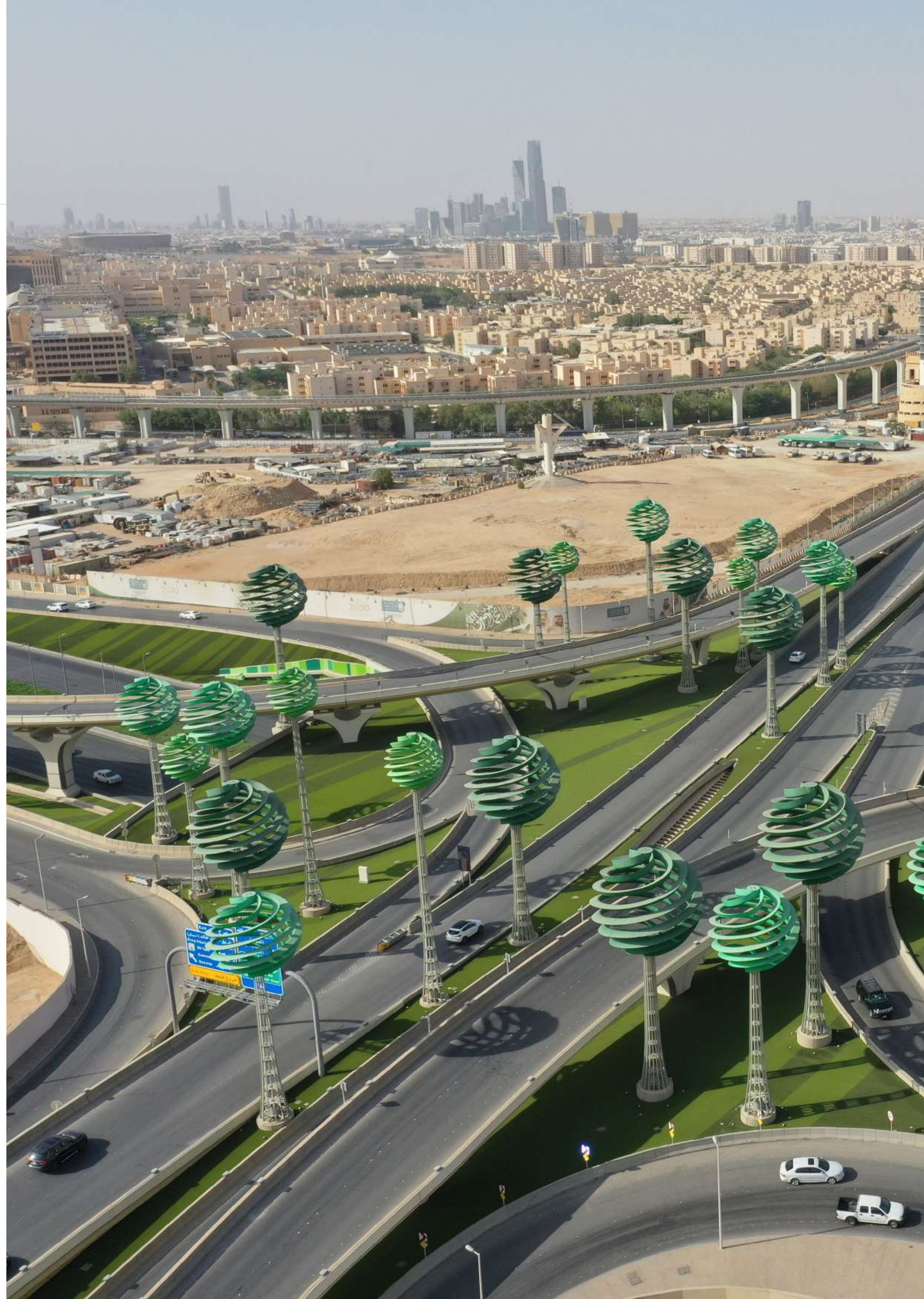
Credit: Los Angeles County Metropolitan Transportation Authority

Fig. 24. Transit corridor, Los Angeles

5.0
Compliance Checklist

Checklist	Yes	No	N/A
Density: population should be 1,000 to 10,000 per km^2 minimum by the density scale, such as low, medium, high, and city center.			
Building permit requirements: maximize the FAR with a minimum of 5 FAR for urban city centers and 2–5 for low-to high-density multi-residential properties, promoting walkability and connecting communities with accessible amenities.			
Land use (low density): local amenities (mosques, community gardens, etc.) should be located within 500 m of homes, and community-wide amenities (gyms, supermarkets, etc.) should be within 1,500 m of homes.			
Land use (medium density): local amenities should be located within 400 m of homes, and community-wide amenities should be within 1,300 m of homes.			
Land use (high density): local amenities should be located within 300 m of homes, and community-wide amenities should be within 1,000 m of homes.			
Land use (urban city center): local amenities should be located within 250 m of homes, and community-wide amenities should be within 800 m of homes.			
TOD: transit stops should be located to create an optimal walking distance of 250–400 m to access work and 400–800 m for residential areas, where feasible. There is potential for 300–400 acres of land for TOD. Sidewalks should be wide: 1.8–2.5m minimum to 4.5m depending on traffic flow intensity.			

For TOD, Riyadh TOD checklist described in “Riyadh Transit Oriented Development Study” document of RCRC may be taken into consideration. However, the checklist can vary and should be aligned with local characteristics.



District Cooling

District Cooling

Introduction

District cooling involves providing cooling to multiple buildings or facilities from one or more central cooling plants interconnected to the cooling users via a network of supply-and-return piping.

It is a highly efficient means of providing locally generated thermal energy for cooling homes, commercial and institutional buildings, and industrial processes. A district energy network combines the energy demands of many buildings to achieve the economies of scale necessary to make these fuels practicable.

A DC system helps the environment by increasing energy efficiency and reducing environmental emissions, including air pollution, GHG, CO2, and ozone-destroying refrigerants. Moving cooling energy production to a district plant centralizes the operations and maintenance processes and eliminates burdens for building owners. This is all possible by reusing wasted energy and utilizing it safely in cooling applications.

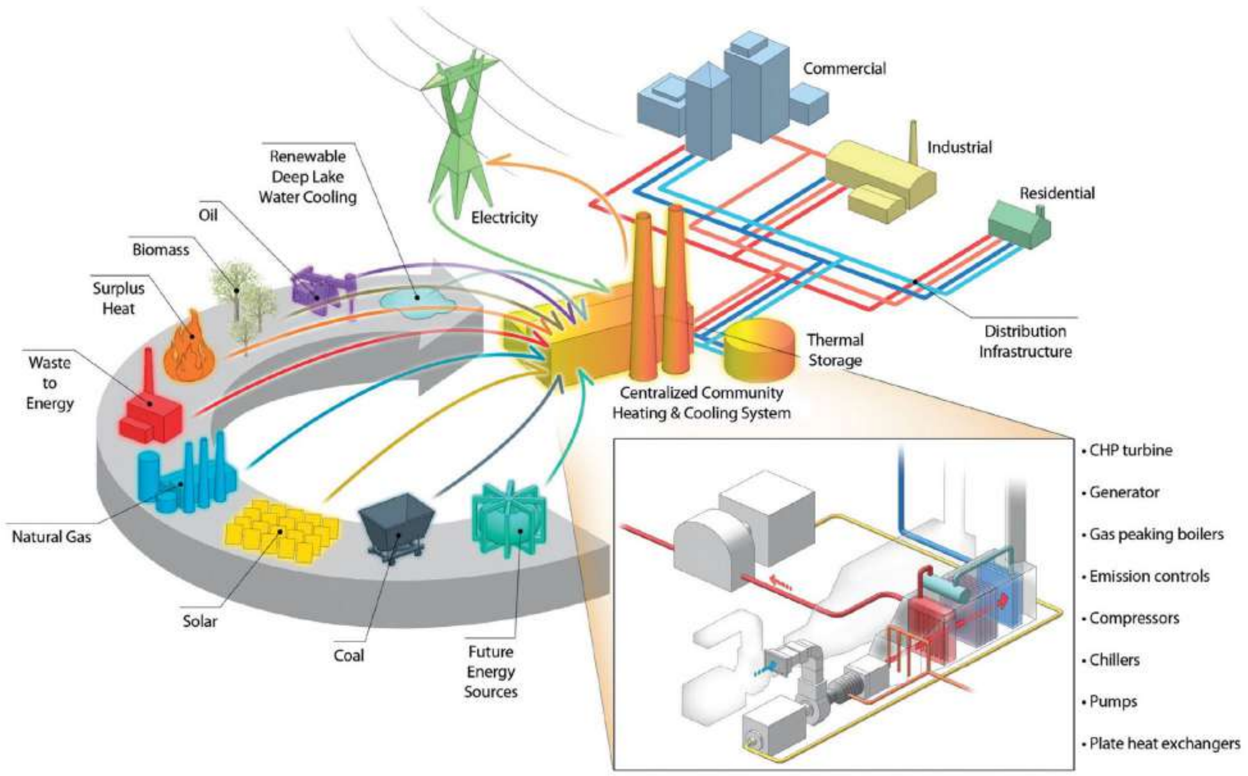


Fig. 25. Multiple fuel sources have potential for district cooling (Community, 2012)

1.0

Components of District Cooling

Water is the primary medium for DC systems, requiring extraction and treatment of water from local aquifers, lakes, rivers, or seas. Chilled water is produced by production plants and distributed by water pipes (the distribution network) to buildings equipped with energy transfer stations (ETSs) (sub-stations). The chilled water then supplies some of its cooling properties to the building's installations. A cooling system operates in a closed circuit and always includes at least two water pipes: one that carries the chilled water to the end user and another to the production plant. There are, therefore, four key components of DC systems:

- Water extraction and treatment.
- DC production plants.
- Distribution network.
- ETSs.

Best Practices

This section provides an analytical response to the existing infrastructure within Saudi Arabia, including recommendations for developing DC systems and energy savings. These best practices for the design of each component vary based on a range of case-specific conditions:

- Seasonal and daily load characteristics.
- Type of cooling load and any special reliability requirements.
- Size of the plant site and any conditions or constraints relating to the site.
- Density of the area and characteristics of the buildings served.
- Availability and prices of electricity, water, and natural gas.
- Local codes and regulations.
- Underground conditions affecting pipe installation.
- Organizational resources.
- Financial criteria and strategic goals of the DC company.

In determining the viability of a DC system, cost-effectiveness is a key factor. Designing the systems requires careful selection and development of water resources, load diversity, optimized operations, and investment in appropriate advanced technologies. Given that water extraction and treatment account for at least one-tenth of the energy sources in a system, and considering the scarcity of resources, the utilization of water resources must be approached with caution and economic foresight. By developing district systems that treat both residential and commercial sectors, load diversity may be accomplished. Not all building types have their peak demand simultaneously; when cooling loads are distributed throughout the day, equipment operation remains in a steady range and can be operated at a lower cost and with less maintenance.

Finally, advanced technologies may help significantly reduce water and energy use. Thermal energy storage (TES), natural gas-driven chillers, reverse solar thermal chillers, and treated sewage effluent (TSE) are constantly evolving systems and methods. It is worth noting that scarcity of TSE does exist and poses a significant challenge that would need to be addressed through enhancements and innovation. The technology and equipment available throughout the planning process for new cities should be evaluated for suitable arrangements.

> *A cooling system operates in a closed circuit and always includes at least two water pipes: one that carries the chilled water to the end user and another to the production plant.*

The Future and Applicability of Cooling in KSA

In Saudi Arabia, space cooling can represent more than 70% of peak residential electricity demand on extremely hot days, according to estimates from research publications and workshops conducted with relevant public stakeholders. To date, electricity consumption has been a major contributor to the country's carbon emissions. However, new clean technologies can support the decarbonization of the electricity sector without requiring customers to change their behavior.

Air conditioning in KSA faces the following challenges: a lack of natural cold sinks (i.e., air, water) for either direct cooling or heat rejection from air-conditioning systems; natural water scarcity; a growing cooling energy demand driven by population and economic developments; elevated energy use per capita and high reliance on fossil fuels, including for cooling production, with an associated environmental impact; high utility tariff subsidies paid by governments; and a lack of air conditioning and urbanization legislation. It is, therefore, imperative to consider a DC system as the most effective cooling solution.

District Cooling Guidelines

The DC process involves cooling multiple buildings or facilities from one or more central cooling plants interconnected to the cooling users via a network of supply-and-return piping. The DC objectives are:

- Reducing overall community energy consumption.
- Reducing peak demand/ infrastructure capacity by balancing loads.

Criteria	Description
Minimum considerations	• Load sharing/demand diversity (two or more building use types with complimentary loads) • Development density and size (5,000–50,000 people minimum, mid density (10HHs/hectare)) • Development land uses
Additional considerations	• Water supply • Energy supply • Long-term cost/operations • Business opportunity
Recommended application	• Mixed-use development areas • City centers • Dense residential developments • Military bases/national guard • Campus (university, healthcare)

In the planning of new towns, cities, and urban infills for future developments, there are critical points when DC should be considered when:

- New developments create dense urban environments with the capacity for shared resources.
- New building or greenfield developments are being planned, particularly TOD.
- The cooling system in existing buildings is approaching the end of its life and needs replacing.
- Existing buildings or developments are being refurbished, or a brownfield environmental clean-up redevelopment is being undertaken.
- A community or campus manager has concerns about energy security, price volatility, and long-term cost.
- Congestion of electricity distribution networks and supply security are issues.
- A business opportunity to profit from the sale of energy presents itself.

1.0

Components of District Cooling cont.

Identifying Opportunities for District Cooling

Developing a DC system requires careful coordination of multiple factors to improve efficiency. Electricity supply, water resources, and water discharge for DC must be developed innovatively to meet the requirements efficiently. Specific chiller plant and system types have different strengths, and by carefully selecting chiller plant designs, these strengths can be optimized. Plant configuration depends on city planning, installation costs, and engineering principles. It is paramount to balance the major factors to achieve the most efficient DC system, given the specifics of climate zones within KSA.

Compact communities that integrate diverse uses and density of buildings enhance the opportunity for district energy with DC and provide densification that reduces sprawl and supports good public transit systems. A diverse and compact community provides residential, civic, retail, cultural, and entertainment facilities within easily walkable distances. This, together with district energy and DC, creates a high-quality and attractive place to live and work. A good mix of uses increases the project's financial viability and will attract the attention of commercial energy services, investors, and financiers.

Neighborhood Type	Housing Density	Population Density	Mixed Use	Efficiency	Payback	Other Benefits	Recommended
Low density	4–8 HHs/ hectare	1,000–3,999 people/km^2	0%	No—the extensive distribution network counteracts the efficiency of the system.	No—the extensive distribution network increases infrastructure costs.	N/A	No
Mid density	9–14 HHs/ hectare	4,000–6,999 people/km^2	15-20%	Yes—the system is more efficient than individual direct expansion (DX) units.	No—not without incentives; the low energy cost in KSA extends the payback timeframe beyond the lifespan of the equipment.	N/A	Do a study
High density	15–20 HHs/ hectare	7,000–9,999 people/km^2	35-40%	Yes —it is significantly more efficient than individual DX units.	Possibly—the energy savings may offset the investment, but incentives would support a shorter payback.	Improved redundancy and reliability; consolidated land use and operations and maintenance staff; no tower on rooftops.	Yes
City center	>20 HHs/ hectare	>10,000 people/km^2	>40%	Yes—it is significantly more efficient than individual DX units but has equal efficiency to a series of central utility plants (CUPs).	Possibly—the energy savings may offset the investment, but incentives would support a shorter payback.	Improved redundancy and reliability; consolidated land use and operations and maintenance staff; no tower on rooftops.	Yes

2.0

Energy Guidelines

Energy Efficiency by Considering Different Scenarios/Criteria

The energy savings contributed by implementing DC systems compared to onsite cooling systems are largely due to the higher efficiency of large-scale central water-cooled chiller plants compared to onsite small-capacity cooling systems. In addition, a cool thermal storage (CTS) system shifts electricity/thermal energy consumption from peak to off-peak periods, which can significantly contribute to more effective energy use. For example, a leading DC provider has reported average energy savings of 0.78 kWh (46%) per ton-hour of cooling for several conventional water-cooled DC systems implemented in the Gulf Corporation Council (GCC) relative to air-cooled building chillers. Such DC systems were based on fossil electricity vapor compression cooling and standard design/operational practices rather than energy conversation-driven, state-of-the-art designs/operations.

Further, DC systems' energy savings could be achieved using sustainable energy sources and cooling, storage, and cold distribution technologies in conjunction with appropriate control strategies.

The replacement of fossil electricity-driven compression cooling with either renewable electricity-driven compression cooling and/or with waste/renewable-heat–driven absorption cooling, which have been the most widely investigated options, have led to a wide range of reported reductions in DC system energy consumption (i.e., 10–70%), depending on the DC system design/operating characteristics and modeling methodologies. The benefits of CTS are known to be more significant in regions with large daily ambient temperature variations between day and night, such as in the GCC climate. The benefits of TES include shifting cooling operations from peak to off-peak demand periods, which can:

- Reduce peak electricity demand.
- Reduce energy costs for both the cooling supplier and consumer.
- Enable more efficient use of solar thermal energy through absorption of excess heat/electricity generated during sunshine hours, the use of which is shifted to non-sunshine demand periods.
- Reduce installed cooling capacity requirements.
- Improve system reliability by using stored thermal energy as a backup.

In addition to saving energy by consolidating cooling at the district level, DC systems can save energy by employing energy-efficient water extraction or desalination technology, including renewable energy in the power supply to the cooling plant, and maximizing equipment efficiency.

> *For example, a leading DC provider has reported average energy savings of 0.78 kWh (46%) per ton-hour of cooling for several conventional water-cooled DC systems implemented in the Gulf Corporation Council (GCC) relative to air-cooled building chillers.*

Fig. 26. A desalination plant in Shaiba, Saudi Arabia (Aramco)

Fig. 27. Systems within a district cooling plant (Aramco)

3.0

District Cooling Development Path

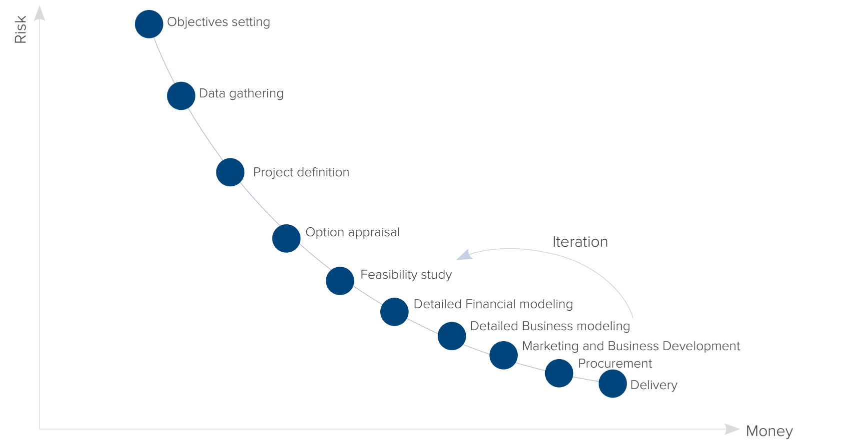
Objective-Setting for the Delivery and Life Cycle of District Cooling—District Cooling Development Path

According to the International District Energy Association, there is a well-established approach for developing DC systems while minimizing risk. This approach has a staged trajectory from inception to delivery and forms the basis of the 10 stages recommended for the execution of DC systems:

- **Stage 1** considers the objectives frequently adopted by communities and municipalities for DC system projects.
- **Stage 2** covers the types of data that must be gathered, focusing particularly on building density, a mix of uses, and anchor loads. It also discusses how this data may be assembled and presented as cooling energy maps to facilitate the planning of thermal networks.
- **Stage 3** addresses how to identify the buildings to be connected to form a DC system project and what may motivate different types of building owners to commit to the project's development.
- **Stage 4** tests what technical option may best meet the cooling energy needs of the buildings comprising the project while meeting the project objectives. This is sometimes referred to as a "high-level feasibility study."
- **Stage 5** subjects the project to a feasibility study. This is a technical exercise to investigate the selected option in detail. It considers the different fuel types and generation options; the configuration of thermal production equipment and storage within the plant facility and its optimum location, network design, and route; and the phasing of development. It will also provide a high-level assessment of the financial viability of the option.
- **Stage 6** develops the financial model for the project. It considers its overall capital cost and operating costs. Potential sources of capital are suggested, and revenues are listed. Risks to the project's financial viability are identified, with suggestions for how these may be appropriately allocated. The financial model should be subjected to a sensitivity analysis or "stress test" to determine its robustness.
- **Stage 7** considers different business or commercial models that may be put in place to take the project forward. The relationship between risk and control is discussed, in addition to how these factors can impact the cost of capital.
- **Stages 8, 9, and 10** review the legislative and regulatory environments that affect projects. Consideration is given to procurement routes, commissioning, and delivery.

Overall, the project development cost can amount to a significant proportion of the project's total capital cost. Each stage must be financed and progressively increases in cost. However, the risk of project failure declines as the process progresses.

> *According to the International District Energy Association, there is a well-established approach for developing DC systems while minimizing risk. This approach has a staged trajectory from inception to delivery and forms the basis of the 10 stages recommended.*



Credit: Community Energy: Planning, Development, and Delivery, International District Energy Association, 2008

Fig. 28. District cooling development path

Therefore, while not prescriptive, the 10-stage approach helps avoid spending substantial amounts of money to no effect and provides an appropriate sequence of increasing specificity. The closer a project gets to delivery, the more details come into view, and the clarity and scope of the project improve.

Each of these stages will be iterative within every new development. Although financial and business modeling is carried out in detail later, it is important that they are considered from the start and revisited throughout the process. For example, different investors have different expectations of rates of return, so understanding the business model at the outset is crucial. This is particularly critical where a project developer (PD) has choices of different procurement, financing, and operation models because technology selections may change slightly, or participants may desire comparative scenarios for risk assessment. In addition to the 10-stage approach to executing a project for DC systems, it is worth considering that based on the Saudi Cabinet's approval of Resolution No. 111, which entails the approval of introducing a tariff for heavy consumption of electricity, this resolution is headed by the Ministry of Energy and targets qualified sectors that form a committee to indulge in approaches and innovations that promote sustainable cooling and efficient electricity and water consumption. Members include the Ministry of Finance, the Ministry of Investment, the Ministry of Economy and Planning, and the Authorities of Water and Electricity Regulation, Local Content, and Government Procurement. In summary, the financial guidelines of this guide will delve deeper into development costs, business models, assessment methods, policies, tariffs, and legal frameworks.

> *In summary, the financial guidelines of this guide will delve deeper into development costs, business models, assessment methods, policies, tariffs, and legal frameworks.*

4.0
Zoning and Density

Development of new buildings, developments, towns, and cities may provide enough density and growth factor to make DC economically, energy, and environmentally efficient. Some of the factors contributing to the proper development of a DC system include:

- Demand loads.
- Demand profiles.
- Development density.

To properly design and develop a DC system, each new urban development area will require detailed data gathering. The survey of existing infrastructure and use will help make informed decisions regarding future masterplan developments and support energy generation. Activities to design and develop a DC system include the following:

- Collect data on existing and future energy consumption of new construction and existing buildings, considering improvements to their energy efficiency.
- Take account of the rate of construction for new buildings.
- Consider fuel and power sources and how the energy will be delivered or transported.
- Recognize the pros and cons particular to the location in terms of energy sources, distribution, transport, land use, form, and character.
- Consider the sustainability of low- and zero-carbon energy technologies.

Demand load is the cooling energy consumed in each building or development. This varies with the weather and the activity patterns of the building's occupants. For example, residential and hospitality uses tend to have an inverse daily pattern to commercial uses (they typically use cooling energy at different times of the day). Some buildings, such as arenas, convention centers, and stadiums, will exhibit event loads that occur only on dates when events are scheduled. In contrast, buildings such as hospitals, universities, and hotels are used 24 hours a day and have steady loads.

Daily load profiles are compiled to form annual load profiles. These show different profiles in summer and in winter. The peak load is the period of highest demand, and the base load is the period of lowest demand. It is important to create cooling load profiles for any project so that a cooling energy system of the right size can be designed to meet cooling demand.

Having a mix of end uses, reflected in different load profiles, helps to match demand to supply to get the most out of the central cooling plant. District cooling plants operate most efficiently with a steady, smooth load. Most individual loads contain abrupt increases or "spikes" of demand.

A cooling system for a single building must be sized to meet peak load, but cooling energy use is only at peak demand for a fraction of the time. As a result, most chilled water systems are oversized, running below their optimum performance, and are most effective after a steady period of demand. If several residential properties share a cooling plant via a DC energy network, "spikes" are smoothed out by the overlapping demands of the customer buildings. If commercial buildings are added to the DC network, they smooth the load out even further with their complementary energy-use pattern. This gives a smooth load curve over 18 hours.

Air conditioning imposes the greatest strain on the electricity grid and often accounts for 50–60% of the electric peak demand in a building with its own cooling equipment.

A good mix of uses (or load diversity) increases the project's financial viability and will attract the attention of commercial DC services, investors, and financiers. Mixed-use developments with greater load diversity are more viable than entirely residential developments. Certain buildings, such as hospitals, hotels, large housing complexes, prisons, swimming pools, ice rinks, military bases, and universities, have a large and steady demand for cooling energy over 24 hours. Buildings like these also often have space available where cooling plants could be placed. Therefore, they make ideal cornerstones for developing DC energy networks and are known as anchor loads.

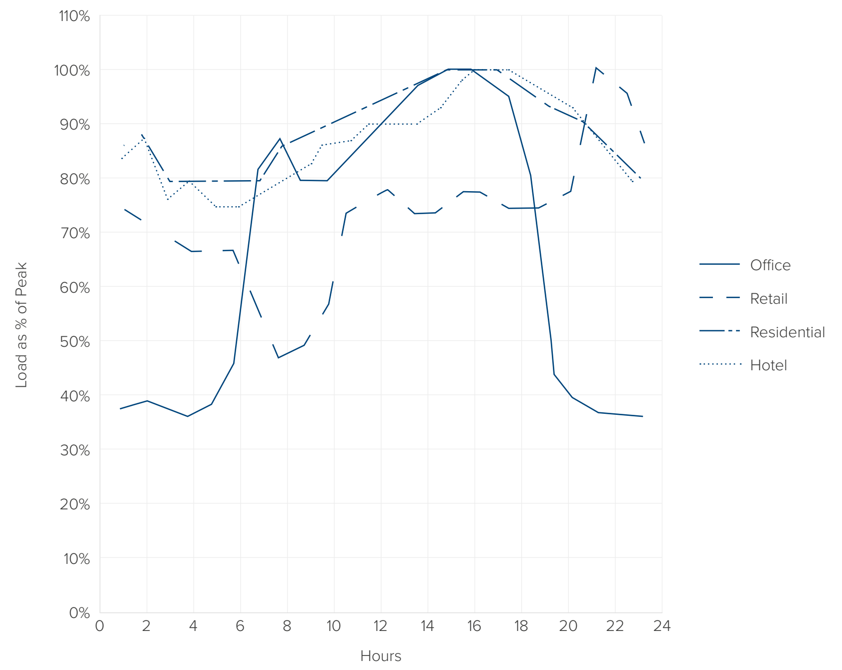


Fig. 29. Example of peak-day load profiles for various building types (District, 2008)

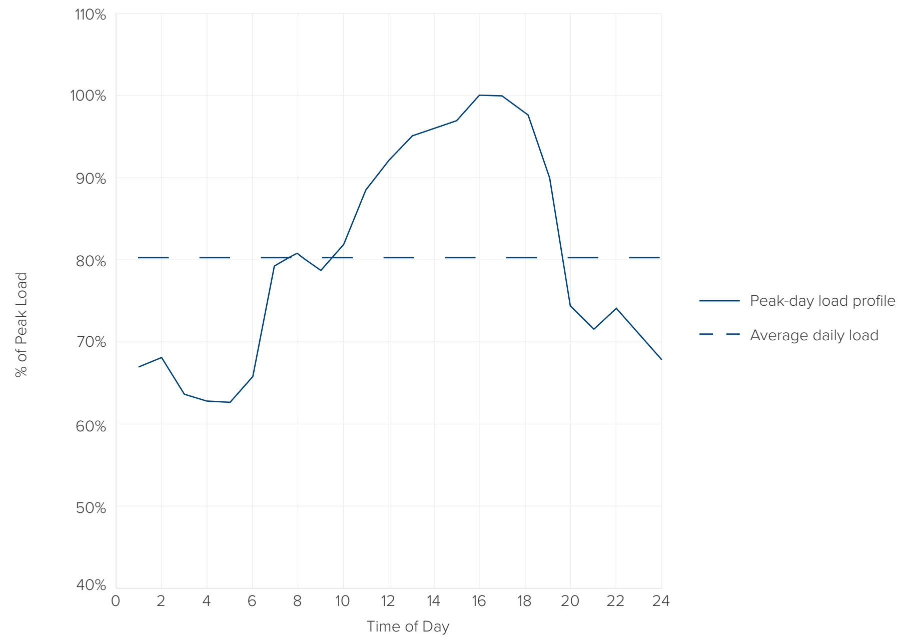


Fig. 30. Illustrative peak-day load profile for district cooling serving mixed building types (District, 2008)

4.0

Zoning and Density cont.

Low-density residential neighborhoods with single-family detached housing will be the least viable for a broad-spread DC. The spacing between homes results in excessive pipework that must be maintained at great expense over time. Individual home hook-ups to a DC network will be cost-prohibitive. There is no appropriate long-term payback. Shopping centers, schools, and business districts within such low-density development may generate the potential for a more isolated DC system or shared central chiller plant. The key process will be to appropriately assess those buildings' cooling energy and water demand loads so that an energy system and a cooling system can be designed to meet demand.

Medim-density developments and urban edge developments may not be viable for broad-spread DC systems; however, mixed-use zones in those developments will likely meet threshold requirements to roll out DC systems. Modular systems should always be used when installed in these developments, as they may expand as density increases.

> *Medim-density developments and urban edge developments may not be viable for broad-spread DC systems.*

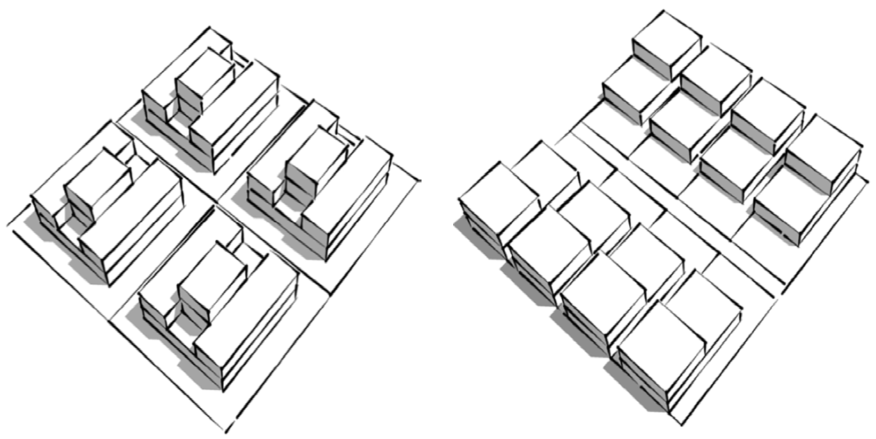


Fig. 31. Example of low density (large, single-family villas on larger lots)

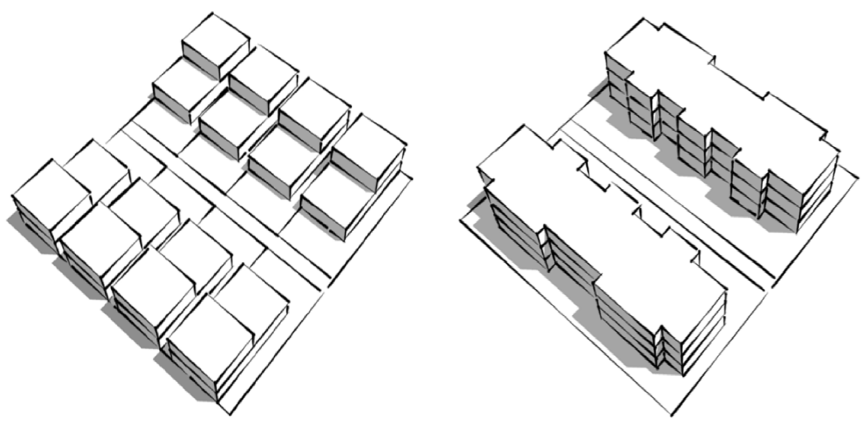


Fig. 32. Example of mid density (single-family villas on smaller lots)

High-density developments within downtown centers or urban city centers are densely populated areas with heavy cooling demands and will provide sufficient density for broad-spread DC. Mixed-use zones and building types will enable the most efficient DC operation, and modular phase-in of DC will ensure flexibility for growth.

Anchor loads include certain buildings, such as hospitals, hotels, large housing complexes, prisons, swimming pools, ice rinks, military bases, and universities, with a large and steady demand for cooling energy over a 24-hour period. Managers of such public-sector buildings can take a long-term view of energy provision. They increasingly must try to achieve carbon reductions, energy security, and an affordable cooling energy supply. Buildings such as these also often have space where DC plants could be placed. Therefore, they make ideal cornerstones for the development of DC energy networks. Similarly, convention centers, arenas, and stadiums have large but infrequent singular cooling demands linked to the number and frequency of full-occupancy events. They can also act as anchor loads.

> *Mixed-use zones and building types will enable the most efficient DC operation, and modular phase-in of DC will ensure flexibility for growth.*

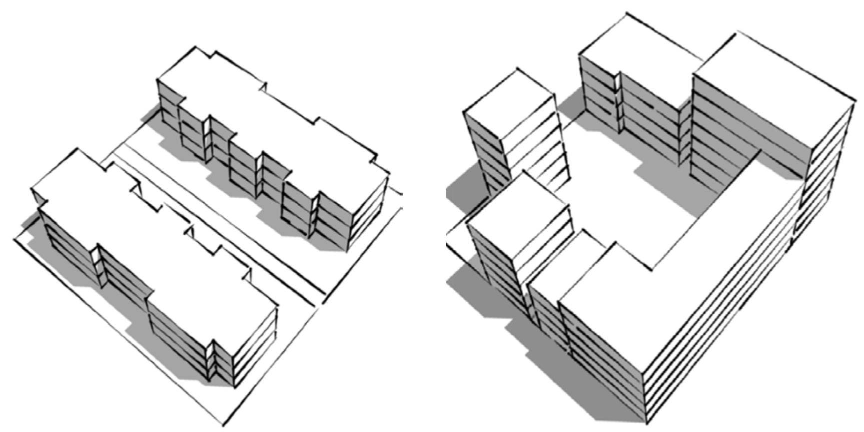


Fig. 33. Example of high density (midrise apartments or townhouses)

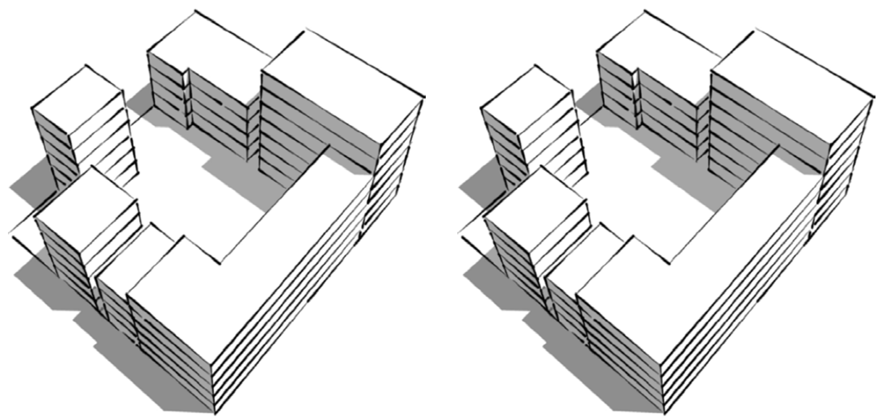


Fig. 34. Example of a city center (residential towers)

5.0

Development Density and Modularity

For DC to function optimally, certain energy density thresholds must be met. A major portion of the cost of DC systems is a chilled-water pipe network that carries cooling energy (the distribution system). The shorter the distance the cooling energy travels, the lower the cost. The more densely packed the buildings, and the greater the demand for cooling, the more efficient and viable the network is likely to be.

Another perspective in considering the market potential for a DC energy system involves the prospective energy consumption volume of connected buildings per square foot of chilled water network (distribution piping) to be installed. Typical US energy density considerations on a distribution square-foot basis appear in the box below. Project designers can optimize the network layout to minimize the costs associated with different energy density levels.

Defining the cooling load is the foundation for designing a DC system. It ensures sufficient but not excessive plant and distribution capacity, provides the ability to cost-effectively meet the daily and seasonal range of loads, and provides a basis for accurate revenue projections. Daily cooling load profiles are calculated to form annual load profiles. These show different profiles throughout each season. The peak load is the period of highest demand, and the base load is the period of lowest demand.

DC systems typically provide cooling to various building types, including commercial offices, retail shopping centers, hotels, schools, hospitals, industrial complexes, and residential buildings. The climate is a key driver in cooling load needs, and future development should be designed in response to environmental opportunities for passive design, load reduction, and improved thermal performance. The program and internal functioning of buildings develop their own cooling load needs; therefore, management of operational practices may help to reduce unnecessary loads in a building or community. For edge developments and urban infills, historical data will help estimate loads and plan for future conservation efforts.

Accurate modeling of the future needs of a community is essential, as overestimation brings a false sense of security. Overestimation of loads for a new district or city can lead to:

- Overinvestment in DC infrastructure.
- Over projection of revenues.
- Disagreements with prospective customers' engineers regarding contract loads.
- Poor efficiencies in meeting low loads in the early years of DC system growth.

> “
> *The climate is a key driver in cooling load needs, and future development should be designed in response to environmental opportunities for passive design, load reduction, and improved thermal performance.*

Modularity

At present, DC is limited in the Kingdom. Existing plants require significant demand or anticipated demand to be operated efficiently. Modular chiller plants will more efficiently cover the cooling energy loads required in regions where development is expected to occur over a 10–20-year span. Even in fast-track development, modular buildouts may help reach operational efficiency goals more effectively than single remote plants.

Building with modular cooling units allows developers to focus on the overall DC loop, pumping scheme, and site issues. An aggressive schedule with limited time for permitting and site development frequently reduces the amount of site construction time for the project. Manufacturing the central cooling system in a factory environment allows the modular system to be built and tested in parallel with the site permitting, foundation, and DC chilled-water piping network preparations. In addition, the guaranteed system efficiency will provide the owner with life-cycle value savings. With these multiple benefits, it is easy to understand why modular cooling solutions are gaining popularity.

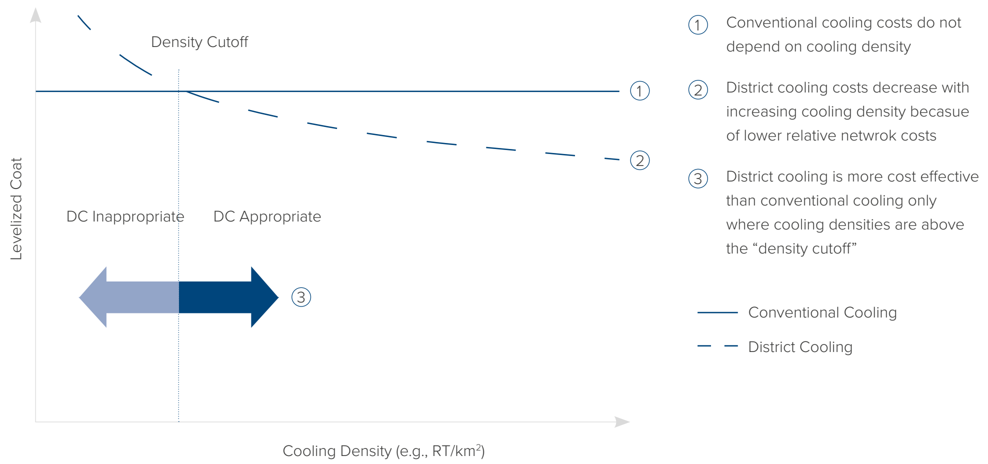


Fig. 35. Cost of cooling technologies vs. cooling densities (Booz and Company)

Note: RT/km^2 = refrigeration tons per square kilometer; levelized cost = price required to break even

6.0

Roadmap of Payback

District cooling is a long-term commitment that fits poorly with a focus on short-term returns on investment. Community benefits include avoiding additional energy costs through surplus and wasted heat energy and reduced investment in individual HH or building heating equipment. Central chillers, DC networks, and cogeneration plants require high initial capital expenditure and financing. Only if considered as long-term investments will these translate into profitable operations for the owners of DC systems. District cooling is less attractive for areas with low population or energy densities, as the investment per HH is considerably higher. Payback indicates when investing in a particular technology will break even and begin paying back, giving a general indication of viability without placing value on future cash flows. Net present value (NPV) uses discounted cash flow to give a project an overall value that is either positive or negative. If it is positive, the project is viable. If it is negative, it will need more capital to bring it to a positive value. Using a life-cycle cost analysis over a 25-year term is important to determine if a public-sector DC project is a sound investment. This approach considers the capital costs of each option and other costs over an extended period, typically 25 years or more. This includes the capital costs for each option while considering other costs.

Based on data collection on new developments, Figure 36 below illustrates some payback ranges for different system options. In high-density urban areas or dense energy zones, DC shows the highest rate of return but only after 10–15 years. There will need to be a long-term commitment to the roll-out and development of a DC system to reap the financial and other benefits.

Principal Benefits of Community-Scale District Energy

Economic: Community-scale district energy helps to reduce capital and operational costs. Economic development aids in introducing a vibrant downtown connected to DC energy, as it will result in an economic multiplier effect, attracting new businesses and creating a thriving district that attracts new residents. Building owners connected to DC energy enjoy cost savings, capital avoidance, and space savings. The energy from DC can also help building owners earn Leadership in Energy and Environmental Design or other environmental certification, a valuable tool for attracting commercial and residential tenants. Building owners will subsequently be able to offer “green” space on the rental market.

Cooling energy security: Local DC energy gives communities reliability, greater local control, and fuel flexibility over their cooling energy supply. Moving cooling energy production to a district plant centralizes the operations and maintenance and eliminates this burden for building owners. The opportunity to generate electricity and cooling using combined heat and power (CHP) reduces reliance on potentially vulnerable electricity grids. Finally, many DC energy technologies safely operate on more than one fuel type, further enhancing autonomy and increasing the security of supply, reliability, and cost savings.

> “
> *Payback indicates when investing in a particular technology will break even and begin paying back, giving a general indication of viability without placing value on future cash flows.*

Environmental: A DC system is energy efficient, reduces emissions, and protects the environment through the benefits of greater economies of scale by using energy that is typically wasted and deploying energy sources that are not viable at the building scale.

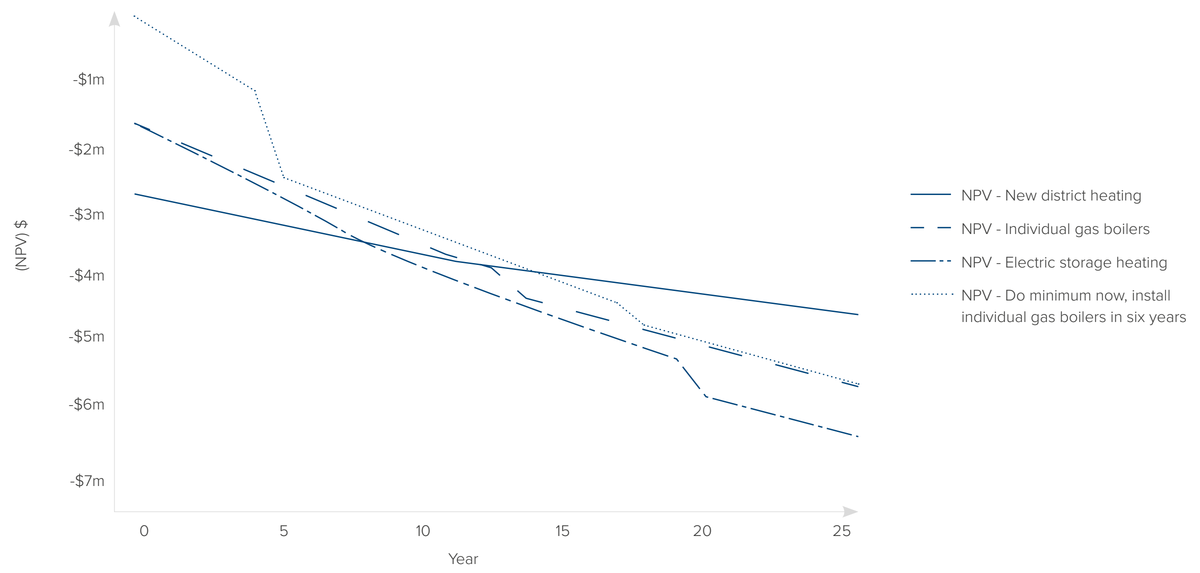


Fig. 36. Community energy life-cycle cost analysis

6.0

Roadmap of Payback cont.

Financial feasibility: Initiating a successful DC energy system is a significant task and will eventually require a significant investment of time and money. It is important to conduct a financial feasibility study that addresses the potential benefits and viability in relation to financial impacts, the business model, and development and delivery.

1. Financial Impact	
Detailed technical study	• Develop a basic feasibility study and financial model. • Evaluate connectivity and compatibility via the age of the building(s) and the existing energy systems. • Determine the appropriate location for the central plant. • Explore opportunities for efficiency and reducing peaking load through thermal storage, CHP, phasing, routing, and network measurements.
Financial modeling	• Develop the financial model in more detail. • Calculate the upfront capital cost and long-term operational cost.
2. Business Model	
Four types of ownership paths	• Private project development companies • Public project development companies • Hybrid public/private partnership arrangements • Stakeholder-owned special purpose vehicles (SPVs)
Recommended application	Mixed-use development areas: • City centers • Military bases/national guard • Campus (university, healthcare) • Industrial cities

3. Development and Delivery	
Private project development companies	• Prepare documentation • Decide evaluation criteria (establish evaluation panel) • Award preferred bidder • Final negotiation • Financial close • Contracts commence
Public project development companies	• Public project development companies procure separate project elements • Procure as a turnkey contract • Procure operation, maintenance, and billing/revenue collection services • Franchise turnkey contract • Contracts commence
Hybrid public/private partnership arrangements	Option 1 • Decide on business structure • Decide role allocation • Prepare documentation • Decide evaluation criteria (establish evaluation panel) • Award preferred bidder • Final negotiation • Financial close • Contracts commence
Hybrid public/private partnership arrangements	Option 2 • Decide on business structure • Decide role allocation • Procure separate project elements • Procure as turnkey contract • Procure operation, maintenance, and billing/revenue collection services • Franchise turnkey contract • Contracts commence

7.0 Financial Feasibility

Financial Impact—Detailed Technical Study

Feasibility studies and financial modeling must be pursued iteratively. They will inform and have consequences for each other. Once the appropriate technology option has been identified, it must pass through a detailed technical feasibility study. The age of buildings and existing energy systems must be evaluated for connectivity and compatibility with future cooling systems. The appropriate location for the central plant will need to be determined. Exploring TES as a potential buffer in the system to reduce peak loads and optimizing DC-wide system use should be considered. Exploration of CHP can create greater efficiency in producing thermal and electrical energy from a single fuel source. For new development, the phasing and timing of construction of new buildings must be considered. It can help reveal the optimum route and size of pipes for the chilled-water network and good locations for the central DC plant, which may influence the phasing plan. Routing and chilled-water network measurements are needed to calculate the temperature and pressure of the chilled-water network. The type and scale of connections and pressure breaks between different chilled-water network elements must be determined to transfer the thermal energy to the building's internal system.

Many projects develop gradually until the chilled-water network; therefore, the load is large enough to justify a full DC plant or CHP. Modular units may allow for this gradual build-out, maintaining simple but stable support of new buildings while future buildings or phases are still under construction. Another approach is to build a nodal network that involves developing smaller, localized DC energy systems sized to meet the needs of the immediate area. Ultimately, these smaller systems can be linked together as market penetration and system interconnection improve.

The capital, operational, and maintenance costs and potential revenues from cooling and electricity sales should be roughly estimated at this stage. Rates of return can be calculated and reviewed based on various sensitivity analyses, including debt-to-equity ratios, the weighted average cost of capital, and various forms of capital resources. This feasibility study may produce a range of options using different technologies and design arrangements to identify the optimum technical solution. Project revenue should be calculated conservatively and include reasonable capital costs and contingencies to capture the capital risk. Rates of return should be calculated considering different scenarios based on technical options, economic growth rate, and development objectives.

Financial Modeling

Financial modeling undertaken during the technical feasibility study is typically basic and will now require detailed investigation. In all developments, factors beyond the project boundary will impact a project's viability. Other considerations may include linkages to other developments, future expansion, anchor loads, and economies of scale. The type of business model chosen for the project will impact short- and long-term viability. Expert financial and legal consulting may be necessary in more complex projects to help structure the business case to complete a DC energy system.

- **Financial viability**: The financial model must have a positive value.
- **Affordability to consumers**: For commercial customers, connection to a district energy network must be a competitive proposition compared to the BAU case (gas supply and cost, source of water supply and cost, and operation and maintenance of the plant). For residential customers, convenience and quality of service are equally important.
- **Reducing emissions**: This may be considered on a regional basis. It is important to determine what market mechanisms may exist to monetize progress in emission reductions.
- **Supply security**: This has value to commercial customers and is especially important for mission-critical facilities such as hospitals.
- **Sustainability**: Communities that pursue TOD to achieve livable communities centered on lifestyle and convenience create a valuable local economy that can attract new businesses and residents. Companies want to be located in eco-districts and see a strategic value in investing in such locations.

Considering these developmental factors, the next task is calculating upfront capital costs with long-term operational costs.

Capital costs (required for the delivery of the project):

- Land for plant utility.
- Plant.
- CHP engine sized to meet base load; backup and peak chillers to meet peak load and necessary pumps.
- DC plant with the latest available technology chillers, pumps, and controls achieving the highest energy efficiency.
- Pipes for the chilled-water distribution network.
- Consumer hydraulic interface units and ETSs for thermal energy exchange between the chilled-water network and the building.
- Soft costs, including engineering permitting, land-use approvals, and ROW and utility connection charges.
- Construction and installation costs.

Operational costs (associated with the project over a 25-year term):

- Input fuel (natural gas, oil, and/or biomass).
- Electricity for chillers, lighting, and pumping.
- Maintenance.
- Billing and revenue collection.
- Operational management.
- Customer care, including emergency cover.
- Capital interest and repayments.
- Insurance.
- Property and income taxes.
- Contributions to a sinking fund for replacement of the system at the end of its life; to ease the financial burden, this may be introduced after the senior debt has been discharged.
- Legal and financial advisor fees.
- Reoccurring governmental charges for permits and/or environmental clearance.
- Annual energy audits.

Revenues may be generated through traditional utility service offerings, but other revenues, charges, or tax benefits may be developed to improve profitability. Electricity revenues may apply when a power-generating plan (e.g., CHP) is included. Payment for the supply of thermal energy includes two principal components: a capacity charge and a consumption charge. The capacity charge is based on the fixed-cost recovery of the plant, piping network, customer interconnection costs and operations, and maintenance of the DC plant and chilled-water network. The consumption charge is based on the recovery of direct variable costs, such as fuel and water with water chemical treatment. Maintenance charges may be billed separately to cover maintenance of the plant, network, and equipment for the customer. Development fee benefits could be incorporated to incentivize the expansion of the system. Here, credits, exemptions, and depreciation can reduce rates.

The financial model will be vulnerable to a variety of risks. Therefore, a risk assessment must be developed. Ideally, the risk assessment is drawn up with other stakeholders in the project, as they may identify risks the PD has overlooked. The risks then need to be evaluated regarding how likely they are and how significant the consequences are. They can then be designated as high, medium, or low risk and allocated to the party best placed to manage them. Strategies must be developed to manage risks that remain with the project.

Risks frequently include:

- Balancing generation and demand and low delta-T syndrome management.
- Permitting and regulatory risks of plant siting.
- Cost overrun in construction.
- Plant efficiencies failing to reach design specification.
- Plant failure.
- Fuel price variation.
- Water price variation and water source availability.
- Customer non-payment.
- Delay in insurance payments for property damage.

Business Models

Ownership of a DC energy development may follow multiple paths. Public project managers may adopt the commercial approach of a PD. Diverse and compact communities provide residential, civic, retail, cultural, and entertainment facilities within close distances. This generates high-quality, attractive places to live, work, and create businesses. The selected business model should balance the development goals, stable operation and control, and appropriate risk management. There are four basic business models within the context of DC energy projects: private project development companies, public project development companies, hybrid public/private partnerships, and stakeholder-owned SPVs. Sources of finance, the roles required to deliver and operate a low-carbon energy project, and the proportion of private and public-sector involvement must all be considered.

7.0

Financial Feasibility cont.

Project developers vary in the scope of services that they offer. They may offer a broad base, including the Design-Build-Own-Operate-Maintain (DBOOM) method, while others may specialize in only subsets of those services. The key features of a PD are that it has a separate budget and business plan from the host organization and provides focused management of the energy project. The business plan will typically be over a long period and should be sound enough to attract external investment into the project.

Private project development companies provide energy management services to municipalities, governments, institutions, and other private-sector entities. They may also be interested in extending existing systems to new or existing buildings where the cost of connection will be lower for the building owner than installing or replacing their plant. These companies can arrange external funding, although the building owners or developers may still need to contribute capital for the project to be viable within a reasonable contract length.

Strengths of the Approach	Weaknesses of the Approach
• The private company invests and carries the financial risk. • It brings substantial expertise specific to the technology, with extensive project management and operational skills, enabling it to carry the technical risk. • It continues ownership and operation over the long term.	• Higher rates of return are required, and energy charges may be higher. • Public-sector sponsors lose control and cannot direct future development, particularly for projects with a low rate of return. • Customers are tied into a private company with the risk of monopoly abuse unless the federal government imposes caps on charges to the end users.

Public project development companies generally serve the buildings and clients within their city or town's border confines. Local governments can also form municipal utilities to build, own, and operate DC energy companies. It is possible to establish a municipal utility or special-purpose entity with a defined business plan separate from the municipality, which provides tightly focused management. It can borrow against its assets and revenue streams by utilizing a project financing strategy. However, any debts are likely to be consolidated into the municipality's accounts, meaning it carries financial risk. Thus, the business case should be soundly based on "invest to save" principles. This also allows it to access capital at close to public-sector rates. Although ownership is municipal, the technical design, build, and operation can be contracted out to specialist professional private companies, and the private sector may hold the assets under manufacturer financing arrangements or forward revenue purchase deals from banks. Thus, technical and financial risk is reduced or passed through.

> "
> *Private project development companies provide energy management services to municipalities, governments, institutions, and other private-sector entities.*

Strengths of the Approach	Weaknesses of the Approach
• Municipal ownership and control ensure close alignment with municipality social and environmental policies. • Municipal ownership provides covenant strength in obtaining finance, and this will be at a lower cost compared to private-sector borrowing. • Dividends can support the delivery of other services. • Future expansion can be coordinated and controlled by the municipality.	• The company relies on the municipality's financial strength, and it will remain on the municipality's balance sheet. • The municipality must be rated as fair or better. • The municipality carries the financial risk.

Recommended Business Model

Hybrid public/private partnership arrangements may be established to share risk between the public and private sectors and to allow them to access external capital at the lower rates available to the public sector. These hybrids could be structured as joint ventures or SPVs in which the different parties have a shareholding or membership. It is helpful to think about the different roles necessary for the delivery and operation of a DC energy project and to assign these to different parties or contract them out to specialist professional companies. Establishing a joint venture or an SPV requires specialized legal assistance. The company's purposes and structure must be defined in the memorandum of understanding and the articles of association. Below these will be a suite of contracts defining relationships necessary for providing energy services. Although sample contracts are available in various publications, they will inevitably require refining to meet the specific requirements of the host organization.

Strengths of the Approach	Weaknesses of the Approach
• It is closely aligned with the socio-environmental aims of the public sector. • It has greater flexibility than either wholly public or private approaches. • It is possible to access capital at lower-cost, public-sector rates.	• Some risk remains with the public sector. • Liabilities are consolidated into public-sector accounts. • It must comply with public-sector procurement procedures.

> "
> *Hybrid public/private partnership arrangements may be established to share risk between the public and private sectors and to allow them to access external capital at the lower rates available to the public sector.*

7.0

Financial Feasibility cont.

Stakeholder-owned SPVs are like the hybrid approach, except ownership is shared among various stakeholders. These may be customers receiving the cooling energy, strategic bodies such as the municipality, or communities and cooperatives.

Successful execution and management of a DC energy project will require specific roles and responsibilities. A project champion will identify and define the project, achieve stakeholder buy-in, and initiate technical feasibility studies, financial investment appraisals, initial fundraising, and project promotion. Regulation is necessary to establish and monitor standards of performance and consumer protection. Governance must be specific to the entity and concerned with providing strategic guidance, stakeholder accountability, and high-level relationships. The developer has more limited engagement and is primarily concerned with the design, construction, and overall delivery of the DC energy system. An asset owner provides the physical assets and may be a bank or financial investor. The operator is responsible for the project's technical operation. The retailer is responsible for the sale of energy across the project, and the supply chain manager is responsible for the procurement of fuels, utilities, equipment, and services necessary for the development and operation of the project.

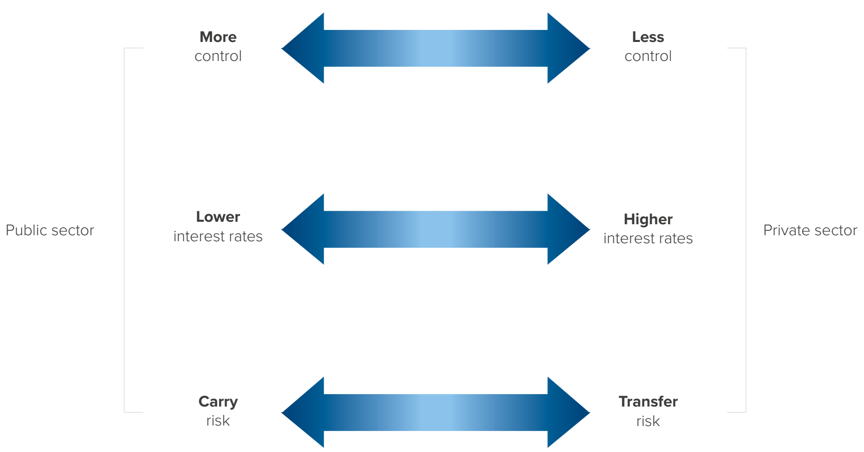


Fig. 37. Business model scenarios, control factors, rates, and risk (US Community Energy Guide)*

Development and Delivery

With a defined project, preliminary schedules, and maps, it is important to contact potential funders, shareholders, and other relevant parties for approvals and support. It is necessary to describe the physical project and preliminary project phases and provide an overview of the features and benefits of a local DC energy system. Throughout the project development phase, it is important that potential end users are identified and that a communications strategy is developed to cultivate buyer interest and identify critical customer locations. Government and municipal buildings often serve as anchor loads, and their energy requirements must be fully understood, including the timing of major renovations, equipment replacements, or adaptive reuse. From the outset, market intelligence on the potential customer buildings is strategically important and should be a high priority for a professional business development specialist on the team.

Costs and prices in the financial modeling are only estimates and assumptions. It is necessary to determine if budgets are correct, assess if qualified vendors are present, and verify the project fundamentals. If the project is tendered to the private sector, testing will reveal if there is an appetite in the market to bid for the project as defined. An experienced consultant must undertake this activity as this is a specialist area. The market for energy services is evolving rapidly. It is best to seek advice on the range of services available and from whom they can be accessed.

Market testing can be done through a project information memorandum (PIM) describing the project and key documents, such as the technical feasibility study. This market testing provides a chance to adjust the model to make it more attractive to the market. Potential providers can be identified by issuing a request for qualifications (RFQ) through an industry clearinghouse to alert regional industry participants of the potential opportunity. This will develop a list of pre-qualified bidders and allow project sponsors to verify projections in the financial model.

The procurement route will depend on the business model pursued. In the private-sector route, public authorities procure a private company to DBOOM a project. They will have to establish an evaluation panel representing a range of skills and expertise and appropriate interests within the host organization. A specialist consultant's services will be needed to prepare tender documentation based on a refined PIM or RFQ. This will then be published in appropriate media as an invitation to participate. This is a pre-qualification exercise in which the financial and technical credibility of potential contractors and/or partners and the relevance of their track record can be evaluated. Considerations such as relevant experience and bonding capability can be used to evaluate and compare respondents.

With an in-house provision route, public authorities can establish in-house entities to produce plans and specifications for partial bidding and procurement. This route would typically involve the host retaining the services of a qualified consulting engineering firm, architect, legal and permitting specialists, and owner's engineer to oversee quality and project implementation. With qualified technical and project staff, this approach can be useful in mitigating project costs, but the host organization also retains a larger share of the project's financial risk.

In a hybrid/SPV route, municipalities may have the option to establish a special-purpose entity, such as a project partnership or a limited liability corporation, that will establish a separate functional organization with a distinct charter and may include shareholder definitions and financial records. If this route is chosen, the services of a specialist lawyer will be required to draw up the documentation to establish the organization. If the plans include a public authority, it must still comply with relevant public bidding and procurement procedures and the above mentioned process.

In a stakeholder-owned route, the procurement route can also depend on who the stakeholders are. Private, non-profit organizations can be formed to act on behalf of the principal customers, as in a cooperative model. Tax implications, ownership and business objectives, market penetration, and capital availability are all important considerations that factor into the final structure.

The delivery plan must include key milestones set in the final contract. It is advisable to appoint a contracts supervision officer to provide a focal point between the two parties, oversee the delivery of the contract, and deal with any problems that may arise. Additionally, project delivery will involve permits, ROW, traffic planning, and street construction disruption, and it will be appropriate to appoint a community-relations or resident-relations officer.

> *"With an in-house provision route, public authorities can establish in-house entities to produce plans and specifications for partial bidding and procurement.*

8.0

Compliance Checklist

This compliance checklist is to be completed by the Licensee.

Licensee: Any person holding a valid license or self-consumption license issued by the Authority, allowing them to carry out DC service-provision activities.

Technical Standards and Requirements

National Threshold Criria Government projects that meets the following criteria must incorporate DC in their projects:
Governmental project
New project
The need for cooling exceeds 15,000 RT
Availability of sufficient quantities of treated water
Development density (diversity—mixed-used zones) allows maximum FAR and close proximity to plants and high-rise buildings. **The FAR maintains a range of 1.2–1.5**. A 1.5 FAR accommodates horizontal villas, and a 1.2 FAR accommodates vertical high-rise office buildings.

Source: Regulatory Framework of District Cooling, WERA

A. Technical Regulations	Yes	No	N/A
An environmental impact assessment is conducted for DC activity projects to ensure compliance with environmental standards, the National Water Strategy, and local station supply and drainage regulations.			
The water quality must be monitored and maintained at the required level at all times during the operation of the DC plant by using systems that continuously and automatically monitor water quality standards.			
The concentrations of cooled water (closed loop) should not exceed the values set by the Presidency of Meteorology and Environment (PME).			
Requirements stipulated by the ASHRAE Guideline (ASHRAE 12-2000) to reduce the risks of Legionella in building water systems (or a similar guideline) must be abided by, and local requirements (as defined by PME) to prevent Legionella in cooling towers must be met.			
The following readings must be recorded for the condensers or compensation water: • Inhibitor level • Calcium/total hardness • Conductivity • Chloride • Calcium Balance • M alkalinity • Legionella • Iron • Bacterial count • pH			
Designated tanks and pumps for supplying saline compensation water to cooling towers and preventing contamination in any of the potable water tanks must be provided. The minimum required reserve of compensation water, equivalent to 24 hours of consumption, must be provided in the cooling towers for all DC plants (based on the estimated peak consumption at the plant).			
The wastewater from DC plants must comply with the requirements of the Ministry of Municipal and Rural Affairs, the National Water Company, PME, and the Ministry of Environment, Water, and Agriculture.			

8.0

Compliance Checklist cont.

B. Authorization to Use Saline or Seawater	Yes	No	N/A
The Licensee must use treated wastewater or seawater and is prohibited from using any other water, such as desalinated or underground water.			
Potable water can be used in cases of emergency, where a case of emergency is defined as an interruption or shortage of the supply of treated wastewater or graywater for reasons unrelated to the Licensee. The approval of the Authority must be taken if the emergency case lasts more than 30 days.			
After receiving the approval of the Authority, it is permissible to use potable water as compensation water permanently if wastewater is unavailable and no other alternative water sources can be made available after coordination with the water service provider.			

C. Using Thermal Energy Storage Systems	Yes	No	N/A
A TES system must be installed in all permanent and future DC plants if the technical and economic viability is proven. This may include ice or chilled-water storage techniques, refrigerated-liquid storage, or phase-change material storage techniques (the most suitable technique is determined according to the characteristics of each project), and any request for exemption from this requirement must be submitted to the Authority for review and approval or rejection.			
When adopting the operating strategy to displace the peak load, the real-time peak load of the TES system must equal a minimum of 20% of the designed real-time peak load of the cooling load in the factory.			
When adopting a full or partial load displacement strategy, the tank capacity (measured in tons/hour) and the storage device size should be determined based on the expected load, design standards, storage type, and peak hours required for operation.			
The storage tanks of the TES system must be designed so that the maximum heat gain does not exceed 1% of the storage capacity in 24 hours at the maximum design temperature.			

D. The Minimum Performance Standards for Electrical Energy and Water Consumption	Yes	No	N/A
The Licensee must abide by the minimum consumption of electrical energy and water approved by the Authority and any other technical regulations issued by the Authority in this regard, which must be included in the project procurement documents.			

E. Wastewater in District Cooling Plants	Yes	No	N/A
The Licensee must abide by the optimal method of drainage for each project separately, in accordance with the standards of disposal issued by PME regarding industrial and municipal wastewater drainage.			
The Licensee must abide by the supply code approved by the Authority and any other technical regulations the Authority occasionally issues while exempting the self-consumption Licensee from the second paragraph below and any provisions related to service provision to end consumers. **Second**: The Licensee to provide DC services must abide by the regulations approved by the Authority that governs the relationship between the service provider and the end consumer, including the following: a) Rights and obligations between the Licensee and the consumer; b) operational performance requirements for the DC service; c) technical conditions for service connection; d) specifications and standards of reading meters; e) billing and payment services.			

8.0

Compliance Checklist cont.

F. Compliance with Key Performance Indicators

Compliance with KPIs for DC ensures optimum use and operation.

Compliance with Key Performance Indicators			
Key Performance Indicator		**Key Performance Indicator Formula**	**Target Set**
DC1	Availability factor	**DC1 = (available hours/period hours) × 100%** *Available hours (Hrs)*: period in which DC provider services are capable of providing service whether or not it is actually in service *Period hours (Hrs)*: total number of hours during the reporting period	Minimum availability of 99.5% for producing chilled water
DC2	Water consumption for cooling tower makeup	**DC2 = water consumption (m^3) / total actual amount of refrigeration (RT/h)** Performance differs depending on the type of water used for cooling. If a polishing plant is used, water consumption refers to water input to the polishing plant. If there is no polishing plant, water consumption is equal to total makeup water.	Potable water 0.008 m^3/RT-h TSE 0.012 m^3/RT-h
DC3	Quantity of wastewater discharge	**DC3 = wastewater quantity (m^3) / total actual amount of refrigeration (RT–h)** Performance differs depending on the type of water used for cooling. Wastewater quantity refers to water discharged from a polishing plant (if any) plus cooling tower blowdown water.	Potable water 0.0015 m^3/RT-h TSE 0055m^3/RT-h
DC4	Electricity consumption	**ECF = E=electricity consumption (kWh) / total actual amount of refrigeration (RT–h)** Electricity consumption refers to total DC plant consumption, including chillers, cooling towers, polishing plants (if applicable), process pumps, distribution pumps, and all other auxiliary equipment.	1 kWh/RT-h

G. District Cooling Supply Code

The elements for monitoring DCSC compliance are defined in the below table and are subject to amendment as needed.

The District Cooling Supply Code			
Element Description	**Description**	**Reporting Period**	**Responsible**
Supply temperature	Number of cases where the Licensee did not supply chilled water within 6 °C ± 0.5 °C under normal operating conditions.	Quarterly	Licensee
Return temperature	Number of cases where the Consumer did not return the chilled water at 14 °C or higher.	Quarterly	Consumer
System interruptions	Number of cases of planned interruptions where the Licensee did not give the Consumer at least 14 days prior written notice stating the date(s) on which the planned interruptions would occur and the duration of the planned interruption.	Quarterly	Licensee
Billing	Number of cases where the Licensee failed to issue invoices to the Consumer at least monthly/quarterly in accordance with its published tariffs.	Quarterly	Licensee

9.0

District Cooling: Annex

Cooling Tower Water Management—Improving Water Efficiency for DC Plants Equipped with Water-Cooled Chillers

The cooling tower systems of DC are large consumers of water in the process, requiring approximately three gallons of water per minute for each refrigeration ton (RT) the system must provide. Thus, an average commercial building requiring 500 tons of cooling will use more than 1,500 gallons of water per minute to cool the entire building. The supplied and returned water temperatures usually vary depending on the cooling energy delivered. Furthermore, it must be noted that the temperatures of supplied and returned water must correspond respectively with distinct DC code requirements for quality and efficiency purposes. Proper cooling tower maintenance can conserve significant amounts of water. In addition, water management for cooling towers requires investment in regular, comprehensive maintenance programs to save money and energy while increasing the tower's life expectancy. It is imperative to reduce potable water consumption for cooling tower equipment through effective water management and/or the use of non-potable makeup water. Makeup water should be used that consists of at least 50% non-potable water, such as harvested rainwater, harvested stormwater, air-conditioning condensate, swimming pool filter backwash water, cooling tower blowdown, contaminated groundwater, treated municipal effluent, industrial process water or wastewater, irrigation return water, brackish water, other types of water affected by humans or naturally occurring minerals, and any other appropriate onsite water source that is not naturally occurring groundwater or surface water. Water meters installed to ensure cooling tower makeup and bleed-off help conserve and lower operating costs. In addition, conductivity control systems provide the tools to operate and maintain equipment at higher cycles that reduce cooling tower water consumption. Conductivity meters connected to automatic controls can be used to adjust bleed-off rates to modulate with changes in evaporation rates and ensure a higher concentration ratio. A higher concentration ratio improves water efficiency by eliminating unnecessary makeup water consumption. Water-saving strategies and technologies applied to cooling towers could affect onsite energy performance, require commissioning, and should be addressed within a project's energy-management plan.

The amount of water required to operate a cooling tower depends on how the system is operated and how much "unwanted energy" is sent to the tower to be disposed of by evaporation. Water loss in a tower is due to evaporation, water discharge to keep mineral build-up under control (bleed-off or blowdown), drift loss, and water lost through leaks, spills, or overflows. The amount of water fed back into the system to replace what is lost is referred to as makeup water. Proper cooling tower maintenance keeps water losses very low, allowing projects to conserve significant amounts of water. Conductivity meters that adjust the bleed rate and well-maintained drift eliminators reduce water loss and conserve resources.

> “
> *An average commercial building requiring 500 tons of cooling will use more than 1,500 gallons of water per minute to cool the entire building.*

Non-potable water supply: Makeup water from non-potable supplies can lessen the demand for potable water supplies. Because microbial growth in cooling towers must be controlled, it is important to ensure that non-potable sources do not introduce biological contamination and food sources for bacteria and that treatment programs are appropriate for the non-potable supply. Condensation from air-conditioning systems is an excellent alternative water source for cooling towers because it is generally cleaner than other potential sources. It eliminates the need for extensive treatment before being introduced into the cooling tower system and is cold, providing a potential efficiency advantage. Harvested rainwater or stormwater may be a reasonable source, particularly when the building or site has large surfaces that facilitate collection and in climates with abundant and regular rainfall. Recycled graywater can be used as cooling tower makeup water if it is treated to an appropriate quality. Because compounds in insufficiently treated graywater can increase the potential for bacterial growth, scaling, and corrosion of some metals, systems that use treated recycled water should be carefully designed and monitored to manage these risks. Reusing process water in cooling towers may be feasible in some building types drawing from non-potable water sources such as foundation drain water, swimming pool filter backwash water, reverse osmosis (RO) reject water, and pass-through cooling water. In some areas, municipal utilities offer a non-potable reclaimed water supply.

Chemical control and biological control: Engage water treatment professionals to administer a program that meets water conservation objectives and controls corrosion, scaling, sediment, and biological growth. Controlling mineral deposits and corrosion helps maintain system efficiency and prevents microbial growth. Mineral content is typically managed through a combination of bleed-off and chemical treatments that prevent the precipitation of dissolved solids. Effective treatment reduces the need for bleed-off, thereby conserving water. Water conservation can be optimized by aligning bleed-off and chemical treatment strategies.

Outbreaks of Legionella pneumophila have been associated with ineffective treatment practices, but the bacterium is easy to control. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Guideline 12–2000, Minimizing the Risk of Legionellosis Associated with Building Water Systems, offers guidance for developing an effective biological control program. When using chemicals to control biological growth, develop an effective biocide treatment regime using appropriate dosing equipment. Consider using corrosion monitoring to ensure that treatment chemicals are appropriate for the metals in the systems. Establish performance indicators to help assess the effectiveness of a treatment, such as acceptable corrosion rates based on metal type and maximum acceptable microbe concentrations. Maintain treatment records of what

> “
> *Condensation from air-conditioning systems is an excellent alternative water source for cooling towers because it is generally cleaner than other potential sources.*

9.0

District Cooling: Annex cont.

chemicals are used, and investigate the use of newer, environmentally friendly treatment chemicals and control solutions or physical treatment systems, such as pulsed power. Service schedules will help ensure regular and effective maintenance, including checks for leaks or overflow problems and regular cleaning and recalibration of conductivity sensors per the manufacturer's recommendations.

Customized solutions to improve cooling tower efficiency could involve developing and integrating innovative dehumidification technologies to reduce the moisture content of cooling tower inlet air. Approaches to improve the sustainability of water provision/use for DC should also be pursued.
The water required by cooling towers is either scarce or difficult to access in the region and requires treatment before being used. Although seawater can be employed in cooling towers, it requires more costly corrosion- and foul-resistant equipment, with higher maintenance costs. Similarly, alternative low-quality water, such as TSE, brackish groundwater, and partially desalinated water, could be used but also with increased capital and maintenance costs.

For example, TSE is used as makeup water in the cooling tower of the Sheikh Zayed Road DC plant in Dubai. Challenges are encountered with the use of TSE in DC systems, including fluctuating availability (i.e., quantity, quality, pressure) that may not match the demand and management of discharge products. Seawater, TSE, or other water sources could be employed directly as heat-rejection medium-cool chiller condensers rather than as working fluids for a cooling tower. This approach has been employed in a DC system in Bahrain.

> *Customized solutions to improve cooling tower efficiency could involve developing and integrating innovative dehumidification technologies to reduce the moisture content of cooling tower inlet air.*

Credit: Sustainable District Cooling Systems: Status, Challenges, and Future Opportunities, with Emphasis on Cooling-Dominated Regions

Fig. 38. Typical district cooling plant's cooling tower

9.0

District Cooling: Annex cont.

District Cooling Distribution

Determining the best DC plant configuration depends on city planning, installation costs, and engineering principles. When designing large, chilled-water distribution systems, the piping size is based on the maximum water velocity rather than pressure drop, as it would in smaller CUPs. The corresponding pressure drop at the maximum velocity is very low for large plants. Because of this, DC utility plants can be located remotely to the loads with little pumping energy impact. Of course, the further away the plant is from the load, the more the pumping energy will rise; however, the added pumping energy is a much smaller impact than the added cost of the piping installation itself. The plant's location becomes as much an economic study as an engineering study.

The denser the city, the more economical the DC will be. These factors include commercial vs. residential proportions, commercial building size, and residential densities. Larger commercial buildings will likely be served by chilled water whether from a district plant or a building CUP. Because of this, the energy savings from a DC plant in a city with large commercial buildings may be smaller; however, the cost of providing DC vs. individual building CUPs may be much lower.

The chilled-water distribution within the district itself is best designed as a loop system or concentric loops for larger systems. The loop allows the piping to be smaller than it would be with a straight-through system because it allows system diversity to shift with the location of the load. The loop system is also easier to expand, as new chiller plants can be plugged in anywhere within the loop.

“The loop system is also easier to expand, as new chiller plants can be plugged in anywhere within the loop.

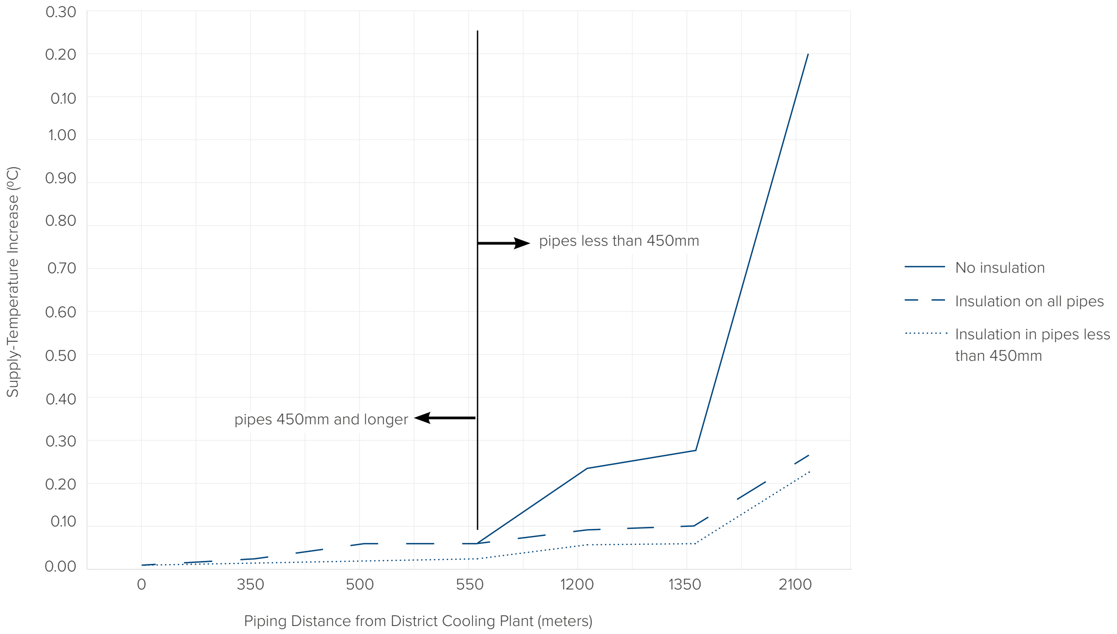


Fig. 39. Distribution system supply temperature rise, e.g., a system at partial load (District 2008)

Multiple Plants along District Loop

Benefits	Disadvantages
• There is redundancy in case one plant goes down. • They are easier to expand if another plant is needed to add to the district loop.	• A higher initial cost is associated with constructing multiple plants. • The system must account for plant and service roads to the plant within the city boundaries. • They require more maintenance staff to service multiple plants. This is the recommended plant configuration if a new city is being planned, and multiple plants can be planned within the city's outskirts.

Single Remove Plant

Benefits	Disadvantages
• It is the easiest arrangement for the service, as all equipment is in one location. • The plant is remote from the city and is not seen by residents.	• There is no redundancy if there is an event at the plant that shuts it down. • It is costly due to the long lengths of piping runs. • The main line to feed the district loop must be sized for full flow. • It is difficult to expand because of the size limitation of the main line to the district loop.

Due to the lack of redundancy, this is not a recommended plant configuration when a new city is being planned. This option may be viable if an existing city plans to add a DC plant.

Single Centrally Located Plant

Benefits	Disadvantages
• It is the easiest arrangement for the service, as all equipment is in one location. • There is a lower cost due to the plant's proximity to the district loop.	• There is no redundancy if there is an event at the plant that shuts it down. • It must account for plant and service roads to the plant within the city boundaries.

Due to the lack of redundancy and planning difficulties of getting service into the city center, this is not a recommended plant.

9.0

District Cooling: Annex cont.

Transfer Stations

Within each facility, building, or residence is an ETS, the equipment that carries chilled water from the delivery network to customer installations. The purpose of the ETS is to carry the cold properties of the water to a secondary one by an exchange process. The stations adapt the incoming and outgoing outputs to adjust the temperature in accordance with the customer's needs. The refrigerating energy is counted at the station outlet level to measure the energy consumed vs. the energy returned to the central network. In buildings, it replaces all the equipment usually required for stand-alone air-conditioning installations: refrigeration units, pumps, and cooling towers.

Distribution Piping Network

As the principle behind DC lies in producing cooling energy in a centralized location, the cooling energy should be delivered to the consumers. Chilled water is then conducted to the consumption points by means of a distribution piping network (DPN). The routing of the distribution pipe implies two different conductions: one for the chilled-water supply and another for chilled-water return. **The temperatures of the supply-and-return water will vary depending on the cooling energy delivered:**

- **Direct chilled-water utilization**: The water from the DPN is pumped directly through the end-user heat exchangers. It is used for small installations where any failure on the end-user side can be easily solved (they usually have the same owner). The typical temperatures for this method are 7 °C for the supply and 12 °C for the return.
- **ETS**: The energy is transferred in a heat exchanger to another water circuit. It is extensively used, as it allows normal network performance in case of a failure on the end-user side. The typical temperatures for this method are 4.4 °C for the supply and 13.3 °C for the return. Depending on the conditions of the area where the DC will be deployed, the distribution network can be above ground or underground. The underground piping could be directly buried, lying on a gallery or trench, or traveling along a basement. Any of those arrangements should provide access to the piping every few meters in case maintenance is required. To do that, cutting points should be isolated. The deployment area and the chilled-water network analysis determine the piping material selection. Suitable materials include, for example, polyvinyl chloride or carbon steel. In any case, the pipe should be thermally isolated to minimize energy losses. Typically, several DC plants supply energy to the network from different locations. Therefore, selecting an appropriate topology is a key aspect of the supply of critical loads.

The recently constructed DC plants, especially in the Middle East, have a total cooling capacity in the range of 10,000 to 100,000 tons of refrigeration (TR). Large-scale projects in cities like Dubai and Abu Dhabi have District Cooling plants with capacities exceeding 500,000 TR. Some individual District Cooling plants in the Middle East have been reported to have capacities of over 1 million TR. These high capacities result in large, chilled-water flows that require a thorough analysis of the water pipe network:

"The recently constructed DC plants, especially in the Middle East, have a total cooling capacity in the range of 10,000 to 100,000 tons of refrigeration (TR). Large-scale projects in cities like Dubai and Abu Dhabi have District Cooling plants with capacities exceeding 500,000 TR.

- **Pressure drop**: This is the difference in pressure between two points of fluid in the piping network due to frictional forces. This calculation is necessary to select the correct size of the pumps for the system.
- **Pipe stress calculation**: It is necessary to adhere to relevant design codes and standards, obtaining system specifications, piping layout and support information, equipment details, fluid properties, operating conditions, utilizing analysis software, and considering safety factors and allowable stresses. This analysis ensures the mechanical life cycle of the pipe system.
- **Water analysis**: The water is studied to prevent corrosion in pipes and equipment. With this data, we select suitable equipment materials, required chemical products, and water treatments.
- **Water hammer analysis**: A water hammer is a pressure surge, or wave, caused when a fluid in motion is forced to stop or change direction suddenly. This pressure wave can cause major problems, from noise and vibration to pipe collapse. Conducting simulations in the design phase is necessary to avoid these problems during operation.
- **Hydraulic balance**: Hydraulic balance studies are prepared to avoid a shortage of service at any point of the network and ensure the equipment is working optimally, which translates into energy efficiency, cost savings, and client satisfaction.

Infrastructure Integration

There is a distinct separation of infrastructure types within the Kingdom. As the implementation of sustainable design strategies strengthens within Saudi Arabia, the merging of roadworks and water pipeline infrastructure should be developed, preventing redundancy and wastage in planning and materials. The incorporation of piping within the roadwork layout should be explored for upcoming or developing cities.

"As the implementation of sustainable design strategies strengthens within Saudi Arabia, the merging of roadworks and water pipeline infrastructure should be developed, preventing redundancy and wastage in planning and materials.

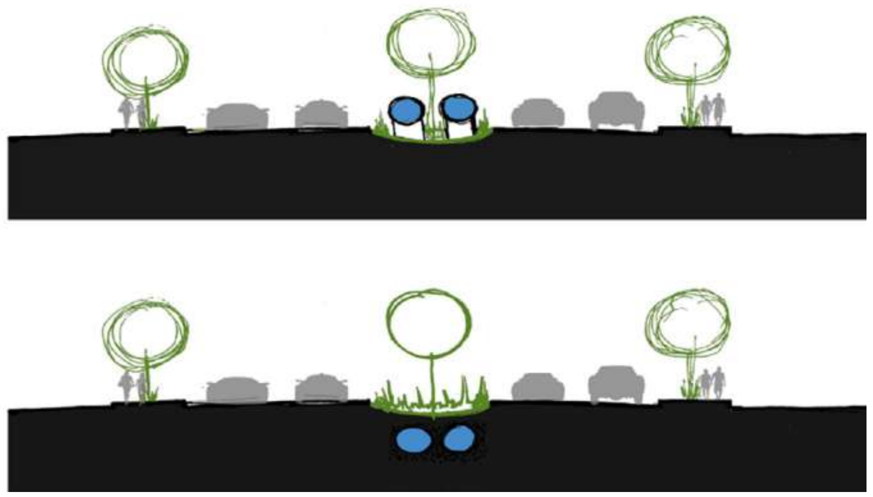


Fig. 40. Roadwork Integration (above and below ground)

9.0
District Cooling: Annex cont.

Treatment Technologies for Cooling Water Blowdown

Cooling towers are units that provide an energy-efficient and cost-effective operation for devices needing cooling. During the process of cooling, water is continuously recirculated, while some water evaporates; this leads to an increase in the concentration of salt and contaminants to high levels. As the number of recirculation cycles increases, the solubility of various solids is reduced; consequently, solids will form a shale shape on the warm surface of the condenser pipes. The formed scales in the cooling tower unit cause a reduction in the heat-transfer efficiency as they insulate the metal surface of the tower. With further recirculation of the concentrated water, permanent damage can occur to the cooling system. Therefore, this highly concentrated water stream is discharged from the system as cooling water blowdown (CWBD). The discharge may contain iron oxides, calcium phosphate, calcium carbonate, magnesium silicate, silica, and many other contaminants and pollutants. Cooling water blowdown discharge helps enhance heat-transfer efficiency, as the concentration of the silica and hardness ions in the circulated water is kept under the level where scales can be formed. A makeup stream of fresh water is used to compensate for the amount of water lost in evaporation and CWBD discharge.

Different technologies have been used to treat CWBD, such as RO, electrodialysis (ED), nanofiltration (NF), electrocoagulation (EC), vibratory shear enhanced process (VSEP), ballasted sand flocculation (BSF), and membrane distillation (MD).

Cooling water blowdown is a very concentrated wastewater stream with various contaminants that can affect the entire ecosystem if handled and treated properly. Various processes can be implemented to treat a CWBD stream. Some of these technologies, such as RO, ED, MD, and BSF, are already established, while others are emerging, such as EC, VSEP, and NF. In terms of choosing the best technology, being green and environmentally friendly are among the key considerations, in addition to the cost and the treatment performance. Based on an evaluation, membrane-based technologies result in high-quality treated water, but some of them, such as NF and RO, are prone to fouling problems, resulting in higher maintenance requirements. Additionally, EC and VSEP also produce high-quality permeate; however, they are energy-intensive processes. The only process that requires a large quantity of chemicals as a part of the system is BSF. For the most cost-effective technologies, EC and MD should be considered; ED and NF can also be considered if a pre-treatment step is available. Compared to the ultrafiltration membrane method (65% reduction in colloidal silica), EC has a high treatment performance (99.54% for silica ions). To treat contaminants, ED, MD, and EC processes treat a wide range of contaminants in CWBD. Regarding energy consumption, both EC~0.18–3.05 kWh/m3 and VSEP~2.1 kWh/m3 technologies have high energy demand, limiting their implementation for large-scale applications unless renewable energy sources are used. When it comes to recovering and reusing treated wastewater or even discharging it to the marine environment, standards and regulations must be obeyed. Treatment and reuse of CWBD can help overcome the water scarcity problem and achieve a more sustainable environment.

> “
> *In terms of choosing the best technology, being green and environmentally friendly are among the key considerations, in addition to the cost and the treatment performance.*

Cooling water blowdown is considered a wastewater stream discharged from cooling towers into the marine environment or sewage treatment plants or reused in applications such as irrigation. Each of these discharge points has certain regulations and permissible limits for the water contaminants; the constraints are there to avoid negative and long-term consequences for the environment and society.

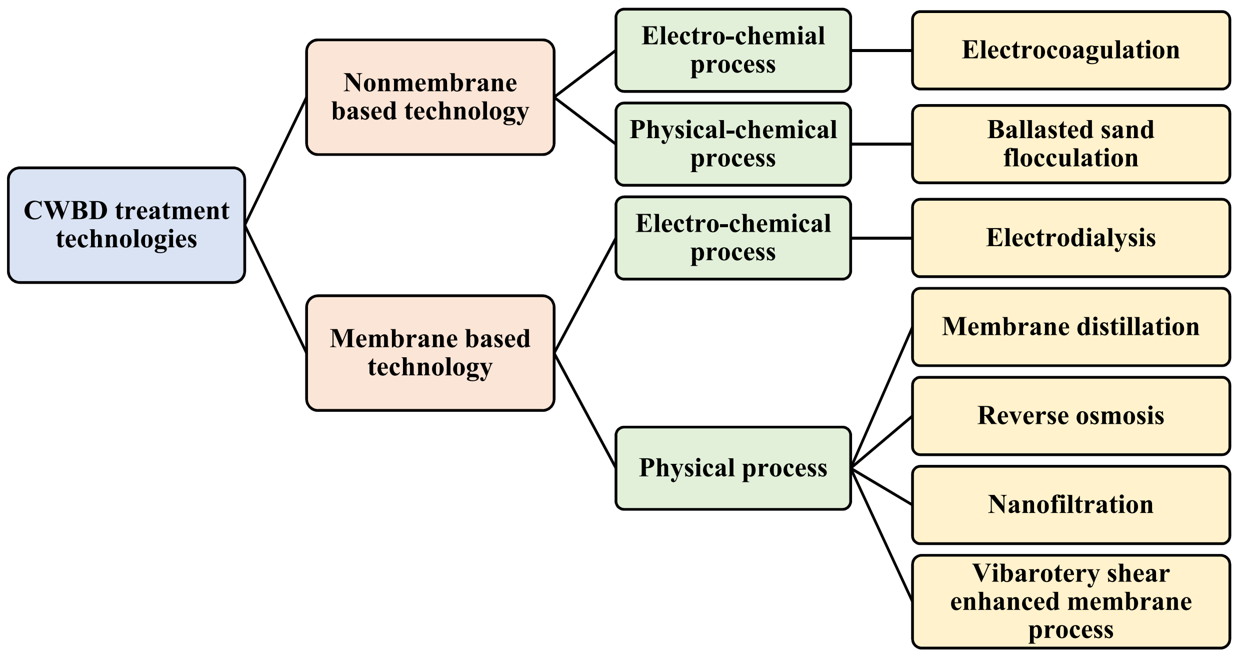


Fig. 41. CWBD treatment technologies (Soliman et al., 2022 https://www.mdpi.com/2071-1050/14/1/376/pdf

> “
> *Cooling water blowdown is considered a wastewater stream discharged from cooling towers into the marine environment or sewage treatment plants or reused in applications such as irrigation.*

9.0

District Cooling: Annex cont.

District Cooling System Options

District cooling is the centralized production and distribution of cooling energy. Chilled water is delivered via a piping network, commonly an insulated pipeline buried underground to condition the indoor space of the buildings within a district. The output of one cooling plant is enough to meet the cooling-energy demand of dozens of buildings. District cooling can run on electricity or natural gas and use either regular water, seawater, or other water sources. Along with electricity and water, DC constitutes a new form of energy service. It is worth noting that, in most cases, using fuel for heat generation requires an approved permit from the Ministry of Energy.

District cooling systems can generally replace any type of air-conditioning system but primarily compete with air-cooled reciprocating chiller systems serving large buildings, which consume large amounts of electricity. This air-conditioning system is subject to a difficult operating environment, including extreme heat, saline humidity, and windborne sand. Over time, performance, efficiency, and reliability suffer, leading to significant maintenance costs and equipment replacement.

The choices of chiller type and chiller plant design are inherently linked. Different chiller types have different strengths, and with a careful selection of a chiller plant design, these strengths can be optimized. Most large plants consist of water-cooled centrifugal chillers. Hybrid plants may also include absorption chillers. The following paragraphs explain several system types and the benefits and disadvantages of each system.

Air-Cooled Chiller Plant:

An air-cooled chiller plant is exactly what it sounds like, a plant consisting of air-cooled chillers configured in parallel. Many small-to-medium chiller plants use air-cooled chillers, with air-cooled screw chillers being common in the 150–400 ton range. Air-cooled screw chillers offer very good performance, particularly at partial load. Air-cooled chillers avoid the need for cooling towers, condenser pumps, and condensers, and they do not consume water like water-cooled chillers.

An air-cooled chiller plant is not recommended in low- and mid-density districts due to the limited energy savings associated with this system. The energy model results at the end of this report show only a 12% saving for an air-cooled chiller system over distributed DX units at individual residences. This should only be considered for very high-density districts where water is scarce, such as the central region.

"Air-cooled chillers avoid the need for cooling towers, condenser pumps, and condensers, and they do not consume water like water-cooled chillers.

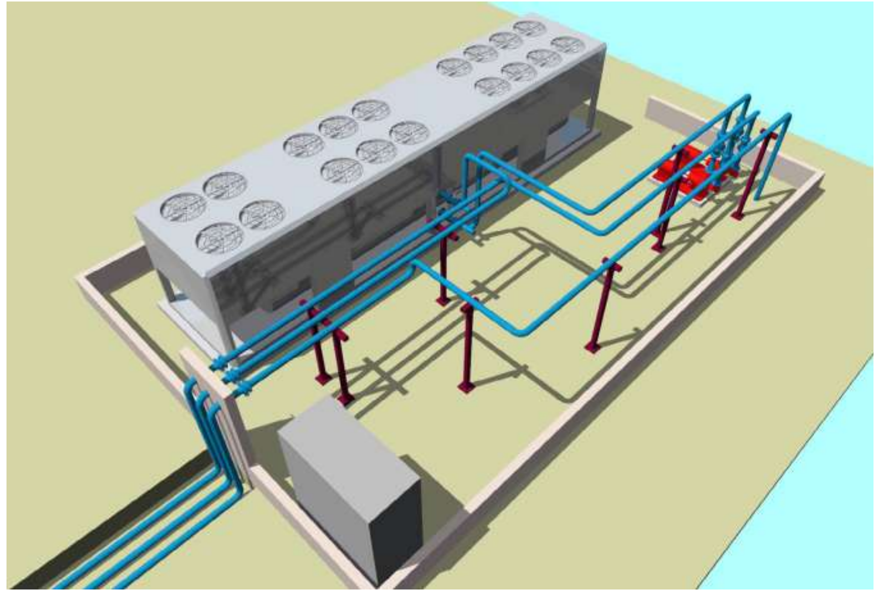


Fig. 42. Air-cooled chiller plant

Benefits	Disadvantages
• No makeup water is required. • Air-cooled chillers can be purchased as a complete package from the factory. • They are lower maintenance than water-cooled systems. • There is less equipment and a lower initial cost due to the exclusion of a condenser water system.	• They are only slightly more efficient than distributed packaged DX units. • The largest air-cooled chiller is only 550 tons, so a plant would need to have many air-cooled chillers, which would likely be cost restrictive.

"District cooling is the centralized production and distribution of cooling energy.

9.0

District Cooling: Annex cont.

Evaporatively Cooled Chiller Plant:

Evaporatively cooled chillers are essentially water-cooled chillers in a box. The hot, gaseous refrigerant is condensed by water flowing over the condenser tubes and evaporating. This ties the condensing temperature to an ambient wet bulb like a water-cooled chiller. The condenser, water sump, pump, etc., are integral parts of the chiller. Whereas a water-cooled chiller will require a cooling tower, condenser pump, and field-erected piping, the evaporatively cooled chiller comes as a complete package from the factory. Evaporatively cooled chillers offer the ease and savings of air-cooled chiller installation while providing performance comparable to water-cooled chillers. Evaporatively cooled chillers will require makeup water, water treatment, and drains.

Benefits	Disadvantages
• Evaporatively cooled chillers can be purchased as a complete package from the factory. • They are lower maintenance than water-cooled systems. • There is less equipment and a lower initial cost due to the exclusion of a condenser water system. • The efficiencies are close to water-cooled chillers in a dry climate.	• They are not as efficient in humid environments. • They are similar in size to air-cooled chillers, and their maximum sizes are approximately 500 tons, so a plant would need to consist of many evaporatively cooled chillers, which would likely be cost restrictive.

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Evaporatively cooled chillers offer the ease and savings of air-cooled chiller installation while providing performance comparable to water-cooled chillers.

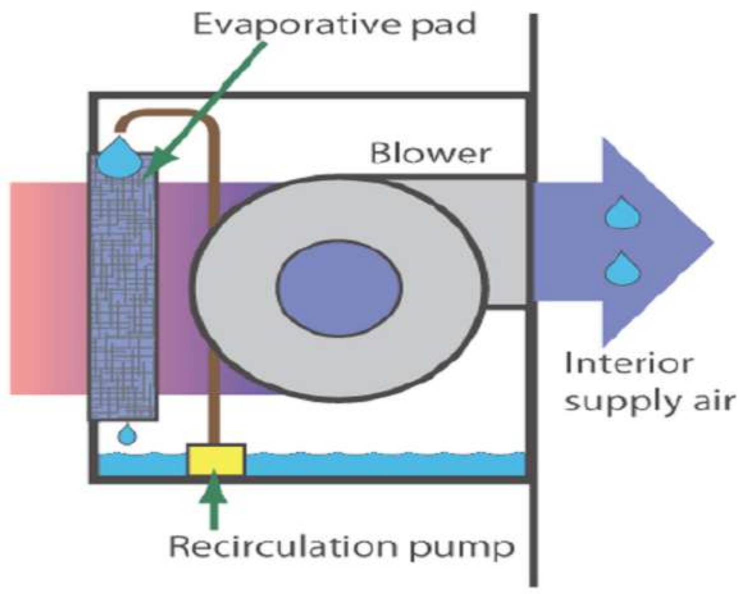

Fig. 43. Evaporatively cooled chiller plant: direct

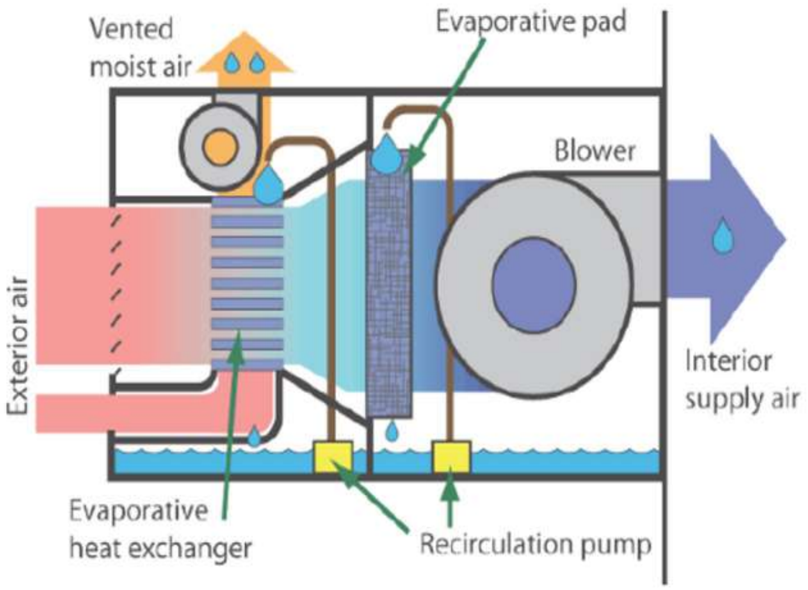

Fig. 44. Evaporatively cooled chiller plant: indirect

9.0

District Cooling: Annex cont.

Water-Cooled Centrifugal Chiller/ Cooling Tower Plant:

Water-cooled chillers and cooling towers are the most common systems used in DC plants. Like an air-cooled chiller, a water-cooled chiller consists of an evaporator, compressor, and condenser. The evaporator is a heat exchanger that removes the building heat from the chilled water, lowering the water temperature in the process. The heat is used to boil the refrigerant, changing it from a liquid to a gas. Like the evaporator, the condenser is a heat exchanger. In this case, it removes heat from the refrigerant, causing it to condense from a gas to a liquid. The heat raises the water temperature. The condenser water then carries the heat to the cooling tower, where the heat is rejected into the atmosphere. A cooling tower rejects the heat collected from the building plus the work of compression from the chiller. Cooling towers expose the condenser water directly to the ambient air in a process that resembles a waterfall. The process can cool condenser water to below an ambient dry bulb. The water is cooled by a combination of sensible and latent cooling. A portion of the water evaporates, which provides the latent cooling.

Water-cooled chillers, combined with cooling towers, are a very efficient system recommended whenever there is sufficient water supply for the makeup water requirements. The energy model results at the end of this report show annual savings of almost 25% for a water-cooled chiller system over distributed DX units at individual residences. Peak demand is cut by almost 40%.

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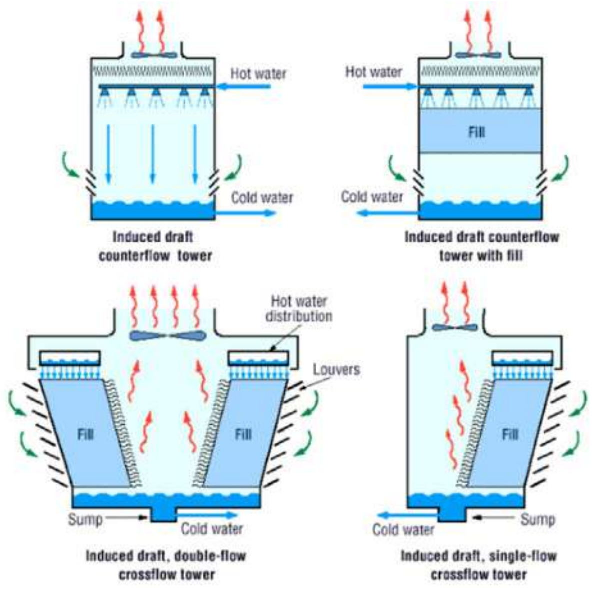

Fig. 45. Water-cooled centrifugal chiller/cooling tower plant

Benefits	Disadvantages
• Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons. • They have the lowest initial cost of water-cooled chiller options. • The efficiencies are close to water-cooled chillers in a dry climate.	• They require a large amount of makeup water.

9.0

District Cooling: Annex cont.

Water-Cooled Centrifugal Chiller/ Geothermal Loop:

Water-cooled chillers combined with a geothermal loop use the same chillers as the cooling tower option. However, rather than rejecting the heat into the atmosphere, it is rejected into the ground through a vertical bore field.

The feasibility of using ground-coupled condensers is dependent on soil conditions, such as ground temperature and water tables. A high-water table is necessary to dissipate the heat of the condenser water in the bore field. Studies conducted in KSA show the soil is suitable for ground-source systems, though not currently economic due to low electricity prices and high drilling costs.

Water-cooled chillers with a geothermal loop should be considered where water is scarce and where soil conditions allow. The energy model results show annual savings of over 33% for a water-cooled chiller with geothermal heat rejection over distributed DX units at individual residences. Peak demand is cut by almost 50%. Soil conditions would need to be tested at each possible site for feasibility. However, both the Western and Eastern regions are likely good candidates for geothermal heat loops due to their proximity to the sea and likely high-water table. This system should also be considered for the Riyadh area, as this type of system is being utilized in the King Abdullah Financial District (KAFD).

“The feasibility of using ground-coupled condensers is dependent on soil conditions, such as ground temperature and water tables.

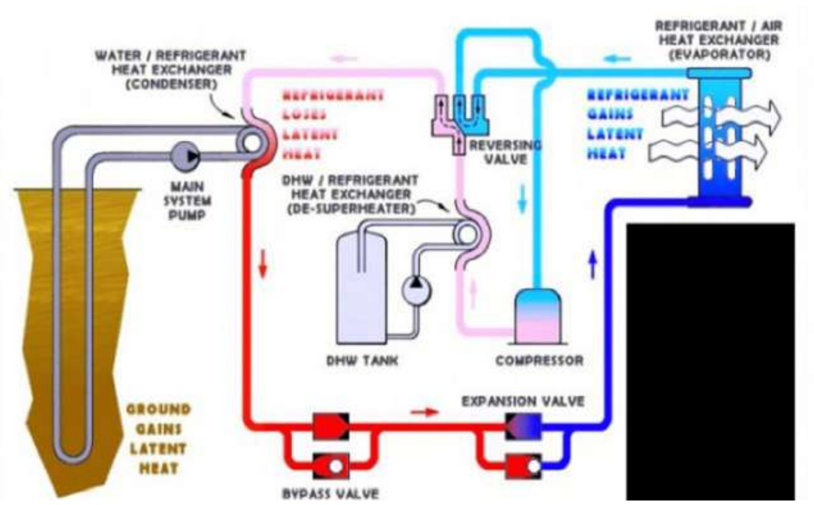

Fig. 46. Water-cooled centrifugal chiller/geothermal loop

Benefits	Disadvantages
• No makeup water is required. • Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons.	• There is a high cost for drilling a vertical bore field. • The system is dependent on soil properties. • The system works best with a balanced cooling and heating load, which the Saudi climate does not have.

Water-Cooled Centrifugal Chiller/ Seawater Heat Rejection:

Water-cooled chillers with seawater heat rejection use the same chillers as the cooling tower option. Rather than rejecting the heat into the atmosphere, it is rejected into the seawater through a submerged piping loop.

Water-cooled chillers in conjunction with seawater heat rejection should be considered where the cooling plant is adjacent to the sea. There currently are plants operating in the Western Region along the Red Sea that reject heat into the sea. However, there are environmental concerns with the rise in salinity in the Red Sea.

“There currently are plants operating in the Western Region along the Red Sea that reject heat into the sea.

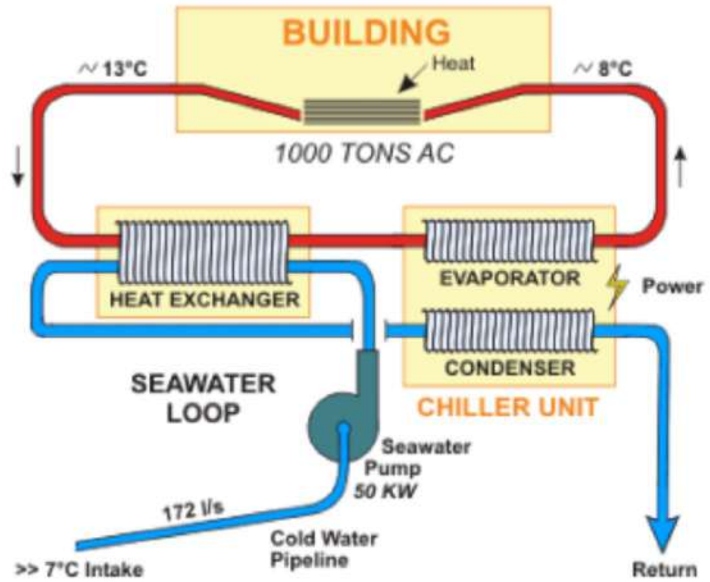

Fig. 47. Water-cooled centrifugal chiller/seawater heat rejection

Benefits	Disadvantages
• No makeup water is required. • Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons.	• They are only suitable if a plant is located close to the sea. • There are environmental concerns with locating piping in the sea. • There is a high cost due to the corrosion-resistant piping that is required.

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District Cooling: Annex cont.

Water-Cooled Absorption Chiller:

Another option is the use of absorption chillers. An absorption chiller uses a heat source to provide the energy needed to drive the cooling system. Absorption chillers are an alternative to centrifugal chillers where there is a heat source, such as solar collectors, thermal springs, or plant-waste heat.

Absorption chillers should be considered where sufficient makeup water and a heat source are available. According to the available information, there are 10 thermal springs in Saudi Arabia. Of these, six are in Gizan and four in Al-Lith; the estimated deep temperatures are reported to be approximately 100 °C.

> *According to the available information, there are 10 thermal springs in Saudi Arabia. Of these, six are in Gizan and four in Al-Lith; the estimated deep temperatures are reported to be approximately 100 °C.*

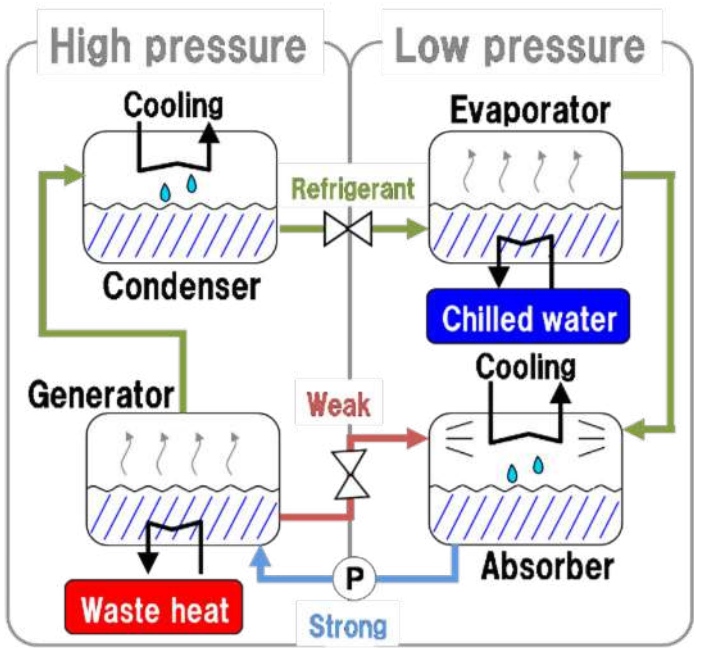

Fig. 48. Water-cooled absorption chiller

Benefits	Disadvantages
• They have the lowest electricity requirements of any chiller system in the order of 15 to 1 vs. a centrifugal chiller. • There is a higher makeup water requirement.	• They are only suitable if a heat source, such as solar collectors, is available. • There is a high cost due to the solar collector system if used. • Additional skills are required by maintenance staff compared to a traditional centrifugal chiller plant.

Sustainable Chilled-Water System:

All-variable-speed chilled-water distribution systems are configured very similarly to newer conventional systems but employ new operating strategies. Network-enabled iterative and demand-based control methods can be adopted for all-variable-speed distribution systems. When properly configured and operated, new-technology all-variable-speed chilled-water distribution systems ensure every load served is satisfied while providing ultra-efficient operation.

Implementing an all-variable-speed chilled-water system achieves approximately 0.5 kW/ton overall annual plant and distribution system performance, which is half the energy use of most existing plants. In addition, it provides simple, stable, ultra-efficient control with reduced system maintenance. Network control coordinates all-variable-speed equipment for optimum operation in response to actual demand on the system. The plant is designed for direct control among the components and distribution system to minimize pressure drops and variations.

New variable-speed system technologies require special effort through design/construction/turnover. The owner and design team must work together to ensure all problems will be solved. Nearly every chiller plant is a good potential application for all variable-speed technologies. It is important to focus on performance and let the overall plant performance drive the selection of configuration, equipment, and controls. It's necessary to ensure that the project incorporates measurement, verification, and accountability for achieving the projected performance of sustainable chilled-water systems.

> *When properly configured and operated, new-technology all-variable-speed chilled-water distribution systems ensure every load served is satisfied while providing ultra-efficient operation.*

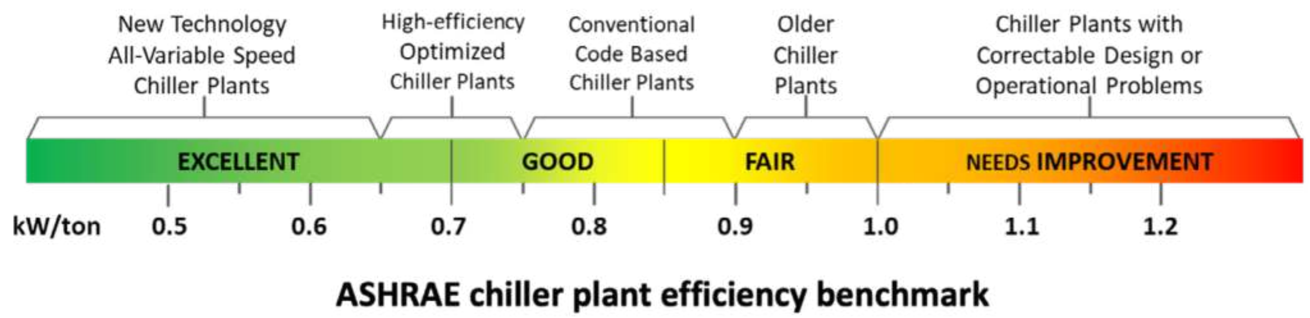

Fig. 49. American Society of Heating, Refrigerating, and Air-Conditioning Engineers chiller plant efficiency benchmark (Hioki, 2021)

9.0
District Cooling: Annex cont.

District Cooling Instrumentation Control System and Management

Current industrial plants are full of sensors providing large amounts of data. **Data without control is unavailing information.** Collecting, saving, sorting, and analyzing data represents a complex process that must be developed quickly and efficiently to provide valuable information. A district cooling instrumentation control system (DCICS) provides control and monitoring of plant equipment and alarms for unacceptable conditions, in addition to data for maintenance, troubleshooting, management reporting, monitoring key performance indicators (KPIs) that the service providers should submit to the Water and Electricity Regulatory Authority (WERA), performance optimization, clouding Internet of Things (IoT), artificial intelligence, machine learning, accounting, and billing purposes. A DCICS monitors and controls the entire network of intake stations. It provides operators with real-time information on network and equipment performance. With this amount of knowledge and feedback, the system can be automated to optimize plant performance in line with demand and energy rates. This capability results in improved energy efficiency and lower operating costs.

District cooling instrumentation and control systems help with the management and operation of active DC plants and systems through the **following potential functions:**

- Controlling and monitoring process conditions at the DC provider's various plants automatically with little or no user intervention.
- Providing a common user interface for the provider's personnel, allowing them to monitor and control their plants either locally within the plant or from command centers located strategically through the provider's district.
- Automatically gathering accurate and real-time energy metering data and storing this data in a format and location readily accessible by the provider's accounting systems for billing, monitoring, and reporting purposes.
- Automatically gathering and storing other types of data for maintenance and energy efficiency optimization purposes.
- Raising the alarm when process conditions move outside of established normal operating ranges or when equipment failure is detected both locally and at the affected plant and remotely as mandated by the provider's standard operating procedures.
- Indicating certain process parameters local to where the parameters are being measured.
- Allowing any device that is usually controlled by the DCICS to be overridden and controlled at the site where the device is installed.
- Providing a common data input-output interface for real-time data exchange with external applications such as expert energy management systems and real-time thermal modeling and simulation systems (District Cooling Best Practice Guide).
- Reporting services, which allows the maintenance team to receive a daily report of the maintenance activities to be done, and advising if any equipment is demonstrating unusual performance.
- Optimizing performance by conducting system checks of several parameters such as the weather forecast, the weekday, and the historical demand and selecting how many chillers to run and when to reduce energy costs.

> *Current industrial plants are full of sensors providing large amounts of data. Data without control is unavailing information. Collecting, saving, sorting, and analyzing data represents a complex process that must be developed quickly and efficiently to provide valuable information.*

Several general factors must be considered before undertaking any DCICS design effort. These factors will greatly influence the overall design and deployment of the system:

- How will the provider operate and maintain the system? Will control and monitoring functions be performed locally at the plant level, remotely at strategically positioned command centers, or a combination of both?
- If remotely, is the communication infrastructure in place in the provider's district to support the large amount of interplant networking required with this approach?
- Will the plants be manned or unmanned? How will the equipment be sequenced on and off—manually, automatically, or semi-automatically?
- How will energy metering data be gathered—manually or automatically by the DCICS? Will submetering of the individual tenants be performed, or will the provider simply meter their customers' buildings and/or complexes as whole units?
- How will data be "forwarded" to the provider's accounting systems?
- Will the DCICS be required to interface with third-party packages such as energy efficiency optimization or maintenance scheduling programs?
- Consider the system's ability to control and monitor the plant, distribution, energy transfer, and storage systems most efficiently and cost-effectively to satisfy customers' chilled-water demand.
- Stability of the system: the system should be available for provider use 24 hours a day, 365 days per year, with minimal or no downtime. Frequent or random "crashes" are not acceptable.
- Consider the reliability of the system.
- Clouding, IoT: cyber security is a very important factor in control systems. Cyber security is not at odds with accessibility.
- DCICS provides the owner safety access to their plant from anywhere in the world if required.
- Supervising KPIs or checking the plant performance during a meeting is now a real possibility.
- Smart features can include receiving emails in the case of important alarms or starting a pump from a tablet in front of it to monitor the pressures.

Other factors include:

- Accuracy and availability of the data generated by the system.
- Ability of the system to monitor energy generation, demand, and consumption and to act on that data to increase the DC provider's overall efficiency.
- Ease of use for the provider's operational personnel.
- Ease of development and serviceability.
- Supportability of the system by multiple vendors, as opposed to being tied to one vendor for the life of the system.
- Ease of disaster recovery.
- Ability to interface with the different types of equipment that can be found in typical plant, distribution, energy transfer, and storage systems.
- Initial and ongoing operating costs of the system.
- Ability to grow as the provider's chilled water infrastructure grows, including integrating new equipment without affecting existing operations (District Cooling Best Practice Guide).

A DCICS is the final component of the operation of any DC system. A centralized system operation station can provide control over water treatment, DC plants, distribution networks, and end-user ETSs. This centralized and continuous control over the DC network allows constant improvement of the energy efficiency of the entire system. When centrally managed, the coefficient of performance (COP) can be up to 60% greater than stand-alone cooling systems managed separately (Climespace), where technicians switch cooling plants on and off based on several parameters (weather, network usage, etc.).

9.0

District Cooling: Annex cont.

Thermal Energy Storage

The above system allows for mixed-use development to distribute the use of TES and maintain system operation at a consistent efficiency rate. The technical teams use multiple automated monitoring systems data to ensure the network's performance. In the planning of a new district energy system, it is essential that the DCICS operator establish formal relationships with relevant local authorities, private institutions, and security agencies to ensure uninterrupted and safe service. Thermal energy storage can economically and efficiently shift peak air conditioning and other cooling loads from on-peak to off-peak periods. The main benefit of using TES is reduced peak power demand and, therefore, reduced operating energy costs resulting from lower demand charges and/or lower time-of-use energy charges. Even with "flat rates" for energy charges, there is real value in the use of TES by energy consumers. The reality is that the cost and value of electrical energy vary continuously (based on supply and demand). The variability between day and night is significant, with the incremental power plant costs during peak-demand periods in the daytime being far more than those during low-demand periods at night. The energy providers continue to realize these variable costs even if they charge their customers a "flat rate" for energy. Using TES to "shape" the load usage profile—specifically to minimize energy consumed during high-demand (high-value) periods and to maximize use during lower-demand (low-value) periods—makes the energy consumer a more attractive buyer to the energy provider. The energy provider can offer a substantially lower "flat rate" to those consumers with these more attractive load shapes, as it costs less to serve them. In large-scale applications, such as DC systems, the economy-of-scale of TES (especially sensible heat TES systems using chilled water or low-temperature fluid storage) often produces immediate net capital cost savings compared to the equivalent conventional (non-TES) chilled-water capacity. In particular, the net capital cost saving can be captured from using TES at times of:

- New system construction.
- Retrofit expansions.
- Chiller plant rehabilitation.

In each case, the savings occur because TES allows the installed chiller plant capacity to be "downsized"; instead of needing chillers equal to the peak day's peak load (plus any necessary spare capacity), the chillers only need to be equal to the peak day's average load (Cogeneration & On-Site Power Production).

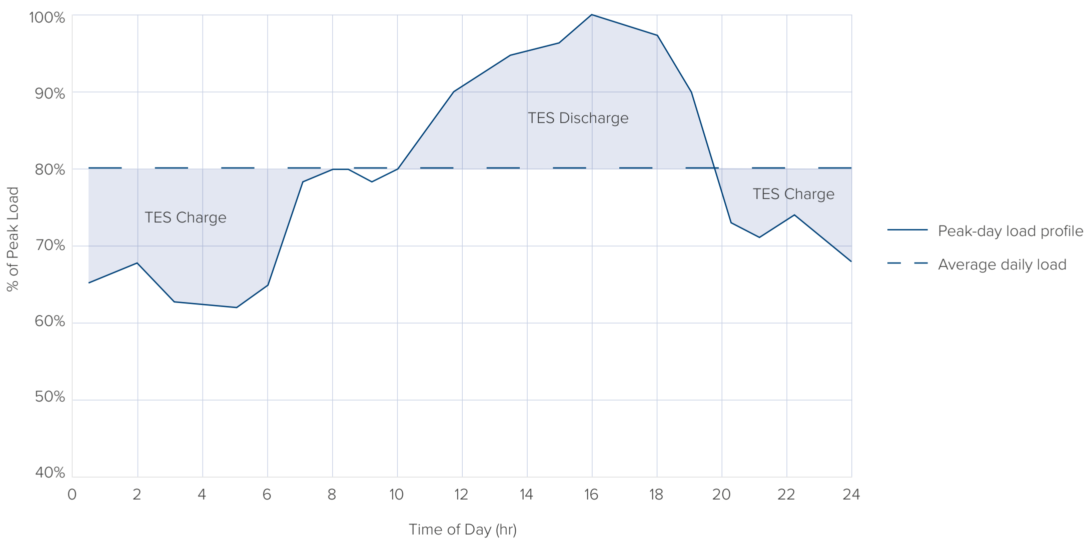

Fig. 50. Load-levelling potential with thermal energy storage (District, 2008)

District Cooling Technologies Selected for KSA

The Middle East District Cooling Bifurcation

The Middle East DC market size is set to grow rapidly over the next decade. This is credited mainly to the growing preference for integrating sustainable, energy-efficient cooling technologies owing to various environmental and economic benefits.

Energy consumption has grown rapidly in the Middle East, with the region recording one of the world's highest consumption rates. Therefore, regional governments and industry leaders are prioritizing sustainability while devising urban development plans.

Considering the climatic conditions across the Middle East, air conditioning is an all-year-round requirement that further increases the importance of sustainability. The demand for central DC systems is thus expected to rise, given their ability to reduce carbon footprints and improve sustainability.

The Middle East DC market is bifurcated regarding **production technique**, **application**, and **country**.

Based on **production technique**, the Middle East DC industry is classified into **free cooling**, **electric chillers**, and **absorption cooling**. Of these, the electric chillers segment is set to record a significant growth rate through 2030, owing to stringent regulatory norms to reduce carbon emissions and existing policies related to developing sustainable heating, ventilation, and air-conditioning (HVAC) systems.

Water-cooled chillers use less electricity to deliver the same level of cooling compared to an air-cooled chiller.

However, upgrades to air-cooled chiller systems are improving their compatibility with Middle Eastern temperatures. Air-cooled chiller technologies are being developed to work under environmental conditions specific to the region.

Regarding **application**, the Middle East DC market is segmented into **residential**, **commercial**, and **industrial**. The industrial segment is expected to experience substantial growth through the next decade. This is credited to growing investments in infrastructural development, which may escalate the demand for industrial DC solutions.

Based on country, the industry is segmented into **Saudi Arabia**, **the United Arab Emirates**, **Qatar**, **Kuwait**, and **Bahrain**. The Middle East market for DC is projected to register a substantial value owing to rapidly increasing temperatures and supportive government initiatives for DC system installation.

Free Cooling

Free cooling involves using colder ambient air (colder than the supply chilled-water set point) to perform cooling rather than the refrigeration cycle of the chiller. The technical name in the HVAC systems world is "waterside economizer."

An airside economizer is typically used on a packaged rooftop or tied to an indoor air-handling unit (AHU), allowing filtered outside air into the space when outdoor temperatures drop below 55 °F (12 °C; the common supply air temperature of indoor spaces), thus alleviating the need for the refrigeration cycle to be running. Interior space is being cooled, yet the refrigeration system is not running, hence the name "free cooling."

> "This is credited mainly to the growing preference for integrating sustainable, energy-efficient cooling technologies owing to various environmental and economic benefits.

Types of Free Cooling

For water-cooled systems, it is common to use a large plate-and-frame heat exchanger to transfer cooling between the cooling tower loop (when temperatures are beneficially low) and the chilled-water loop. There is also a thermosyphon system using colder-than-normal condenser water temperatures to move refrigerant around without the use of the compressor while still achieving some heat exchange at various levels, depending on the exact temperature difference.

9.0

District Cooling: Annex cont.

Operation of Free Cooling

Operation of these systems has proven to be highly reliable and surprisingly simple. The engagement of the free cooling system is through a modulating three-way valve connected to the building load or load side of the chilled-water system, the chiller system, and the free cooling system, composed of a copper-tube/aluminum-fin water coil with condenser fans.

In an integrated system, there is a water coil sandwiched directly against the normal copper tube/aluminum fin refrigerant coil being used as the condensing surface of the air-cooled chiller, with condenser fans pulling air simultaneously across both (see Figure 51).

- **High ambient**: Under high ambient conditions, there is no potential for free cooling; therefore, the free cooling coils or modules are bypassed, and 100% mechanical cooling will be used.
- **Mid-range or pre-cooling**: Depending on how aggressively you want to control your system, the three-way valve can begin to open to the free-cooling coils between 2 °F (–16 °C) and 4 °F (–15 °C) below your chilled water set point. This temperature approach (the difference between the set-point temperature and free-cooling activation) is much lower than most people realize until they study air-cooled designs. If a system is running at a standard chilled-water temperature (44 °F or 6 °C), it will start to take advantage of free cooling when the outside ambient dry-bulb temperature reaches 42 °F (5 °C). At these temperatures, you will still need the mechanical cooling system for full capacity, but the load is now being shared, and the system is gaining everything it can from the ambient environment. The refrigeration system then finishes off whatever is left with perhaps 50% of your compressors/capacity. Energy use is cut in half in this example.
- **Winter operation**: Once the system reaches the range between 5 °F (–15 °C) and 9 °F (–12 °C) below its chilled-water set point, it can achieve 100% of its capacity with the free-cooling coils. At this point, the three-way valve will be 100% open to the free-cooling coils, and the mechanical refrigeration system will be shut down. You cannot get more efficient than when the system is off. Of course, the condenser fans will continue to draw ambient air over the free-cooling coils, but it will also slow down and shut off if ambient temperatures continue to fall, further increasing energy savings.
- **Limitations**: The final operation stage is reached when cooling demand is exceeded; at this point, the three-way valve will then begin to throttle back to avoid overcooling and maintain the set point. In northern climates, a glycol solution will be in use, reducing the risk of freezing the free-cooling coils. However, a new limitation around the freezing point is introduced in southern climates, where water would be used. In this case, operation below 34 °F (1 °C) would be prohibited.

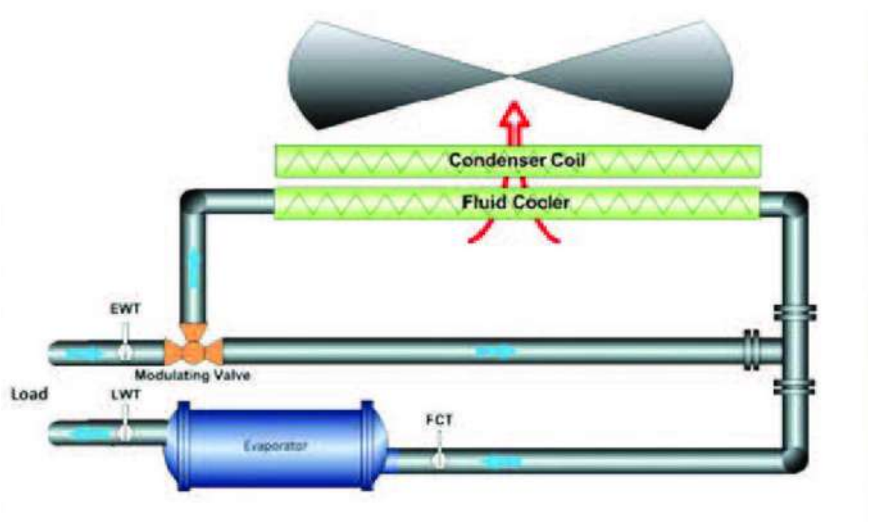

Fig. 51. An integrated system displaying the operations of free cooling

Electric Chillers

Electric chillers convert electrical energy to cooling energy to meet the cooling demand. There are two types of chillers: water-cooled and air-cooled chillers. They work similarly throughout most of the process until the refrigerant reaches the condenser. Water-cooled chillers use water to surround the refrigerant pipes and draw in the heat. The water is then pumped into a cooling tower to release the heat. Air-cooled chillers use condenser fans that circulate outside air through the condenser, which absorbs heat from the refrigerant. Water conducts heat more effectively than air. This is why water-cooled chillers are known for being more consistent and efficient in their performance and for having a longer lifespan than their air-cooled counterparts. Water-cooled chillers are common in medium and larger facilities (as long as they have an adequate water supply), such as airports, hospitals, hotels, shopping malls, and commercial buildings. Air-cooled chillers are more prevalent in small to medium-sized facilities, where space and water may be limited. The costs to install and maintain these chillers are lower than those of their water-cooled counterparts, but they typically have a shorter lifespan. These chillers are commonly used for individual buildings, restaurants, corporate and sporting events, and temporary structures.

Absorption Chillers

The refrigeration cycle for a conventional vapor-compression chiller and an absorption chiller is similar in that both produce chilled water through the evaporation and condensation of a refrigerant at different pressures within the machine. However, a conventional chiller uses a mechanical means to compress and transport the refrigerant vapor to the condenser. In contrast, an absorption chiller depends on a thermo-chemical process involving lithium bromide and water to establish the pressure differential instead of mechanical compression. While most vapor-compression chillers utilize electricity as their energy source to operate the machine, absorption chillers use heat as their energy. Typically, the heat is in the form of steam or hot water or generated through the direct combustion of natural gas.

Absorption chiller energy efficiency is based upon fuel consumption per ton of cooling, whereas motor-driven vapor-compression chiller energy efficiency is based on kW/ton cooling. The COP is a method for determining overall chiller energy performance. As per the original equipment manufacturer (OEM)-supplied information, the COP ranges for the different absorption chiller types are as follows (the higher the COP number, the more efficient the chiller):

Absorption Chiller Type	COP Range
Hot water or steam single-effect chiller	0.60–0.75
Hot water or stream double-effect chiller	1.19–1.35
Direct-fired double-effect chiller	1.07–1.18

As per OEM-supplied information, the water-cooled rotary screw chiller has a COP range of 3.90–5.40, whereas the water-cooled centrifugal chiller has a COP range of 7.00–8.79. The result is that motor-driven vapor-compression chillers are 4–7 times more energy efficient than absorption chillers.

"The refrigeration cycle for a conventional vapor-compression chiller and an absorption chiller is similar in that both produce chilled water through the evaporation and condensation of a refrigerant at different pressures within the machine.

9.0

District Cooling: Annex cont.

Absorption chillers have other major disadvantages compared to centrifugal chillers:

- Larger capacity cooling towers are required for absorption chillers, which would add USD25–30 per ton to the cost of the plant. For a 25,000 RT plant, that is USD625,000/AED2,300,000 plus additional capital expense (capex) to the plant construction.
- Absorption chillers are more expensive than centrifugal chillers, which means additional capex.
- Absorption chillers have a much higher maintenance cost, which means additional operational expenses.
- Absorption chillers require larger pumps because more water flow is required with absorption chillers, which translates to additional capex.
- Absorption chillers utilize substantially more condenser water consumption in evaporation than centrifugal chillers (50% more condenser water is consumed in evaporation with an absorption chiller versus an electric-driven centrifugal chiller). As water is a critical issue in the GCC region and worldwide, this is a major disadvantage.
- Absorption chillers have a large footprint compared to centrifugal chillers.

In a head-to-head energy-efficiency competition, motor-driven vapor-compression chillers will beat absorption chillers every time. However, there are specific applications where absorption chillers may have an advantage over motor-driven vapor-compression chillers. Typically:

- For a facility with a cogeneration power plant or some other thermal energy-generating process with excess (waste) thermal energy, absorption chillers can utilize the excess thermal energy to produce chilled water instead of all the excess thermal energy being wasted.
- For a facility with inadequate electrical infrastructure, or if bringing electrical infrastructure to the facility is cost-prohibitive, absorption chillers have a substantially lower electrical power requirement than motor-driven vapor-compression chillers.
- For a facility with high electrical power and low fuel costs, absorption chillers may have a lower operating cost than motor-driven vapor-compression chillers. However, the fuel cost must be very low to make it work.
- For a facility that requires substantial system reliability, the lower electrical requirements for absorption chillers will reduce emergency generator load requirements.

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In a head-to-head energy-efficiency competition, motor-driven vapor-compression chillers will beat absorption chillers every time.

Integration of Renewable Sources into District Cooling

The integration of renewable sources into DC energy systems is a way to increase environmental sustainability, despite the impact on the initial investment. Solar-assisted DC systems are characterized by a high investment cost and low operational cost. The main issues are the variability of the source, requiring a TES system. To avoid these problems while keeping the solar contribution high, designing powerful predictive models of load management and storage tanks is essential. Therefore, it is imperative to focus on improving the efficiency of the production plant and the network using detailed computer models, simulation tools, and genetic optimization algorithms.

Compilation of District Cooling Technology Options and Potential Advantages/Disadvantages

District Cooling Energy System	Advantages	Disadvantages	Recommendations/Examples of Application
Air-cooled chiller plant	• No makeup water is required. • Air-cooled chillers can be purchased as a complete package from the factory. • They are lower maintenance than a water-cooled system. • There is less equipment and a lower initial cost due to excluding a condenser water system.	• They are only slightly more efficient than distributed packaged DX units. • The largest air-cooled chiller is only 550 tons, so a plant would need to consist of many air-cooled chillers, which would likely be cost restrictive.	An air-cooled chiller plant is not recommended in low and mid-density districts due to the limited energy savings associated with this system. This should only be considered for very high-density districts where water is scarce, such as the central region. (Case study: Abdali Boulevar, Jordan)
Evaporatively cooled chiller plant	• Evaporatively cooled chillers can be purchased as a complete package from the factory. • They are lower maintenance than water-cooled systems. • There is less equipment and a lower initial cost due to excluding a condenser water system. • The efficiencies are close to water-cooled chillers in a dry climate.	• They are not as efficient in humid environments. • They are similar in size to air-cooled chillers, and the maximum sizes are approximately 500 tons, so a plant would need to consist of many evaporatively cooled chillers, which would likely be cost restrictive.	Evaporatively cooled chillers offer the ease and savings of air-cooled chiller installation while providing performance comparable to water-cooled chillers. Evaporatively cooled chillers will require makeup water, water treatment, and drains. This should be considered in dry climates, such as the central region.
Water-cooled centrifugal chiller/ cooling tower plant	• Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons. • They have the lowest initial cost of water-cooled chiller options.	• They require a large amount of makeup water.	Water-cooled chillers combined with cooling towers are a very efficient system recommended whenever there is a sufficient water supply for the makeup water requirements. (Case study: Empower—The Emirates Towers, United Arab Emirates)

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District Cooling: Annex cont.

District Cooling Energy System	Advantages	Disadvantages	Recommendations/Examples of Application
Water-cooled centrifugal chiller/ geothermal loop	• No makeup water is required. • Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons.	• There is a high cost for drilling a vertical bore field. • The system is dependent on soil properties. • The system works best with a balanced cooling and heating load, which the Saudi climate does not have.	Water-cooled chillers with a geothermal loop should be considered where water is scarce and where soil conditions allow. This system should also be considered for the Riyadh area, as this type of system is being utilized in KAFD, Saudi Arabia.
Water-cooled centrifugal chiller/ seawater heat rejection	• No makeup water is required. • Water-cooled chillers can be twice as efficient as air-cooled chillers. • Common water-cooled chillers have capacities of up to 2,000 tons.	• They are only suitable if the plant is located near the sea. • There are environmental concerns with locating piping in the sea. • There is a high cost due to the required corrosion-resistant piping.	Water-cooled chillers in conjunction with seawater heat rejection should be considered where the cooling plant is adjacent to the sea. Currently, plants operating in the Western Region along the Red Sea reject heat into the sea. However, there are environmental concerns with the rise in salinity in the Red Sea.
Water-cooled absorption chiller	• They have the lowest electricity requirements of any chiller system in the order of 15 to 1 vs. a centrifugal chiller. • There is a higher makeup water requirement.	• They are only suitable if a heat source, such as solar collectors, is available. • There is a high cost due to the solar collector system if used. • Additional skills are required by maintenance staff compared to a traditional centrifugal chiller plant.	Absorption chillers should be considered where sufficient makeup water and a heat source are available, such as solar collectors, thermal springs, or plant waste heat. According to the available information, there are 10 thermal springs in Saudi Arabia. Of these, six are in Gizan and four in Al-Lith; the estimated deep temperatures are reported to be approximately 100 °C.

Note: DC energy systems may have to be decided on a case-by-case basis depending on the given circumstances of a project.

Summary of District Cooling Technology Options Adoptable in Saudi Arabia

District Cooling Energy System	Suitable Climate/Density	Applied Region	Example of Cities
Air-cooled chiller plant	• Applicable in very high-density districts where water is scarce • Applicable climate ranges between Mediterranean climate and desert climate	• Central region	• Riyadh
Evaporatively cooled chiller plant	• Applicable in dry climates	• Central region	• Riyadh
Water-cooled centrifugal chiller/ cooling tower plant	• Applicable and recommended in areas that have sufficient water supply	• Coastal cities • Western region • Eastern region	• Jeddah • Yanbu • Dammam
Water-cooled centrifugal chiller/ geothermal loop	• Applicable in very high-density districts where water is scarce • Applicable in desert climates	• Central region	• Riyadh
Water-cooled centrifugal chiller/ seawater heat rejection	• Applicable where the cooling plant is adjacent to seawater	• Coastal cities • Western region/ • Eastern region	• Jeddah • Yanbu • Dammam
Water-cooled absorption chiller	• Applicable where there is sufficient makeup water • Applicable where there is a heat source available, such as solar collectors, thermal springs, or plant waste heat	• Southern region	• Jizan • Al-Lith

9.0

District Cooling: Annex cont.

Current District Cooling Projects in Saudi Arabia

King Abdullah Financial District

Raidah Investment Company (employer) has awarded Saudi Tabreed the operation and maintenance of the two DC plants in KAFD, one of the Kingdom's most ambitious and distinguished projects.

Each plant has a 50,000 RT cooling load, and the contract comprises the operation and maintenance of the two DC plants for 10 years (which may be further be extended by mutual agreement between the employer and the contractor). The total plant capacity, that utilizes a reticulation network system, is 100,000 RT. Project specifications are detailed below:

- AREA: Riyadh
- PROPERTY AREA: 1.6million m^2
- AREA TYPE: Commercial and residential
- TERM: 10 years
- CONTRACT CAPACITY: 100,000 RT
- TYPE: Operation and maintenance
- PROJECT SPONSORS: Saudi Tabreed (100%)
- TARIFF: Fixed-price contract
- OFF-TAKER: Customers within the financial sector, the economic epicenter of KSA

Red Sea

The Red Sea Project is being created as a unique luxury tourism destination that will embrace nature, culture, and adventure, setting new standards in sustainable development and positioning Saudi Arabia on the global tourism map.

Saudi Tabreed has a 15% share in the private–public partnership. There is a utility concession under the Build-Operate-Transfer framework with the Red Sea Development Company to supply cooling services to the Red Sea Project through two DC plants, each of 16,250 RT. This agreement makes Saudi Tabreed the exclusive cooling service provider to the Red Sea Project. Project specifications are detailed below:

- AREA: Western coast of Saudi Arabia, between the cities of Umluj and Al Wajh
- AREA TYPE: Island gateways, mountain retreats, and desert adventures
- TERM: 25 Years
- CONTRACT CAPACITY: 32,500 RT
- TYPE: Build, own, operate, and transfer
- PROJECT SPONSORS: Saudi Tabreed/Acwa Power
- TARIFF: Capacity charge, consumption charge
- OFF-TAKER: The Red Sea Development Company

> “
> *The Red Sea Project is being created as a unique luxury tourism destination that will embrace nature, culture, and adventure, setting new standards in sustainable development and positioning Saudi Arabia on the global tourism map.*

10.0

Key Terms

Biological control: The use of chemical or physical water treatments to inhibit bacterial growth in cooling towers.

Bleed-off or blowdown: The release of a portion of the recirculating water from a cooling tower; this water carries dissolved solids that can cause mineral build-up.

Chemical treatment: Includes the use of biocidal, conditioning, dispersant, and scale-inhibiting chemicals to control biological growth, scale, and corrosion in cooling towers. Alternatives to conventional chemical treatment include ozonation, ionization, and exposure to ultraviolet light. A cooling tower uses water to absorb heat from air-conditioning systems and regulate air temperature in a facility.

Concentration ratio: The ratio of the level of dissolved solids in the recirculating water to the level found in the entering makeup water. A higher concentration ratio results from a lower bleed-off rate; however, increasing the ratio above a certain point leads to scaling, and water savings diminish after a certain level. This ratio is also called the “cycles of concentration.” Cycles refer to the number of times dissolved minerals in the water are concentrated compared to makeup water, not to water flow over the tower or on–off cycles.

Graywater: Defined by the Uniform Plumbing Code (UPC) in Appendix G, Gray Water Systems for Single-Family Dwellings, as “untreated household wastewater which has not encountered toilet waste. Graywater includes used water from bathtubs, showers, bathroom wash basins, and water from clothes-washer and laundry tubs. It must not include wastewater from kitchen sinks or dishwashers.” The International Plumbing Code (IPC) defines graywater in its Appendix C, Gray Water Recycling Systems, as “wastewater discharged from lavatories, bathtubs, showers, clothes washers, and laundry sinks.” Some states and local authorities allow kitchen sink wastewater to be included in graywater. Other differences between the UPC and IPC definitions can likely be found in state and local codes. Project teams should comply with graywater definitions as established by the authority with jurisdiction in the project areas.

Legionella pneumophila: A waterborne bacterium that causes Legionnaire's disease. It grows in slow-moving or still-warm water and can be found in plumbing, showerheads, and water-storage tanks. Outbreaks of Legionella pneumonia have been attributed to evaporative condensers and cooling towers.

Makeup water: Fed into a cooling tower system to replace water lost through evaporation, drift, bleed-off, or other causes.

Potable water: Meets or exceeds the Environmental Protection Agency's drinking water quality standards and is approved for human consumption by the state or local authorities with jurisdiction; it may be supplied from wells or municipal water systems.

Process water: Used for industrial processes and building systems such as cooling towers, boilers, and chillers. The term can also refer to water used in operational processes, such as dishwashing, clothes washing, and ice making.

Reclaimed water: Wastewater that has been treated and purified for reuse.

Wastewater: The spent or used water from a home, community, farm, or industry that contains dissolved or suspended matter (Federal Remediation Technologies Roundtable).

Building Energy Efficiency and Water Conservation

Building Energy Efficiency and Water Conservation

Introduction

Decarbonizing cities has a critical role in achieving climate and sustainability objectives. Yet, the energy demands of buildings continue to grow.

Consumption has increased from 115 exajoules (EJ) in 2010 to nearly 135 EJ in 2021 (IEA, 2022). Buildings account for approximately 28% of the primary energy consumed in the Kingdom.

They consume more than 75% of the total electrical energy produced in the Kingdom, with an annual growth rate of approximately 5%. The population growth dynamic will lead to more intensive domestic energy use and GHG emissions. Within this context, officials and policymakers of Saudi Arabia's major cities are pursuing different initiatives to improve citizens' urban life and make cities resilient and more sustainable.

Making energy and water efficiency a top priority is crucial for moving toward a more sustainable and secure energy future. With its ability to enhance well-being and living standards and address energy poverty, energy efficiency has proven to be an essential policy option that plays a significant role in achieving climate goals.

As Saudi Arabia strives to become carbon neutral by 2060, improving energy and water efficiency in the built environment is a valuable way to accelerate the energy transition and achieve climate goals.

With energy and water powering the most attractive aspects of the urban environment in modern society, they are ideally situated to shape future sustainable cities in the Kingdom. Building energy and water efficiency offers tremendous potential to boost productivity and increase wealth while reducing waste and curbing emissions. Improvements in energy efficiency also have the potential to moderate the tension between economic performance goals and sustainability pledges.

Technological progress over the past decade has substantially decreased the energy inputs required to support essential energy services such as cooking, lighting, space cooling, and heating. Energy efficiency improvements are estimated to achieve more than a third of aggregated GHG emissions reductions needed to mitigate climate change (IEA, 2021).

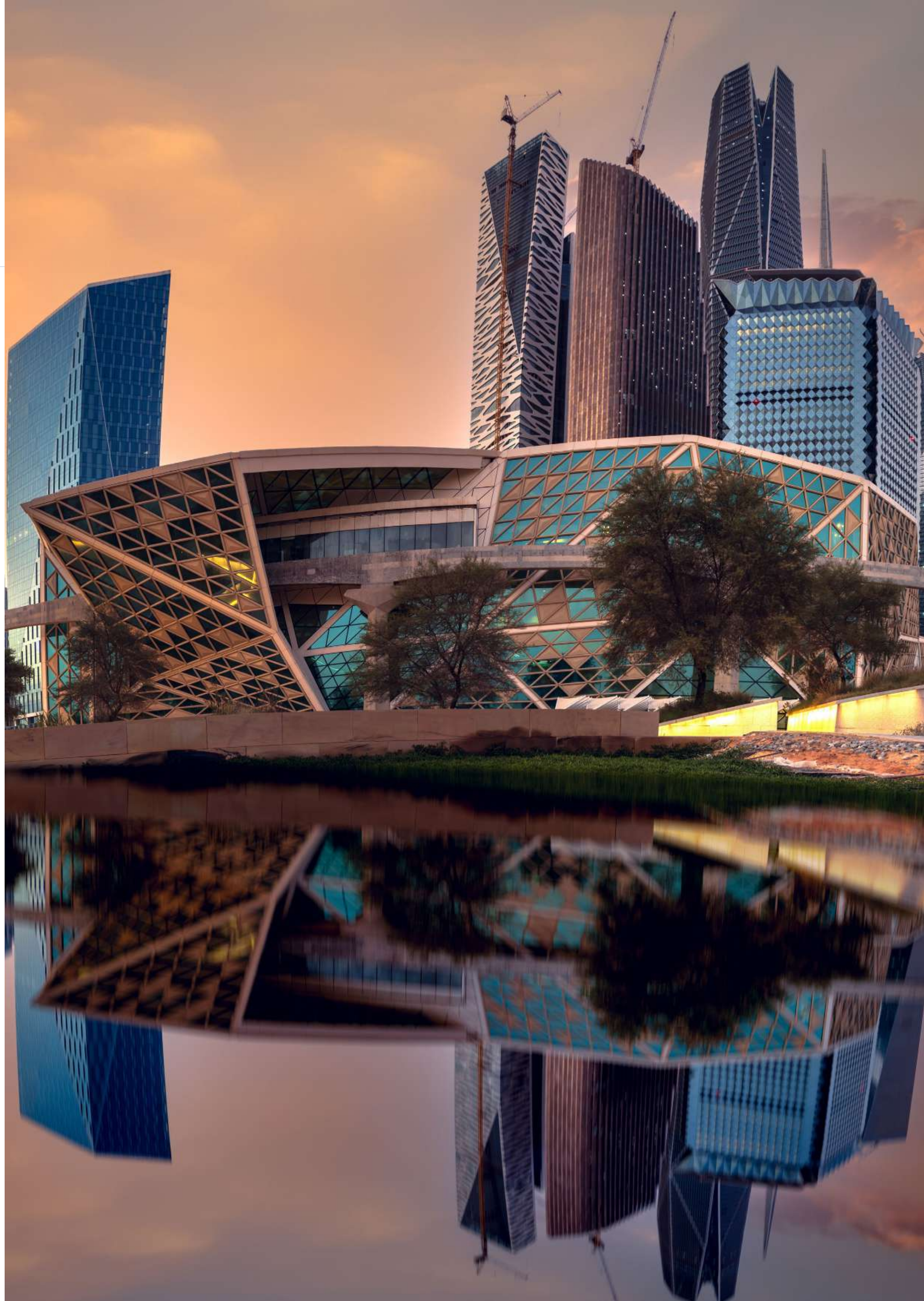
Here, we provide a systematic framework to reinforce and accelerate existing efforts to achieve a greener and more resilient built environment.

Purpose

The following guidelines, focusing on buildings' energy and water uses, offer high-level recommendations to support the Kingdom's efforts to decarbonize the built environment and save water. They detail how cities can harness a variety of proven enabling policies, technologies, and financing mechanisms to improve energy and water efficiency and deliver cost-effective energy savings in the built environment.

The ultimate objective of these guidelines is to help policymakers harness energy and water efficiency promises to achieve the following goals:

- Improve energy efficiency and conservation.
- Reduce water use in cities.
- Improve building design.
- Promote local and sustainable construction materials.
- Improve the recycling and reuse of building materials.
- Improve citizens' indoor comfort and urban life and make cities resilient.

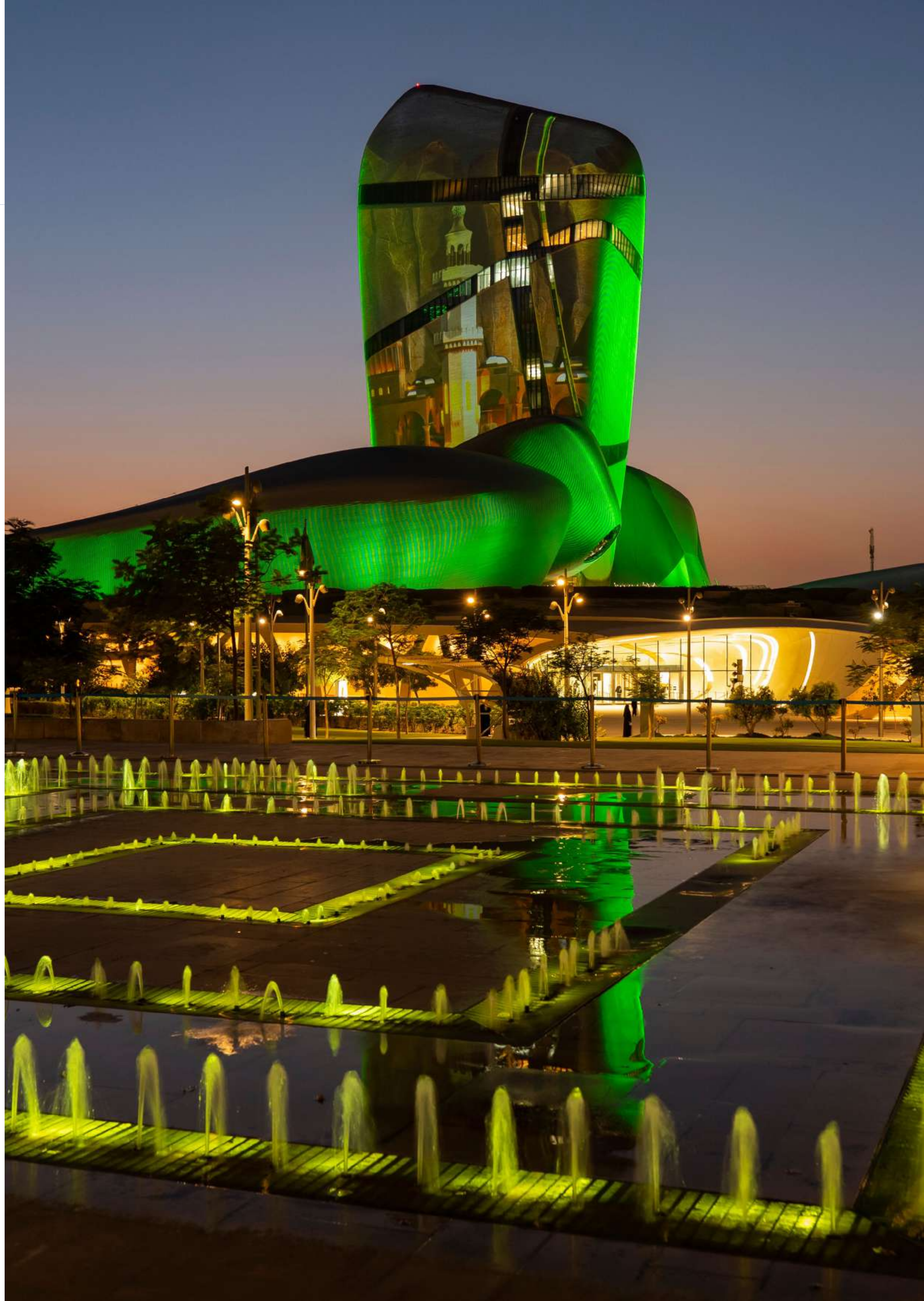


1.0

Building Energy Use and Conservation

Critical ways to improve energy efficiency in the built environment	
Improved construction and design	• Proper design and delivery of new buildings offers the greatest opportunity to lower heating, cooling, ventilation and lighting loads. • Introducing new and enforcing energy efficiency codes of existing buildings to ensure that energy efficiency is reflected in the design and build process. Recently, all new KSA building must comply with the SBC 601-602.
Renovation of the existing stock	• Renovation of oldest structures and renewal of energy-intensive systems are essential to improve energy efficiency in the built environment where stock turnover rate is very low. • A stimulating policy framework, innovative renovation business models, and cost-effective financing and project delivery processes are essential.
Energy management	• Monitoring and energy management systems are extremely valuable in reducing energy consumption and improving efficiency. • Introduce and maintain smart energy management devices and systems. • Implementing smart grids for balanced energy supply and demand and enhancing the distribution system's efficiency.
Behavioral change	• Promote energy-efficient behavior among residents to reduce energy consumption and save money. • Integrating behavior in energy efficiency problems.

Critical steps to improve energy efficiency in the built environment	
Performance evaluation	• Enhance knowledge about the context and drivers of energy demand in the built environemtn and energy demand. • Conduct an energy efficiency evaluation of the existing building stock. • Identify demand reduction potential and challneges, assess required resources, and outline priorities and milestones.
Lead by examples	• Testing renovation solutions and deployment of smart energy technologies before deployment at large scales. • Renovate and implement energy-efficient technologies in public buildings to demonstrate and set as example.
Upscale successful experiences	• Leveraging the expertise and capabilities of key stakeholders • Build on successful experiences and national and international expertise to implement and upscale energy efficiency programs.



1.0

Building Energy Use and Conservation cont.

1. Importance and Benefits of Improving Buildings' Energy Efficiency and Water Use

Energy efficiency and water conservation bring various benefits to individuals and society, including:

- Lowering GHG emissions by reducing the amount of burned fuels.
- Helping HHs and businesses save money on their utility bills.
- Saving energy and water resources, which will result in a reduction in the operating and life-cycle costs of buildings.
- Saving water and energy, which can help reduce the need for costly infrastructure investments, such as building new power plants or expanding water treatment facilities.
- Energy and water conservation, which can help promote sustainable development by lowering the environmental impact of urbanization and supporting a more sustainable future for cities.

Building Types

The guidelines outlined below are relevant to all building types in the Kingdom. Figure 53 enumerates the different categories of buildings.

2. Building Design and Orientation to Reduce Energy and Increase Indoor Comfort

Conceive new construction projects to integrate sustainable design and energy efficiency concepts. Stimulating integrative design innovation and sustainability will contribute to energy reduction and occupant comfort improvement.

> *"Energy efficiency and water conservation bring various benefits to individuals and society.*

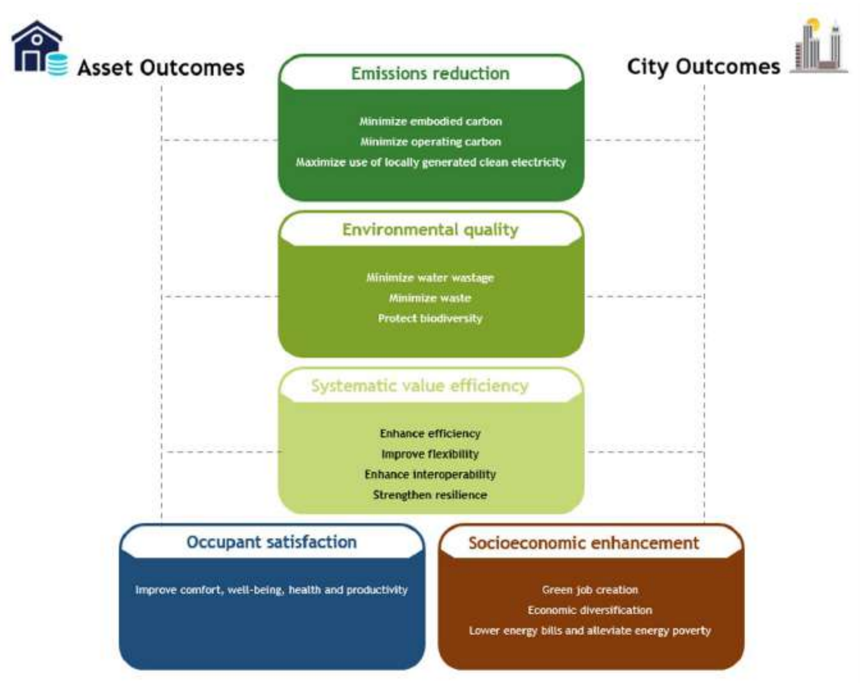
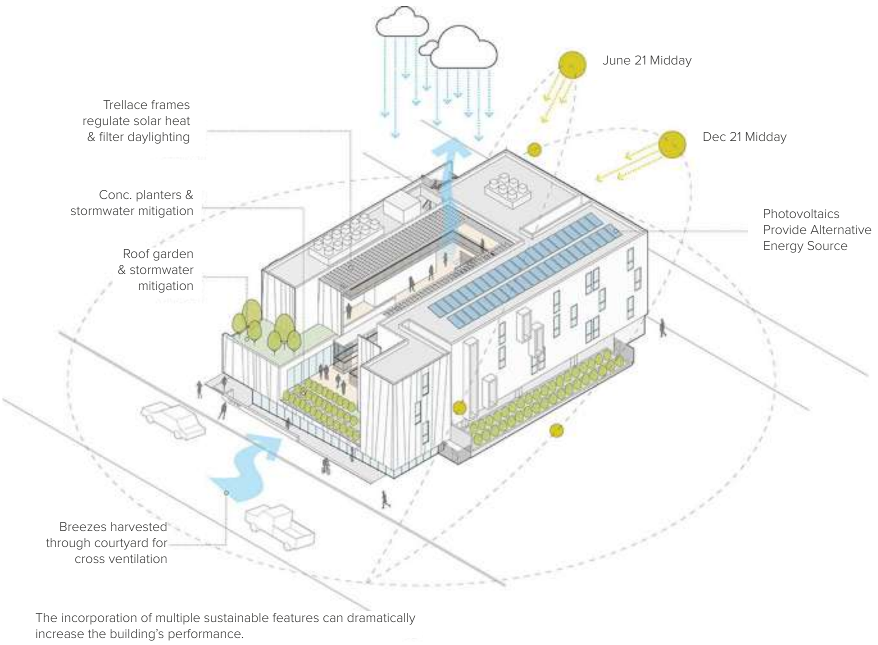


Fig. 52. Energy efficiency benefits

Fig. 53. Relevant buildings typologies. Credits: Authors' elaboration



Credit: Brooks + Scarpa Architect, Inc.
Source: City Wide Guidelines, Los Angeles City Planning

Fig. 54. Incorporating Sustainability Features: Enhancing Site and Building Design

1.0

Building Energy Use and Conservation cont.

Here are the best guidelines needed to harness building orientation and design to reduce buildings' carbon footprint:

Structure Design

- Leverage features and components such as shallow floors, operable windows, and skylights to enable occupant access to daylight and natural ventilation **within the limitations of of SBC 602-601**.
- Include overhead architectural elements, such as canopies, awnings, trellises, or cornices at entrances and windows, that create shade and minimize heat gain during the day, particularly on south-facing facades.
- Utilize a combination of shading techniques to accommodate solar orientation through balconies, overhangs, awnings, and sunshades.
- Use feasible natural ventilation and light for parking structures/ podiums while preserving architectural integrity.
- Utilize reflective or white paint on roofs and lightweight paving materials to redirect heat away from buildings and decrease mechanical cooling requirements.
- Integrate brise soleil elements to minimize heat and divert sunlight.
- Do not rely on highly reflective building materials and finishes that radiate heat and glare to adjacent buildings.
- Promote stairs by situating them close to the entrance and providing orientation signs at all elevator stations to direct visitors to the closest stairway.
- Design exit stairwells to be a visually appealing first choice for vertical circulation.
- Utilize components such as green roofs that incorporate plants that are locally adapted.

Site Design

- Locate structures to optimize cross-flow ventilation and daylighting options while reducing heat gain, mainly from southern and western orientations.
- Use shade trees and structures to improve comfort and generate passive cooling options. Include cover trees in planting areas to provide shade and reduce energy use, particularly on south-facing facades.
- Install solar-powered lighting to reduce electricity use.

3. Envelope and Thermal Performance

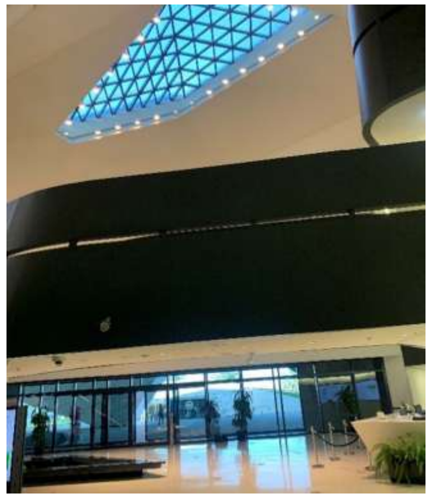
Envelope

The thermal performance of the building envelope influences the energy demand of a building. To reduce energy use, it is critical to set minimum building envelope performance standards for all new construction projects. The following guidelines will assist in limiting the heat gain through the facades and roof of the building and, therefore, reduce the cooling load, which contributes significantly to the building's total energy consumption.

To achieve high energy performance, all new construction projects are encouraged to meet and exceed criteria provided by the **Saudi building codes 601 and 602 (see SBC 601-chapter 5 for buildings except low-rise residential and SBC 602 -chapter 5 for low-rise residential buildings)**.

Credit: Chatamee Suriya, Shutterstock

Fig. 55. Appealing and convivial stairway



Credit: KAPSARC

Fig. 56. Natural light

Credit: KAPSARC

Fig. 57. Shade trees

Credit: KAPSARC

Fig. 58. Landscaping that complements the scale and type of the project

Credit: KAPSARC

Fig. 59. Transitional spaces, window details, and landscaping to express a cohesive identity

Credit: KAPSARC

Fig. 60. Landscape and hardscape elements complementing each other to reduce the heat, reinforce the site's design, and shape attractive, welcoming spaces

1.0

Building Energy Use and Conservation cont.

Thermal Bridges

Thermal bridges in all new air-conditioned buildings must be either insulated effectively or eliminated to minimize heat transfer. Heat bridges can exist at the junctions between concrete or steel beams, exterior walls and columns, and openings around doors and windows.

Thermal bridges can be avoided in all villas by increasing the efficiency of the envelope. The building envelope's average thermal transmittance (U-value) should not exceed 0.40 W/m²K.

Thermal Comfort Requirement

The heating, ventilation, and air conditioning (HVAC) systems in all existing and new buildings are required to provide the conditions provided by **Saudi building codes 601 and 602 (see SBC 601- chapter 5 for buildings except low-rise residential and SBC 602 -chapter 5 for low-rise residential buildings)**.

4. Building Systems

HVAC Equipment and Systems

To ensure efficient HVAC and heating systems and provide occupants with appropriate controls to regulate ventilation and temperature parameters, all new buildings' heat and cooling loads must be assessed according to the parameters specified in **SBCs 601 and 602 (see SBC 601, Chapter 6, for buildings except low-rise residential and SBC 602, Chapter 6, for low-rise residential buildings)**.

Lighting

Designing a premium energy-efficient lighting system using both electric and natural sources and lighting controls provides a comfortable and visually appealing environment for the space occupants. **The lighting systems shall meet the requirements of Saudi building codes 601 and 602 (see SBC 601- chapter 9 for buildings except low-rise residential and SBC 602 -chapter 9 for low-rise residential buildings)**.

Energy-efficient lighting solutions can be implemented in new construction, modernization, and renovation projects.

- Use light-emitting diode (LED) lights: LED lamps are recommended over incandescent lamps due to their high energy efficiency and long life. LED bulbs use 70–90% less power than a standard incandescent or compact fluorescent bulb.
- Install light controls: it is also recommended that multiple dimmers or switches be provided (near room entrances) to accommodate the occupants' ability to adjust the lighting according to their specific occupancy and preferences.

5. Renovation of Existing Buildings Objectives

TTo increase the energy performance of the existing building stock, each municipality has to set medium and long-term renovation objectives identifying. **The renovation initiatives should be selected based on their cost-effectiveness**. To fulfill this objective, the following steps are critical:

- Design a database at the city level to collect the critical information that helps assess the energy performance of the building units, e.g., size, construction year, construction system, and type of energy system.

> *“LED bulbs use 70–90% less power than a standard incandescent or compact fluorescent bulb.*

- Use the collected data to identify the buildings with lower energy efficiency.
- Implement a strategy to upscale the energy performance of the identified buildings.

6. Smart Technology Integration

Smart energy-saving devices (SESDs) have the potential to significantly improve building operation efficiency, reduce energy waste, and lower energy costs. Integrating smart technologies in buildings requires careful planning and execution. Here are some guidelines for integrating SESDs in buildings.

Build a Positive Mindset and Sustainable Digital Eco-System

- **Adopt a holistic approach** to involve all stakeholders; allowing time to adapt may help accelerate adoption and foster users' acceptance.
- **Conduct pilot studies** to test the behavior, sustainability, and capabilities of different technologies and services.
- **Harness the data collected** from pilots to enhance energy efficiency at the system and user levels.
- **Raise awareness** and show the impact of switching to SESD and the benefit of energy efficiency.
- **Provide financial incentives** to users to install SESDs, e.g., subsidies, rebates, tax credits, or other innovative mechanisms where the investment in SESDs will be covered by energy-costs savings resulting from the deployment of the SESDs.

Design Sustainability and Energy Conservation Goals

- Introduce energy rating labels.
- Introduce specifications to consider the standby energy consumption: e.g., stringent legislation has been introduced by the Energy STAR (2019) program and the EU Commission directive EU Directive 2005/32/EC (2017).
- Use the communication protocol to nudge users to reduce their energy consumption, e.g., sending information about their historical energy use, their optimal consumption regarding their characteristics, etc.

7. Improve Material Use and Resources Recycling

- Increase the quantities of recycled construction materials and reduce landfill waste. The recycling target is subject to the availability and cost-effectiveness of the recycled materials.
- Improve construction waste collection and separation. Waste construction containers must be available for the following material streams to facilitate source separation and recycling:
  - Metal
  - Concrete
  - Wood
  - Plastic
  - Other waste
- Improve waste recovery services during construction and demolition phases to increase re-used and recycled materials.
- Enforcing a recycled concrete use rate for major construction projects.

The recycling target is subject to the availability and cost-effectiveness of the recycled materials.

- Stimulate the use of sustainable materials that are appropriate for re-use and/or recycling.
- Increase the use of local and renewable inputs. For example, increase the use of cross-laminated timber, which serves to sequester carbon while replacing steel and concrete in structures.
- Renovate and extend the use of old buildings to make the building stock more sustainable and extend its life cycle. **This is subject to the cost-effectiveness of the different renovation options**.
- Strategic focus on reducing the weight of structures through innovative designs and materials.

Checklist	Yes	No	N/A
Comply with existing building codes and standards.			
Implement energy-efficient building practices, e.g., passive solar design, efficient lighting, and HVAC systems, and use energy-efficient appliances and equipment.			
Renovate existing buildings: implement programs offering incentives or financing for energy efficiency renovations.			
Encourage onsite renewable energy and smart technology integration.			
Enhance building energy efficiency through continuous monitoring and benchmarking of performance.			
Use a smart readiness indicator for buildings.			
Use a behavioral intervention and public awareness strategy.			
Collaborate with stakeholders to implement energy efficiency initiatives.			

1.0

Building Energy Use and Conservation cont.

Water Use and Recycling

1. Water Efficient Fittings

- Use highly efficient low-flow, low-flush fixtures to decrease potable water usage and reduce water waste. Conserving fixtures and fittings are encouraged to meet and exceed the Saudi Standards, Metrology and Quality Organization (SASO) criteria.
- Equip faucets with aerators to ensure maximum water efficiency.
- Dry urinals represent an alternative way to minimize the total consumption of potable water.
- Flushing devices serving toilets or urinals shall be of sufficient capacity and shall be adjusted to provide a volume of water for each operation to completely flush the fixture or fixtures they serve.
- For all buildings, if water condensation is generated by the air conditioning system, the condensation water must be properly collected and disposed of. To ensure proper drainage and to avoid standing water, condensate pans, and drainpipes must be installed. The condensate pipe must have a minimum air gap of 25 mm from the waste water pipe.

2. Water Metering

Meters should be installed in all new buildings to monitor and report water demand and consumption for the entire facility.

Additional water meters shall be installed for all buildings with a cooling load of 1 MW or more or a gross floor area of 5,000 m2 or more to record consumption data for major water uses in the building, and the primary water uses in and around the building (Al Sa'fat, 2023).

3. Reuse of Condensate Water

For all new buildings with a cooling load of 350 kW or more, condensate water from all air-conditioning equipment, air handling units or equipment handling a mixture of return air and outside air, where the outside air is not preconditioned, must be recovered and re-used. The condensate water can be re-used for irrigation, toilet flushing, or other on-site purposes wherein it will not come into direct contact with the human body.

4. Efficient Irrigation

For all new buildings, 100% water requirement for the total exterior landscaping must be irrigated using non-potable water or by use of drip or subsoil water delivery systems. The landscaping shall also include the area for green roofs.

All irrigation systems must incorporate backflow prevention devices if, at any point, they get connected to a potable water supply. The backflow prevention devices must be checked in line with the manufacturer's recommended practice.

Leverage smart technologies, such as IoT and Artificial intelligence, to optimize irrigation systems by integrating with weather observatories. This strategic alignment enhances rescheduling and management, ensuring more efficient use of resources and promoting sustainability in agriculture.

5. Wastewater Reuse

For all new construction, the building must be provided with a system for the collection and re-use of greywater (15 to 30%) (Al- Safat, 2020).

The following guidelines must be followed in all situations where a system is installed for the collection and re-use of greywater generated within the building or where it uses treated wastewater effluent from an exterior source:

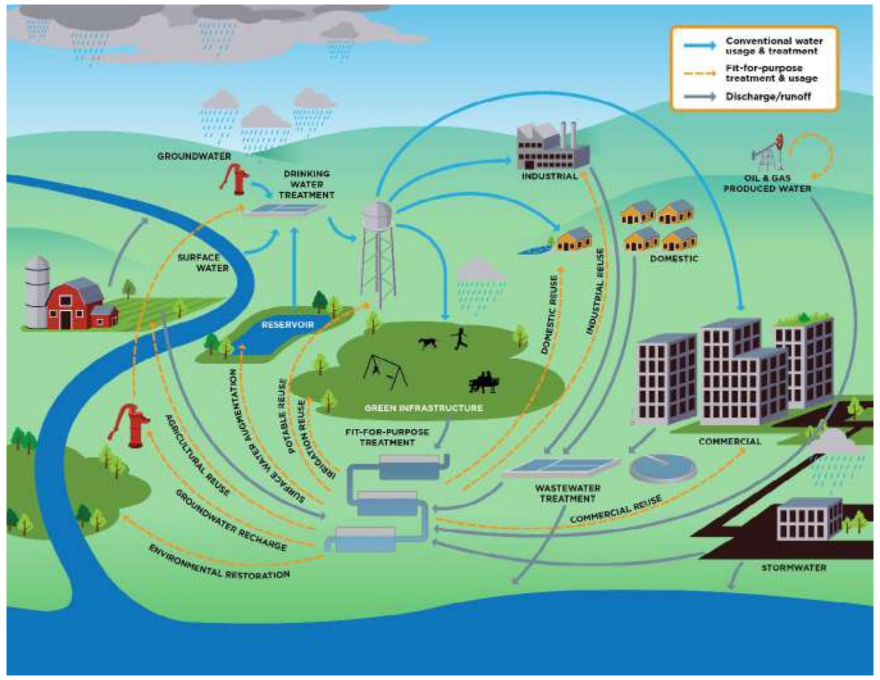
- The building shall be equipped with a dual piping system for collecting and recycling grey water. Pipes carrying grey water shall be color coded distinct from those used for potable water and shall be marked "non-potable".
- There must be a minimum air break of 25 mm between any potable water sources and greywater collection systems.
- An air gap of at least 25 mm shall be provided between any potable water source and the grey water collection systems.

A minimum of 50% of the wastewater generated by all new commercial car wash facilities must be recovered and re-used.

6. Water Conservation Programs

Implement water conservation initiatives that focus on educating businesses, industries and residents on water conservation practices.

Programs may include information on water-saving techniques, e.g., installing low-flow showerheads, as well as landscaping and irrigation practices.



Credit: Environmental Protection Agency https://www.epa.gov/waterreuse/basic-information-about-water-reuse

Fig. 61. Examples of water sources and uses

Credit: Adapted by the authors from the World Energy Forum, 2022, Accelerating the Decarbonization of Buildings: The Net-Zero Carbon Cities Building Value Framework

Fig. 62. Key focus areas and operational checklist

2.0

Key Terms

Air break: A plumbing configuration in which a discharge drain from a device or fixture flows into an open space before entering another fixture, container, or backflow preventer aimed at preventing the flow of contaminated water back into the system.

Building envelope: The building envelope comprises the outer components of a structure that serve as a boundary between the interior and exterior areas. In the case of a building with air conditioning, the building envelope is limited to the parts of the structure that isolate the controlled areas from the outside environment.

Building management system: A computer-based control system installed to oversee and regulate the mechanical and electrical equipment of the building, such as lighting, ventilation, fire systems, power systems, and security systems.

Blackwater: A type of waste water that is heavily polluted and contains human waste. Blackwater requires additional processing over greywater in order to neutralize any pathogens and remove organic matter before the water is safe for re-use.

Daylighting: The use of natural light from the sun or sky to illuminate interior spaces.

Desalination: The process of removing salt and minerals from sea water to be safe for irrigation or human consumption.

Ecological footprint: A measure of the land and sea area needed to supply the resources for human consumption.

Environmental education programs: A method of creating public awareness of environmental concerns and the potential benefits of conservation within a community or development. The program will engage residents by educating them about opportunities for individual contributions to the community's resource conservation efforts.

Glazed elements: All the building envelope components that allow light to enter, such as windows, plastic panels, skylights, and walls made of glass blocks.

Green roof: A roof that has been partially or fully covered with plants. It typically includes vegetation and soil, also known as a growing medium, carefully placed over a waterproof membrane. Sometimes, green roofs may have additional layers, such as a root barrier, drainage, or irrigation system.

Greywater: Greywater is a type of waste water that is generated from domestic sources other than waste conveyance from a water closet. Greywater can be filtered on-site for use in irrigation, waste conveyance, or washing.

Infiltration: The unintentional introduction of outside air into a building, typically through cracks in the building envelope and through use of doors for passage. Infiltration is often called air leakage. Infiltration is caused by wind, negative pressurization of the building, and by air buoyancy forces.

Primary energy: Is the raw fuel that is burned to create heat and electricity, such as natural gas or fuel oil used in on-site generation.

Recycling: Processing and converting used materials into new products, which avoids squandering useful resources, limits the usage of raw materials, minimizes energy consumption, and mitigates air and water pollution that may result from traditional waste disposal methods.

Reflectivity (solar reflectance): Describes how efficiently a material reflects solar radiation.

R-Value: A measure of thermal resistance used in building and construction. Under uniform conditions, it is the ratio of the temperature difference across an insulator and the heat flux. R is the inverse of U.

Secondary energy: The energy product (heat or electricity) created from a raw fuel, such as electricity purchased from the grid or heat received from a district steam system.

Sewage treatment plant: A facility that receives sewage from the municipality via a system of pipes and pumps for treatment to tertiary standards.

Site energy: The energy (electricity and natural gas) consumed per square foot of gross building area. This energy is measured at the site. To show electricity and natural gas together, they are converted into British thermal units.

Solar heat gain coefficient (SHGC): The fraction of incident solar radiation admitted through a window, door, or skylight, either directly transmitted and/or absorbed and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower a window's SHGC, the less solar heat it transmits.

Source energy: Takes into account the fuels consumed in the generation, transmission, and distribution of electricity, in addition to the energy losses from storing, distributing, and dispensing natural gas.

Treated sewage effluent (TSE): A fluid generated from sewage treatment that is free of contaminants and safe for reuse or release into the natural environment.

Thermal insulation: The techniques, procedures, or materials that are employed to decrease heat. Heat can be conveyed through conduction, convection, or radiation, but its effects can be mitigated by tackling one or more of these factors. This approach is contingent on the material's physical traits used for this purpose.

Thermal transmittance (U-value): The overall heat transfer coefficient (in watts). It is expressed in W/m^2K and describes how well a building element conducts heat. It measures the heat transfer rate through a building element over a given area under standardized conditions. U is the inverse of R.

U-Value: is the overall heat transfer coefficient; it describes how well a building element conducts heat. It measures the rate of heat transfer through a building element over a given area, under standardized conditions. U is the inverse of R

Visible transmittance (Tvis): A fraction of the visible spectrum of sunlight, weighted by the sensitivity of the human eye, that is transmitted through the glazing of a window, door, or skylight. Visible transmittance is expressed as a number between 0 and 1. A product with a higher Tvis value transmits more visible light.

Waste heat: Heat produced by mechanical and electrical equipment or industrial processes that can be reused for energy generation or pre-heating to reduce some demands of an HVAC system.

3.0

Compliance Checklist

Checklist	Yes	No	N/A
Implement water-efficient fixtures and appliances, e.g., reducing water consumption per capita and the percentage of recycled water in the city water supply.			
Establish water conservation and recycling targets.			
Develop and enforce water-reuse systems, e.g., graywater and rainwater collection systems.			
Enhance irrigation practices, e.g., drip irrigation and soil moisture systems.			
Use preventative maintenance to reduce water losses: repairing leaks and improving infrastructures.			
Develop water-sensitive urban design, e.g., permeable pavements and green roofs.			

Public Realm

Public Realm

Introduction

Every day, light-duty vehicles (LDVs) and heavy-duty vehicles (HDVs) consume over 800,000 barrels of oil equivalent, representing approximately 18% of the primary energy consumption in Saudi Arabia. (*Saudi Energy Efficiency Center, 2022*).

In the past decade, Saudi Energy Efficiency Center (SEEC) has worked in collaboration with various transport stakeholders to realize a reduction of roughly 75,000 barrels of oil equivalent per day in the road transport sector compared to a business-as-usual scenario. (*Land Transport Sector, n.d.; Saudi Energy Efficiency Center, 2022*). The pursuit of maximal energy efficiency has led to the exploration of novel focus areas, encompassing initiatives that integrate energy efficiency considerations into urban planning and district cooling systems. The public realm guidelines emphasize the significance of energy efficiency in outdoor spaces, ultimately contributing to the development of energy-efficient cities.

The development of the Saudi regulated public realm is remarked with the Royal Decree no. 8723, 20/07/1357H. in 1937 to establish Makkah Municipality with planning responsibilities to enhance the public realm surrounding Masjid al-Haram. (*Ali Al-Hathloul & Anis-ur-Rahmaan, 1985*). Early Saudi planning efforts focused on pedestrian-oriented development (POD) in the historic public realm of Makkah, Madina, Jeddah, and Riyadh demonstrating urban compacted development, mixed land uses, mix of housing types. (*al Naim, 2013; BACKGROUND AND PURPOSE, n.d.; Fathil et al., n.d.; Saoud Ba, M'phil & Salem Bsc, 2002*). On the other hand, in 1938, the Arabian-American Oil Company (ARAMCO) established its first oil camp based on vehicular-oriented development emerging a gridiron street pattern. (*Ali Al-Hathloul & Anis-ur-Rahmaan, 1985; Osra et al., 2017*). In 1947, Aramco's surveying engineers prepared land subdivision plans for parts of Dammam and Khobar as ordered by the Governor of Eastern Province. (*Ali Al-Hathloul & Anis-ur-Rahmaan, 1985*). Shortly, Aramco land subdivision patterns became exemplary for Saudi modern neighborhoods accommodating the comfortable movement of pedestrians and vehicles.

The modern history of Saudi public realm is made with the marvelous support of the Administrative Console of Makkah Municipality and Aramco. In the early 1950s, Saudi Ministerial headquarters had been relocated to Riyadh, where labor market equilibrium demanded employees. (*Harrington, 1958*). In response to Riyadh's growing demand for housing, social amenities, and commercial activities, al Malaz Land Subdivision Project had been developing between 1953 and 1957 based on the gridiron street pattern. (*Harrington, 1958; M Al-Said, 2003*). In late 1960, Saudi planning regulations have been developed to cover city-wide master plans as the supergrid and superblock have adapted to accommodate the rapid urban development. (*Ali Al-Hathloul & Anis-ur-Rahmaan, 1985; M Al-Said, 2003*). Since then, Saudi urbanization has been rapidly growing with unprecedented population growth, economic development, and industrialization ranking Saudi Arabia in the top 10 oil consumption countries worldwide. (*Kahouli et al., 2022; Mezghani & ben Haddad, 2017; Oil Consumption by Country - Worldometer, n.d.*).

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Early Saudi planning efforts focused on pedestrian-oriented development (POD) in the historic public realm of Makkah, Madina, Jeddah, and Riyadh demonstrating urban compacted development, mixed land uses, mix of housing types.

The visionary leadership of Saudi Arabia responded to the increasing energy consumption growth with a course of conservation strategies leading an energy-efficient country. In 2020, SEEC has achieved over 350 thousands barrel of oil equivalent per day compared to business as usual. (*Saudi Energy Efficiency Center, 2022*). And, Saudi efforts are expected to make approximately 1 million barrels of oil equivalent per day compared to business as usual by 2030. (*Saudi Energy Efficiency Center, 2022*). Saudi Arabian inter-agency efforts are leading to the adaptation of transit-oriented development strategies observed in the public realm of areas surrounding the King Abdulaziz Project for Riyadh Public Transport, Riyadh Sports Boulevard, and Alpin Project in Yanbu Industrial City, and Diriyah Giga-Project.

Guidelines and principles contribute toward sustainable and energy-efficient cities under the pressure of future urbanization and population growth. The emerging public realm guidelines aim to cover a range of development strategies that directly support energy efficiency. In addition, it helps Saudi communities to be more attractive, economically stronger, and more socially diverse. The guidelines are developed with Saudi planning agencies collaborating with SEEC for future adaptation as a reference for developing planning ordinances, development regulations, and planning and design technical guidelines. Developing multi-layer planning processes including guidelines, principles, and modeling is critical before execution to mitigate the risk of missing the comprehensive objective to which planning policies were designed to tackle such as increasing energy efficiency in the city.

Provisioning for energy efficiency in the public realm to reduce vehicle kilometers traveled (VKT) per capita is primarily placed into three major subsections including alternative transportation methods, urban forestation, and urban infrastructure. There are three strategic measures for walkability and cyclability which are the most critical aspect of the energy-efficient public realm. (*Doğan, 2021; Frank et al., 2010; Juul & Nordbø, 2023; Kim et al., 2019; Lam et al., 2022; Rahman & Nahiduzzaman, 2019; Rogers et al., 2011; Wey & Chiu, 2013*). First, objective measures include the density of facilities (points), proximity (distance), and pattern (area) as essential elements for GIS modeling. The objective measures would support monitoring walkability in neighborhoods from a distance perspective. Second, infrastructure design measures and includes bike lanes, cycling facilities, tree-lined and shaded streetscapes, traffic flow, sidewalks, and crosswalks. Third, subjective measures such as cultural changes, social perception, and attitudes towards walking and cycling.

RELATED DOCUEMNTS

Reference made to the following national public realm guidelines and principles:

- National Public Realm Design Manual by MoMRAH
- National Urban Design Thematic Guidelines by MoMRAH
- Executive Guidelines for Energy Efficient Cities by MoMRAH

Public Realm

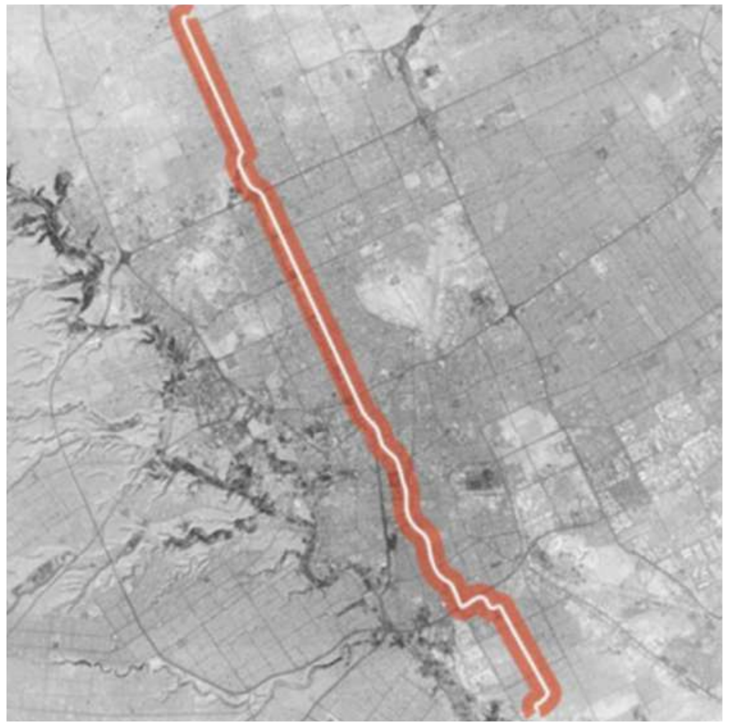
Introduction cont.

Best Practices

Olaya–Bat'ha Corridor, Riyadh City

The Royal Commission for Riyadh City developed Olaya Bat'ha Corridor Streetscape Renovation as part of the King Abdulaziz Project for Riyadh Public Transport, Metro Line 1, which finds its North-South axis through 8 different streets including Olaya St. – King Faisal St. - al Mansuriya St. – Bat'ha St. – Islamabad St. – Hwy 500 – Shabab St. – and Mohammad Rashid Rida St. as shown on Figure 63. The streetscape renovation covers over 3,000 km^2 including Olaya Bat'ha Corridor's length of approx. 38 km and 100 m of each intersecting street with different street widths. (*Schares et al., 2014*). The Project challenge is to create a consistent and interconnected public realm supporting the provision of alternative transportation methods. Building, underground parking ramps, walls, on-street parking lots, and other barriers are critical hardships to shift Olaya Bat'ha Corridor from vehicular-oriented development to transit-oriented development as shown in Figure 64 and Figure 65.

The Metro Urban Design and Streetscape Manual (UDM) by RCRC has guided the contractor to create a flexible yet consistent public realm for Olaya Bat'ha Corridor with priority on comfortable movement of pedestrians to support the transit system to be functional and operational. Olaya Bat'ha Corridor Public Realm Strategy based on UMD employs the 'Link and Place' method to balance priorities between Street Section Zones in each Character Area as shown in Figure 66. (*Bishop et al., 2014*). And, the strategy classifies Olaya Bat'ha Corridor into five Character Areas including Heritage Street, Civic Street, Shopping Street, Central Olaya, and Access Street as shown in Figure 67. Street Section Zones include Pedestrian Zone, Cycle Zone, Buffer Zone, Median Zone, 2 Carriageway Zones, Parking Zone, and Frontage Zone. The highest



Credit: (Bishop et al.)

Fig. 63. Olaya Bat'ha Corridor

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Building, underground parking ramps, walls, on-street parking lots, and other barriers are critical hardships to shift Olaya Bat'ha Corridor from vehicular-oriented development to transit-oriented development.

Credit: Lars Pertwee

Fig. 64. OBC before renovation

Credit: Nawaf Alnafisee

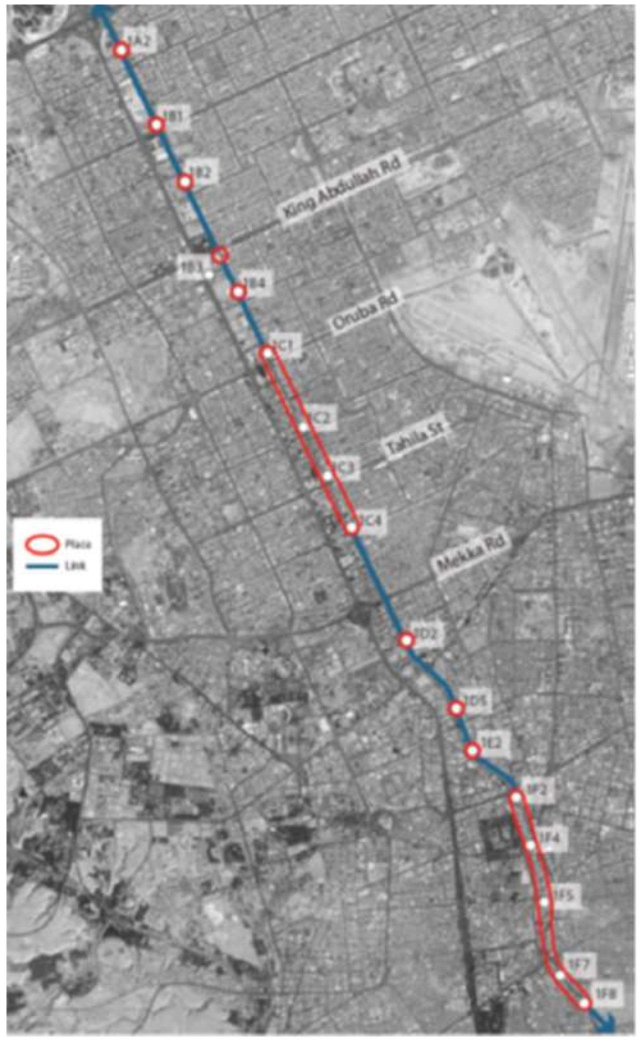
Fig. 65. OBC after renovation

Public Realm

Introduction cont.

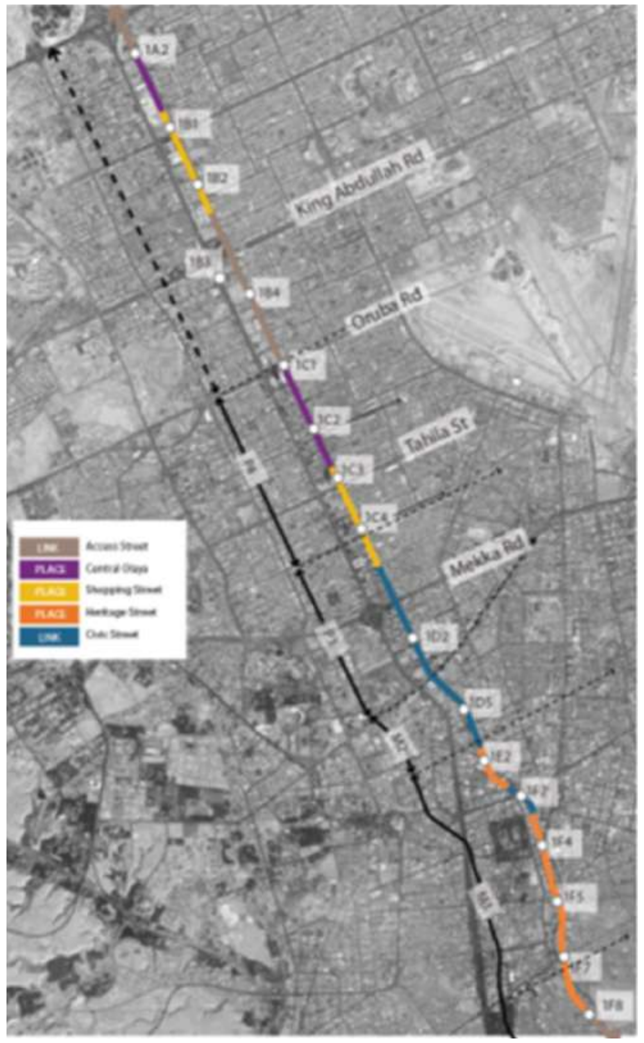
priority is made for the Pedestrian Zone. The public realm along Olaya Bat'ha Corridor responds to different pedestrian barriers, land uses, building typologies, street typologies, urban morphologies, and water resources enabling alternative transportation methods.

The transit-oriented development of Olaya Bat'ha Corridor provides biodiversity, and local character to reduce energy and water consumption, and life-cycle costs. The xeriscaping methodology shows sustainable plants and irrigation systems reducing urban heat island enabling energy efficiency in Olaya Bat'ha Corridor public realm. The sustainability principles of Olaya Bat'ha Corridor are observed in the water management system, materials, culture and local community, public health, and design. The five sustainability principles optimize energy efficiency by encouraging alternative transportation methods. Olaya Bat'ha Corridor enables Riyadh City to become a global cultural capital that puts humans first preserving the surrounding urban ecology. The transit-oriented development of Olaya Bat'ha Corridor along with the rest of the public transit system components redefines the concept of urban development made in Saudi modern history.



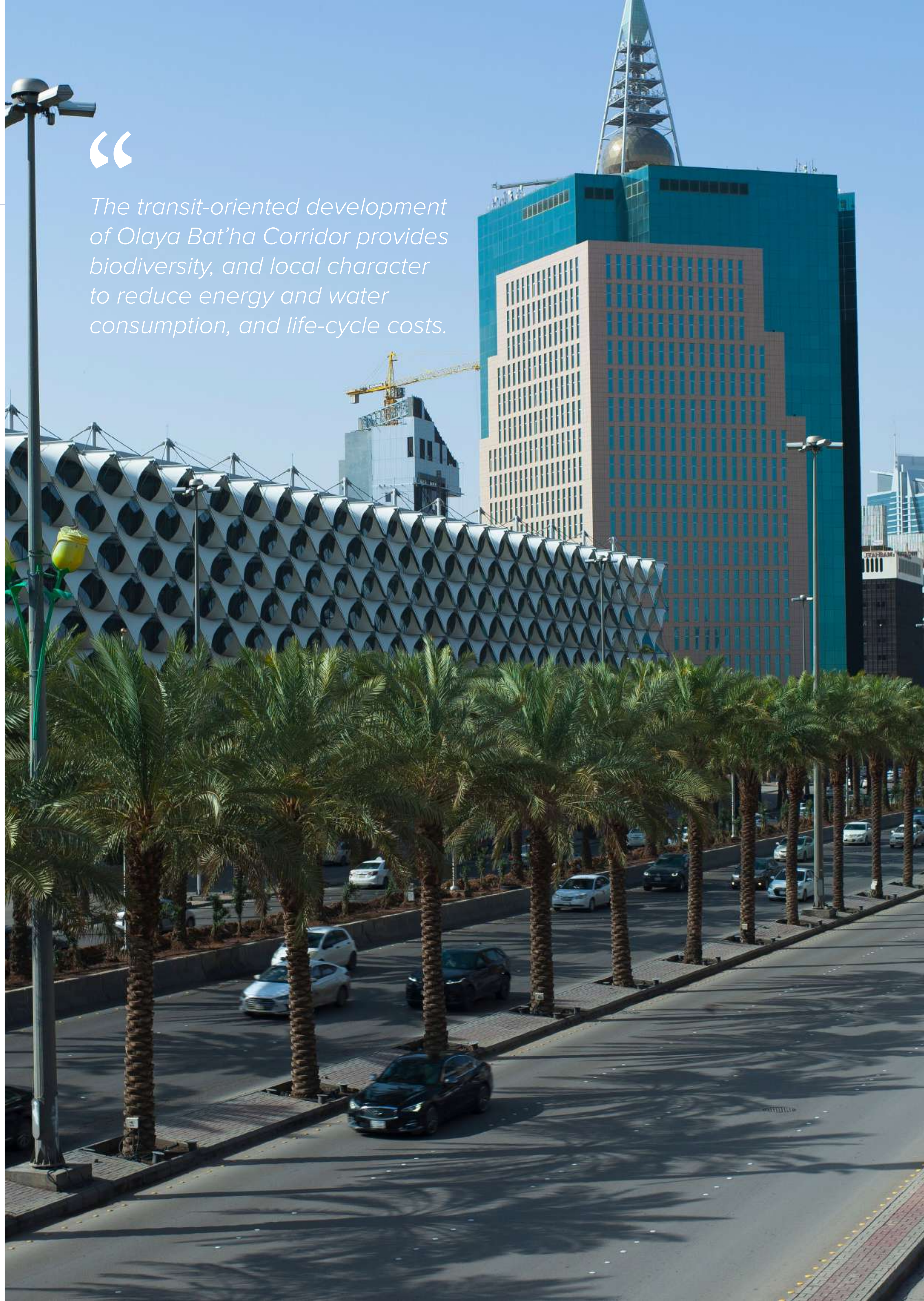
Source: (Bishop et al.)

Fig. 66. OBC Link and Place



Source: (Bishop et al.)

Fig. 67. OBC character area integrated with Link and Place



> *"The transit-oriented development of Olaya Bat'ha Corridor provides biodiversity, and local character to reduce energy and water consumption, and life-cycle costs.*

Public Realm

Introduction cont.

Wadi Hanifa, Riyadh City

The Royal Commission for Riyadh City instituted the Environmental Rehabilitation Program for Wadi Hanifah and its Tributaries to thrive Riyadh's urban resilience. Wadi Hanifah Comprehensive Development Plan gave priority to preserving and rehabilitating the public realm using landscape as an ecological infrastructure to restore and enhance the urban ecological systems' capacity to support humanity along 120 kilometers with different width ranges from 100 to 1000 meters as shown in Figure 69. (*Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries, n.d.*). The wadi has five sections including bed, floodplain, horizontal alluvial terraces, valleys, and branches as shown in Figure 68.

Wadi Hanifah was treated as a source of stone and aggregates for construction, a construction waste dump, and a sewer from the early 1970s to the late 1980s due to the rapid urbanization of Riyadh City as shown in Figure 70. (*Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries, n.d.; Saudi Aramco World: A Wadi Runs Through It, n.d.*). In response to the deterioration of Riyadh's urban ecological balance, RCRC has developed Wadi Hanifah Comprehensive Development Plan with the aim of managing natural and human-made disasters, protecting human life, preventing the impact of economic, environmental, and social hazards, and promoting well-being and inclusive and sustainable growth. In November 2010, Wadi Hanifah became one of the World's flagship urban ecological developments with a unique public realm supporting alternative transportation methods, urban forestation, and energy-efficient infrastructure as shown in Figure 71. (*Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries, n.d.; Saudi Aramco World: A Wadi Runs Through It, n.d.*).

The public realm of Wadi Hanifah supports walkability and cyclability with over 45 kilometers of pedestrian walkways paved with rocks, and 30,000 desert trees and 7000 palms were planted in the wadi's bed. (*Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries, n.d.*). In addition, 6 open parks are made interconnected to the wadi. The public realm shows flexibility and consistency in supporting sustainable urban development. Wadi Hanifah became an international reference in the field of urban ecological development with the World's 5 most admired international awards for the new standards of excellence in built environment practices.

> *"In addition, 6 open parks are made interconnected to the wadi. The public realm shows flexibility and consistency in supporting sustainable urban development.*

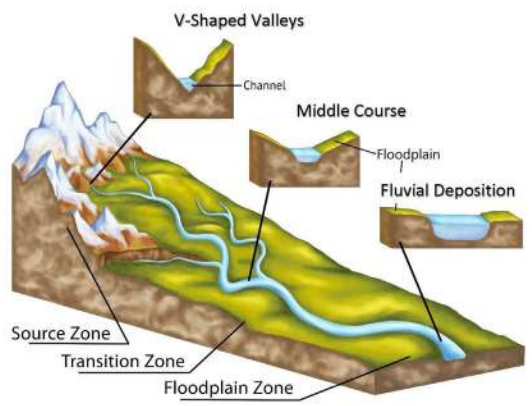


Fig. 68. The anatomy of Wadi Hanifa: bed, floodplain, horizontal alluvial terraces, valleys and branches

Source: Adopted from (Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries).

Fig. 69. Wadi Hanifa and its Tributaries

Source: Adopted from (Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries)

Fig. 70. Wadi Hanifa before the RCRC's Environmental Rehabilitation Program

Source: Adopted from (Royal Commission for Riyadh City - Environmental Rehabilitation Program for Wadi Hanifa and Its Tributaries)

Fig. 71. Wadi Hanifa after the RCRC's Environmental Rehabilitation Program

1.0

Alternative Transportation Methods

Walkability and Accessibility

Energy efficient public realm is measured by its walkability that ensures comfortable movement of pedestrians from a geographical point to another within urban areas with less dependency on vehicles. The rate of walkability is measured by three principal measures including the accessibility of amenities, pedestrian walkway conditions, and willingness to walk. First, the accessibility of amenities is an objective measure with three latent variables including the density of facilities (points), proximity (distance), and pattern (area) as essential elements for geographic information system modeling. Second, the quality of pedestrian walkway conditions is another objective measure considered with the physical aspects of safely accessible walkways, curb ramps, street crossings, underpasses, and road traffic. Third, the willingness to walk is a subjective measure that depends on the social perception of walking the streets.

There are a number of factors that contribute to the walkability of a place. Among them: sidewalks, street crossings, and microclimate are the most important factors. It is recommended that all streets connecting destination points within a neighborhood be designed with sidewalks adjacent to them. Just the presence of a sidewalk presents an opportunity for travel on foot. Sidewalks are also key ways that residents and visitors move between parallel parking spaces and destinations on foot. Street crossings are ways that pedestrians on a sidewalk on one side of the street can move safely on foot to the other side of the street. The most common and cost effective way of accomplishing this is with a marked crosswalk on the road connecting curb ramps. Bridges and tunnels are also ways of crossing streets but are much less cost effective. For street crossings at larger roads, it is important to provide for a median of at least 1.5 meters wide to allow a pedestrian a point of respite before continuing to safely cross the rest of the street.

Microclimate is another factor that contributes to walkability. Microclimate refers to a localized zone where the climate differs from the surrounding area. In the case of pedestrian zones, it's the desire to create walking paths that are shaded and feel cool. This can be accomplished in a number of ways. One way this can be accomplished is through the use of vegetation. A more effective way is by utilizing shade from built elements like buildings, walls, or canopies. These built structures do not need irrigation or maintenance like vegetation. Even using walkway materials that are light in color and have a high reflective value helps in cooling the immediate environment. Hardscape materials (i.e. color, texture, size, pattern, etc.), also influence walkability. In denser residential areas, retail areas, and heavily used public open space areas, it is desirable to use smaller pavers made of concrete or stone rather than poured concrete or asphalt for pedestrian sidewalks. This is because the pedestrian experience is heightened by walking over smaller paving units that contrast in size and color from the paving used in the roadways.

A good land plan will consider how closely amenities are located to homes. A good rule of thumb in hot desert environments such as Saudi Arabia, is that amenities with close neighborhood ties should be located within a brief five-minute walk from all homes. These types of neighborhood amenities include schools, mosques, neighborhood parks, local neighborhood commercial centers, and playgrounds. This is not because everyone is expected to walk to them every time they want to use them, but it gives someone the option to do so if they feel like it or if it happens to be a cooler part of the day. If they do happen to drive to a neighborhood amenity, by locating it closer, at least the total vehicle miles traveled is reduced. Community-wide amenities like retail shops, libraries, restaurants, and food markets can be located at a farther distance from homes, but still an easy walk. This still keeps the amenities close enough to walk or bike to during the cooler part of the day if someone is willing to travel a little farther.

> “*The rate of walkability is measured by three principal measures including the accessibility of amenities, pedestrian walkway conditions, and willingness to walk.*

Open Space and Connectivity

Open spaces are urban nodes and pathways where community get connected promoting multimodal transportation. Open space comes in many forms including parks, playgrounds, plazas, sidewalks, recreation areas, drainage areas, and buffer zones. Recent sustainable land developments in Saudi Arabia such as Olaya Bat'ha Corridor and KAPSARC that include open space ideas as central elements to their design. Although the exact percentages of open space differ per plan, a good minimum benchmark to use in new developments is 10% of all land area should be devoted to open space. These spaces should all be publicly accessible and ideally incorporated into the plan in such a way that they are visible and part of the character of the overall development. Civic and other important public buildings should be sited on or near public open space. Various-sized open spaces should be accounted for as well. Neighborhood parks are best kept smaller while larger parks should draw from many neighborhoods. Squares and plazas should be sited central to denser development to allow for outdoor use within it. Pedestrian corridors like trails and sikkas should be the open space links that help to tie different parts of the plan together.

Walkway Conditions Quality

Consideration needs to be given to creating pedestrian walkways that are relatively easy to use without being interrupted with unnecessary obstructions. A good rule of thumb in pedestrian- friendly streetscapes is to provide a "clear zone" for pedestrians. The range of sizes for the clear zone is from 1.5 meters wide along smaller streets and 3 meters along retail streets with wider sidewalks. The clear zone needs to be free from any vertical obstructions including: pole lights, sign poles, trees, fire hydrants, transformers, walls, fences, curbs, etc. Since many of these types of items belong within the streetscape environment, their placement needs to be considered in relation to how pedestrians will move through the space.

Another accessibility issue which tends to discourage walking and biking is abrupt changes in elevation along a path. The most comfortable sidewalks to walk are those which are almost flat to gently sloping. Abrupt changes to elevation include: curbs, steps, steep grades, etc. Ideal slopes for walkways range from 1%-5% longitudinal slope and 1%-2% cross slope. For walkways that need to connect elevations that force steeper grades, ramps with handrails and steps are to be provided. A common way that designers and engineers create gently sloping sidewalks in the urban environment is with the use of curb ramps. Curb ramps allow pedestrians to walk from a surface at the top of the curb to walk to a surface at the bottom of the curb without having to encounter a vertical step. All intersection crossings need to employ curb ramps that lead to crosswalks across the roadway, see figure 14. Ideally driveways, alleys, and minor vehicular crossings are raised to sidewalk level, avoiding the need for a curb ramp.

The design of the public realm plays a crucial role in accommodating bicycles and pedestrians. There are a number of ways in which planners and landscape architects design roadways to slow down traffic, allow free and safe movement of people, and create pleasing, aesthetically appealing environments. The design of the various road sections in a project, from the very largest roads to the small alleys, is the primary way to accomplish sustainable goals within the public realm. Keeping drive lanes as narrow as possible will prevent cars from driving too fast within neighborhood environments. Parallel parking needs to be provided on a majority of neighborhood streets. Parked cars on the side of the road do good things for an urban design. First, parked cars provide protection to pedestrians walking on the sidewalk from adjacent travel lanes. Also, by distributing the parking for the community along roads, it is easier for people to park closer to their destinations. This has the added benefit of reducing the amount of parking lots needed to be planned for in the community. Curb extensions (ie. bulb outs), should be utilized at intersections. Curb extensions slow down moving traffic, provide safety to parking cars, and allow pedestrians a shorter distance to cross the street. All curb radii at intersections need to be kept as tight as possible. Wider curb radii presents problems in the design of the public realm because it increases the distance for pedestrians to cross the street. There may be instances where larger curb radii has to be provided to accommodate trucks and/ or oversized emergency vehicles, but in most cases these types of vehicles can maneuver through fairly tight radii.

> “*Although the exact percentages of open space differ per plan, a good minimum benchmark to use in new developments is 10% of all land area should be devoted to open space.*

1.0

Alternative Transportation Methods cont.

Bike Lanes

Bicycle lanes define a dedicated area for bikes to travel one way on the road and are typically utilized on slower-moving higher-order roadways. Bicycle lanes may be found on the left or in a contra-flow configuration on one-way roadways. Buffered bicycle lanes offer more lateral space between the bicycle lane and the adjacent vehicle travel lane, like regular bicycle lanes (usually through striping). The direction of the bike lane and the lane designated only for usage by cyclists should be indicated by pavement markings (perhaps including pavement coloring).

Drainage inlets and utility covers must be flushed with the surface and positioned so as not to obstruct a cyclist's course of movement. Bicycle lanes are best when they are 2 meters wide for curb-tight lanes next to on-street parking and 1.8 meters wide with a buffer between them and the parking lane. The preferred buffer width is 0.6 meters, and the preferred buffer treatment is two solid white lines, with diagonal crosshatching or chevron markings if the buffer area is wider than 0.9 meters.

Bicycle lanes need to be kept separate from sidewalks meant for walking pedestrians. The mingling of the bicycles and pedestrians on narrow pathways can be dangerous. People on bicycles generally travel farther distances than people on foot, so it is often most appropriate to design bike lanes next to vehicular travel lanes. Also, bike lanes are usually paved with asphalt since the fast moving bikes travel better over smooth materials. Sidewalks, on the other hand, can be smooth or textured.

Street Sections

Based on a number of factors, there will be different types of streets within developments. Streets which need to carry lots of traffic are to be the widest and are characterized as arterial roads. Intermediate and low traffic streets are to be narrower as they primarily feed residential developments and are called collector roads. Alleys and driveways carry very little traffic, and therefore have the narrowest street sections. Public transport lines run alongside higher traffic roads, such as arterials, because the street section of an arterial roadway is wide enough to accommodate the added lanes/ tracks.

Whether running down the center of the street or off to the side, transport lines and dedicated transport lanes need to be considered in concert with overall vehicular and pedestrian circulation pathways. Medians, strips of land running between travel lanes of opposite directions, can be employed in any width of street section, but should be at least 1.5 meters wide. Still, the uses of medians are recommended primarily in larger arterial roads where transport lines or roads are designed in a more naturalized setting.

On larger streets, bicycle lanes need to be separated from vehicular travel lanes and given their own trail in the median. On smaller streets, a dedicated bicycle lane adjacent to the vehicular travel lanes will suffice. Parallel parking, if used in the street section, should always occur on the right hand side of the direction of travel. The spaces for parallel parking are to be narrower than the adjacent travel lanes. Sidewalks, which are to be installed along all streets that are connecting neighborhood destinations, need to be on both sides of the street.

> *“Bicycle lanes may be found on the left or in a contra-flow configuration on one-way roadways.*

For larger roadways, it is highly recommended that the sidewalk be offset from the adjacent travel lanes with a buffer of trees, planting, or gravel strip in between. This is because it feels more comfortable to walk down a street when not directly adjacent to moving traffic. Lastly, streetscape elements such as furnishings (i.e. benches, litter receptacles, ash receptacles, bike racks, parking meters, etc.), lighting, transport stops, trees, and signage is best placed within the buffer section, as this preserves the pedestrian “clear zone.”

The following is a list of elements that a streetscape section typically, although not always, needs to address:

- Adequate number of lanes in each direction of the road per traffic impact studies and engineered road designs.
- Appropriate width of travel lanes based upon anticipated speed of travel. Faster moving cars need wider lanes than slow moving cars.
- Placement of parallel parking on one or both sides of the street.
- Placement or omission of median in center of road.
- Location of transport lines/ dedicated bus lanes.
- Location of bicycle lanes or bike trail.
- Placement and width of sidewalk on each side of the street.
- Placement of street trees and/ or shade canopies.
- Placement of streetscape elements: site furnishings, lighting, transport stops, trees, and signage.

Streetscape Elements

Elements like benches, trash receptacles, ash receptacles, and lighting play a role in creating a welcoming experience along pedestrian sidewalks. It is best to strategically place benches along walkways to provide respite from long distances. It is also a good idea to place benches near building entrances and busy retail streets- places where people will like to rest. Trash receptacles and ash receptacles are important parts of successful streetscape designs.

Without receptacles, trash and cigarettes are more apt to end up as litter. Receptacles should be placed near seating areas and building entrances. Lastly, lighting is important from a safety and aesthetic standpoint along sidewalks. A well-lit streetscape, is not too brightly nor too dimly lit. Successfully lit streetscapes tend to have an even distribution of light rather than hot spots of bright light juxtaposed with gaps of no light. Pedestrian scaled light fixtures (3.5 to 5 meter height) are to be used along streetscapes to aid in the pedestrian experience and with the even distribution of light. Lights pole locations need to be coordinated with tree planting locations so the leaves/ fronds of the trees do not adversely impact the dispersal of light on the sidewalks.

Transport Stops

Since communities will be incorporating public transport into the development, there needs to be dedicated transport stops where buses/ light rail trains stop and allow pedestrians to get on or off. In some cases where transport stops will be frequently used (i.e. a bus/ shuttle stop that is used every 5-10 minutes), a basic sign and marked road pavement marks the transfer point.
In cases where the public transport stops more infrequently, covered transport stops need to be designed to shield pedestrians from direct sun and wind. For larger transfer points between bus circulation lines or from bus to light rail, an air-conditioned transport stop is recommended. The air-conditioned stop will keep pedestrians cool and protected while waiting for their bus/ train. If waiting for transport is a comfortable experience, it will encourage more widespread use of public transport.

Wayfinding Signage

Signage is an important element in the public realm because it helps direct pedestrians, bicyclists and vehicles to destination points. The most effective signage is either mounted on freestanding poles or incorporated into the architecture of adjacent buildings. Site wall signage should generally be avoided in urban areas if not needed for the additional function of retaining earth. Freestanding wall signs tend to take up lots of space which could otherwise be used for pedestrian circulation. The size of the text needs to be thought about as well. The text size needs to be large enough to easily be read when walking up close and at a reasonable distance as well if meant for cars. Arrows and other related symbols should be used to give direction. Contrasting and complimentary colors on signs help make the signs more readable and to stand out from their surroundings. Many times, graphic symbols are used on signs instead of words because graphic symbols are easy to recognize from a distance and keep the signs from having too much text. For pedestrians, maps, bus schedules, or other more detailed information can be located at eye level in a smaller text and graphic size.

Tree Canopy

Providing a healthy tree canopy within a development does a number of positive things from a sustainability standpoint. Trees need relatively little irrigation water when compared to turfgrass. They also shade the surrounding environment. On a grand scale this has an effect on building energy use and the ambient temperature of the public realm. Trees also have a way of bringing life and character to a neighborhood. The sound of wind passing through palm fronds, the smell of flowers, and the various shades of green reinforce the importance of nature within the built environment. Within the recent Saudi Arabian development projects of KAPSARC, Jebel Heights, and the South Dhahran Housing District, at least half of the roads within the projects have street trees. These street trees frame the driving corridors, shade the parallel parking spaces, and shade the sidewalks. All new developments need to strive to dedicate enough reclaimed water in the irrigation water budget to support street trees on at least 50% of the roads.

2.0

Urban Forestation

Urban Heat Island Reduction

Urban heat island reduction refers to the efforts made to mitigate the effects of urbanization on the local climate, particularly the increased temperature in urban areas compared to surrounding rural areas. This phenomenon is caused by the absorption and re-radiation of solar energy by urban surfaces like buildings, roads, and pavements, as well as the reduced vegetation cover and increased human activities. Increasing green spaces and vegetation cover can help cool the surrounding air by providing shade and releasing moisture through transpiration. Using reflective or cool materials or light-colored materials can reduce the absorption of solar radiation and reflect more sunlight back into the atmosphere. Enhancing natural ventilation and designing buildings and streets to promote natural ventilation can reduce the need for air conditioning and improve air quality. Implementing green roofs and walls can reduce the amount of heat absorbed by buildings and improve air quality by trapping pollutants. Promoting sustainable transport by encouraging cycling, walking, and public transportation can reduce the number of vehicles on the road, which contribute to the urban heat island effect. Urban heat island reduction strategies can reduce the temperature in urban areas and improve the overall quality of life for residents.

Community Gardening

Community gardening refers to the shared space in which individuals or groups of people come together to cultivate and harvest plants, vegetables, and fruits. These gardens can be located in urban or suburban areas and are often created on vacant lots, rooftops, or other unused spaces. Community gardens can provide a source of fresh produce for residents who may not have access to healthy food options. Gardening is an excellent form of physical activity, and community gardens provide a space for people to get outdoors and move their bodies. Working together in a shared space, community members can build relationships, share knowledge and skills, and work towards a common goal. Community gardens can improve the environment by reducing stormwater runoff, improving soil quality, and increasing biodiversity. Community gardens can serve as an educational resource, teaching participants about gardening techniques, sustainable agriculture practices, and the importance of healthy eating. Overall, community gardens are a valuable asset to the public realm providing a range of benefits to its participants and the surrounding environment.

> “
> *Community gardens can provide a source of fresh produce for residents who may not have access to healthy food options. Gardening is an excellent form of physical activity, and community gardens provide a space for people to get outdoors and move their bodies.*

Xeriscaping Approach

Xeriscape is a type of landscaping that conserves water by using drought-tolerant plants, efficient irrigation systems, and other water-saving techniques. The term “xeriscape” was coined in Colorado in the 1980s and is derived from the Greek word “xeros,” which means dry. Xeriscaping emphasizes the use of native plants and other low-water plants that require little or no supplemental watering, reducing the need for irrigation and saving water. Other practices that are commonly used in xeriscaping include using mulch to retain moisture in the soil, grouping plants with similar water needs together, and reducing the amount of turf grass in the landscape. Xeriscaping can be used in any climate, but is especially important in arid regions where water is scarce.

Irrigation Guidelines

1. 100% of water for irrigation to be sourced from a reclaimed source such as treated gray water, treated black water, stormwater collection, cooling system byproduct, or other secondary source.
2. Quantity of irrigation water should be limited using a water budget. Limit the total amount of irrigation needed to sustain the landscape to what is available as a reclaimed source-no well or potable water used. Based on the amount of reclaimed water available, limit the amount of plantings to what can be sustained by that quantity at peak times of the year. For the first 30 days after initial landscape installation, unlimited water use will be allowed for plant establishment. A permit must be applied for which allows this one time easing of the water budget. After the 30 day establishment period, the water budget goes back into effect.
3. No surface spray irrigation allowed except in public recreation areas or play fields. This will limit turfgrass areas only to play fields and recreation areas. Turfgrass is prohibited from streetscapes, parking lots, buffer areas, building entrances, and other non-recreation spaces.
4. Irrigate only during non-daylight hours unless using capillary irrigation delivery. Irrigation is prohibited between the hours of 9:00am and 7:00pm.
5. Mulch all irrigated planting areas (non-turf) with locally-available mulching materials to cover bare planting soil in irrigated areas to a 50-75mm depth.
6. Provide regular maintenance and monitoring of the irrigation system. Monitoring should be constantly occurring by maintenance crews. Any issues should be reported and addressed. Maintenance of the entire system should occur at least four times a year. Adjust water delivery according to dry and wet spots in the landscape. Adjust spray pattern for individual heads. Adjust water delivery based on sun exposure. Adjust water delivery according to seasonal needs. Adjust water delivery according to any new plantings. Check valve boxes. Check the controller if power has been lost. It may need to be reset.
7. Provide irrigation zones with independent control valves, segregated by plan needs. Install a flow sensor and master valve on the entire system. Install a controller that can read the flow of each zone valve and shut down in the event of inconsistent/programmed flow. All turfgrass spray heads should be on separate zones from drip. All drip irrigation areas should be zoned according to plant water need categories.
8. Restrictions apply to all publicly-accessible irrigated areas (not single family villas).

> “
> *Quantity of irrigation water should be limited using a water budget. Limit the total amount of irrigation needed to sustain the landscape to what is available as a reclaimed source-no well or potable water used.*

2.0

Urban Forestation cont.

Water Budgeting Guidelines

1. Determine the source of reclaimed water to be used for irrigation. Most projects in Saudi Arabia should consider using Treated Sewage Effluent (TSE) as the primary water source for irrigation.
2. Consult with the Project Engineer to determine total daily TSE amounts for the development.
3. Categorize the types of landscapes desired in the project. Typical categories of the irrigated landscape can include: Street Trees, Parks, Playgrounds, Schoolyards, Public Plazas, Buffer areas, Sikkas, and Residential yards.
4. Calculate areas for each of the categories of landscape. For Street Trees, measure the length of the streets and figure a tree will be planted at least every 10 meters on center on each side of the road.
5. Allocate percentages of the overall quantity of available irrigation water to the different categories of landscape area. First, set aside a water contingency of 20% to cover any unforseen water needs. The primary goal is to provide enough water to sustain 50% of roads with street trees. Priority after that should be given to public parks, civic squares, and playgrounds. The next priority should be for residential yards. Lastly, remaining water can be given to buffer areas which should only be supporting plant material needed for screening.
6. Utilize the Nakheel Landscape Management Regulations, or other similar middle-eastern irrigation standards to determine how much water per day different types of plants will need to survive during the hottest days of the year- trees, palms, shrubs, groundcovers, etc.
7. Create landscape scenarios for each landscape type to gain a design understanding of how much plant material can be supported by the allocated quantity of water (See PR I Figure 45 which illustrates how much plant material can be supported in various landscape categories in a typical 1,000 square meter area).
8. Change the percentages of irrigation water given to different landscape categories based upon the landscape scenario studies and whether they meet the needs of the project.
9. Use the final water budget as the basis of designing the planting of the development.

The opposite table shows KAPSARC Landscape Water Budget

> “
> *Categorize the types of landscapes desired in the project. Typical categories of the irrigated landscape can include: Street Trees, Parks, Playgrounds, Schoolyards, Public Plazas, Buffer areas, Sikkas, and Residential yards.*

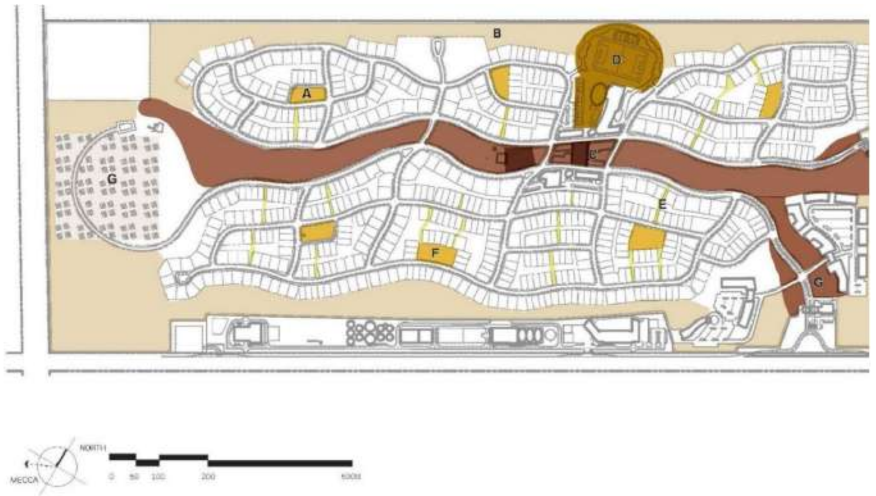


Fig. 72. Highlighted programmed landscape space at KAPSARC

Pre-design Estimated Numbers				
Place/Program	**Area % of Total**	**Liters**	**% of Total**	**Liters**
Competition zone	25%	275,000	25.00%	275,000
Street trees	4.50%	49,500	16.47%	181,152
Units	10.40%	114,400	10.40%	114,400
Place of worship	5.45%	59,950	4.40%	48,439
Place of Mashrabiya	7.00%	77,000	3.07%	33,766
Place of community	5.20%	57,200	2.57%	28,245
Community parks	6.75%	74,250	5.13%	56,419
Place of immersion **	25.70%	282,700	14.62%	160,830
Place of renewal***			4.94%	54,355
Place of shadow****			1.67%	18,334
Contingency	10%	110,000	10%	110,000
Total	**100%**	**1,100,000**	**98.27%**	**1,080,939**

Total treated water *= 1,100 cubic meters (1,100,000 liters)

* From the Masterplan SD Report

** For the purpose of the water budget estimates, this included the place of renewal and arrival gates.

*** This was included under the place of immersion for the water budget (see above).

**** This was not included in the original water budget estimates.

3.0
Public Realm Infrastructure

Energy-Efficient Lighting

Energy efficiency in the public realm involves designing and implementing systems and technologies that reduce energy consumption and greenhouse gas emissions while maintaining or improving the functionality and safety of these spaces. One element of energy-efficient public realm design is the use of LED lighting in streetlights and other outdoor lighting fixtures. LED lights are much more energy-efficient than traditional incandescent or fluorescent bulbs, and they can last up to 25 times longer, reducing maintenance costs. Smart lighting systems that use sensors to turn lights on and off based on occupancy or daylight levels can also save energy. Reference to energy-efficient lighting is made to SASO 2927:2019. Energy-efficient public realm design is important for reducing energy consumption, improving the quality of public spaces, and mitigating the impacts of climate change.

“

One element of energy-efficient public realm design is the use of LED lighting in streetlights and other outdoor lighting fixtures. LED lights are much more energy-efficient than traditional incandescent or fluorescent bulbs, and they can last up to 25 times longer, reducing maintenance costs. Smart lighting systems that use sensors to turn lights on and off based on occupancy or daylight levels can also save energy.

4.0
Key Terms

Adapted plants: Reliably grow well in a given habitat with minimal winter protection, pest control, fertilization, or irrigation once their root systems are established. Adapted plants are considered low maintenance, not invasive.

Drip Irrigation: A method that saves water and fertilizer by allowing water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant.

Fossil Aquifer: A non-renewable water resource. Whereas most aquifers are naturally replenished by infiltration of water from precipitation, fossil aquifers are those that get little or no recharge.

Green Infrastructure: The concept of prioritizing the natural environment in land-use planning decisions. Green Infrastructure uses a natural or created ecosystem network to support the needs of the human development through ecological processes such as water purification, soil enrichment, and erosion control. While more sustainable than grey infrastructure, green infrastructure requires more open space so is sometimes only viable for new developments and not for urban retrofits.

Grey Infrastructure: Conventional man-made drainage and water treatment systems including pipes, tanks, and energy-intensive mechanical treatment systems.

Greywater: Greywater is a type of waste water that is generated from domestic sources other than waste conveyance from a water closet. Greywater can be filtered on-site for use in irrigation, waste conveyance, or washing.

Microclimate: Local atmospheric zone where the climate differs from the surrounding area. Microclimates exist near bodies of water which may cool the local atmosphere, in shaded and landscaped areas where protection from direct solar radiation and evapotranspiration cool the area, or in heavily urban areas where brick, concrete, and asphalt absorb the sun's energy, heat up, and reradiate that heat to the ambient air: the resulting urban heat island is a kind of microclimate.

Native Plants: Have evolved over thousands of years in a particular region. They have adapted to the geography, hydrology, and climate of that region. Native plants occur in communities, that is, they have evolved together with other plants. As a result, a community of native plants provides habitat for a variety of native wildlife species such as songbirds and butterflies.

Pedestrian-oriented design: Street-level design strategies to increase the safety and enjoyment of walking. Examples of strategies for pedestrian-oriented design include streetscaping, crosswalks, attractive street-level storefronts, and continuous and even sidewalk paving.

Spray Irrigation: A common irrigation method where water is shot from high-pressure sprayers onto vegetation. Because water shoots high into the air, some water is lost to evaporation.

Stormwater management: Management of the quantity and quality of stormwater such that it does not cause erosion, sedimentation, or pollution problems or exceed the capacity of municipal stormwater systems.

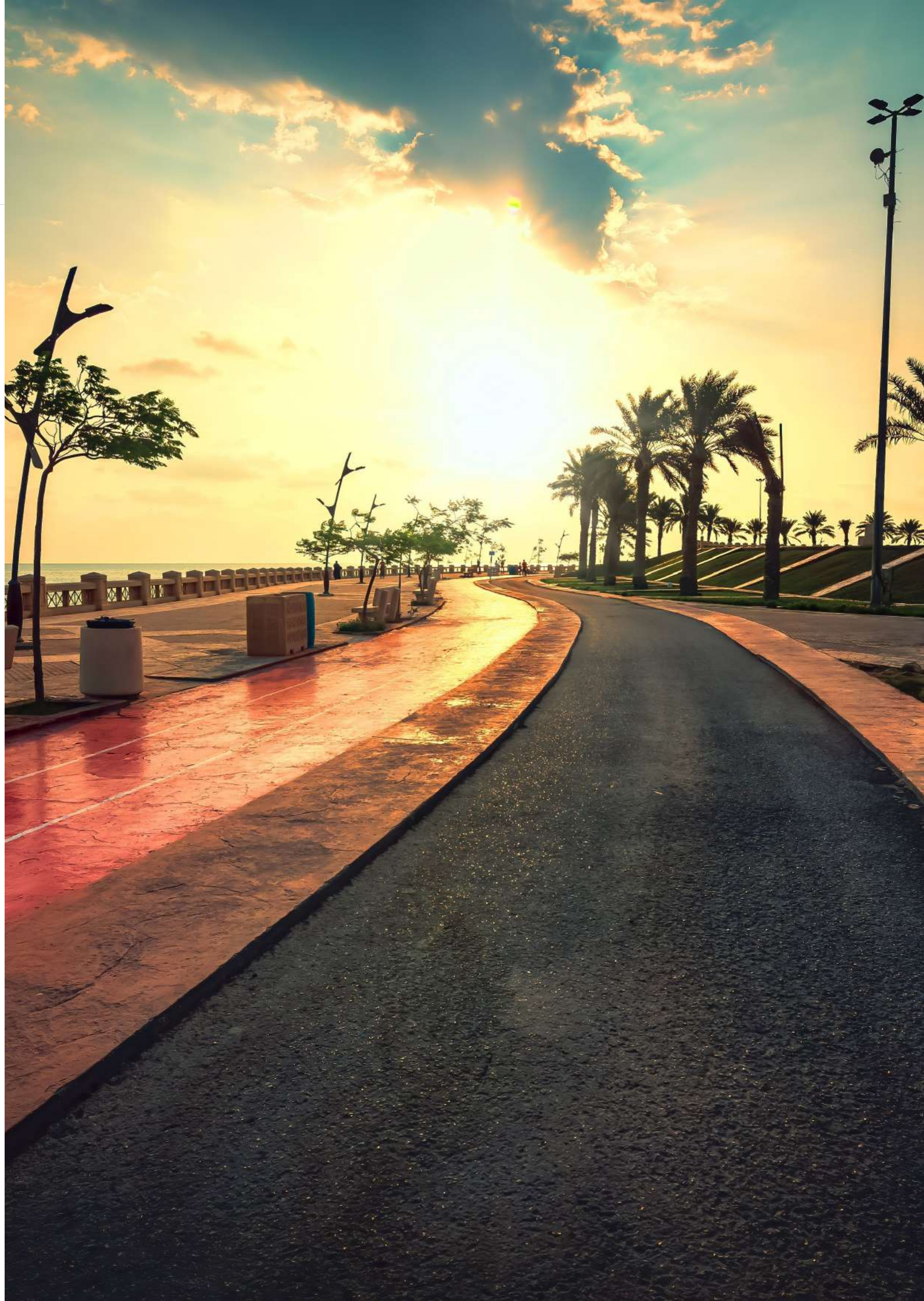
Stormwater Runoff: Water shedding that occurs when the soil is infiltrated to full capacity and excess water from rain flows over the land OR when there is insufficient permeable surface area to infiltrate and stormwater accumulates to cause flooding. Urbanization increases surface runoff, by creating more impervious surfaces such as pavement and buildings that do not allow percolation of the water down through the soil to the aquifer. Increased runoff reduces groundwater recharge, thus lowering the water table and making droughts worse.

Treated Sewage Effluent (TSE): A fluid generated from sewage treatment that is free of contaminants and safe for reuse or release into the natural environment.

Urban Heat Island: An urban heat island is a typically a metropolitan area which is significantly warmer than its surrounding rural areas. The main cause of the urban heat island is modification of the land surface by urban development which uses materials which effectively retain heat, such as concrete, asphalt and other materials.

Walkability: Walkability is a measure of how much an environment encourages walking.

Xeriscaping: Designing a landscape with appropriate placement and selection of native plants such that continued supplemental irrigation is not needed.



5.0
Compliance Checklist

The compliance checklist assists in provisioning for energy efficiency, generation, and co-generation in public realm. The below compliance checklist was compiled based on MOMRAH regulations and approved plans, controls and actions delegated from MOMRAH's Agency for City Planning.

Provisioning for Energy Efficiency with Alternative Transportation Methods	Yes	No	N/A
Land Subdivision Permit Requirements order a Provision for Energy Efficiency with Alternative Transportation Methods as part of required studies such as Hydrogeological Study, Morphological Study, and Geotechnical Study.			
Land Subdivision Permit Requirements order a continuous pedestrian network covering 100% of the subdivision.			
Land Subdivision Permit Requirements order a continuous cycling network covering at least 90% of the subdivision.			
Land Subdivision Permit Requirements minimize the percentage area of roads and asphalt footprint.			
Land Subdivision Permit Requirements minimize the parking footprint.			
Land Subdivision Permit Requirements order at least 1 alley every 100 meters of the block length.			
Land Subdivision Permit Requirements order sidewalks on commercial corridors to be at least 2.5 meters wide.			
Land Subdivision Permit Requirements order sidewalks on residential corridors to be at least 1.5 meters wide.			
Building Permit Requirements order buildings to have a functional entry onto the pedestrian network including plaza or square, but not a parking lot.			
Building Permit Requirements order buildings to have a functional entry connected to a sidewalk within 30 meters, measured at all pathway lengths.			
Land Subdivision Permit Requirements order 10% minimum open space including parks, pedestrian network circulation, cycling lanes, plazas, and squares – excluding carriageways, parking footprint, and private properties.			

Provisioning for Energy Efficiency with Urban Forestation	Yes	No	N/A
Land Subdivision Permit Requirements order a Provision for Energy Efficiency with Urban Forestation covering xeriscaping methodology, types of plants and irrigation systems, and water budget management plan.			
Land Subdivision Permit Requirements order at least 80% of the pedestrian circulation network to be shaded by trees.			
Land Subdivision Permit Requirements order 9% green coverage of the total land area of the planned subdivision.			
Land Subdivision Permit Requirements order 1% of total land subdivision area for agricultural community gardens.			
Building Permit Requirements order a minimum of 75% of parking spaces to be underground reducing urban heat island.			

Provisioning for Energy Efficiency in Public Realm Infrastructure	Yes	No	N/A
Land Subdivision Permit Requirements order a plan to retain on-site wastewater generated by public realm and municipal buildings and reuse the treated water for district cooling and irrigation.			
Land Subdivision Permit Requirements order Street Lighting to be designed in compliance with SASO 2927:2019.			
Park Permit Requirements order landscape Lighting to be designed in compliance with SASO 2927:2019			

Abbreviations

Abbreviation	Full term
UPT	Urban planning and transportation
NSS	National Spatial Strategy
MoMRAH	Ministry of Municipal and Rural Affairs and Housing
BAU	Business as usual
EV	Electric vehicle
FAR	Floor area ratio
HH	Household
km^2	Square kilometer
LGA	Local government authority
M&P	Movement and place
m	Meter
ft	Feet
LUM	Land use map
MaaS	Mobility-as-a-Service
Min	Minimum
ROW	Right of way
TOD	Transit-oriented development
VKT	Vehicle kilometers traveled
CWBD	Cooling water blowdown
GCC	Gulf Corporation Council
RO	Reverse osmosis
ED	Electrodialysis
KAFD	King Abdullah Financial District
CO2	Carbon dioxide
MD	Membrane distillation
EC	Electrocoagulation
NF	Nanofiltration
BSF	Ballasted sand flocculation
VSEP	Vibratory shear-enhanced processing
CTS	Cool thermal storage
DC	District cooling
kWh	Kilowatt-hour
NPV	Net present value
TES	Thermal energy storage
PME	Presidency of Meteorology and Environment
CHP	Combined heat and power
ETS	Energy transfer station
SPV	Special purpose vehicle

Abbreviation	Full term
PD	Project developer
PIM	Project information memorandum
TSE	Treated sewage effluent
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CUP	Central utility plant
KPI	Key performance indicator
UPC	Uniform Plumbing Code
IPC	International Plumbing Code
DPN	Distribution piping network
DCICS	District cooling instrumentation control system
WERA	Water and Electricity Regulatory Authority
IoT	Internet of Things
Capex	Capital expense
GIS	Geographic information system
OEM	Original equipment manufacturer
RT	Refrigeration ton
COP	Coefficient of performance
AHU	Air-handling unit
DX	Direct expansion (type of air-conditioning unit)
EJ	Exajoule
IEA	International Energy Agency
SBC	Saudi Building Code
HVAC	Heating, ventilation, and air-conditioning
LED	Light-emitting diode
DBOOM	Design-Build-Own-Operate-Maintain
SESD	Smart energy-saving device
SASO	Saudi Standards, Metrology, and Quality Organization
MW	Megawatt
SHGC	Solar heat gain coefficient
Tvis	Visible transmittance
GHG	Greenhouse gas
W/m^2K	Watt per square meter per Kelvin (unit of thermal insulation)
SEEC	Saudi Energy Efficiency Center
Aramco	Arabian American Oil Company
UDM	Urban Design and Streetscape Manual
KAPSARC	King Abdullah Petroleum Studies and Research Center
RCRC	Royal Commission for Riyadh City
OBC	Olaya–Bat'ha Corridor

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