Cool Up
Upscaling Sustainable Cooling

# Catalogue of Technical Solutions for Sustainable Cooling in Lebanon

March 2022

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# Table of Contents

# Figures

# Tables

# Acronyms

| | |
|---|---|
| AC | Air conditioning |
| °C | Degree Celsius |
| CHP | Combined heat and power |
| COP | Coefficient of performance |
| DX Chillers | Direct expansion chillers (refrigerant circulating within the building) |
| EEI | Energy efficiency index |
| EER | Energy efficiency ratio |
| EKK | Overall seasonal system efficiency including all AC system components according to German Standard DIN SPEC 15240:2019-03 |
| e.g. | For example |
| GWP | Global warming potential |
| HC | Hydrocarbon |
| HCFC | Hydrochlorofluorocarbons |
| HFC | Hydrofluorocarbon |
| kW | Kilo watt (metric unit for capacity/power) |
| MENA region | Middle East and Northern Africa region |
| MT | Medium temperature (refrigeration) |
| N.A. | Not available |
| LT | Low temperature (refrigeration) |
| PV | Photovoltaic |
| SEER | Seasonal energy efficiency ratio |
| RE | Renewable energies |
| RT | Refrigeration ton (unit for cooling capacity: 1 RT = 3.52 kW) |
| VRF Systems | Variable volume flow systems (advanced multi-split systems) |

# 1. Introduction

With energy demand expected to increase 50% by 2040,[1] Middle East and North Africa (MENA) countries are facing a range of climate-change related challenges. The region's energy challenges include rapidly growing populations, urbanisation, and a heavily strained energy infrastructure. Cooling in air conditioning (AC)-equipped households already represents a major source of energy consumption in the region. The use of cooling is expected to grow further since, with an improved standard of living, more households are using air conditioning (AC) systems. There is large potential for energy saving as many of the space cooling and refrigeration systems in use have a low energy efficiency. An additional climate impact from cooling comes from the refrigerants still used in many of today's air conditioners and refrigerators. Such refrigerants with a high global warming potential are 2,000 times more potent for the climate (direct greenhouse gas emissions) than carbon dioxide and natural refrigerant alternatives. Without further policy intervention, direct and indirect emissions from cooling and refrigeration may rise 90% above 2017 levels by 2050, creating a vicious feedback loop.

## 1.1. The Cool Up programme

The Cool Up programme promotes accelerated technological change and early implementation of the Kigali Amendment to the Montreal Protocol and Paris Agreement in Egypt, Jordan, Lebanon, and Türkiye. The programme focuses on enabling natural refrigerants and energy efficient solutions to mitigate the effects of rising cooling demand. The Cool Up approach is based on four pillars: reducing cooling demand, phasing down hydrofluorocarbons (HFCs), replacing and recycling inefficient equipment and refrigerants, and training and raising awareness.

The programme's cross-segment approach focuses on the residential and commercial AC (air conditioning) sector and on the commercial refrigeration sector.

The programme aims to develop lasting institutional capacity and increase the deployment of sustainable cooling technologies in the market. To enable a cooling market transformation towards sustainable cooling technologies, the Cool Up programme will:

- Enhance cross-sectoral dialogue between national actors to build ownership to support long-term impact.
- Develop policy actions to create a supportive regulatory environment.
- Develop financial mechanisms and funding structures to enable the cooling market transition.
- Support the commercial deployment and dissemination of existing and emerging technologies with natural refrigerants.
- Provide resources for capacity development on sustainable cooling in the four target countries.

In Middle East and North Africa (MENA) countries, cooling constitutes a major source of energy consumption; it produces indirect greenhouse gas (GHG) emissions and contributes to ozone depletion and global warming. The Cool Up programme seeks to address this challenge in its partner countries by mitigating the adverse impacts of refrigerants through promoting accelerated technological change and facilitating early implementation of the Kigali Amendment and Paris Agreement.

The programme is divided into three pillars:

- Policy and regulation
- Technology and markets
- Financing and business models

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[1] British Patrol, "BP Energy Outlook 2018 Edition"

## 1.2. Aim and scope of this report

This report provides information about options for sustainable cooling in Lebanon. The report addresses stakeholders from different sectors, such as policy makers and financing bodies but it also addresses planners, manufacturers, and everyone who is interested. The key intention is to facilitate the uptake of sustainable cooling in Lebanon with a specific focus on air conditioning and commercial refrigeration. The detailed background of the country cooling market has been presented in the Cooling Sector Status Report Lebanon published by the Cool Up programme.[2]

- Chapter 2 provides a broad summary about international cooling technologies including descriptions of the current common technologies and their sustainable alternatives.
- Chapter 3 provides an overview about existing activities regarding the national best practice examples of sustainable cooling elements.
- In Chapter 4 the findings of the previous chapters were considered, and a multidimensional evaluation is performed to derive recommended sustainable cooling solutions for Lebanon. Those recommended solutions should face the lowest implementation barriers and simultaneously have high equivalent $CO_2$ saving potentials, without creating lock-in effects for the long-term aim of climate neutrality.

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[2] For more information, go to: https://www.coolupprogramme.org/knowledge-base/reports/cooling-sector-status-report-lebanon/

# 2. International cooling technology overview

Cooling generally refers to the transfer of heat from a substance of higher temperature to a substance of lower temperature. Three segments are distinguished in the following: Air conditioning, refrigeration, and process cooling as shown in **Figure 1**.

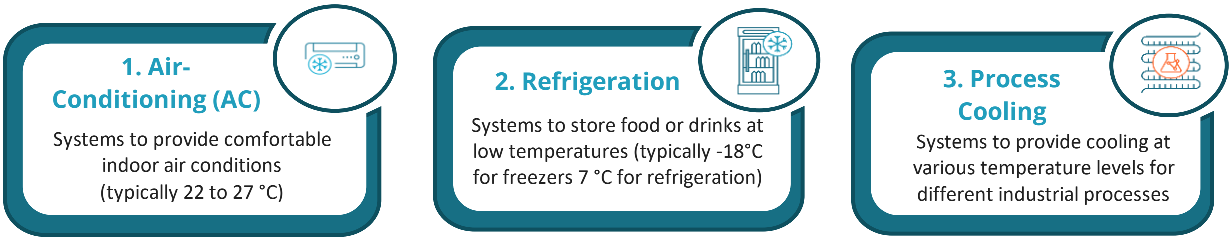

**Figure 1** Different subsegments of cooling

The Cool Up programme focusses on air conditioning and commercial refrigeration. In the following sections the key facts for those two subsegments are explained further.

## 2.1. Air conditioning

Air conditioning technologies can be divided into two general categories, each with sub-categories:

1. Central systems, where several transmission units are served by a central cold production unit
    - A. Compression water/brine chillers
    - B. DX-systems (including rooftop units)
    - C. Sorption water/brine chillers
    - D. VRF-/ multi-split systems
2. Decentralized systems, where every transmission unit is served by one cold production unit
    - A. Single split units
    - B. Window/wall units
    - C. Movable compact units (portable units)

The following table provides an overview about the main characteristics of the most common AC systems in the MENA region.

**Table 1** Overview of the top characteristics of the most relevant AC systems for the MENA region[3]

| AC technology | Typical capacity range | Average annual leakage rate[10] | Refrigerants in use still available old /common/new alternatives[12] | Efficiency EER[1] | Efficiency $E_{KK}$[2] EU / hot climate (e.g., Cairo) | Remarks |
|---|---|---|---|---|---|---|
| Compression chillers (air to water) | > 10 kW | 1-22 % | R22 / R134a, R410A, 407C/ R32, R1234ze, R513A | 2.8[3]-4.0[4] | 3.4-5.3[5]/ 2.8-4.3[5] | Possibility of thermal storage and humidity control |
| Compression chillers (water to water) | > 10 kW | 1-22 % | R22 / R134a, R410A, 407C/ R1234ze, R513A | *4.0-6.0*[6] | *3.7-6.2*[6]<br>*3.3-5.5*[6] | Possibility of thermal storage and humidity control |

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[3] Unless stated differently, the information is based on estimates and calculations by experts involved in the project.

| AC technology | Typical capacity range | Average annual leakage rate[10] | Refrigerants in use still available old /common/new alternatives[12] | Efficiency EER[1] | Efficiency $E_{KK}$[2] EU / hot climate (e.g., Cairo) | Remarks |
|---|---|---|---|---|---|---|
| Rooftop units | up to 300 kW | 1-10 % | R22 /<br>R134a, R410A, 407C/<br>R32, R1234ze, R513A | 2.4-4.3 | 3.2-5.8/<br>2.7/4.9 | Possibility of humidity control |
| Sorption chillers (water to water) | 5- 5000 kW | N.A. | R717, R718 | heat:<br>0.5 - 1.3[11] | heat:<br>1.9-2.5/<br>1.9/2.5[7] | Water requirement for re-cooling at high ambient temperatures<br>possibility of thermal storage (like compression chillers) |
| VRF-/ multi-split systems | 5-50 kW | 1-11 % | R22/<br>R410A, R407C/R32 | 2,2-4,7 | 4.6[8]-9.0/<br>3.4-7.1 | Highest leakage rates of specified systems<br>highest investment costs for specified systems<br>low comfort and no controlled dehumidification |
| Single split units | < 12 kW | 1-10% | R22/<br>R410A, R407C/<br>R32 | 2.2-5.2 | 4.4-9.5[9]/<br>3.3-7.3 | Highest possible efficiency and lowest costs of specified systems, but also<br>low comfort and no controlled dehumidification |

1) EER energy efficiency ratio at design conditions (chillers: 35/7/12, others: 35/27): value for minimum new derived from EU Ecodesign (for central systems: EU 2281/2016, for unit < 12 kW: EU 206/2012) calculated according to EN 14511; best available according to Eurovent (https://www.eurovent-certification.com/en/)

2) The $E_{KK}$ is calculated according to DIN SPEC 15240:2019-03. It specifies the overall seasonal system efficiency including all AC system components. This allows to compare the efficiencies of different systems. That is not possible by the common efficiency parameters like EER or SEER, as e.g. for AC systems with a central chiller as those just take into consideration the efficiency of the chiller itself but not of the required distribution and transmission systems. The $E_{KK}$ for absorption chillers considers the ratio of primary energy factors of electricity (assumption 2.5) and heat (assumption 0.7).

3) EU Ecodesign for < 400 kW

4) Category packaged systems, cooling only

5) Assumption of very efficient distribution and transmission systems

6) Excluding energy for re-cooling unit

7) Considered primary factors: electricity 2.5; heat from CHP 0.7

8) Derived requirement for units with refrigerant GWP>150 and capacity < 6 kW

9) SEER (EU): 10.6

10) Statistical values, including seldom full loss cases by huge cracks, derived from various sources, e.g. (pae-engineers.com 2020); (Research Division of the California Air Resources Board 2017); (Offermann et al. 2016); (United Nations Development Programme 2021); (SBZ-Online.de 2018); (Paul Ashford et al. 2006)

11) 0.5 (adsorption and $NH_3$); 1.3 (double effect water/LiBr). The specified EER values do NOT include the electrical consumption of the auxiliary equipment.

12) An overview about the key specifications of the different refrigerants can be found in the appendix

## 2.2. Commercial refrigeration

Commercial refrigeration systems differ from the home refrigerators known to everyone in size, technology, and setup. They are typically more powerful than residential units and may have the compressors and condensers in a different location than the refrigerated case. They can be divided, in terms of market segmentation, into three general categories, each with sub-categories:

- Centralised systems which are large distributed systems with multiple evaporators connected to remote compressor pack and external condenser. These systems can serve multiple cooling loads,
  - Central direct systems: The primary refrigerant is cooled in a direct expansion process and then circulated to cool the targeted medium, typically food.
  - Central indirect systems: Include an intermediate heat transfer step, where a secondary refrigerant is cooled by a primary refrigerant and is then circulated to cool the targeted medium.
- Condensing units where the evaporator in the refrigerated space is connected to a remote compressor and condenser. These systems can serve up to three cooling loads.
- Stand-alone units are small, compact plug-in appliances that are similar to home refrigeration appliances. These systems can serve only one cooling load.

Commercial refrigeration systems operate at two temperature levels:

- Medium temperature (MT): for chilled products such as dairy products, fruit, etc., typically operating in the temperature range between 0 °C and 8 °C.
- Low temperature (LT): for frozen products, such as fish, meat, etc., typically operating in the temperature range between -18 °C and -25 °C.

The following table provides an overview of the main characteristics of commercial refrigeration systems:

**Table 2** Overview of the top characteristics of the main commercial refrigeration system types[4]

| Commercial refrigeration system | Typical capacity range[7] | Average annual leakage rate[4] | Refrigerants in use still available old /common/new alternatives[5] | Efficiency COP[1]/EEI | Efficiency EER[2] at hot conditions | Remarks |
|---|---|---|---|---|---|---|
| Centralised systems | 40 – 200 kW | 10% - 35% | O: R22<br>C: R404A, R134a, R407A.F<br>N: R744, R449A, R450A | 1.7 – 4.4[1] | N.A. | The specified efficiency belongs to the minimum COP requirements for systems below 200 kW and greater than 300 kW |
| Condensing units | 2 – 20 kW | 10%-35% | O: R22<br>C: R404A, R134a, R407A/F<br>N: R1234yf, R1234ze, R454A | LT: 0.8 – 2.5[1]<br>MT: 1.5 – 2.5[1] | LT: 0.65 – 2[2]<br>MT: 1.24 – 2[2] | The efficiency ranges are based on the lowest and best performing certified/listed products on ASERCOM[6] database for the specified operational capacity range. |
| Stand-alone units | 0.1 – 1 kW | 1-15% | O: R12, R22<br>C: R404A, R134a,<br>N: R290, R600a, R1234ze, R1234yf | Min EEI: 170[3]<br>Max EEI: 20[3] | N.A. | Upper and lower EEI for stand-alone units as per the European Commission Delegated Regulation 2019/2018. The value ranges differ among different product categories. |

1) Parameters at full load and ambient temperature 32°C
2) Parameters at full load and ambient temperature 43°C
3) EEI range is taken between different stand-alone product categories including supermarket freezers, supermarket refrigerator, ice-cream freezer, beverage coolers, vending machines and Artisan gelato ice-cream display cabinets.
4) Source: (Paul Ashford et al. 2006)
5) An overview about the key specifications of the different refrigerants can be found in the appendix
6) See https://www.asercom.org/
7) Source: (UNEP Ozone Secretariat 2015)

## 2.3. Sustainable cooling solutions

This chapter provides an overview of sustainable cooling solutions in the fields of air conditioning and commercial refrigeration.

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[4] Unless stated differently, the information is based on estimates and calculations by experts involved in the project.

The ongoing HCFC phase-out in developing countries under the Montreal Protocol and the global HFC phase down offer the chance to adopt energy efficient climate-friendly alternatives. This has been recognized by the Parties to the Montreal Protocol in decisions taken at the 2016 Kigali Meeting of the Parties in conjunction with the HFC amendment. Linking energy efficiency with the HFC phase-down can significantly increase the climate benefits of the Kigali Amendment and should not be a missed opportunity. Also, the countries' commitments to the Paris Agreement demand for progressive introduction and market uptake of clean, energy efficient and climate-friendly technologies.

Sustainable cooling aims for zero-carbon emissions with the following criteria:

- No use of fluorinated refrigerants (possible solutions: use of natural refrigerants or considering so called "not in-kind technologies" without refrigerants)
- High energy efficiency
- Supplied by renewable energies

The technical solutions recommended in this report seek to include these aspects to guide technology choices for maximum emission reductions. The following overviews are non-exclusive. Further technical solutions employing natural refrigerants may also be possible and energy efficient.

### 2.3.1. Overview of natural refrigerants

Sustainable cooling requires the absence of environmentally harmful refrigerants like fluorinated gases. Cooling systems using natural refrigerants fulfil this requirement. Natural refrigerants are non-synthetic substances that occur in nature's biochemical process and thus do not lead to persistent and toxic emissions and decomposition products. Furthermore, natural refrigerants have only a negligible climate effect, if any. These refrigerants are available locally and are not subject to reductions under the Montreal Protocol and Kigali Amendment, therefore refrigerant prices are expected to remain relatively stable compared to HFCs.

The following table provides an overview about the general pros and cons of the most common natural refrigerants.

**Table 3** Overview about the most common natural refrigerants

| Refrigerant | Pros | Challenges |
|---|---|---|
| R744<br>(Carbon dioxide)<br>transcritical operations<br>Subcritical operation (typically requires a cascade with another refrigerant) | ▶ Non-flammable<br>▶ Non-toxic<br>▶ Transcritical[1] operation mode<br>▶ Well known technology, widely used in developed countries<br>▶ Subcritical[2] operation mode:<br>▶ Less costly than transcritical<br>▶ Suitable at high ambient temperatures | ▶ Operates at high pressure requiring components and pipes featuring higher stability. Upfront investments are therefore higher than for other equipment.<br>▶ Asphyxiant gas: Specific security measures apply<br>▶ Transcritical:<br>▶ Efficiency issues with transcritical operation in high ambient temperature countries<br>▶ Technically challenging solutions to install and service, in particular due to high pressure (requires specialist personnel for planning, installation and maintenance)<br>▶ Subcritical:<br>▶ Safety requirements and trained servicing personal are when using flammable refrigerants in the cascade system[3] |

| Refrigerant | Pros | Challenges |
|---|---|---|
| Hydrocarbons such as R290, R1270, R600a | ▶ Widely established in domestic refrigeration for decades<br>▶ Most product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency typically higher than traditional refrigerants | ▶ Flammability rating A3[4] :<br>▶ Requires specific safety measures e.g., with R290 (propane) solutions, refrigerant should not be circulating inside buildings. However smaller charges in e.g., stand-alone systems and residential split air conditioners are allowed<br>▶ Service personal need to be trained in servicing flammable refrigerants if not already in place<br>▶ Maximum load restrictions due to safety standards[5] |
| R717 (ammonia) | High energy efficiency | ▶ Toxicity rating B: Requires specific safety measures, e.g., equipment needs to be placed in a machine room with access for technical personnel only<br>▶ Personnel for installation, maintenance, and servicing needs to hold special training certificates |
| R718 (water)[6] | ▶ Non-flammable<br>▶ Non-toxic<br>▶ Energy efficiency typically higher than traditional refrigerants<br>▶ Avoiding any safety issues | ▶ Only few chillers available so far<br>▶ Higher space requirement than conventional chillers<br>▶ Limited temperature lift of available chillers |

[1]) Different from other refrigerants, $CO_2$, enters in a 'Critical Condition' between vapor and liquid phase. This happens at the temperature range at approx. 32 °C which is in the same temperature range as common ambient temperatures in warm countries. Two solutions are available, run with systems designed transcritical $CO_2$ operation, leading to need of very high pressures in the system, resulting in expensive components and advanced operation, OR run with sub critical systems where the condenser temperature of the $CO_2$ system is kept below the critical temperature, using a secondary system (in our case a R290 chiller)

[2]) Cascade systems includes a number (one or more) of heat exchangers, and each heat exchanger leads to a loss on energy efficiency

[3]) But also, non-flammable (R718) or mildly flammable (R717), natural refrigerants could be used for the high temperature stage of the cascade.

[4]) ASHRAE Standard 34 distinguishes: A1-no flame propagation; A2L-lower flammability with maximum burning velocity < 10 cm/s; A2-lower flammability; A3 higher flammability

[5]) Currently updates of several standards are taking place. Relevant is specifically IEC 60335-2-40: The revised IEC 60335-2-40 standard was approved in April 2022: Now significantly higher charges of flammable refrigerants are possible in residential air conditioners, heat pumps and dehumidifiers so that also bigger equipment types can run on hydrocarbons.

[6]) Early technology stage: Only few product types commercially available so far

## 2.3.2. Sustainable air conditioning solutions

### 2.3.2.1. Overview

The following table gives an overview about the main characteristics of AC systems with natural refrigerants:

**Table 4** Overview of the top characteristics of the most relevant alternative AC systems with natural refrigerants[5]

| AC technology | Capacity range | Refrigerant | Efficiency EER[1] | Comments | Pros | Challenges |
|---|---|---|---|---|---|---|
| **Compression chillers (air to water)** | 60-400 kW | R744 | 2[2] | Transcritical- or subcritical-operation | | ▶ Higher investment cost than other technologies with natural refrigerants<br>▶ Low efficiency |
| | 50-650 kW | R290 | 2.7-3.8 | | ▶ Product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency typically higher than traditional refrigerants | ▶ A3 flammability rating<br>▶ Specific design requirements to prevent refrigerant circulating into the use areas buildings |
| | 100-1700 kW | R717 | 2.7-5.4 | | ▶ Higher energy efficiency than above alternatives | ▶ Toxic: additional safety measures apply, refrigerant should not be circulating in inside building<br>▶ Specialized personnel needed for installation, maintenance, and servicing |
| | 35-120 kW | R718 | 3.1-10[3] | single or double stage turbo[4] | ▶ No safety issues<br>▶ No refrigerant related know-how required | ▶ Higher investment cost than conventional technology<br>▶ Limited temperature range/lift |
| **Compression chillers (water-to-water)** | N.A. | R290 | N.A. | | ▶ Product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency typically higher than traditional refrigerants | ▶ A3 flammability rating<br>▶ Specific design requirements to prevent refrigerant circulating into the use areas buildings |

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[5] Unless stated differently, the information is based on estimates and calculations by experts involved in the project.

| AC technology | Capacity range | Refrigerant | Efficiency EER[1] | Comments | Pros | Challenges |
|---|---|---|---|---|---|---|
|  | 100-3500 kW | R717 | 3.5-5.5 |  | ▶ Higher energy efficiency than above alternatives | ▶ Toxic: Additional safety measures apply, refrigerant should not be circulating in inside building<br>▶ Specialized personnel needed for installation, maintenance, and servicing |
|  | 35-350 kW | R718 | 5.1[5] |  | ▶ No safety issues<br>▶ No refrigerant related know-how required | ▶ Higher investment cost than conventional technology<br>▶ Limited temperature range/lift |
| **Rooftop units** | N.A. | R290 | N.A. | Currently just demo-project[6] | ▶ Indication of higher energy efficiency than conventional alternatives<br>▶ Operation at higher ambient temperatures than conventional alternatives might be possible | ▶ Unknown cost levels<br>▶ A3 flammability rating (=> Additional safety measures needed to mitigate the risk of refrigerant leakage, mix with air delivered to spaces.) |
| **Sorption water/brine chillers** | >50 kW | R717 | 0.6[7] | Working pair- absorption: R717/water | ▶ Can be a part of an efficient co- or tri-generation system (electricity +cooling (+heating))<br>▶ Higher temperature lifts possible vs. R718 based sorption, dry re-cooling<br>▶ Good option to use (Renewable / waste) heat sources | ▶ Higher recooling demand than compression |
|  | 15 -4.000 kW<br>N.A. | R718 | 0.75 | Working pair – absorption: R718/LiBr | ▶ Can be a part of an efficient co- or tri-generation system (electricity +cooling (+heating))<br>▶ Good option to use (Renewable / waste) heat sources<br>▶ No safety issues | ▶ Limited temperature lift (evaporative re-coolers or high chilled water temperature) |

| AC technology | Capacity range | Refrigerant | Efficiency EER[1] | Comments | Pros | Challenges |
|---|---|---|---|---|---|---|
|  | 8-100 kW<br>N.A. | R718 | 0.6 | Working pairs-adsorption:<br>R718/silica gel<br>R718/zeolite | ▶ Can be a part of an efficient co- or tri-generation system (electricity +cooling (+heating))<br>▶ Good option to use (Renewable / waste) heat sources<br>▶ No safety issues | ▶ Limited temperature lift (evaporative re-coolers or high chilled water temperature<br>▶ cycling operation |
| **VRF-/ multi-split systems[8]** | N.A. | R744 | N.A. |  |  | ▶ High investment costs<br>▶ Low efficiency |
| **Single split units** | N.A. | R744 | N.A. |  |  | ▶ Not cost efficient for small systems |
|  | Up to 5 kW | R290 | N.A.[9] |  | ▶ Well known technology already used in some regions<br>▶ Product design and safety standards already in place[10]<br>▶ Energy efficient<br>▶ Expected cost reduction when technology becomes mature with volume | ▶ Specific safety requirements to be considered for installation and servicing |
| **Direct ground- or seawater cooling** | 50-1000 kW | - | >20 (pump energy) | ▶ Only applicable, when water temperatures are < 14 °C (moderate climate, not suitable for warmer climates) |  |  |

1) EER energy efficiency ratio at design conditions according to EN 14511 (chillers: 35/7/12, others: 35/27)
2) Value only considers cooling efficiency, further benefits possible when also hot water is also required
3) No standard condition efficiency is available, mainly designed for high chilled water temperatures
4) The identified currently available chillers cannot clearly specified as "air to water" but use a dry recooler delivered as a package.
5) According to EN 14511 design conditions: 12/7 - 30/35 for 350 kW chiller
6) See: Yoshimoto 2020
7) Thermal efficiency: Cooling energy / Driving Heat
8) Early technology stage: Only few product types commercially available so far. No solutions for flammable or toxic refrigerants as of high indoor refrigerant loads
9) At least one product with SEER (EU) > 7
10) With the approval of the revised IEC 60335-2-40 standard in April 2022 significantly higher charges of flammable refrigerants are possible now in residential air conditioners, heat pumps and dehumidifiers so that also bigger equipment types can run on hydrocarbons.

Excellent overviews about the actual sustainable AC technologies can be derived from the product databases of the Energy Information Administration (EIA)/ Greenpeace.

Sources:

- Domestic air conditioning:
  https://cooltechnologies.org/sector/domestic-air-conditioning/
- Commercial/industrial air conditioning:
  https://cooltechnologies.org/sector/commercial-industrial-air-conditioning/
- Additionally, the database https://hydrocarbons21.com/ provides information specifically about hydrocarbon technologies

### 2.3.2.2. Key barriers for implementation of sustainable AC

The following barriers for the implementation of the presented sustainable solutions were identified:

- Pushback from market leaders, who have either economical interest to promote synthetic refrigerants or are hesitant as the demand for sustainable AC is currently comparably low[6].
- Lack of experience with sustainable AC products, especially at installers who play a key role for increasing the market uptake of natural refrigerant solutions.
- Lack of know-how and skills, especially with the handling of flammable refrigerants (installation, maintenance, repair, and servicing).
- Comparably high investment costs due to smaller production capacities, low market competition and lack of experience.

It should be noted that international safety standards previously limiting charge sizes of flammable refrigerants and thus impeding increasing market uptake of natural refrigerants have been revised. The updated version of the IEC 60335-2-40 has been published in summer 2022 and is expected to remove earlier barriers for the use of hydrocarbons in residential air conditioning and heat pumps.

### 2.3.2.3. Measures to reduce the AC demand

A reduced energy demand is one key element of sustainable cooling. There are various options to reduce the air conditioning demand. The following list provides an overview about the most relevant measures:

- Effective solar shading (usually most effective: automatic controlled movable external shading)
- Airtight construction
- Demand controlled ventilation, including night cooling ventilation (passive cooling) and/or economizers
- Window and door contacts (to stop the AC when a door or window is opened)
- Low-heat-transfer building shell (Insulation and at least double glazing), or at least bright colours of roof and façade to reduce solar heat gains (Use materials with High Solar Reflectance Index (SRI))
- High thermal masses (allow for peak load reduction and an increased efficiency of passive cooling)
- Internal load reduction (efficient appliances and lighting)
- Adequate (AC-demand) monitoring and control systems (AC only in the zones where need and setpoints set to highest acceptable temperature and in larger buildings: Implementation of a central building automation system)
- Efficient distribution systems (water better than air; well insulated piping- and duct-systems)
- Efficient cold transfer systems to rooms (passive systems like chilled ceilings or chilled beams need less energy than fan coil units or AC via central ventilation)
- In case of central chillers: High system temperatures (cold water cycle) and low cooling water (e.g. by using geothermal energy or seawater)

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[6] See e.g.: Hasse, "Statement of Volkmar Hasse Cooling (Cooling expert and former head of GIZ Proklima) on day 3 of the Green Cooling Summit"

- Proper maintenance
- Ensure optimized operation by proper commissioning of technical building systems and regular inspections

### 2.3.2.4. Solutions for a renewable energy supply

A renewable energy supply is another precondition for sustainable cooling. It can be achieved either by on-site or off-site renewable energy sources. The options indicated below can serve AC and commercial refrigeration but usually also other consumers on site.

***On-site options:***

- Solar PV
- Solar thermal
- Storage for load shifting (thermal, batteries)

***Off-site options:***

- Renewable electricity supply from:
  - Solar PV from PV Farms
  - Concentrated solar thermal plants
  - Wind energy
- 100 % renewable district cooling

## 2.3.3. Sustainable commercial refrigeration solutions

### 2.3.3.1. Overview refrigerants

The following table gives an overview of the main characteristics of the most relevant refrigeration systems with natural refrigerants:

**Table 5** Overview of main characterizations of most relevant alternative refrigeration systems with natural refrigerants[7]

| Commercial refrigeration system | Refrigerant | Efficiency COP[1] | Remarks | Pros | Challenges |
|---|---|---|---|---|---|
| Central direct systems | R744[1] | N.A. | Trans critical operation | ▶ Well-known technology is widely used in developed countries | ▶ Comparably higher upfront investment costs<br>▶ Efficiency issues with trans critical operation in high ambient temperature countries<br>▶ Technically challenging solutions to install and service, in particular due to high pressure (requires specialist personnel for planning, installation and maintenance) |
| | | | Sub critical operation | ▶ Solution can be based on 100% natural refrigerants in a cascade system combined with R290 or R717 to generate chilled water to maintain $CO_2$ in sub critical state<br>▶ Solutions for e.g., hotels can be based on well-known technologies<br>▶ Less complicated technology to service<br>▶ Can be used in countries with higher ambient temperatures | ▶ Comparably higher investment costs<br>▶ Specialized personnel needed for installation, maintenance, and servicing |

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[7] Unless stated differently, the information is based on estimates and calculations by experts involved in the project.

| Commercial refrigeration system | Refrigerant | Efficiency COP[1] | Remarks | Pros | Challenges |
|---|---|---|---|---|---|
| Central indirect-systems | R744 | N.A. | Sub critical operation | ▶ Less costly than transcritical systems<br>▶ Solutions with secondary loop R744 units, solutions can be used for both refrigeration and freezer solutions | ▶ Safety requirements when using e.g., R290 in the cascade system<br>▶ Specialized personnel needed for installation, maintenance, and servicing |
| | R290 | N.A. | | ▶ Product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency typically higher than traditional refrigerants | ▶ A3 flammability rating |
| | R717 | N.A. | | ▶ Product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency higher than traditional refrigerants | ▶ Toxicity issues to be handled |
| Condensing units (small to midsize) | R744 | MT: 1.76 – 3.83<br>LT: 0.96 – 1.92[2] | | Good energy efficiency | ▶ Comparably high upfront investment costs |
| | R290 | N.A. | | ▶ Product design standards already established<br>▶ Relatively simple and cost-efficient technology<br>▶ Energy efficiency typically higher than traditional refrigerants<br>▶ Good availability of components and refrigerant | ▶ Specialized personnel needed for installation, maintenance, and servicing |

| Commercial refrigeration system | Refrigerant | Efficiency COP[1] | Remarks | Pros | Challenges |
|---|---|---|---|---|---|
| Stand-alone units (refrigerators) | R290/R600a | N.A. | R600a is typically used for smaller units | ▶ Widely-used by larger manufactures of standalone display units<br>▶ High energy efficiency<br>▶ Good component and refrigerants availability | ▶ Specialized personnel needed for installation, maintenance, and servicing<br>▶ Higher capital costs for manufacturing lines, for smaller manufactures |
|  | R744 | N.A. |  | Good energy efficiency | ▶ High cost and limited availability of components e.g., compressors |
| Stand-alone units (freezers) | R290 | N.A. |  | ▶ Widely used by larger manufactures of standalone display units<br>▶ Energy efficient<br>▶ Component and availability | ▶ Service capabilities related to handling of flammable refrigerant<br>▶ Higher capital costs for manufacturing lines, for smaller manufactures[3] |

[1]) Because of toxicity of R717 and flammability of HCs R744 is currently the only available option for direct systems
[2]) Efficiency ranges (MT and LT) are based on a very limited number of products and is not to be considered exhaustive
[3])Mainly due to that several test systems by Coca-Cola and others have been discontinued

An excellent overview of the actual sustainable commercial refrigeration technologies can be found in the database of the EIA/Greenpeace.

Source: https://cooltechnologies.org/sector/commercial-refrigeration/

### 2.3.3.2. Key barriers for implementation of sustainable commercial cooling

The following barriers for the implementation of the presented sustainable solutions were identified:

- Lack of local experience with sustainable commercial refrigeration solution, especially for central systems and condensing units,
- Fear of flammable refrigerants,
- Lack of know-how and skills, especially with the handling of flammable refrigerants (installation, maintenance and disposal),
- Comparably higher investment costs due to smaller production capacities, low market competition and lack of experience.

### 2.3.3.3. Measures to reduce the energy demand of commercial cooling systems

Besides the efficiency of compressions systems and the selection of an environment-friendly refrigerant, further measures to ensure a low energy demand are key elements for a sustainable commercial cooling. There are various options to reduce energy demand of commercial cooling. The following list provides an overview about the most relevant measures:

- Measures to reduce convection losses of cooled display cabinets and counters (e.g., by using glass doors, air curtains, etc.)
- Low-heat-transfer by good insulation
- Efficient display lighting e.g., LED
- Use of energy management systems to reduce electrical consumption e.g., for commercial display refrigerators
- Proper preventive and curative maintenance, specifically central systems and condensing units:
  - Well insulated distribution systems
  - Adequate monitoring and control systems
  - Ensure optimized operation by proper commissioning of technical building systems and regular inspections

# 3. National good practice examples

The following table provides an overview about projects covering certain aspects of sustainable cooling (natural refrigerants / energy efficiency / renewable energy) in buildings or sustainable commercial refrigeration. The list is a result of secondary research and contributions of different national stakeholders (for sources, see right-hand column below).

The specified good practice projects consist of at least one aspect, this is in line with the Cool Up programme's sustainable (climate neutral) goals.

Those are (among others): cooling systems without fluorinated refrigerants (e.g., natural refrigerants, thermal cooling systems), measures of significant cooling demand reduction, cooling with renewable energies, ice-storages (which may enable a climate neutral cooling with solar energy), efficient cooling technology components (which could be used in systems with natural refrigerants, e.g., district cooling).

**Table 6** National good practice examples

| No | Name of project | Description<br>Project info/key findings | Info<br>Year/location/funding- and implementation entity | Source<br>Links |
|---|---|---|---|---|
| **1** | LEED certified residential building with a high efficiency HVAC | LEED certified residential building/ installation of high efficiency HVAC with fresh air double flux and energy recovery. The systems used for air conditioning are equipped with VRF technology with a COP of 4.24. The projects make use of the ventilated air, the double flux ventilation with heat exchanger allows up to 78% of energy recovery. | 2018/ Beirut/ Lebanon/ NEEREA financed | LCEC database |
| **2** | Ice bank as cold storage for load shifting | The project is replacing two of three existing chillers with screw type compressor chillers and installation of ice bank system on the remaining chiller. The ice bank system requires the installation of ice storage tanks to a modified existing chiller to provide brine at -4°C. The chiller will be run during night hours (lower energy tariff) and store the produced capacity in the ice bank, the stored material will then be used during peak hours or when the facility is running on diesel generator. The project is estimated to save 571046 kWh annually with 400 tons $CO_2$ reduction | 2013, Broumana, Lebanon NEEREA financed | LCEC database |
| **3** | High efficiency HVAC system at an educational building | Installation of high efficiency HVAC system for an educational building that yields annual energy savings of 577629 kWh in addition to 380 tons $CO_2$ reduction. | 2017, Baabda Lebanon NEEREA financed | LCEC database |

| No | Name of project | Description<br>Project info/key findings | Info<br>Year/location/funding- and implementation entity | Source<br>Links |
|---|---|---|---|---|
| **4** | Absorption chiller that runs on excess steam produced onsite, using renewable sources | A commercial facility has decided to implement an absorption chiller that runs on excess steam produced on-site using renewable sources: a biomass boiler and the combustion of gas produced by a gasifier. This solution is another step toward increasing the share of renewable energies at the facility and reducing its environmental impact while reducing the running cost. The site has a high cooling consumption throughout the year to satisfy the cooling demand of the gasifier, the control rooms of the biomass boiler, the paper machine, and the plant offices. Cooling requires about 463kW of electrical power and totals an annual energy consumption of around 2,402 MWh.<br>This project aims to drastically reduce electrical consumption for cooling using an absorption chiller. The project will use a BROAD X absorption chiller, it has a good COP and a designed life span of 25 years. The steam absorption chiller uses excess on-site produced steam to produce chilled water for air-conditioning and machine cooling.<br>The project also produces steam using renewable sources: a biomass boiler and the combustion of gas produced by a gasifier. Electricity is only used for the pump that circulates the water in the cooling tower, the pump that will distribute the chilled water, the fan of the cooling tower, the pump that will circulate the lithium bromide solution in the chiller, and other minor miscellaneous electrical needs. The absorption chiller that will help to decrease power consumption from traditional sources (EDL and on-site generators) resulting in a reduction in the greenhouse gas emissions. The project yields to 2,074,737 kWh of energy savings annually, $127,398 USD cost savings per year, and 1477 of $tCO_2$ reduction. | 2016/ Halat, Lebanon/ NEEREA financed project | LCEC database |

| No | Name of project | Description<br>Project info/key findings | Info<br>Year/location/funding- and implementation entity | Source<br>Links |
|---|---|---|---|---|
| **5** | Absorption chiller run on exhaust and heat from generators | A non-electric absorption chiller that runs on the exhaust and heat from the generators was implemented to provide cooling/heating to the facility. This solution allows the facility to reduce all the consumption of the electric chillers while the generators are running, thus reducing cost and emissions with the system. The heat recovery absorption chiller recovers nearly all of the "waste heat" produced by the diesel engine generating the electricity. The system will simultaneously generate electricity to power factory and machines; the absorption chiller uses the heat from the engine to produce chilled water for air-conditioning and machine cooling. The broad absorption chiller operates by receiving the hot water coming from the jacket water and the exhaust gas. Compared with mechanical chillers, absorption plants have a low coefficient of performance; however, it only uses electricity for the pumps which circulates the water in the different circuits and a small pump to circulate the lithium bromide solution in the chiller. The project saves 902512 kWh annually with 632 tons $CO_2$ reduction | 2015/Zouk Mosbeh, Lebanon/ NEEREA financed | LCEC database |
| **6** | Geothermal cooling project | This project is the installation of a geothermal cooling network. This will replace two cooling towers whereby water drawn from wells will cool down the condenser water through two heat exchangers and then be returned back to the underground in a closed pipe system.<br>The project provides savings on three different levels:<br>▶ Water and water treatment savings<br>▶ Energy savings on fans/pumps<br>▶ Energy savings on chiller’s efficiency improvements<br>Combined savings of the project includes:<br>▶ 805,678 kWh annually<br>▶ 26,411 cubic meters of water<br>▶ 524 tons $CO_2$ reduction | 2017/ Beirut/ NEERA financed | LCEC database |
| **7** | Implementation of new R-600a and R-290 product lines | A leading national manufacturer of refrigerators and freezers implemented R-600a and R-290 production lines also for small commercial refrigerators including display bottle coolers | 2019/MLF funded project, implemented by local manufacturer Lemantec (Concord) initiated by UNIDO | https://open.unido.org/api/documents/14626583/download/Lematic%20Demo%20UNIDO%2081Excom%2020042018.pdf |

## Summary

Projects 1, 3, and 6 are good practice examples regarding high overall system efficiency. Whereas project 6, the geothermal condenser heat exchanger, may be a suitable solution for new buildings. Although that solution may still use HFCs as refrigerant, it is seen as good practice for high-efficiency being also possible for solutions without fluorinated refrigerants. Project 2 is a good example of a potential load shifting, which allows for better integration of renewable energies. Only project 4 is a fully sustainable cooling solutions as it works without fluorinated refrigerant (as Project 5) and is operated 100% by renewable energy. The conversion of the product lines of the leading national manufacturer to natural refrigerant systems is a promising indication for the national uptake of sustainable standalone commercial refrigeration units.

Despite those promising examples, there seem to be no AC solution operated with natural refrigerants in Lebanon.

# 4. Suggestions for implementation of sustainable cooling

This chapter provides recommendations about the most suitable options for sustainable cooling solutions in Lebanon. The previous chapters were taken into consideration when compiling these recommendations.

A longlist of technical solutions, which are proved to be relevant and mature solutions in many developed/developing countries, has been developed for each of the two main areas, air conditioning and commercial refrigeration. A systematic evaluation of the listed solutions has been done resulting in recommendations for sustainable cooling solutions for Lebanon.

The recommended solutions should face the lowest implementation barriers while simultaneously having high equivalent $CO_2$ saving potentials without creating lock-in effects for the long-term aim of climate neutrality.

The suggested sustainable cooling solutions are in line with the Cool Up goals, which implies the absence of environmentally harmful refrigerants such as fluorinated gases, a low energy demand through high efficiency and compatibility with a fully renewable energy supply.

In this way, direct $CO_2$ emissions from refrigerant use will be almost eliminated.

## 4.1. Longlist

### 4.1.1. Air conditioning solutions

The target location should be a building that is a leading example in energy efficiency, not just for the cooling systems. Ideally the building should be supplied with renewable energy (e.g., on site PV solar thermal).

**Central HC chiller**
Due to the flammability of hydrocarbon refrigerants, the refrigerant should not be circulated inside the building. Therefore, the suggested solutions are a roof-mounted or remote area from the building water chiller that generates chilled water/glycol mix to be circulated into the building and air handling units (AHU) in each area of the building uses the chilled liquid to circulate cold air.

The target location should be a role model building in energy efficiency, not just for the cooling systems. A slight saving on energy consumption is expected due to modern technology and use of R290 as refrigerant.

**Central ammonia chiller**
Due to the toxicity of ammonia (R717), the refrigerant should not be circulated inside the building. Therefore, the suggested solutions are an outside mounted water chiller that generates chilled water/glycol mix to be circulated into the building and air handling units in each area of the building uses the chilled liquid to circulate cold air in the area.

A slight saving on energy consumption is expected due to more modern technology and use of R717 as refrigerant.
As the installation is expected to be in existing buildings, the building should already be prepared with central water AC systems.

**Decentralized AC R290 split units**
Residential split air conditioners cause a large part of HCFC and HFC emissions as their use is common and an increase of use in the sector is expected due to an increase in population, rising living standards and increasing need for comfort cooling. The suggested solution is split units with R290 instead of HFCs. Market acceptance can be limited, and the activity depends on the service sector development as personnel would need to be trained in the handling of flammable refrigerants. However, this training need also exists for other flammable refrigerants such as the HFC R32.

**Central R718 chiller**

A preferable application is data centres. This is because oftentimes chilled water temperatures >20 °C are sufficient and existing R718 chillers can be fully deployed. Additionally, operators might have a sustainability approach. A saving on energy consumption is expected due the high efficiency of the refrigerant and the high chilled water temperature.

**Central absorption chillers**

Absorption chillers use heat as the main operating energy source. The efficiency (COP) of absorption chillers ranges between 0.6 and 0.8 depending on the chiller's type, see also chapter 1.3) heat source temperatures, higher temperatures lead to higher the COPs; and size, increasing efficiency with size. The condenser's heat release is double compared to electrical compression chillers. Therefore, these systems are especially advantageous when the rejected heat can be reused e.g., in hotels or hospitals. The system is also flexible, as it allows for thermal energy storage on both the cold and hot side. Compared to electrical compressions chillers, absorption chillers have low efficiencies and are required to be operated with renewable or waste heat to be sustainable.

**Monitoring solutions**

Monitoring solutions with data collection and storage of essential parameters like energy consumption, cooling performance, maintenance information, leakage etc. can provide further insights into system efficiency and help to identify optimization potentials. As actual data on system efficiency from the region are scarce, solid data would also allow for comparison of data from other regions and across technologies. Also, the solution should be used for energy audits for existing installations.

The suggested solution should be built up around a central data collection unit with inputs to interface different kind of sensors for measurement of e.g., temperatures and power consumption. The controller should have communication functionality to maintain the data in a central database, e.g., a cloud solution. Software functionality should include benchmarking features between different locations of installations.

**Passive cooling measures to prevent use of air conditioners**

Solutions might include ventilation systems or others to increase comfort in warm areas without use of air conditioners.

As the AC saturation, specifically at residential buildings is still very low, passive measures to improve the comfort can offer an affordable alternative to the installation of a AC. One key element is an effective solar shading. Also, bright colours of roof and façade reduce solar heat gains. Uncontrolled external ventilation should be prevented, meaning close obvious holes of the building shell and keep windows and doors closed when it is hot outside.

For ventilation cooling, install thermometers (inside and outside) to be able decide when it is wise to open the windows or door to be able to cool down the rooms. Furthermore, also the reduction of internal loads (e.g., switch-off instead of standby, consider efficiency when buying new equipment). Finally simple fans can increase the comfort by air movement, which reduces the operative (felt) temperature by up to 3 °C.

**District cooling without using synthetic substances like HFC**

District cooling can be an economic solution for new districts/compounds. The central plants usually allow for significant cost reductions, higher efficiencies, and better maintenance of generation systems. However, district systems require high additional investments for the creation of the networks. This additional financing can usually only be provided through long-term contracts and connection obligations.

To be sustainable, district cooling plants must not contain fluorinated refrigerants and should be powered by renewable energy sources. For large systems, it is usually more economical to meet the special safety requirements that arise from the use of the natural refrigerant R717. The same also applies to the implementation of renewable energies. The necessary storage tanks are considerably more economical and efficient than with smaller, decentralised refrigeration equipment.

### 4.1.2. Commercial refrigeration solutions

**Supermarket solution (sub critical CO2 working principle)**
$CO_2$ trans-critical systems are widely used in developed countries, especially across Europe. However, these systems are costly, mainly due to initial investments, and require special knowledge and skills to maintain and service. As supermarkets have two specific demands for cooling, e.g., medium temperature and low temperature, the proposed solution is to use a HC-based water/glycol chiller that circulates chilled liquid into the supermarket for the MT range. For the LT range, it's suggested to use smaller individual $CO_2$ subcritical units. The condensers are kept below the critical temperature using the return of the chilled liquid from the refrigerators already in place. Standalone display units are allowed with hydrocarbon refrigerant, after the revision of the IEC standard 60335-2-89 higher charges are also possible.

Two parallel R290 chillers are recommended to be placed outside the building, either existing or new are acceptable, and several, depending on supermarket size, $CO_2$ sub-critical units are placed inside the building.

A slight savings on energy consumption is expected due to more modern technology and use of R290/R744 as refrigerant. Even compared to latest generation of conventional cooling systems a slight energy savings is expected. For existing supermarkets, it should be noted that existing cabinets and display units must be replaced implementing the above solution.

**Supermarket solutions (trans-critical $CO_2$ working principle)**
Trans-critical $CO_2$ systems are widely used in larger supermarket in developed countries. These systems are energy efficient, however still comparably costly, and a technically complex solution to install and maintain.

**Cost effective manufacturing concept for conversion of smaller commercial refrigerators manufactures**
Today, most large manufactures of stand-alone display units use HCs (R290 or R600a) as refrigerants. Due to safety regulations, inside the factory buildings the technical installation of production equipment is slightly more expensive than for HFC refrigerants, based on experience from other HC installations in domestic and commercial refrigeration.

Another segment is the specially designed commercial refrigerators and freezers for e.g., restaurants and bars. The products are typically produced by smaller companies according to each order, and the smaller companies cannot afford the upfront investment needed like the high-volume producers. The companies today still use traditional HFC refrigerants like R134a or R404A.

One recommendation is to design a low-cost manufacturing setup, following international safety standards, but designed for low volume producers.

**HC residential and commercial service sector development**
Availability of relevant servicing infrastructure has been seen as one of the main barriers for a faster deployment of RAC technologies using natural refrigerants. Proper training and equipment are needed to service products with flammable refrigerant. This is especially true in countries with a large, informal service sector that makes implementing training requirements at large scale a complex, long-term task. Therefore, development of a training program is recommended, especially for the informal segment of the service sector.

**Monitoring solutions**
As in the AC segment, monitoring data collection and data storage of energy consumption, cooling performance, maintenance information, leakage, etc. can provide further insights into system efficiency and help identify optimisation potential and the relevance of preventive maintenance and provide incentives for building/sections complying with natural refrigerants.

## 4.2. Multidimensional evaluation

Based on the country specific characteristics, each technical solution is evaluated based on six main criteria. These include environmental impact, financial aspects, multiplication possibilities, market acceptance, safety aspects, and implementation risks (**Figure 2**).

Finally, in this section the findings of the previous chapters were considered, and a multidimensional evaluation is performed to derive recommended sustainable cooling solutions for Lebanon. Those recommended solutions are supposed to face the lowest implementation barriers and simultaneously have high equivalent $CO_2$ emissions saving potentials, without creating lock-in effects for the long-term aim of climate neutrality. The longlisted solutions are evaluated according to the following criteria's, listed by priority.

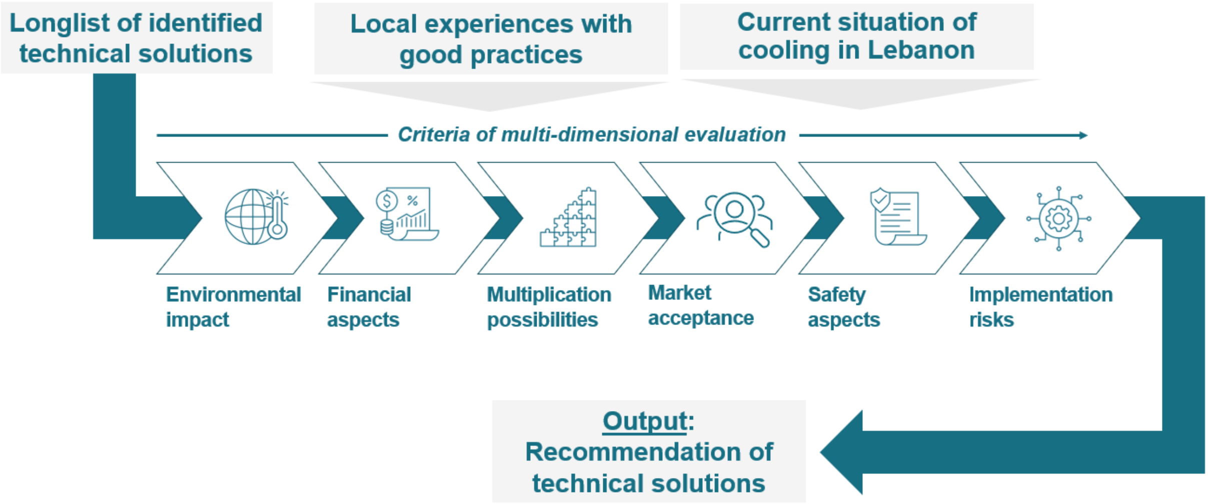

**Figure 2:** Overview of multidimensional evaluation

### 4.2.1. Air conditioning

Table 7 Multidimensional evaluation of air conditioning

| Type | Applicable building type | Environmental impact | Financial aspects | Multiplication possibilities | Market acceptance | Safety aspects | Implementation risks | Recommendation |
|---|---|---|---|---|---|---|---|---|
| **Central HC chiller** | Hotels or larger commercial buildings | Replacement of HFC and HCFC-based systems with high GWP or new systems slightly lower energy consumption than HFC-based solutions | Costly for replacement of existing systems, however due to the number of new projects the solution seems cost effective considering use of natural refrigerants | Multiplication possibilities and possible transfer of good practice from Saudi Arabia. | Resistance to use flammable refrigerants in public areas are considered limited as the chillers are located outside the buildings in an open-air environment | Well established international standards, requirement for certified installers and service network | Local norms and standards for use of flammable refrigerants to be respected | **Ready for implementation:** Possible technology transfer from Saudi Arabia. |
| **Central ammonia chiller (R717)** | Hotels or larger commercial buildings | No use of HFCs/HCFCs high energy efficiency | Costly for replacement of existing systems. But lower financial impact for new installations. | Limited multiplication possibilities mainly due to marked acceptance of NH3 technology[8] | Resistance to use toxic refrigerants in public areas | Well established international standards, requirement for certified installers and service network, location in a separate machine room without access to the public | Local norms and standards for use of toxic refrigerants, lack of qualified and experienced technicians | **Opportunity for future implementation:** Due to lack of knowledge to existing public building constructions, and insecurity related to market acceptance |

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[8] The main resistance against Ammonia ($NH_3$) comes from the civil construction companies and decision makers for technology to use.

| Type | Applicable building type | Environmental impact | Financial aspects | Multiplication possibilities | Market acceptance | Safety aspects | Implementation risks | Recommendation |
|---|---|---|---|---|---|---|---|---|
| **Residential split AC with hydrocarbons (R290)** | Residential buildings, hotels, and offices | No use of HFCs/HCFCs | R290 split AC units are currently more costly than HFC products. However, the price is likely to decrease as production quantities increase and HCs are cheaper than HFCs might be in future. | High potential due to wide application | Risk as domestic manufacturers in Lebanon opted for R32 | Updated international standard on charge sizes. Certified installers and service personnel needed. | Preparation of service sector personnel is a key requirement. | **Opportunity for future implementation:** Service sector currently not prepared to handle flammable refrigerant |
| **Central water chiller (R718)** | Data Centers | Natural refrigerant with no flammability and toxicity issues with energy efficiency | No info available | Limited due to climate conditions in Lebanon | No risk | No safety risks related to flammability or toxicity | No regulation to be expected. Risk of performance issues in high ambient temperature countries | **Opportunity for future implementation:** Efficiency in high ambient temperature countries is questionable |
| **Central absorption chiller** | Hotels or larger commercial buildings | Very low GWP due to solar heating | No info available | High considering that other constraints can be overcome | Low risk | Low safety risks | Complex technical solution to install and maintain | **Opportunity for future implementation:** PV + efficient chiller with natural refrigerant seems to be the more favourable solution, however further investigation is needed |
| **Monitoring solutions** | Building with central chillers solutions | Optimization of energy efficiency, information on leakage and system failures | Low investment compared to benefit | Large | Low risk | No safety risks | Practical issues with sensor installation, trained personnel needed, stable IT needed. | **Ready for implementation** |

| Type | Applicable building type | Environmental impact | Financial aspects | Multiplication possibilities | Market acceptance | Safety aspects | Implementation risks | Recommendation |
|---|---|---|---|---|---|---|---|---|
| **Passive cooling measures** | Medium to large size office and store surroundings | Low energy consumption | Less costly than A/C solutions | Large | Limited cooling capacity can lead to limited comfort. | No safety risks | Low risk | **Ready for implementation** Low-cost solution with low energy consumption |
| **Sustainable district cooling (Efficient R717 compression chillers, renew. electr. supply, local PV generation. thermal storage integration)** | New districts (different building types) and conversion of existing district cooling systems | High, as the solution ensures a sustainable cooling for whole districts and allows good storage and renewable integration | District cooling with gas fired absorption chillers is/was economically attractive and common but not sustainable and future proof. Systems need to adjust to future energy supply. | Limited to new districts and conversion of existing district cooling systems. | High for district cooling | Sufficient expertise to cope with safety risk (toxicity of R717) | Additional space required for redundant systems and storages, administrative problems when integrating distributed PV systems on the supplied buildings e.g., other owners). | **Recommended** to check options to integrate local PV, R717-compression chillers and thermal storage to new or existing district cooling systems |

## 4.2.2. Commercial refrigeration

**Table 8** Multidimensional evaluation of commercial refrigeration

| Type | Environmental Impact | Financial aspects | Multiplication possibilities | Market acceptance | Safety aspects | Implementation Risks | Recommendation |
|---|---|---|---|---|---|---|---|
| **Supermarket solution subcritical $CO_2$** | Slightly lower energy consumption than HFC-based solutions | Costly conversion for existing supermarkets | Large - one per 50,000 inhabitants - mainly at midsize to large supermarkets. Combined solution with sub critical $CO_2$ and HC systems. | High acceptance | Well-developed safety concepts, trained installers and service personnel needed | Low risk, combination of well-known technologies | **Ready for implementation:** The country size has a multiplication potential and capability to maintain such systems |
| **Supermarket solution trans-critical $CO_2$** | Improved energy efficiency compared to HFC-based solutions | High initial investment | Limited - one per 50,000 inhabitants - mainly at midsize to large supermarkets. Combined solution with sub critical $CO_2$ and HC systems to replace all HCFC/HFC-based systems | Complicated technical solution combined with high initial investment limits market acceptance | Well-developed safety concepts, trained installers and service personnel needed | Medium-high risk, very complicated solutions to install and maintain for Lebanon | **Opportunity for future implementation:** Due to risk of implementation of technical complicated and costly solutions for Lebanon |
| **Manufacturing concept for small manufacturers of commercial appliances with hydrocarbons** | Eliminate the use of HFC-based systems in commercial refrigeration | Cost efficiency to be evaluated case-by-case as some companies has very low production volume | Multiplication possibilities are medium - due to the number of small manufactures | High acceptance | Well developed technology for larger manufactures. To be refined for smaller manufactures. | Low risk, safety and charging concepts well developed | **Ready for implementation** Well known technology and due to the country size of Lebanon a medium number of multiplication possibilities~~.~~ |

| Type | Environmental Impact | Financial aspects | Multiplication possibilities | Market acceptance | Safety aspects | Implementation Risks | Recommendation |
|---|---|---|---|---|---|---|---|
| **Residential and commercial service sector development for handling flammable refrigerants, with focus on hydrocarbons** | Large potential for implementation of appliances with natural refrigerants. | Costly tools for service technicians needed.<br>Cost of technicians training high. | Large due to the number of refrigeration workshops in Lebanon. | Low risk as HC refrigerants are already used widely in the sector. | Risk in countries with less developed informal service network | Low risk - Well known technologies available | **Ready for implementation:** Programs to be continued for the service sector to establish best and safe practices. |
| **Monitoring solutions** | Optimization on energy efficiency | Low investment compared to benefit | Large | Low risk | No safety risks | Practical issues with sensor installation, trained personnel needed, stable IT needed | **Ready for implementation:** Programs to be continued for the service sector to establish best and safe practices |

## 4.3. Conclusions and recommendations

Based on the above evaluation the following technologies are recommended sustainable cooling solutions in Lebanon.

**Air conditioning:**

- Central hydrocarbon-based air-conditioning solutions for hotels and commercial buildings
- Service sector development to secure safe and proper service on AC systems using hydrocarbons
- Monitoring solutions to monitor and track performance of air conditioning installations, to be able to verify improvements and benchmark installations

**Commercial refrigeration:**

- Supermarket solution using sub critical $CO_2$ systems in combination with hydrocarbon chillers
- Service sector development to secure safe and proper service on commercial refrigerators using hydrocarbons
- Monitoring solutions to monitor and track performance of air conditioning installations, to be able to verify improvements and benchmark installations

Overall, this report aims to provide in-depth information for decision-makers in industry, policy, and finance to get an overview of local and international best practices for cooling solutions. It also provides tailored technical solutions recommendations specific for the AC and commercial refrigeration sub-sectors in Lebanon that can help shape regulations, financing instruments, and development of demonstration projects. Recommended technical solutions are already considered mature, sustainable cooling options and can be mainstreamed for early actions. Other longlisted solutions require further policy, economic, and market developments and therefore can be considered in the next stage of sustainable cooling pathways in Lebanon.

# 5. References

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# Annex A: Overview about refrigerant properties

The following table provides an overview of relevant properties of the refrigerants mentioned in this report. In line with the Kigali amendment reporting, the indicated GWP refer to a 100-year time period. Most refrigerants have a significantly higher GWP when looking at shorter timeframes (e.g. 20-year timeframe for R32: 2690 (AR6)). Furthermore, the GWP values do not consider the potential effects of atmosphere decomposition products, which may have a significant effect on the climate change (see research on 1234ze[9])

**Table 9** Overview about relevant refrigerant properties

| Single component refrigerants | Safety Class | GWP(100yrs) | Source |
|---|---|---|---|
| R11 | A1 | 4750 | IPCC AR4 |
| R12 | A1 | 10900 | IPCC AR4 |
| R22 | A1 | 1810 | IPCC AR4 |
| R32 | A2L | 675 | IPCC AR4 |
| R124 | A1 | 609 | IPCC AR4 |
| R125 | A1 | 3500 | IPCC AR4 |
| R134a | A1 | 1430 | IPCC AR4 |
| R143a | A2L | 4470 | IPCC AR4 |
| R152a | A2 | 124 | IPCC AR4 |
| R1234yf | A2L | 0,5 | IPCC AR6 |
| R1234ze(E) | A2L | 1,37 | IPCC AR6 |
| R290 | A3 | 0 | IPCC AR6 |
| R600a | A3 | 3 | Other |
| R1270 | A3 | 2 | Other |
| Zeotropic blends | | | |
| R401B | A1 | 1288 | Calculation based on above (ARI-700 composition definition) |
| R404A | A1 | 3922 | Calculation based on above (ARI-700 composition definition) |
| R407C | A1 | 1774 | Calculation based on above (ARI-700 composition definition) |
| R410A | A1 | 2088 | Calculation based on above (ARI-700 composition definition) |
| R449A | A1 | 1396 | Calculation based on above (ARI-700 composition definition) |
| R450A | A1 | 601 | Calculation based on above (ARI-700 composition definition) |
| R454A | A2L | 237 | Calculation based on above (ARI-700 composition definition) |
| R454B | A2L | 465 | Calculation based on above (ARI-700 composition definition) |
| Azetropic blends | | | |
| R513A | A1 | 631 | IPCC AR4 |
| Others | | | |
| R717 (Ammonia) | B2L | 0 | Other |
| R718 (Water) | A1 | 0 | Other |
| R744 (CO2) | A1 | 1 | As per definition |

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[9] Researchers from the University of New South Wales in Sydney collected evidence that one of the final HFO-1234ze decomposition products is HFC-23, the most powerful HFC regarding climate impact with a GWP of 14,800 according to the 4th IPCC Assessment Report (see: https://assets.researchsquare.com/files/rs-199769/v1_covered.pdf?c=1631852903)