Lawrence Berkeley National Laboratory

Recent Work

Title

Cooling Egypt: Cost and benefits of room air conditioner efficiency improvement in Egypt

Permalink

https://escholarship.org/uc/item/4qf5z8j2

Authors

Shaffie, Ambereen
Shah, Nihar
Karali, Nihan
et al.

Publication Date

2022-10-31

Peer reviewed

eScholarship.org Powered by the California Digital Library
University of California

Sustainable Energy & Environmental Systems Department
Energy Analysis and Environmental Impacts Division
Lawrence Berkeley National Laboratory

Cooling Egypt: Cost and benefits of room air conditioner efficiency improvement in Egypt

Ambereen K. Shaffie[1]
Nihar Shah[1]
Nihan Karali[1]
Won Young Park[1]
Moustafa Al-Sammany[2]
Brian Holuj[3]
Leon Becker[4]

[1] Lawrence Berkeley National Laboratory
[2] UNDP/GEF Appliance Efficiency Project, Egypt
[3] United for Efficiency (U4E) Initiative, UN Environment Program Environment Programme (UNEP)
[4] GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit)

October 2022

This work was supported by US Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

Disclaimer

This document was prepared as an account of work sponsored by the Clean Cooling Collaborative (CCC), formerly known as the Kigali Cooling Efficiency Program (K-CEP). While this document is believed to contain correct information, neither CCC nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by K-CEP or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of K-CEP or any agency thereof, or The Regents of the University of California. Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

Copyright Notice

This manuscript has been authored by Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges, that the U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Acknowledgements

The work described in this study was funded by the Clean Cooling Collaborative (CCC), formerly known as the Kigali Cooling Efficiency Program (K-CEP) under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

The authors would like to thank Eng. Mohammed El Khayat and Eng. Ashraf Afify for their contributions to this report.

This report was reviewed by:
Alex Lekov, Lawrence Berkeley National Laboratory and
Patrick Blake, UNEP, United for Efficiency (U4E) Initiative

Cooling Egypt: Cost and benefits of room air conditioner efficiency improvement in Egypt

Ambereen K. Shaffie[1], Nihar Shah[1], Nihan Karali[1], Won Young Park[1], Moustafa Al-Sammany[2], Brian Holuj[3], Leon Becker[4]

[1] Lawrence Berkeley National Laboratory
[2] UNDP/GEF Appliance Efficiency Project, Egypt
[3] United for Efficiency Initiative, UN Environment Programme
[4] GIZ

Abstract

Egypt is one of the largest countries in the Middle East and North Africa region with a population of a total of 106 million (as of July 2022). Increasing urbanization, population growth, and increasing temperatures will likely continue to drive demand for electricity from air conditioning, with corresponding negative impacts on the peak load, air quality, and greenhouse gas emissions from refrigerant use and energy consumption. Since 2003, Egypt has adopted a standards and labeling program for various appliances, and has improved its room air conditioner (RAC) energy efficiency requirements in 2016 and 2017. However, its market is still dominated by inefficient fixed-speed drive (FSD) RACs due to a price-sensitive market. Seasonal metrics such as Cooling Season Performance Factor (CSPF) measure the energy efficiency of FSD and variable-speed drive (VSD) RACs on the same scale. Leading markets, most notably China, have already adopted a new MEPS in 2020 and 2022, which align largely with the United for Efficiency (U4E) Model Regulations Guidelines. India has also adopted a CSPF metric. Both India and China are now experiencing (1) increased demand and consumption of higher efficiency VSD RACs, as well as (2) a corresponding drop in prices from the economies of scale of production of these higher efficiency RACs. Because China is a leading manufacturer in the global air conditioner (AC) market, its adoption of the model U4E regulations have effectively raised the energy efficiency of the ACs in the global market. To achieve the benefits of taking a similar approach to Egypt's market, we offer the following recommendations:

1. Adopt *a common metric* to measure the efficiency of both FSD and VSD RACs
2. Raise the *stringency of MEPS* to the level of the U4E Model Regulation Guidelines
3. Restructure the *labeling program* from the "A++" labeling scheme to a simpler A through E or a star-rating program
4. Strengthen the *compliance regime* governing the Egyptian AC MEPS
5. Assist *small and medium AC manufacturers* in Egypt to transition manufacturing lines to produce low-cost, high-efficiency VSD RACs.

Adopting these recommendations would reduce Egypt's electricity consumption to 11 TWh in 2030 and 89 TWh in 2050—with corresponding carbon dioxide (CO_2) emissions reductions and avoided generation capacity requirements compared to the baseline.

Contents

Table of Figures

Table of Tables

Acronyms and Abbreviations

AC	Air conditioner
AHU	Air handling unit
CC	Cooling Capacity
CDD	Cooling Degree Days
CFC	Chlorofluorocarbon
CO_2	Carbon dioxide
COP	Coefficient of Performance
CSPF	Cooling Season Performance Factor
CPA	Consumer Protection Agency
DOE	Department of Energy
EE	Energy efficiency
EEAA	Egyptian Environmental Affairs Agency
EECCD	European Economic Community Council Directive
EEHC	Egyptian Electricity Holding Company
EER	Energy Efficiency Ratio
EESLC	Energy Efficiency Standards and Labeling Committee
EGP	Egyptian Pound
EOS	Egyptian Organization for Standards and Quality
EU	European Union
FEI	Federation of Egyptian Industries
FSD	Fixed speed drive
FY	Fiscal year
GDP	Gross Domestic Product
GEF	Global Environment Facility
GHG	Greenhouse gas
GOIEC	General Organization for Imports and Exports Control
HAT	High Ambient Temperature
HBRC	Housing and Building National Research Center
HFC	Hydrofluorocarbon
ICA	Industrial Control Authority
IEA	International Energy Agency
IEELA	Improving the energy efficiency of Lighting and other Building Appliances (Egypt)
IMF	International Monetary Fund
ISES	Integrated Sustainable Energy Strategy
ISO	International Organization for Standardization
JRAIA	The Japan Refrigeration and Air Conditioning Industry Association
LCC	Life cycle cost
MENA	Middle East and North Africa
MEPS	Minimum Energy Performance Standards
MOERE	Ministry of Electricity and Renewable Energy
MOE	Ministry of Environment
MOTI	Ministry of Trade and Industry

NEEAP	National Energy Efficiency Action Plan
NOU	National Ozone Unit
NPV	Net present value
NREA	New and Renewable Energy Authority
PTAC	Packaged terminal air conditioners
QR	Quick response
RAC	Room air conditioner
S&L	Standards and labelling
SDS	Sustainable Development Strategy
SEER	Seasonal energy efficiency factor
SME	Small and medium enterprises
U4E	United for Efficiency
UEC	Annual unit energy consumption
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
US	United States
VAT	Value added tax
VRF	Variable refrigerant flow
VSD	Variable speed drive
WEER	Weighted EER

Executive summary

Egypt is uniquely positioned to capture many environmental and economic co-benefits of implementing a comprehensive cooling energy efficiency strategy. Multiple factors including population growth, rising disposable income, and urbanization at rates above global averages drive growth in demand for air conditioners (ACs) (Sever-Mehmetoglu, 2021). In the absence of targeted reforms, Egyptian electricity demand is expected to grow by 5% to 7% per year for the foreseeable future, dominated by increase in residential electricity consumption (World Bank, 2017), while infrastructure and economic growth lag well behind this demand. Residential consumption of electricity accounted for 39.2% of overall consumption (IEA, 2021). Much of the increased electricity demand is from air conditioning equipment in Egypt's densely populated urban areas, leading to corresponding negative impacts on peak load, air pollution, greenhouse gas (GHG) emissions, and energy consumption. Within this context, increasing the energy efficiency of cooling equipment presents both an urgent and a compelling opportunity (Sever-Mehmetoglu, 2021).

Egypt has steadily improved the energy efficiency of ACs through its market transformation programs, but there is still significant room for improvement. The Egyptian Organization for Standards and Quality (EOS) promulgated the initial standards and labeling program in 2003. Subsequently, Egypt adopted energy efficiency standards for room ACs (RACs) for both the fixed-speed drive (FSD) and variable-speed drive (VSD) RAC standards, with recent revisions in 2016 and 2017, respectively. However, recent trends in large AC markets, such as China and India, create impetus for Egypt to correspondingly increase the energy efficiency of RACs.

In this report, we consider various technologies that improve both AC efficiency and costs, including compressors, VSDs, heat exchangers, and expansion-valve technologies. Further, we propose a policy roadmap to support changes in minimum energy performance standards (MEPS). Increasing the MEPS, in combination with adopting a single metric for measuring the efficiency of FSD and VSD products, would spur significant energy and emission benefits. Adopting our recommendations will also result in a gradual phaseout of low-efficiency FSD RACs. This would, in turn, reduce electricity consumption to 11 TWh by 2030 and 89 TWh by 2050 —with corresponding carbon dioxide (CO_2) emissions reductions and avoided generation capacity requirements as compared to the baseline. Following the more aggressive scenario, which is based on 22.5% more stringent MEPS from 2022 MEPS levels, would result in additional energy savings of over 30% in the 2025-2050 period.[1]

Current RAC Market

The share of total residential electricity consumption in Egypt is relatively high compared to other sectors. This is a result of two trends: (1) ongoing urbanization and (2) increasing demand in the use of appliances and particularly ACs during the summer. The bottom line is that Egyptian residential and commercial RAC ownership continues to grow rapidly (BSRIA, 2018).

[1] Please see Section 3 and 4 and Appendixes A and B for details of the modeling and assumptions used in this analysis.

In 2017, single-split RACs dominated the market with a total volume of about 0.42 million units, representing 85% of the total market (BSRIA, 2018). VSD RACs comprised only 3%-5% of market share. Although the current share of VSDs in Egypt is small, the global supply chain shift toward VSDs will play a significant role in how Egypt's market will transform. For example, in 2018, 100% of all RACs sold in all AC categories across North America, Europe, and Japan had VSDs. Due to the drop in VSD RAC costs and China and India's market shift toward VSDs, Egypt's VSD share is also expected to increase (UNEP, 2019). Therefore, with sufficient policy support and robust regulatory design, Egypt can achieve significant progress in developing and deploying superefficient VSD technologies at a relatively low cost, while simultaneously encouraging the growth of its own small and medium enterprises (SMEs).

Current Energy Efficiency Requirements

Egypt has developed a standards and labeling program implemented by the EOS with assistance from the United Nations Environment Programme and the United Nations Development Programme (UNEP and UNDP). The Egyptian label requirements for split ACs with fixed capacity and fixed speed compressor (ES379-5/2018) were issued in 2018.

Since 2003, the government of Egypt has put in place mandatory MEPS and labeling for various appliances and equipment, including refrigerators, freezers, RACs, washing machines, water heaters, electric motors, and transformers. **Table ES 1** shows the current MEPS requirements for various types of RACs. In addition, **Table ES 2** specifies increasingly stringent energy efficiency label requirements for RACs.

Table ES 1. Current minimum energy performance standard levels for RACs in Egypt

Type	Minimum EER (Btu/Wh)	Minimum EER (W/W)
FSD window RACs	11.0	3.22
FSD split RACs	11.0	3.22
VSD window and split RACs	13.0	3.81

Source: EOS (2017, 2016).[2] Note: EER is Energy Efficiency Ratio.

The best available FSD RACs achieve an overall energy efficiency of EER 4.00 (W/W). Therefore, specifying EERs above 4.00 (W/W) for FSD RACs is inconsequential to policymakers and confusing to consumers. Meanwhile, the EER 3.22 (Grade B) requirement is comparable with the MEPS (EER 3.2) for FSD RACs China adopted in 2010; therefore, Egypt's label appears outdated and needs to align with China's new MEPS which are aligned with the U4E Model Regulations. China revised its MEPS in 2020 and 2022 (Park et. al., 2021). Because China produces 70% of the world's room AC's and its domestic market accounts for roughly 40-50% of the global AC sales, its adoption of higher standards has raised the floor, marking the minimum target for standards. Therefore, low Egyptian MEPS do not achieve economies of scale, low upfront costs, life-cycle cost savings, and environmental benefits that could be

[2] This report is focused on non-ducted split units, and therefore does not refer to ES: 3795-5/2018 Energy Efficiency Label Requirements For Air Conditioner Part 5: Fixed Capacity Ducted Room Air Conditioner With Fixed Speed Compressor.

realized by simply aligning with the U4E MEPS. Furthermore, BSRIA notes that Africa will achieve aggressive rates of AC growth. As a result, Chinese AC manufacturers are keenly interested in investment in this continent (Dickson, 2019). In contrast, WEER 3.81 (Grade A) for VSD RACs is comparable with the minimum efficiency levels defined for RACs with cooling capacity (CC) less than or equal to 4.5 kW (CC≤4.5 kW) in the U4E Model Regulation Guidelines (Park et al., 2019). WEER 5.57 (Grade A++++++) is estimated to be slightly higher than the U4E Model Regulation Guidelines' high efficiency for 2023 for RACs with CC≤4.5 kW. As demonstrated below, the requirements for VSD RACs align well with global best practices.

Table ES 2. The Egyptian energy efficiency label requirements for RACs

June 2020 (Variable-capacity RACs)
June 2021 (Fixed-capacity RACs)

	EER (WEER)	
	W/W	Btu/Wh
A+++++	5.28	18
A++++	4.99	17
A+++	4.69	16
A++	4.40	15
A+	4.10	14
A	3.81	13
B	3.51	12

	EER	
	W/W	Btu/Wh
A+++++	4.98	17
A++++	4.69	16
A+++	4.40	15
A++	4.10	14
A+	3.81	13
A	3.51	12
B	3.22	11

June 2022 (Variable-capacity RACs)

	EER (WEER)	
	W/W	Btu/Wh
A++++++	5.57	19
A+++++	5.28	18
A++++	4.99	17
A+++	4.69	16
A++	4.40	15
A+	4.10	14
A	3.81	13

Note: While we refer to these in the text of this report as FSD and VSD ACs to conform with other literature, the standards refer to these as fixed-capacity and variable-capacity ACs. Both sets of terms are correct and can be used interchangeably.

<u>*Roadmap for RAC Standard Rule Making*</u>

The proposed policy roadmap below supports a more stringent MEPS and updated labeling requirements for Egypt.

1. *Adopt a common metric to measure FSD and VSD RACs.*

The existing two separate standards for FSD and VSD RACs with a much lower MEPS requirement for FSD RACs do not allow consumers to accurately discern the higher efficiency of the VSD RACs. Egypt should rate both types of equipment under the same metric, thus accurately reflecting energy and cost savings associated with VSD RACs. Consumers could then effectively compare the energy efficiency and cost of available FSD and VSD RACs.

Two major AC markets, China and India, have already adopted a common metric for FSD and VSD RACs on their markets (Shah et. al., 2016; Karali et. al., 2020). Rescaling Egypt's efficiency metric to align with these will allow the Egyptian market to benefit from lower costs of VSD RACs due to the economies of scale resulting from the production of VSD RACs in these larger markets. Moreover, when considering a common metric for FSD and VSD RACs, Egypt should consider adopting ISO 16358:2013 and 2019, which were developed for high ambient temperature (HAT) regions (ISO 2019; 2013).

2. *Adopt a common, more stringent minimum energy performance standard for FSD and VSD ACs aligned with the U4E model regulation minimum requirements*.

Our results demonstrate a relatively flat cost curve for higher efficiency RACs indicatign efficiency improvement is possible at relatively low costs. In addition, the Chinese market has largely moved to ~98% VSD ACs, thus, vastly increasing the scale of production of VSD RACs. These levels are aligned with the minimum efficiency requirements for ACs in the U4E Model Regulation Guidelines. Adopting the U4E minimum requirements would give the Egyptian market ample time to effectively transition to higher standards and to benefit from any cost reductions spurred by economies of scale. These levels are also well-aligned with Egypt's current MEPS requirements for VSD RACs. Moreover, the benefits to consumers manifest through shorter payback periods and increased net lifetime savings.

3. *Restructure the labeling program.*

The current labeling system, which utilizes an "A" with ascending, continuous pluses (+es), confuses consumers according to the European Union (EU) and the latest Ecodesign report (EPRS, 2017). A simplified labeling system is more beneficial: either an A through E rating, or the standard star-rating system adopted by many countries. A clear labeling system ensures that Egypt can conform to international standards and properly educate consumers about the energy and cost savings available from more efficient ACs.

4. *Strengthen the compliance regime*.

Anecdotal reports from industry leaders and experts indicate that Egypt has a large informal sector assembling low-cost inefficient FSD RACs. This sector will pose a potential challenge to increasing RAC energy efficiency requirements if not addressed in parallel. A regularized monitoring system for tracking compliance with the mandatory standard and energy information labeling programs will accelerate the replacement of less-efficient products and facilitate the transformation of the regional market for energy-efficient products. A stronger compliance regime should include at a minimum: round-robin testing, more frequent monitoring and testing of ACs, and negative incentives such as public identification of non-compliant companies. Furthermore, existing test laboratories must seek proper accreditation and upgrade capacity. Finally, Egypt should build additional test laboratories capable of testing both FSD and VSD ACs.

5. Assist small and medium AC manufacturers.

Egypt should prioritize the transition of SMEs to VSDs in order to give SMEs competitive advantages, including exporting in the Middle East and North Africa (MENA) region; to incentivize informal markets and SMEs to participate in the compliance regime and adhere to standards; and to increase public outreach and awareness of efficient equipment.

1. Introduction

Egypt's economic prominence in the Middle East and North Africa (MENA) region remains significant (Shaffie, 2015). Egypt has one of the fastest-growing populations in the world (BSRIA, 2018; Harvard University, 2019), which has placed significant strain on the country's infrastructure and energy resources (Blaydes, 2019). Egypt's population rose to 106.7 million as of July 2022 (Worldometer, 2022), increasing at a steady annual rate of about 2.0 percent since 2000 (World Bank, 2022a), and is expected to surpass 128 million by 2030 at current birth rates (Awadalla, 2017). Population density in urban areas poses a significant challenge in Egypt. Even though the country has an area of 1,002,450 km^2, only about 5% of the total area is densely populated; the rest is desert with small or no settlements. According to the UN Department of Economic and Social Affairs (UN DESA, 2019), Cairo alone housed half a million new inhabitants in 2017, making it the fastest-growing city globally. To address this demand, the Ministry of Housing, Utilities, and Urban Communities has begun constructing a new capital city east of Cairo. There are further plans to construct twenty additional planned cities to house 30 million residents (BSRIA, 2018). Meanwhile, projections point to water and energy shortages as early as 2025 (Shaffie, 2015; Charbel, 2017). This resource scarcity is motivating the Egyptian government to emphasize energy efficiency. These trends of a growing population, combined with increasing temperatures and urbanization collectively contribute to a growing demand for air conditioners (ACs).

Most of Egypt lies within a dry arid region with two prominent seasons: a moderate winter from November to March and a hot summer from April to October, usually very dry with extremely high temperatures approaching upper 30-degree ranes (Celsius). According to most estimates, Egypt has a nearly 100% electrification rate (World Bank, 2019; ESMAP, 2019). In fiscal year (FY) 2018, the total consumption of electricity was 157,610 GWh, of which 42.4% was from the residential sector (EEHC, 2018) (see **Figure 1**). In 2021, the share of total residential electricity consumption was higher than other sectors due to growing urbanization and concurrent increase in electricity demand. (Sever-Mehmetoglu, 2021). The Egyptian Organization for Standards and Quality (EOS), the key federal agency in charge of setting and overseeing standards and labels, estimates that AC represents over 45% of electricity consumption in the residential and commercial sectors. A large number of dense urban areas in a hot climate creates a high demand for cooling. Longer durations of hotter temperatures coincide with electricity shortages in the summer when consumption levels are highest (EIA, 2018). In the absence of targeted reforms such as stringent energy efficiency policies, electricity demand is expected to grow at 5% to 7% per year for the foreseeable future (World Bank, 2017). Egypt set forth its National Energy Efficiency Action Plan (NEEAP) which provides for action through 2022 and includes infrastructure upgrades and revising building energy efficiency codes.

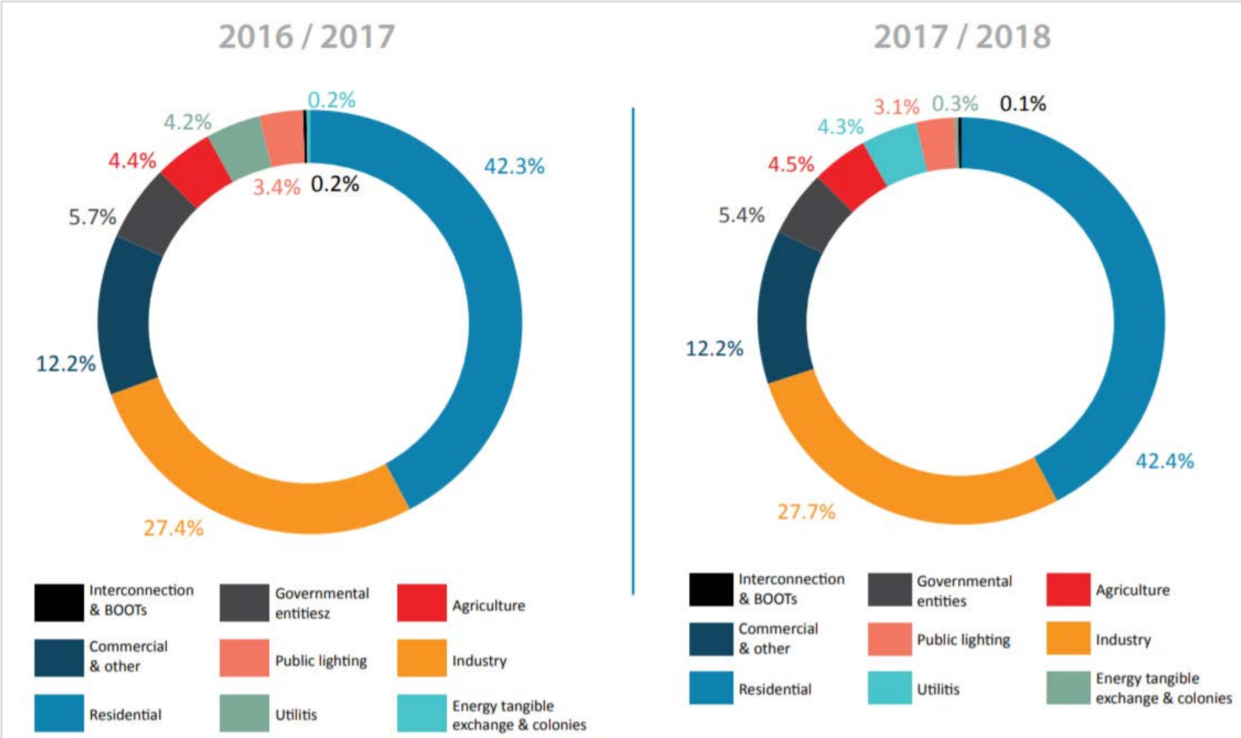

Figure 1. Electricity consumption by customer category
Source: EEHC (2018).

In short, without reforms, Egypt will be unable to sustain the economic and infrastructure growth necessary to keep pace with demand. Further climate change and higher temperatures is expected to reduce agricultural yield, shorten growing seasons, increase pollution, and erode and evaporate the Nile River Delta, exacerbating climate displacement and increasing the potential for conflicts and instability over food, water, and energy (Blaydes, 2019). In fact, Egypt's economic development hinges on the energy sector, which represents 13.1% of its overall national gross domestic product (GDP) (IRENA, 2018). Given this context, energy efficient space cooling becomes even more urgent.

The government has taken steps to develop and implement key energy policies, including developing the Integrated Sustainable Energy Strategy (ISES), which aims to achieve an energy savings of about 18% by 2035. However, as we discuss further, the strategy appears to rely heavily on renewable energy without fully capturing the potential of energy efficiency.[3] Egypt has also developed the National Energy Efficiency Action Plan (NEEAP) I (2012-2015) and NEEAP II (2019-2022) in compliance with the requirements of the Arab Energy Efficiency Framework.[4]

NEEAP II adopted an Energy Efficiency Institutional Framework based on central planning and decentralized implementation by activating and enabling energy efficiency units in the various economic

[3] The Egyptian government has set a renewable target of 20% of the electricity mix by 2022 and 42% (approximately 50 GW) by 2035 (IRENA, 2018), (IEA, 2020). IRENA estimates that Egypt will be able to supply 53% of its electricity mix from renewables by 2030 with the right strategies in place.
[4] See https://sustainableenergyegypt.com/wp-content/uploads/2020/07/The-National-Energy-Efficency-Action-Plan-II.pdf for details of NEEAP.

sectors. In this regard, the plan created a dedicated Energy Efficiency Standards and Labeling Committee (EESLC). Managed by the EOS, the EESLC is comprised of representatives from the Industrial Control Authority (ICA), General Organization for Import and Export Control (GOEIC), Consumer Protection Agency (CPA), Markets Monitory Department, Ministry of Supply, Federation of Chambers of Commerce, Chamber of Engineering Industries at the Federation of Egyptian Industries (FEI), and the Committee of the Ministry of Electricity and Renewable Energy (MOERE). The EESLC has the following mandates:

- Expand the minimum energy efficiency standards for equipment
- Clarify the energy efficiency labeling system
- License laboratories that test the energy efficiency of devices
- Coordinate household appliance distributors, retail outlets, and related stakeholders to promote high-efficiency equipment
- Direct programs to replace low-efficiency equipment and incentives to encourage using high-efficiency equipment
- Establish market control mechanisms to control and verify the placement of energy efficiency labels on equipment
- Identify the reference laboratories for energy efficiency tests for equipment
- Support awareness programs on the importance and advantages of high-efficiency equipment and energy efficiency labeling
- Supervise contracting with specialized agencies to conduct surveys, assess the level of awareness, and monitor the change in consumption patterns in order to periodically review and assess results for continuous development of plans and programs
- Prepare a monthly progress report on all programs

The analysis below supports policy action designed to transform the market towards more efficient RACs and capture the economic and environmental benefits of energy efficient space cooling in Egypt. These benefits include: reducing peak load, increasing energy security, increasing divertible revenue for public needs, and decreasing GHG emissions. The analysis identifies and discusses the remaining potential to improve Egyptian RAC minimum energy performance standards (MEPS), based on global trends. Finally, it supports a policy roadmap towards more stringent MEPS and updated labeling requirements for Egypt.

This paper is organized into seven sections. Section 2 discusses the historical background and relevant macroeconomic drivers and summarizes the current RAC market, programs, and policies; the MEPS and labeling requirements; and rulemaking processes. Section 3 provides an analytical method and approach to assessing the costs of efficiency improvement. Section 4 describes the methodology and results of a national impact analysis of Egyptian RAC MEPS improvements. Section 5 provides policy recommendations based on the assessment in the form of a roadmap, and Section 6 offers conclusions.

2. Egypt market conditions, policies, and standards

2.1. Current RAC market in Egypt

BSRIA (2018) estimates AC market penetration in 2023 to grow to 90% (up from 85% in 2018) in the commercial sector and 55% (up from 49% in 2018) in the residential sector. The split RACs remain the biggest segment of the Egyptian air conditioning market by volume and value. In 2017, the Egyptian single split RACs (unducted) market totaled about 0.42 million units, representing 85% of the total packaged and central AC market (**Figure 2**). Split RACs are primarily installed in residential buildings and small commercial applications. RACs with a capacity of around 12,000 Btu (3.5 kW or 1 refrigerant ton (RT)) account for most of the market (BSRIA, 2018). In addition, the current share of variable speed drive (VSD) ACs in the market is less than 5% due to pricing (**Figure 3**). In Egypt, VSD AC prices were 20% to 30% higher than fixed speed drive (FSD) units of the same capacity, which had tended to deter some buyers historically.

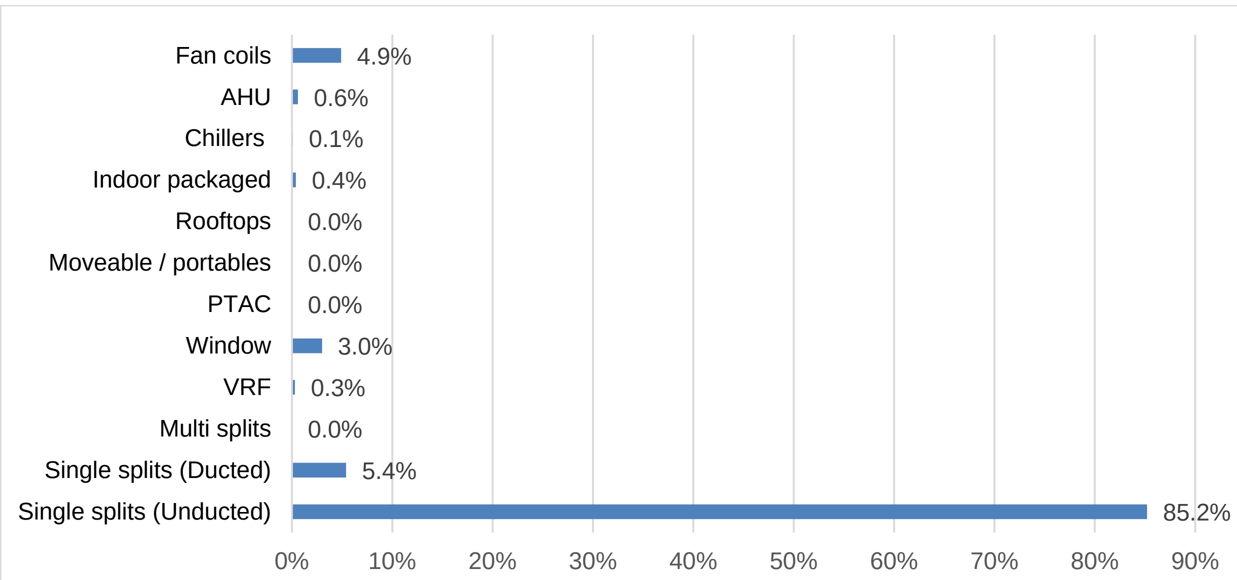

Figure 2. Egyptian packaged and central plant market volume by percent in 2018
Source: BSRIA, 2018. Note: AHU, PTAC, and VRF stand for air handling unit, packaged terminal air conditioners, and variable refrigerant flow, respectively.

Egypt has a large manufacturing base for ACs, including assemblers and manufacturers, and is a regional exporter of these. The Egyptian government prioritizes local production and discourages imports (BSRIA, 2018).

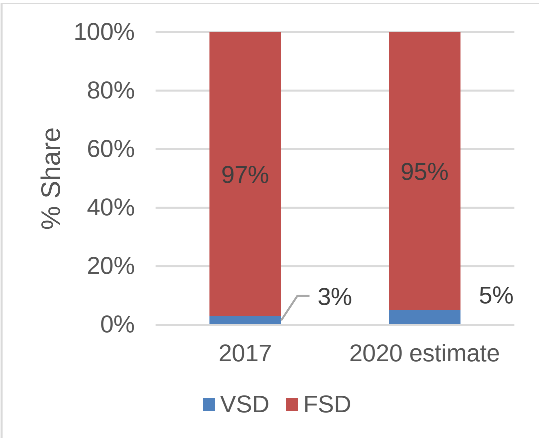

Figure 3. FSD and VSD RAC share in actual 2017 and estimated 2020
Source: BSRIA (2018)

2.2. Current minimum standards and labeling requirements in Egypt

The Egyptian test standard for FSD RACs is based on ISO 5151 T1 conditions (outdoor temperature 35°C). In contrast, the standard for VSD RACs is based on ISO 5151 T1 conditions with additional measurements of two other outdoor temperatures (i.e., 29°C and 43°C, in addition to 35°C).[5] Although the efficiency metrics for FSD and VSD RACs are both expressed in an energy efficiency ratio (EER), the ratios are defined differently. The EER for FSD RACs is the traditional EER, defined by ISO 5151 as the ratio of the total cooling capacity (CC) to the effective power input to the device at any given set of rating conditions (at 35°C). The EER for VSD RACs is a weighted EER (WEER) at 29°C, 35°C, and 43°C calculated as follows:

$$EER_{weighted} = 0.059 * EER_{max} + 0.288 * EER_{rated} + 0.653 * EER_{min} \quad \text{Eq. (1)}$$

According to the energy efficiency label requirements for ACs (ES: 3795 Part 1 /2016; and ES: 3795 Part 2 /2017), the minimum EER for FSD window and split RACs is 11 Btu/Wh (i.e., 3.22 W/W), starting June 2021 (EOS 2017, 2016). The minimum WEER for VSD RACs for both window and split types is 13 Btu/Wh (i.e., 3.81 W/W), effective in June 2022. The ES: 3795 – 1/2016 Part 1 and ES: 3795 – 2/2017 Part 2 documents specify RAC label improvement plans (see **Table 1**).

[5] ISO is short for International Organization for Standardization. Visit https://www.iso.org/standard/63409.html for ISO 5151.

Table 1. The Egyptian energy efficiency label requirements for RACs

June 2020 (Variable-capacity RACs)
June 2021 (Fixed-capacity RACs)

	EER (WEER)	
	W/W	Btu/Wh
A+++++	5.28	18
A++++	4.99	17
A+++	4.69	16
A++	4.40	15
A+	4.10	14
A	3.81	13
B	3.51	12

	EER	
	W/W	Btu/Wh
A+++++	4.98	17
A++++	4.69	16
A+++	4.40	15
A++	4.10	14
A+	3.81	13
A	3.51	12
B	3.22	11

June 2022 (Variable-capacity RACs)

	EER (WEER)	
	W/W	Btu/Wh
A++++++	5.57	19
A+++++	5.28	18
A++++	4.99	17
A+++	4.69	16
A++	4.40	15
A+	4.10	14
A	3.81	13

Source: EOS (2017, 2016)

Currently available FSD RACs can only achieve EERs up to 4.00 – 4.10. Thus, all ratings above A++ are inconsequential for FSD ACs. The New and Renewable Energy Authority (NREA) agrees with this assessment, noting that the current labeling scheme creates confusion among consumers. The minimum allowable EER 3.22 (Grade B) for FSD ACs is comparable with the MEPS China set in 2010 (EER 3.20) and which has subsequently been revised upward significantly. As Table 2 shows, the MEPS for FSD RACs can be updated significantly to better align with global best practice. **Table 2** compares the Egyptian FSD RAC energy efficiency requirements to both the United for Efficiency (U4E) Model Regulation Guidelines, and to those of other major economies. The cooling season performance factor (CSPF) measures the energy efficiency of FSD and VSD ACs on the same scale.

Table 2. The Egyptian energy efficiency label requirements for FSD RACs (effective 2021)

	EER		ISO CSPF (T1)	Notes
	(W/W)	(Btu/Wh)	(Wh/Wh)	
A+++++	4.98	17	5.29	Comparable with U4E Model Regulation Guidelines' Minimum Efficiency for 2023 (ISO CSPF 5.10) for RACs with 4.5<CC≤9.0 kW, and China's proposed

A++++	4.69	16	4.98	2022 MEPS (China SEER 5.0) for RACs with 4.5<CC≤7.1 kW
A+++	4.40	15	4.67	Comparable with Singapore 2020 MEPS (WCOP 3.8 = ISO CSPF 4.52) for RACs
A++	4.10	14	4.35	Comparable with Taiwan 2016 MEPS (ISO CSPF 4.4) for RACs
A+	3.81	13	4.05	Comparable with China 2020 MEPS (China SEER 3.7) for FSD RACs
A	3.51	12	3.73	Comparable with Korea 2010 MEPS (Korea CSPF 3.5) for RACs
B	3.22	11	3.42	Comparable with China 2010 MEPS (EER 3.2) for FSD RACs

Note: (1) Based on Park et al. (2021). Given that predetermined equations in ISO 16358-1: 2013 are used to estimate the performance at 29°C, ISO CSPF for FSD units can be calculated as CSPF = 1.062 × EER, (2). SEER is seasonal energy efficiency factor and WCOP is a weighted COP factor.

Egypt's current minimum requirements for VSD ACs (Grade A) are comparable with U4E Model Regulation Guidelines' Minimum Efficiency (**Table 3**). Meanwhile, Grade A++++++ is estimated to be greater than U4E Model Regulation Guidelines' High Efficiency (5.2 or greater in ISO CSPF T3) for RACs with CC≤4.5 kW and therefore in line with international best practices.

Table 3. The Egyptian energy efficiency label requirements for VSD RACs (effective 2022)

	EER (WEER)		ISO CSPF (T3)	Notes
	(W/W)	(Btu/Wh	(Wh/Wh)	
A++++++	5.57	19	5.99	
A+++++	5.28	18	5.68	
A++++	4.99	17	5.38	
A+++	4.69	16	5.06	Comparable with U4E Model Regulation Guidelines' Medium Efficiency (ISO CSPF (T3) 5.20) for RACs with CC≤4.5 kW
A++	4.40	15	4.76	
A+	4.10	14	4.44	Comparable with U4E Model Regulation Guidelines' Medium Efficiency (ISO CSPF (T3) 4.60) for RACs with CC≤4.5 kW
A	3.81	13	4.13	Comparable with U4E Model Regulation Guidelines' Minimum Efficiency (ISO CSPF (T3) 4.00) for RACs with CC≤4.5 kW

Note: Based on ISO (2019, 2013)

As **Tables 2** and **3** show, there is certainly an opportunity to improve energy efficiency in the RAC sector in Egypt, including increasing the stringency of MEPS and the effectiveness of the standards and labeling (S&L) program to align with major international markets and international best practices, particularly for FSD ACs.

Furthermore, recent revisions of the MEPS in China indicate the potential for significant lifecycle cost, energy, and GHG savings for Egypt. Over 70% of RACs in the world market are manufactured in China and the Chinese market has moved quickly and almost completely to VSD ACs. This shift in the global market, given the size of the Chinese market, also has significant potential for economies of scale in terms of first costs and component costs, which could be further captured for the benefit of consumers in Egypt, particularly by manufacturers and assemblers sourcing components and systems from China.

The next section analyzes the costs of efficiency improvement for RACs.

2.3. Relevant Government Stakeholders

Egypt has developed a standards and labeling program implemented by the EOS with assistance from the United Nations Environment Programme and Development Programme (UNEP and UNDP). Since 2003, the government of Egypt has put in place mandatory MEPS and labeling for various appliances and equipment, including refrigerators, refrigerator/freezers, RACs, washing machines, water heaters, electric motors, and transformers. The MEPS and the labeling scheme are both mandatory, with the most recent effective date for the RAC standard being 2017 for VSD RACs and 2016 for FSD RACs.[6]

Three key ministries impact cooling efficiency programs and policies in Egypt: the Ministry of Electricity and Renewable Energy (MOERE), the Ministry of Environment (MOE), and the Ministry of Trade & Industry (MOTI). In addition, multiple quasi-governmental agencies, industry associations, international bodies, expert consultants, and nonprofits provide stakeholder input. The MOERE houses the Egyptian Electrical Holding Company (EEHC), certain nuclear and power plant authorities, and the New and Renewable Energy Agency (NREA). NREA, a critical component of the ministry, houses the AC test laboratories and maintains its own data.

Currently, Egypt has two accredited test laboratories. One of the labs, financed by a UNDP Global Environment Facility (GEF) grant in 2007, was designed to measure capacity and energy consumption for FSD RACs. These included window types with rated capacity up to 36,000 Btu/hr (10.5 kW) and split types up to 65,000 Btu/hr (19.0 kW) according to the requirements of ISO 5151. The newer test laboratory was also financed as a UNDP/GEF grant project and the IEELA program. The project began at the end of 2019.[7] The new laboratory tests the capacity and energy consumption necessary to calculate the EER for non-ducted FSD RACs and VSD RACs according to ISO 5151. It also performs energy efficiency testing for ducted FSD RACs according to ISO 13253 and VSD RACs according to ISO 16358 (ISO 2020, 2013). Both testing labs are considered neutral testing facilities in Egypt. However, additional labs are housed and run by AC manufacturers, only some of which are accredited. For that reason, EOS relies solely on results obtained from NREA's own test lab to perform its essential functions, including certifying compliance with ISO and Egyptian Standard requirements and issuing the energy label.

MOERE provides electricity to consumers throughout Egypt and publishes statistics and data on electricity and energy consumption and production. This data that is difficult to obtain without government relationships or connections. The MOE houses the Egyptian Environmental Affairs Agency (EEAA). Within the EEAA, the Climate Change Department oversees the National Ozone Unit (NOU). The NOU is responsible for ensuring Egypt's compliance with the Montreal Protocol on Substances that Deplete the Ozone Layer. The NOU monitors, reports, and maintains data on Egypt's consumption of chlorofluorocarbons (CFCs) and hydrofluorocarbons (HFCs) in accordance with the Montreal Protocol (1987) and the 2016 Kigali Amendment to the Montreal Protocol. The NOU leads the National Ozone Committee, an inter-ministerial stakeholder forum with members from the EOS, the Housing and Building National Research Center (HBRC), and EEAA. The MOTI oversees EOS, GOIEC, and FEI (70% of Egypt's industries are FEI members). EOS maintains data on air conditioning standards and compliance and houses a technical committee to manage a database on industries. Importantly, the EOS will be in charge of EESLC and propose all the related standards' recommendations. GOIEC also maintains data on imports and exports and oversees smaller test laboratories (not for ACs) as well as an

[6] This report is focused on non-ducted split units, hence does not refer to ES: 3795-5/2018 Energy Efficiency Label Requirements For Air Conditioner Part 5: Fixed Capacity Ducted Room Air Conditioner With Fixed Speed Compressor.

[7] IEELA stands for "Improving the energy efficiency of Lighting and other Building Appliances (Egypt)".

energy efficiency unit. **Figure 4** shows the details of the Egyptian energy efficiency institutional framework.

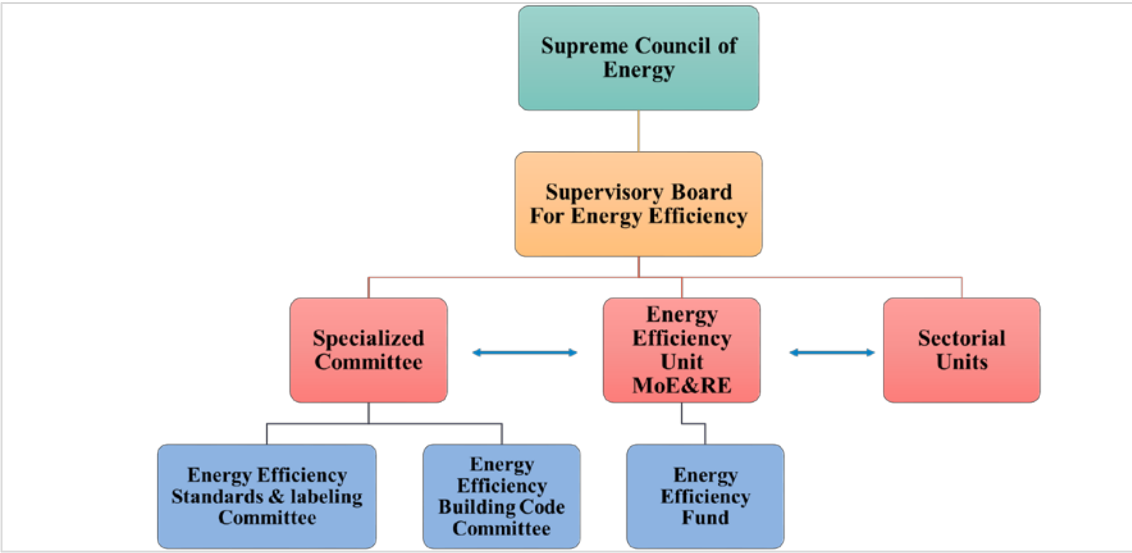

Figure 4. Egyptian energy efficiency institutional framework

2.4. Energy efficiency standard rulemaking and compliance process

This section outlines the general process for creating or revising the minimum energy performance standard (see **Figure 5** for additional detail).

The EOS first conducts a field study to determine whether to issue a new standard or adopt an existing international standard. It also considers requests and arguments from other parties or stakeholders to modify or update the existing standard. A standard is then proposed.

The EOS Technical Committee analyzes this data, reviews the proposal, and develops a strategy in consultation with stakeholders from the Egyptian General Organization for Standards and Quality, GOIEC, ICA, NREA, two to three manufacturer representatives, select faculty members from Cairo University, and select EOS consultants. This multi-stakeholder group may also include representatives from MOERE.

The EOS Technical Committee then discusses and analyzes the proposal, taking into consideration the following:

- The proposed standard must align with the international standard, particularly with respect to testing procedures, testing conditions, and specifications of the testing lab.
- A minimum level of Coefficient of Performance (COP)/EER is set based on the discussion and agreement of the stakeholders, especially the manufacturers.

The proposal is revised to identify energy label grade values. The EOS will then draft a standard, including its analysis and recommendations, and submit this standard to the Ministry of Trade and Industry (MOTI).

The standard is then circulated to related entities, including GOIEC, ICA, manufacturers, universities, relevant ministries, and the CPA. The notice and comment period is typically 60 days.

After the notice and comment process ends, the EOS presents the final proposed standard to the EOS Board of Directors to be approved by the Minister of MOTI. Next, the Minister approves the final standard document, creating a legally binding, mandatory ministerial decree designated by an assigned number, and the MOTI publishes the mandatory decree. All concerned entities must then implement and comply with the standard, including manufacturers, GOIEC, EOS, NREA, CPA, and ICA.

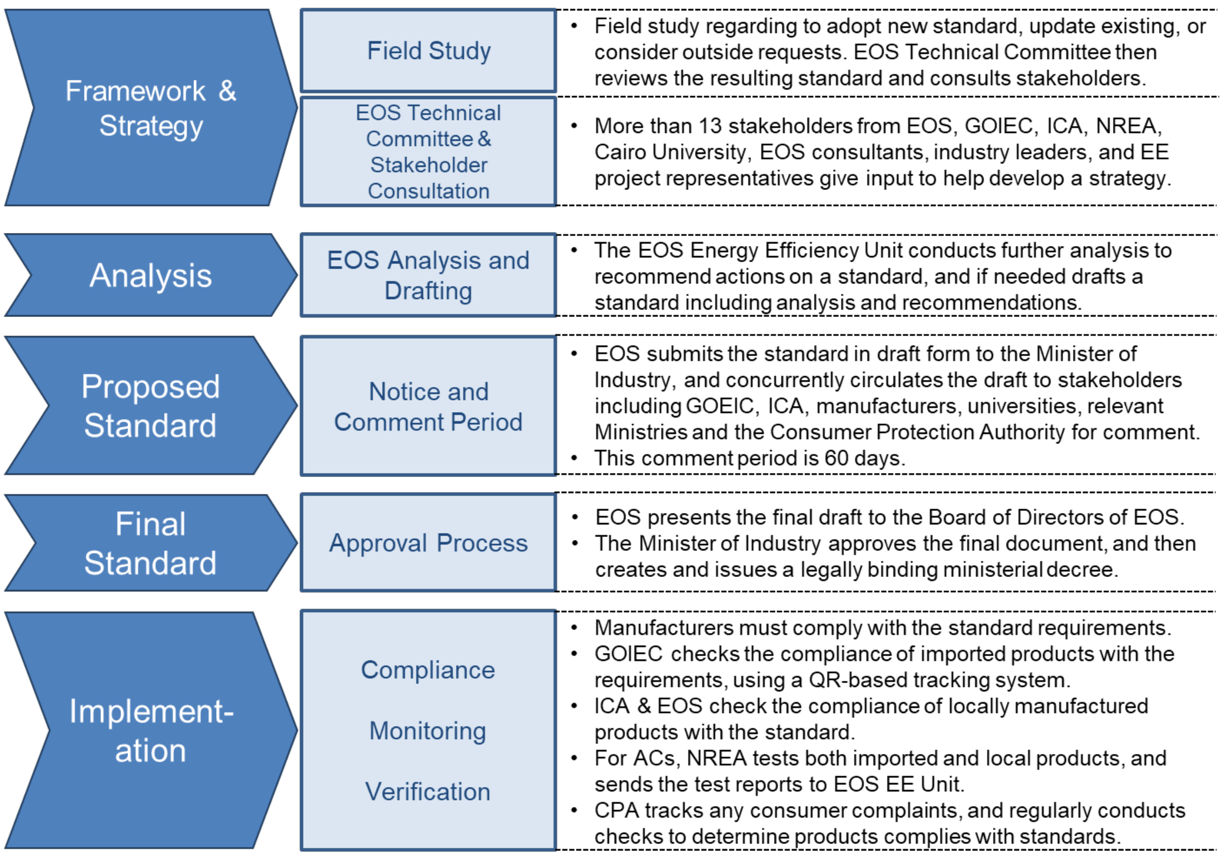

Figure 5. Egypt AC standard rulemaking process
Note: EE stands for energy efficiency.

As part of the compliance process, a quick response (QR) tracking system is developed jointly between EOS and UNDP to monitor and implement the program, and to support the monitoring authorities that must effectively cooperate (EOS, GOIEC, CPA, ICA). After a ministerial decree has been issued and the standard is in place, ACs can be sent from GOIEC (imported ACs) and EOS (locally manufactured ACs) to the NREA for testing. Next, NREA determines whether imported and local products comply with the standard and regularly sends test reports to the EOS energy efficiency unit. EOS enters test results into its national database and the QR-based tracking system, and issues the energy label. NREA's laboratory is currently the sole accredited entity authorized to conduct such tests.

3. Analytical method and approach to assessing cost of efficiency improvement

3.1. Summary of the methodology

This section outlines the analytical framework used to support the recommendation to improve the efficiency of RACs in Egypt. Increasing equipment energy efficiency maximizes cost savings to consumers over the lifetime of the equipment. The United States Department of Energy (US DOE)'s Energy Efficiency Rulemakings and the preparatory studies for the EU Ecodesign Directive (Riviere et al., 2009; Ector et al., 2018) both rely upon bottom-up engineering analysis based on detailed data collection, testing and modeling of more efficient equipment in order to identify the actual manufacturing cost (as opposed to the retail price), and the corresponding lifecycle cost of more efficient equipment. For instance, in the United States, this is due to the statutory requirement in the Energy Policy and Conservation Act (EPCA) that revisions to the Minimum Energy Performance Standards (MEPS) be "technically feasible and economically justified." Prices of higher-efficiency equipment decline over time in various markets as higher-efficiency equipment is produced at scale (Taylor et al., 2015; Abhyankar et al., 2017; Spurlock, 2014). Similar methodologies have been used to a more limited degree to support energy efficiency standards processes in countries such as India, China, Ghana, Mexico, etc. (Shah et al., 2016; Lin and Rosenquist, 2008; Fridley et al., 2001; Van Buskirk et al. 2014; Sanchez et al., 2007).

In prior studies, we have analyzed various combinations of efficient technologies that can be used in higher-efficiency RACs to estimate the total incremental cost and financial benefits of efficiency improvements to RAC owners in India and China (Shah et al., 2015; Karali et al., 2020). This report uses a similar approach to calculate the cost and benefits of using more efficient RAC technologies. **Figure 6** presents the schematic of the methodology we follow in this analysis.

Operating costs typically account for a majority share of lifecycle ownership costs for RAC systems, especially for units installed in hot climates. The net benefits are calculated by adding the costs and benefits of each design option over the lifetime of the RAC and converting the result into net savings using the applicable discount rate. The payback period for each combination of design options is calculated using the annual electricity bill savings provided by that design option relative to the baseline. Key analysis inputs include markup rates, hours of AC use, system lifetime, electricity price, annual growth of electricity price, and consumer discount rate. See Appendix A for the detailed description of the methodology used in this study to develop a cost curve of efficiency improvement and perform a life cycle cost assessment.

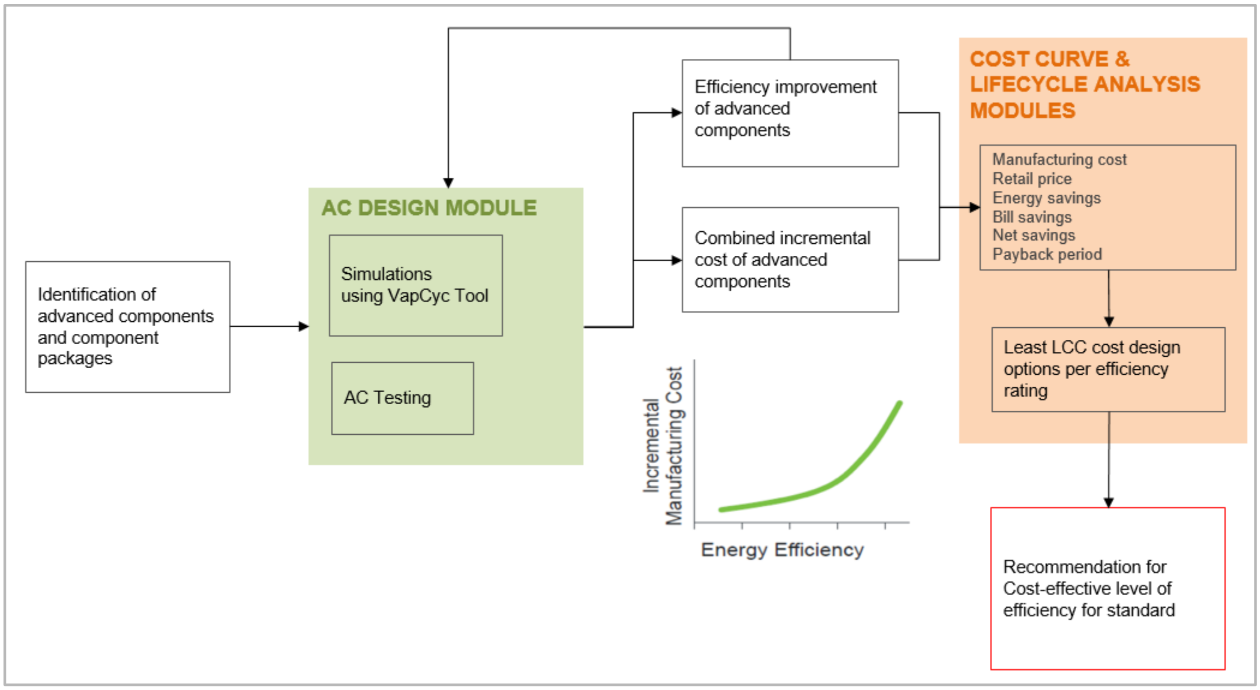

Figure 6. Cost-efficiency curve and lifecycle analysis summary framework
Note: VapCyc is an advanced vapor compression cycle design and simulation tool capable of shortening product development cycles and reducing product development costs. Visit www.optimizedthermalsystems.com for more information. LCC stands for life cycle cost.

3.2. Conversion of EER into WEER and ISO CSPF (T3)

In this analysis, in order to compare the efficiencies of RACs on the Egyptian market with RAC markets in other countries and the energy efficiency levels recommended in the U4E Initiative's Model Regulation Guidelines, we convert EER and WEER into ISO CSPF (T3)-equivalent levels. Eq. 2 and Eq. 3 present the relations used in this study to convert EER and WEER to ISO CSPF (T3). These relations are estimated based on performance data of three FSD ACs and three VSD ACs. Although we use ISO CSPF (T3) calculated with the ISO 16358:2013/Amd:2019 reference temperature bin hours for AC use, it is also possible to calculate CSPF with the Egyptian temperature bin hours specified in ES: 3795-2/2017. The CSPF with the Egyptian temperature bin hours is estimated to be greater by 8% than the CSPF with the ISO temperature bin hours. Therefore, the results presented here are conservative.

$$ISO\ CSPF\ (T3) = 0.875 * EER \qquad \text{Eq. (2)}$$

$$ISO\ CSPF\ (T3) = 1.6755 * exp(0.2332 * WEER) \qquad \text{Eq. (3)}$$

In addition, to calculating the electricity savings, we established a relation between ISO CSPF (T3) and annual unit energy consumption (UEC), based on the performance data of the same three FSD and VSD ACs in accordance with ISO 16358:2013/Amd:2019.

3.3. Baseline unit costs and markup rates

In order to allow comparison across the entire Egyptian RAC market, the baseline RAC is based on one of the least efficient RAC models on the Egyptian market: an FSD 1.0 RT RAC unit with an EER 3.22 rating, which is the current MEPS requirement for FSD RACs, (equivalent to an ISO CSPF (T3) of 2.82), with a retail price of 7,150 EGP (Egyptian Pound). We base manufacturing costs of baseline components on a recent LBNL study based on market and cost data from the Chinese RAC market that estimates the economic benefits and costs of higher-efficiency mini-split RACs to identify cost-effective AC energy efficiency improvements in China (Karali et al., 2020). Because China manufactures over 70% of the RACs globally (Shah et al., 2017), Chinese cost data provides a reasonable proxy for both the baseline and more efficient component costs. The total markup rate over component costs is assumed to be 2.3 (i.e., 130%), based on a calibration of the representative baseline AC unit with real market prices. This markup rate includes labor, depreciation and overhead, manufacturer and retail profit margins, and tax applied to ACs in Egypt. **Figure 7** shows the details of the component cost for the baseline unit and markups used in the study.

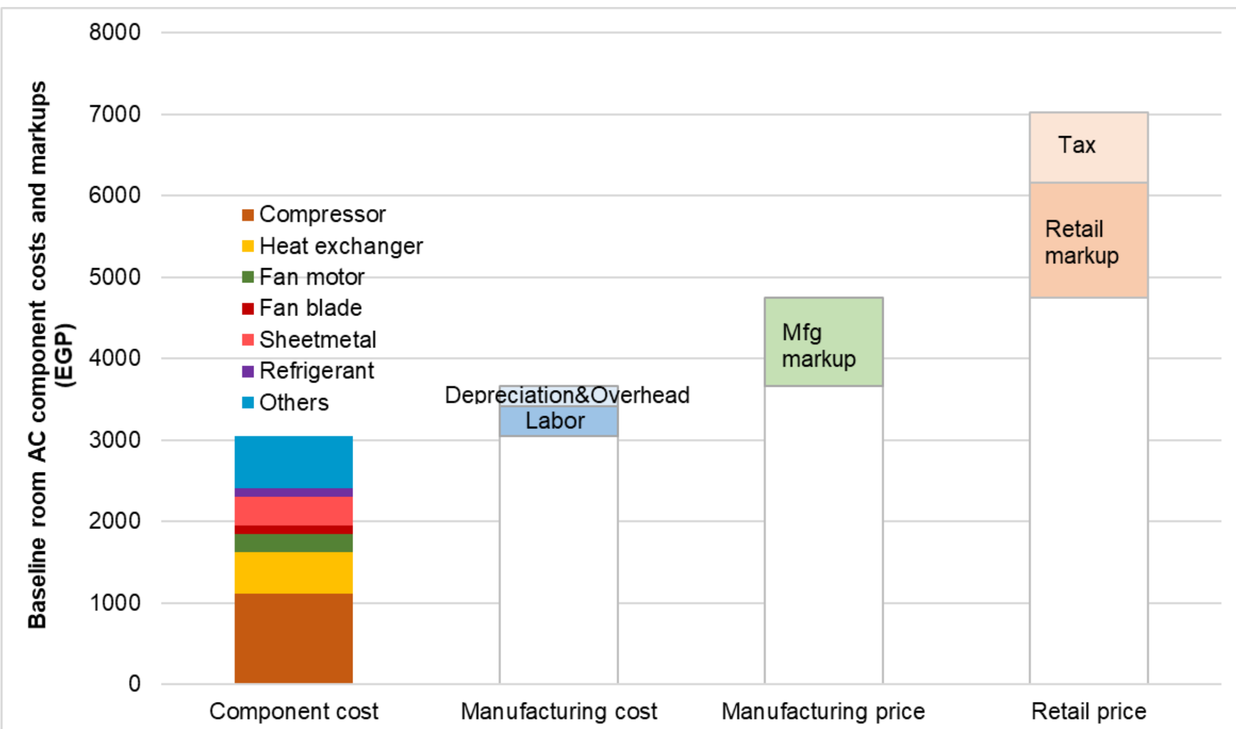

Figure 7. Cost breakdown of the baseline FSD RAC used on this analysis
Note: Mfg represents 'Manufacturing'.

3.4. Efficiency improvement and incremental cost

In recent years, the global AC industry has steadily improved the energy efficiency of AC systems using a combination of technological innovation and market transformation strategies. Manufacturers have introduced several component technologies that improve overall system efficiency, including advanced compressor and variable speed drives (VSDs), advanced fan, motor, and heat exchanger designs; electronic expansion valves; and advanced controls.

In this report, we consider these technologies for increasing the efficiency of RACs: more efficient compressors, VSDs, advanced fans, motors and heat exchanger designs, and electronic expansion valves. We verify the simulated performance of the efficient technologies in this study with data in Karali et al. (2020). **Figure 8** shows the energy savings and incremental costs for each efficiency component. Costs are in absolute values, and electricity efficiency improvements are the percent reduction in electricity demand compared to the baseline RAC. As in the baseline unit, we developed the incremental cost estimates of more efficient technologies based on Karali et al. (2020), who estimate the economic benefits and costs of higher-efficiency mini-split RACs in China. The electricity savings due to the individual components are multiplied when calculating the total electricity savings potential of a design combination. In addition, based on expert input about the Egyptian RAC market, we included only the design combinations with efficiencies below a CSPF of 6.2 (W/W).

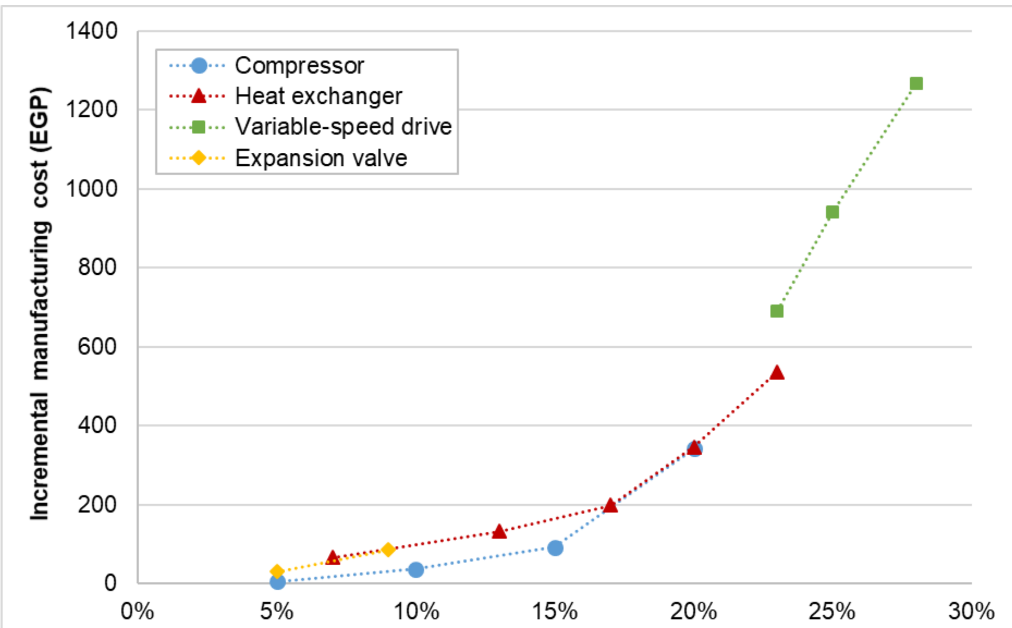

Figure 8. Incremental manufacturing cost of efficient components for Egyptian 1.0 RT mini-split RACs

Note: The baseline compressor has a 2.9 EER rating. The large blue dots from left to right on the compressor line represent 3.0, 3.2, 3.4, and 3.6 EER compressors, respectively. The green squares from left to right on the variable-speed line represent VSDs for an AC (alternating current) compressor, DC (direct current) compressor, and DC compressor and fan, respectively. The red triangles from left to right on the heat exchanger line represent heat exchanger improvements of 20%, 40%, 60%, 80%, and 100%, respectively. The yellow diamonds from left to right on the expansion valve line represent thermostatic and electronic expansion valves, respectively.

Table 4 summarizes other parameters of the average operational characteristics of RACs in Egypt.

Table 4. Operational characteristics of ACs in Egypt

Parameter	Value	Unit	Source
Consumer discount rate	11.75	%	Central Bank of Egypt (2020)[8]
Hours of use	1,800	hour/year	ES: 3795-2/2017 Energy Efficiency Label Requirements for Air Conditioners Part 2
Lifetime	8	year	Authors' assumption
Electricity price	0.84	EGP/kWh	MOERE 2020/2021
Annual average increase rate of electricity price	5	%	Authors' assumption

3.5. Results

Cost of Efficiency Improvement

Figure 9 shows our model of the least manufacturing costs and retail prices for 1.0-RT CC RACs at efficiencies of 2.8–7.0 ISO CSPF (T3), with a ±50% change in incremental cost. The ±50% sensitivity values demonstrate either a decline, owing to learning/economies of scale, or an increase if actual prices turn out to be higher than our estimates. **Figure 9** also presents actual retail prices of some 1.0 RT cooling capacity FSD and VSD RAC units from the Egyptian market to validate our price predictions based on a 2.3 markup rate. Note that current market prices appear to reflect the bundling of AC features other than efficiency related features because prices at the same efficiency level vary widely.

Even though our baseline RAC is based on one of the least efficient RACs, an FSD AC on the current market, the least cost of efficiency improvement could be either FSD or VSD in the analysis. As shown in **Figure 9**, FSD RACs are the least-cost option for efficiency improvement until ISO CSPF (T3) 3.60 is reached. Above this energy efficiency level, manufacturers typically find it more cost-effective to manufacture VSD ACs. Because the current official MEPS rating for VSD RACs is roughly ISO CSPF (T3) 4.07 (converted from WEER 3.81), there are no VSD ACs between ISO CSPF (T3) 3.60 and 4.07 in the modeling. Thus, our results reflect that when improving the efficiency of an ISO CSPF (T3) 2.82 RAC, FSDs are likely more cost-effective than VSDs, but only up until ISO CSPF (T3) 3.60.

As **Figure 9** and **Table 5** demonstrate, a price increase of about 7.5% and 19.5% would allow an efficiency increase of the baseline ISO CSPF (T3) 2.82 (an FSD RAC) to the following levels:

- 7.5%: ISO CSPF (T3) 3.59 (converted from EER 4.1 which is the global maximum for EER currently FSD RACs can achieve),
- 19.5%: ISO CSPF (T3) 4.07 (converted from WEER 3.81 which is the MEPS for VSD RACs)

[8] See https://www.cbe.org.eg/en/EconomicResearch/Statistics/Pages/DiscountRates.aspx for details.

Increasing to ISO CSPF (T3) 4.44, 5.06, and 5.99, which are the efficiency level of Grade A+, Grade A+++, and the highest-grade label, Grade A++++++for VSD RACs, respectively, can be achieved at a price increase of about 20.5%, 23%, and 29%. However, in comparison to a baseline of a VSD RAC with an ISO CSPF (T3) rating of 4.07 (the current official MEPS for this type), improving the MEPS to ISO CSPF (T3) 4.44, 5.06, and 5.99 would result in a much lower incremental price increase (1%-8 %) (see **Table 5**). VSD RACs might be competitive in the Egyptian market with a combined single MEPS rating. This way, relatively inefficient FSD RACs could lose their market dominance and be gradually phased out from the market, in line with trends in other large RAC markets globally, such as China and India.

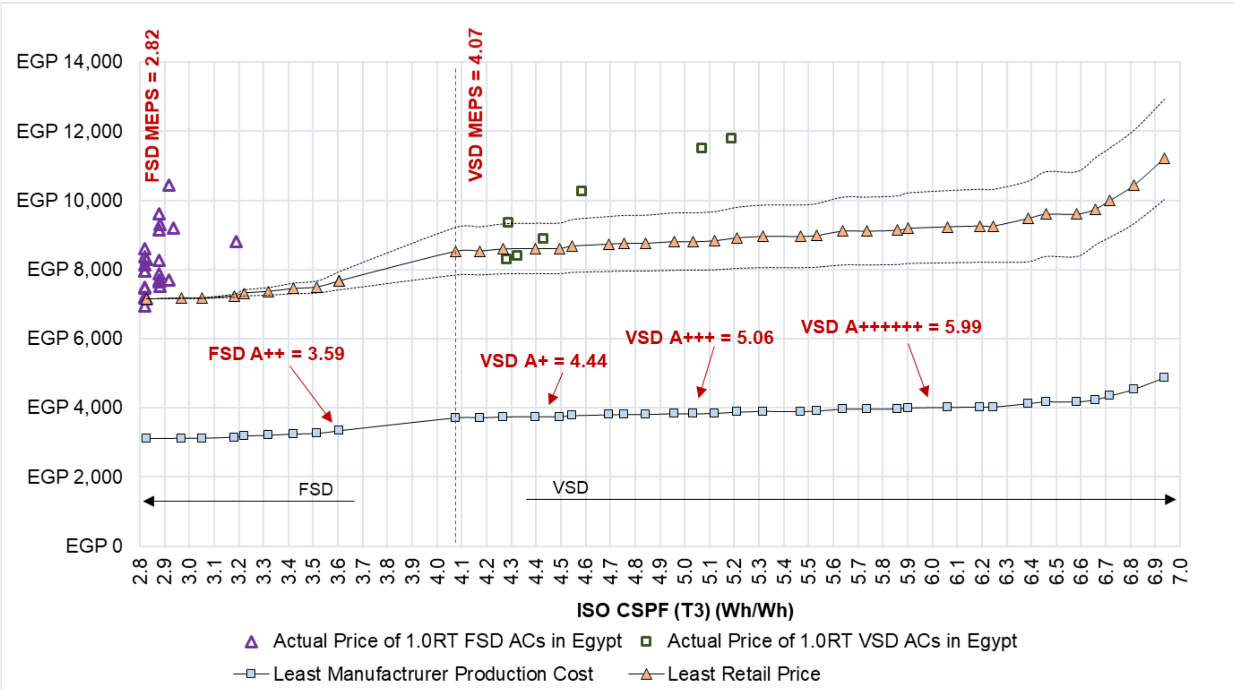

Figure 9. Manufacturing cost and retail price increase per efficiency improvement of 1.0 RT CC mini-split RACs in Egypt

Table 5. Δ Cost of energy efficiency label requirements, compared to current baseline FSD and VSD models

	ISO CSPF (T3)	Type	Δ incremental retail price (compared to the baseline FSD RAC)		Δ incremental retail price (compared to the baseline VSD RAC)	
	Wh/Wh		EGP	%		
VSD A++++++	5.99	VSD	2091.0	29.3%	711.0	8.3%

VSD A+++++	5.68	VSD	1964.5	27.5%	584.5	6.9%
VSD A++++	5.38	VSD	1812.1	25.4%	458.1	5.1%
VSD A+++	5.06	VSD	1660.4	23.2%	280.4	3.3%
VSD A++	4.76	VSD	1612.7	22.6%	232.7	2.7%
VSD A+	4.44	VSD	1464.5	20.5%	84.5	1.0%
FSD A+++++	4.36	FSD	1460.9	20.4%		
FSD A++++ /VSD MEPS	4.10/4.07	VSD	1380.0	19.3%		
FSD A+++	3.85	FSD	525.1	7.3%		
FSD A++	3.59	FSD	347.7	4.9%		
FSD A+	3.33	FSD	221.2	3.1%		
FSD A	3.07	FSD	25.2	0.4%		
FSD MEPS	2.82	FSD				

For shaded rows, that the minimum costs for the indicated efficiency ratings are from VSD RACs, even though the ISO CSPF (T3) is defined for FSD RACs.

Although the results in this section focus on 1.0-RT, RACs (which make up the majority of the Egyptian AC market), the trends and our observations would apply regardless of RAC capacity.

<u>Life-cycle cost analysis</u>

Figure 10 shows net customer savings from higher efficiency over the full AC lifetime, based on accumulated electricity bill savings and the initial AC price. Given the high ambient temperature (HAT) in Egypt, resulting in long RAC operating hours, the AC system's energy consumption comprises up to 80% of a customer's lifecycle costs (Goetzler et al., 2016). In this study, all results are conservatively based on an 8-year operating life. For products with longer equipment lifetimes, the operating costs of higher efficiency equipment would result in even greater lifecycle cost savings.

Net savings increase significantly with higher efficiency levels. As **Figure 10** shows, there is sharp jump from highest efficiency FSD RAC to the lowest efficiency VSD RAC, i.e., ISO CSPF (T3) of 4.00 or greater. This result shows that VSD RACs bring higher savings and increasing the stringency of MEPS to the highest-grade level, Grade A++++++ for VSD RACs, is still likely to provide the great consumer benefits.

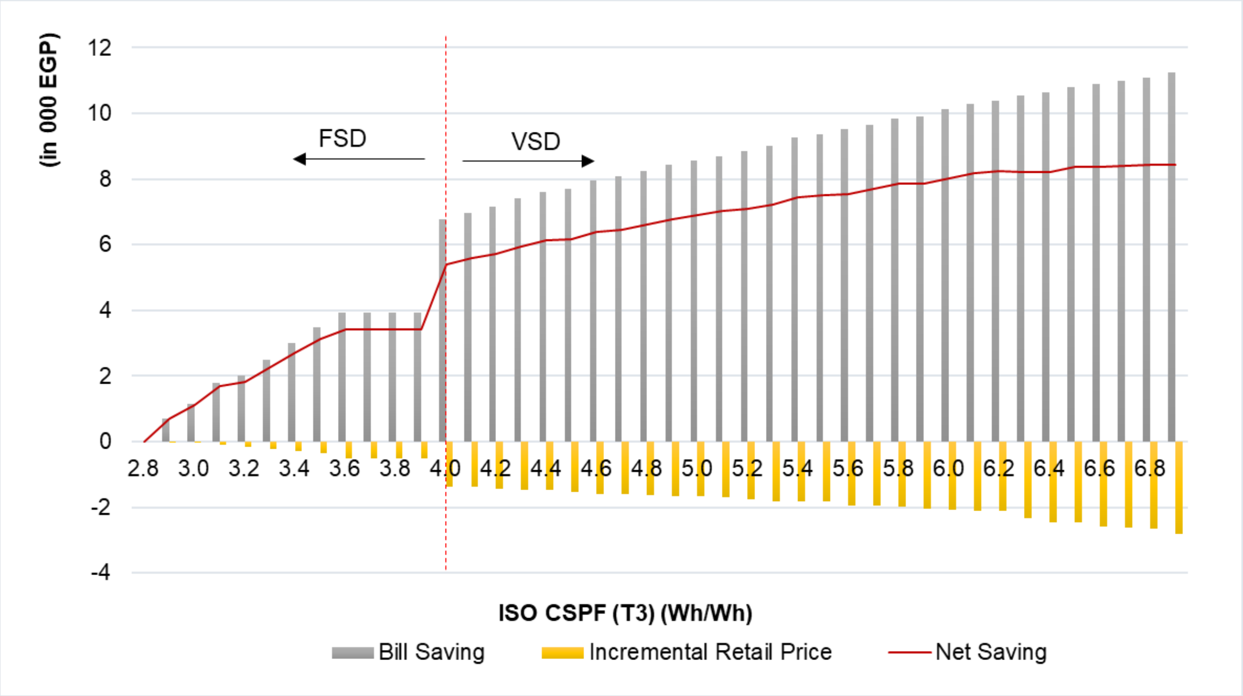

Figure 10. Lifetime net savings for each design level of the least-cost curve

Figure 11 displays the payback periods for RACs at each higher-efficiency design level, compared with the baseline ISO CSPF (T3) 2.82 FSD RAC. The requirement for FSD A++, ISO CSPF (T3) 3.59, achieves payback in about 0.9 year. As demonstrated in **Figure 11**, there is a steep increase in the payback period up to ISO CSPF (T3) 4.07. After that point, the change is minimal until ISO CSPF (T3) 6.2, and is still under 1.5 year. This result shows that there would likely be only a minor increase in consumer costs even if the MEPS ratings for FSD RACs were raised to levels comparable to VSD RAC MEPS ratings and beyond.

Even the highest target efficiency level investigated here achieves payback in much less than 2 year indicating the cost effectiveness of AC efficiency in the Egyptian market. It is notable that even assuming higher upfront costs in our higher cost sensitivity case, VSD ACs are cost effective with payback periods below 3 years. Thus, without further consideration of other relevant issues, it is possible that VSD MEPS can easily be raised with progressively increasing targets over time.

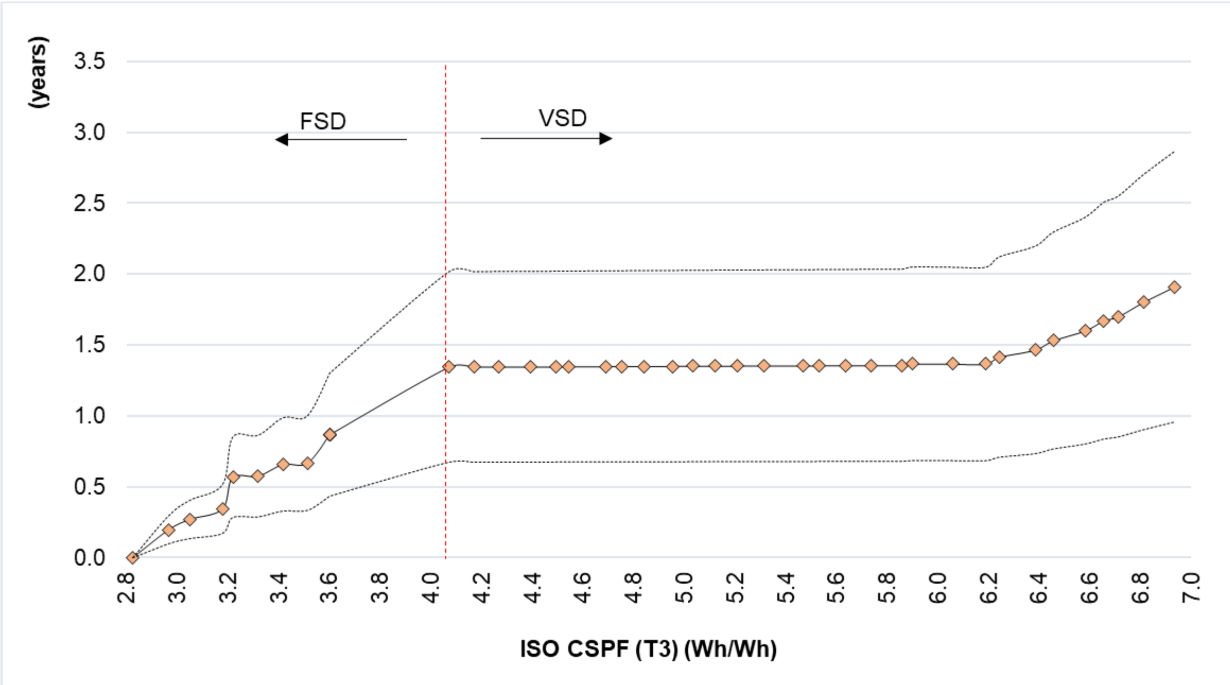

Figure 11. Payback results for each design level of the least-cost curve

4. Methodology and results of national impact analysis

This section summarizes the national impact of the new RAC MEPS on short- and long-term electricity use, net present value (NPV), CO_2 emissions reductions, and avoided generation capacity.

4.1. Methods and main assumptions

Our national impact analysis estimates impacts on the annual RAC sales and accumulated sales, electricity consumption, CO_2 emissions, and electricity generation capacity due to the higher energy efficiency standards. We first estimate new AC sales based on annual AC demand and retirement of existing and new stock, accounting for the median AC lifetime and a growth parameter that determines how quickly ACs are retired at median lifetime. Annual AC demand growth (in number of ACs) in Egypt from the 2020 baseline to 2050 is based on a bottom-up stock-accounting model. The model projects new AC demand using a saturation forecast which is in turn based on macroeconomic drivers.

As discussed in the International Energy Agency's (IEA) *The Future of Cooling* report (IEA, 2018), the rate of household ownership of ACs rises with economic development and household income. The rate of household AC ownership rises more rapidly in the hottest and most humid countries where cooling degree days (CDDs) are over 3000, such as in Egypt. In these countries, cooling is virtually essential to support every aspect of life and an economic driver of growth.

Table 6 summarizes the assumptions used to model the growing AC demand between 2020 and 2050. We assume that residential AC ownership will increase from 15% in 2018 to 50% in 2050, which aligns with the IEA's forecast for household ownership of cooling equipment in 2050 (IEA, 2018).

Appendix B presents a detailed description of the methodology used in this study to evaluate the national impact of efficiency improvements.

Table 6. Demographic and econometric factors considered in this study

	Average annual growth rate		
	2000-2021	2022-30	2031-50
Population	2.0%	1.5%	1.25%
Urbanization growth (%)	2.0%	1.5%	1.2%
Real GDP growth (%)	4.3%	3.7%	3.3%

Source: World Bank (2020; 2022), UN DESA (2019), IEA (2018).

Based on the results of our cost curve analysis, we create two scenarios to investigate the impacts of a harmonized MEPS with higher efficiency requirements compared to the Baseline scenario of the current MEPS requirements set. Scenario 1 is based on the VSD MEPS requirements, while Scenario 2 is based on Grade A+++ of the same MEPS. Based on our results in Section 4, the payback periods to achieve both Scenario 1 and Scenario 2 levels are ~1.3-1.4 years for FSD RACs. **Table 7** details MEPS ratings in each scenario.

Table 7. MEPS ratings in ISO CSPF (T3) (Wh/Wh) used in the scenarios

	2025-2050		
	FSD	VSD	Combined metric
Baseline	2.82	4.07	
Scenario 1			4.44
Scenario 2			5.06

For the Baseline scenario, we assume that FSD RAC sales will be constant at today's rates of ~5% between 2025 and 2050. For the efficiency scenarios (Scenario 1 and 2), we assume the FSD RACs are phased out by 2025 due to the high CSPF ratings set in the scenarios which is a trend in line with global trends. **Table 8** summarizes other parameters considered for the national impact analysis.

Table 8. Other parameters used in this analysis

Grid CO_2 emissions factor (kg CO_2/kWh)	0.6865
Electricity price (EGP/kWh)	0.84
Annual increase rate of electricity price (%)	5%

Note: CO_2 emissions factor includes transmission and distribution losses in the Egyptian grid.

4.2. Result

Figure 12 shows historical (2010–2020) data (JRAIA, 2019; BSRIA, 2022) and projected (2020–2050) annual RAC sales in Egypt. See Appendix B for details on calibration of the parameters β and t_0 of the stock turnover model. Total RAC sales increase from about 0.92 million units in 2020 to 1.43 million units in 2030 and 3.81 million units in 2050.

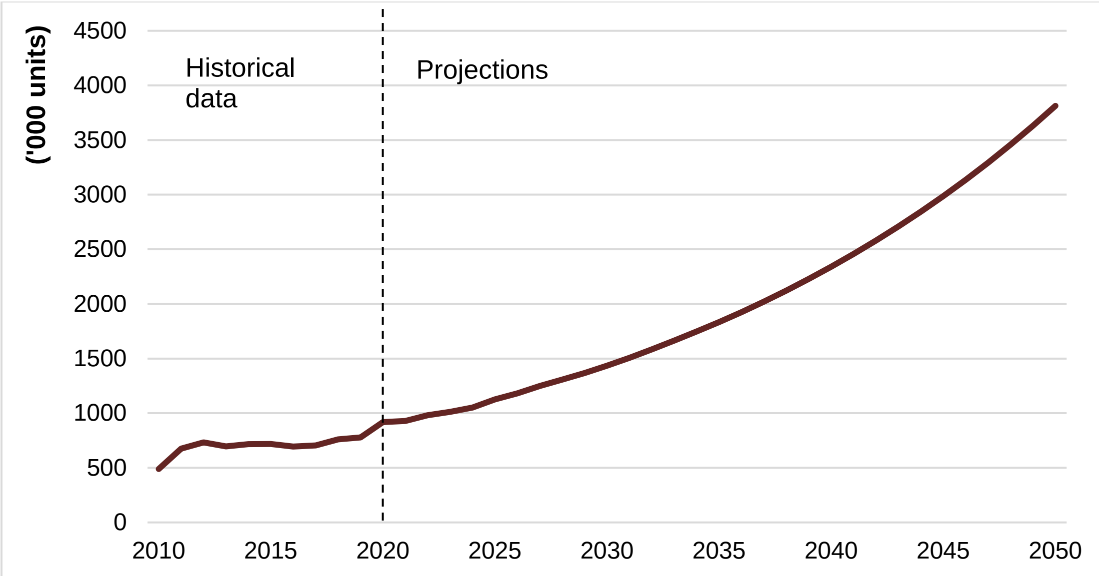

Figure 12. Historical (2010–2020) and projected (2021–2050) annual Egyptian RAC sales

Source of historical data (JRAIA, 2019; BSRIA, 2022)

Figure 13 shows the electricity savings from the RAC efficiency scenarios between 2025 and 2050. Compared with the Baseline, Scenario 1 brings cumulative savings of about11 TWh (equivalent to 7 $MtCO_2$) between 2025 and 2030 and about 78 TWh equivalent to 54 $MtCO_2$) between 2030 and 2050. Scenario 2 brings additional cumulative savings of 4 TWh (equivalent to 2 $MtCO_2$) between 2025 and 2030 and 24 TWh (equivalent to 16 $MtCO_2$) between 2030 and 2050 (see **Table 9**). In addition, by 2030, cumulative bill savings to Egyptian consumers from Scenario 1 and Scenario 2 are about 54 and 69 billion EGP, respectively. These savings increase to 393 and 517 billion EGP between 2030 and 2050. Avoided generation capacities from Scenarios 1 and 2 are 442 MW and 581 MW in 2030 (equivalent to 1 and 1.2 large power plants) and 1,1187 MW and 1,560 MW in 2050 (equivalent to 2.4 and 3.1 large power plants), respectively.

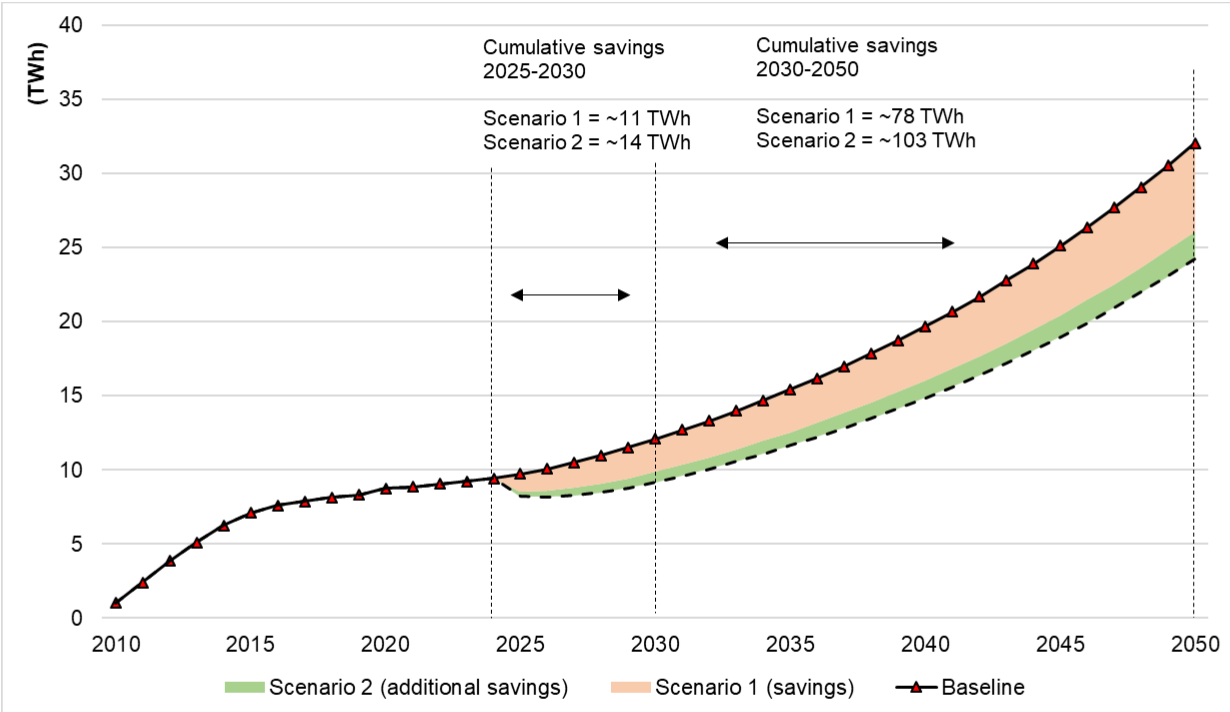

Figure 13. RAC annual electricity savings in the efficiency scenarios

Note: Additional savings in Scenario 2 represents additional savings compared to Scenario 1.

Table 9. Electricity savings, CO_2 emission reductions, bill savings, and avoided generation capacity from efficiency scenarios

		Scenario 1	Scenario 2
2030	Annual electricity savings (GWh)	2,225	2,918
	Annual CO_2 emissions reduction ($MtCO_2$)	2	2
	Annual bill savings (billion EGP)	11	15
	Avoided generation capacity (MW)	443	581
2050	Annual electricity savings (GWh)	5,968	7,841
	Annual CO_2 emissions reduction ($MtCO_2$)	4	5
	Annual bill savings (billion EGP)	30	40
	Avoided generation capacity	1,189	1,562
2020-2030	Cumulative electricity savings (GWh)	10,623	13,775
	Cumulative CO_2 emissions reduction ($MtCO_2$)	7	9
	Cumulative bill savings (billion EGP)	54	69
2030-2050	Cumulative electricity savings (GWh)	78,075	102,567
	Cumulative CO_2 emissions reduction ($MtCO_2$)	54	70
	Cumulative bill savings (billion EGP)	393	517

Note: CO_2 emissions reductions are calculated under the assumption that the current grid emission factor is constant through the analysis period.

5. Policy recommendations

Our analysis indicates that due to increased hours of use in Egypt's hot climate zone, most efficiency levels considered by this study are cost-effective for consumers (from a total lifecycle perspective). Egypt has a substantial opportunity to improve its RAC efficiency using cost-effective technologies, such as microchannel heat exchangers and VSDs. VSD enables an AC unit to respond to changes in cooling requirements, thus improving its performance, increasing thermal comfort and reducing refrigerant flow rates at partial load compared to FSD ACs that cycle on and off.

Although the current share of VSD ACs in Egypt is small (~3% in 2018), the global market has already largely shifted toward VSDs. Almost all RACs sold in North America, Europe, and Japan had VSDs in 2018 (JRAIA, 2019). Similarly, the major manufacturing economies such as China are also moving toward VSD ACs (from ~60% of the Chinese market in 2018 to ~98% in 2022), driven by advances in information technology and semiconductor manufacturing, which have reduced VSD AC costs significantly (BSRIA, 2022). As of 2020, China combined the metrics and labeling for FSD and VSD ACs, further accelerating this trend as consumers recognize the benefits of VSD ACs.

Given the combination of population growth, urbanization, and high outdoor temperatures in Egypt, the benefits of transitioning the AC market to energy-efficient technologies will increase equity among consumers, country's energy and resource security, decrease GHG emissions, and achieve cost savings. Experiences in more developed markets, such as the United States, European Union, and Japan, suggest that with stringent MEPS, sufficient incentives, and robust compliance, high-efficiency ACs can be developed and deployed in Egypt.

Our key recommendations are summarized as follows:

1. *Adopt a common metric* for the measurement of efficiency of FSD and VSD ACs.

    - The current metric scheme in Egypt utilizes two separate energy efficiency metrics for FSD and VSD RACs. The metrics support a lower MEPS requirement for FSD yet employs similar labels between FSD and VSDs. This prevents consumers from distinguishing between inefficient FSD ACs and more efficient VSD ACs. FSD ACs are more cost-effective for manufacturers with an efficiency level below ISO CSPF (T3) 3.60, compared to VSD ACs. While it is technically feasible to manufacture FSD ACs as high as ISO CSPF (T3) 3.60 (~EER 4.10), efforts to retool and redesign manufacturing lines to reach these efficiency levels would be technologically more complicated for FSD RACs and eventually create stranded assets when the markets move with higher efficiency VDS RACs. This is a strategy with proven success in other countries, such as China and India
    - A common metric would help customers identify the most energy-efficient ACs and encourage adoption of the best technology. We recommend the adoption of the ISO 16358:2013/Amd:2019 temperature bin developed for HAT regions.

2. *Adopt a higher and common minimum standard* for FSD and VSD ACs at the level of the U4E model regulations that is equivalent to ISO CSPF (T3) 4.07 (converted from WEER 3.81).

- Increased stringency of MEPS under a single harmonized standard would accelerate the transition toward VSD ACs. In addition, as the results show, the cost curve for higher-efficiency ACs is relatively flat. Transitioning Egypt's FSD manufacturing to VSD manufacturing would require minimal changes beyond the production or import of VSD chips yet simultaneously allow the Egyptian market ample time to adapt and transition to higher standards.
- Because payback periods are shorter and net lifetime savings increase at higher efficiency levels, raising MEPS to such levels will benefit Egyptian consumers. The results show a minor difference in the customer payback periods between the MEPS for VSD RAC ISO CSPF (T3) 4.07 (converted from WEER 3.81) and Grade A++++++for VSD RACs, compared to a baseline FSD RAC.

3. *Restructure the labeling program* from the "A++" scheme to the straightforward A through E scheme used as the energy label for all other appliances in Egypt. Globally, the most efficient FSD RACs available achieve about EER 4.10 (ISO CSPF (T3) 3.60). Therefore, efficiencies above EER 4.40 (ISO CSPF (T3) 3.85), which is the A+++ requirement, are inconsequential for FSD ACs. The continued use of multiple pluses to designate future step-increases in grade is both redundant and confusing to consumers, as noted by the European Union (EU) and as reflected in a recent Ecodesign report (EPRS, 2017).

4. *Strengthen* the *compliance regime* governing the Egyptian AC MEPS. Implementing the prior three recommendations is possible under an effective program for tracking and ensuring compliance with the MEPS requirements. In particular, further increasing the number of test laboratories capable of testing VSD ACs is a prerequisite for recommendations 1 and 2. Establishing a regularized monitoring system for tracking compliance with the mandatory standard and energy information label programs would accelerate the replacement of less-efficient products and facilitate the transformation of the regional market for energy-efficient products. A stronger compliance regime would include round-robin testing, and more frequent monitoring and testing of ACs. It is also essential to improve the test laboratory capacity in Egypt and seek accreditation for existing test laboratories. Currently, Egypt has only one accredited test laboratory, housed within NREA. Finally, NREA recommends changing the energy efficiency testing method and using the new ISO 16358 standard. Such a standard should be developed by a committee that EOS designates specifically to develop and promulgate air conditioner standards.

5. *Assist small and medium AC manufacturers* in Egypt to transition their manufacturing lines to produce low-cost, high-efficiency, variable-speed ACs. Prioritizing the transition for small and medium enterprises (SMEs) to VSD is critical to (1) easing government concerns regarding SME competitive advantages, (2) incentivizing informal markets and SMEs to participate in a compliance regime, and (3) increasing public outreach and awareness of the availability of more efficient equipment.

6. The government and industry should work collaboratively to *identify incentive mechanisms for manufacturers* to adopt VSD ACs. Furthermore, NREA strongly recommends conducting a study to assess the willingness of manufacturers and importers to increase the minimum requirements described herein. Such a study should also assess manufacturers' ability to adopt VSD ACs.

6. Conclusion

In the absence of targeted reforms, Egyptian electricity demand is expected to grow at 5% to 7% per year for the foreseeable future. Much of this demand is from air conditioning applications in Egypt's densely populated urban areas, which are growing even faster than global averages.

Our analysis indicates that Egypt has a substantial opportunity to improve its RAC efficiency using cost-effective technologies, particularly VSDs. In fact, combining FSD and VSD product categories under a single harmonized standard, similar to India and China, and increasing the stringency of MEPS would provide significant energy and climate benefits while saving consumer costs. Globally available FSD RACs are assessed to achieve as high as EER 4.10 (ISO CSPF (T3) 3.60). Thus, any rating above this would eliminate the low-efficiency FSD RACs from the market.

Our results suggest that widespread deployment of VSD RACs with 7.5% more stringent MEPS levels (ISO CSPF (T3) 4.44) can reduce electricity consumption to 11 TWh by 2030 and 89 TWh by 2050—with corresponding CO_2 emissions reductions and avoided generation capacity requirements, compared to the baseline. Under the more aggressive scenario (Scenario 2), 22.5% more stringent MEPS levels (ISO CSPF (T3) 5.06), brings an additional savings of over 30% in the 2025-2050 period. Even though the current RAC market in Egypt is dominated by FSDs (~95%), experiences in more developed markets such as the US, Japan, and EU suggest that—with sufficient incentives and robust regulatory design—Egypt could make significant progress in developing and deploying such efficient VSD technologies. Transitioning Egypt's FSD RAC manufacturing to VSD RAC manufacturing would require few changes beyond adding capacity for semiconductor chip production yet allow the Egyptian market ample time to adapt and transition to higher standards. The cost of such an efficiency increase will be much smaller for RAC manufacturers who transition to manufacture VSD ACs following the prevailing trend in the global market.

References

Abhyankar, N., Shah, N., Park, W.Y., Phadke, A. (2017). *Accelerating Energy Efficiency Improvements in Room Air Conditioners in India: Potential, Costs-Benefits, and Policies*. LBNL-1005798. https://eta-publications.lbl.gov/sites/default/files/lbnl-1005798.pdf

Awadalla, N. (2017). *Egypt Promotes Birth Control to Fight Rapid Population Growth*. Reuters https://www.reuters.com/article/us-egypt-population/egypt-promotes-birth-control-to-fight-rapid-population-growth-idUSKCN1BA153

Blaydes, L. (2019) *Challenges to Stability in Egypt.* Hoover Institution (April 22, 2019) Issue 519.

BSRIA (Building Services Research and Information Association). (2018). *Split Systems 2018−Eygpt. Report*, 61099/2.

BSRIA (2022). *Split Systems 2022−China. Report*, 103659/5.

Charbel, J. (2017). *Report: Nile Delta's Increasing Salinity and Rising Sea Levels May Make Egypt Unihabitable by 2100*. Mada Masr. https://madamasr.com/en/2017/03/16/news/u/nile-deltas-increasing-salinity-and-rising-sea-levels-may-make-egypt-uninhabitable-by-2100-us-geological-report/

Cilluffo, A., Ruiz, N.G. (2019). *World's population is projected to nearly stop gorwin gby the end of the cnetury*, Pew Research https://www.pewresearch.org/fact-tank/2019/06/17/worlds-population-is-projected-to-nearly-stop-growing-by-the-end-of-the-century/

Dickson, S. (2019) Africa tops world AC growth forecasts. BSRIA News. February 2019. Illinois, USA.

Ector et al. (2018) Preparatory study on Smart Appliances (Lot 33) TASK 7 REPORT – POLICY AND SCENARIO ANALYSIS. European Commission report. Belgium, October 2018. http://www.eco-smartappliances.eu/Pages/welcome.aspx

EEHC (Egyptian Electricity Holding Company). (2018). Annual Report 2017/2018. http://www.moee.gov.eg/english_new/EEHC_Rep/2017-2018en.pdf

EIA (US Energy Information Administration). (2018). Egypt Report. https://www.eia.gov/beta/international/analysis.php?iso=EGY

EOS (Egyptian Organization for Standards and Quality). (2020). http://www.eos.org.eg/en/page/24

EOS. (2017). Energy Efficiency Label Requirements for Air Conditioners Part Two: Variable Capacity Room Air Conditioners (window – Split) with Variable Speed Compressor. ES : 3795 – 2 /2017 http://eos.org.eg/en/standard/14613

EOS. (2016). ENERGY EFFICIENCY LABEL REQUIREMENTS FOR AIR CONDITIONERS PART 1: ROOM AIR CONDITIONER (WINDOW-SPLIT) WITH FIXED CAPACITY & FIXED COMPRESSOR. ES: 3785-1/2016. http://eos.org.eg/en/standard/14491

EPRS (European Parliamentary Research Service. (2017). *Framework for energy efficiency labeling. Briefing EU Legislation in Progress*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/599282/EPRS_BRI(2017)599282_EN.pdf

ESMAP (Energy Sector Management Assistance Program). (2019). *Tracking SDG7 in Egypt.* https://trackingsdg7.esmap.org/country/egypt

Fridley, D., Rosenquist, G.J., Lin, J., Aixian, L., Dingguo, X., Jianhong, C. (2001). *Technical and Economic Analysis of Energy Efficiency of Chinese Room Air Conditioners*. Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/lbl-45550-economic-analysis-acfeb-2001.pdf

Goetzler W, Guernsey M, Young J, Fuhrman J, Abdelaziz O, 2016. The future of air conditioning for buildings – executive summary. Washington DC: U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Building Technologies Office.

Harvard University. (2019). *India Slowing, China Resilient in Harvard's New Global Growth Project. Press Release*. http://atlas.cid.harvard.edu/growth-projections

IEA (International Energy Agency). (2020). *Clean Energy Transitions in North Africa*. https://www.iea.org/reports/clean-energy-transitions-in-north-africa

IEA. (2018). *The Future of Cooling - Opportunities for energy-efficient air conditioning*. https://www.iea.org/reports/the-future-of-cooling

International Organization for Standardization (ISO). (2020). 13253:2017/Amd 1:2020 Ducted air-conditioners and air-to-air heat pumps — Testing and rating for performance — Amendment 1. https://www.iso.org/standard/80280.html

ISO. (2019). ISO 16358-1:2013/Amd 1:2019 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 1: Cooling seasonal performance factor — Amendment 1. https://www.iso.org/standard/72399.html

ISO. (2013). ISO 16358-1:2013 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 1: Cooling seasonal performance factor. https://www.iso.org/standard/56467.html

IRENA (International Renewable Energy Agency). (2018). *Renewable Energy Outlook Egypt: Egypt, International Renewable Energy Agency, Abu Dhabi*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Oct/IRENA_Outlook_Egypt_2018_En.pdf.

JRAIA (Japan Refrigeration and Air Conditioning Industry Association). 2019. World air conditioner demand by region; April 2019.

Karali, N.[CO], Shah, N. [CO], Park, W.Y., Khanna, N., Ding, C., Lin, J., Zhou, N. (2020*). Improving the energy efficiency of room air conditioners in China: Costs and benefits*. Applied Energy 258 (2020) 114023. https://eta-publications.lbl.gov/sites/default/files/1-s2.0-s0306261919317106-main_1.pdf

Karasapan, O., Shah, S. (2018). *Egypt's Population: Boom then bust?*, Brookings Institution https://www.brookings.edu/blog/future-development/2018/05/22/egypts-population-boom-then-bust/

Lin, J., Rosenquist, G. (2008). *Stay cool with less work: China's new energy-efficiency standards for air conditioners*. Energy Policy 36 (2008) 1090–1095.

MOERE (Ministry of Electricity and Renewable Energy) (2022) Tariff Category's Customers & Consumption. http://www.moee.gov.eg/english_new/home.aspx

Park, W.Y., Shah, N., Letschert, V., Blake, P. (2021). *Harmonizing Energy-Efficiency Standards for Room Air Conditioners in Southeast Asia*. Berkeley CA: Lawrence Berkeley National Laboratory. https://eta-publications.lbl.gov/sites/default/files/asean_ac_ee_harmonization_final_may_2021.pdf

Park, W.Y, Shah, N., Holuj, B., Horowitz, N., Hillbrand, A. (2019). *Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Air Conditioners*. Paris: UN Environment, 2019. https://eta-publications.lbl.gov/sites/default/files/u4e_ac_model-regulation_20190923.pdf

Riviere, P., Adnot, J., Grignin-Masse, L., Legendre, S., Marchio, D., Nermond, G., Rahim, S., Andre, P., Detroux, L., Lebrun, J., L'honest, J., Teodorose, V., Alexandre, J.L., Benke, G., Bogner, T., Conroy, A., Hitchin, R., Pout, C., Thorpe, W., Karatasou, S. (2009) *ECODESIGN of Energy using Products-Preparatory study on the environmental performance of residential room conditioning appliances* Lot 10, Task 7 Final report.

Sanchez, I., Pulido, H., McNeil, M., Turiel, I., and della Cava, M. (2007). *Assessment of the Impacts of Standards and Labeling Programs in Mexico (four products)*. Instituto de Investigaciones Electricas.

Sever-Mehmetoglu, S.D. (2021). *Understanding Egypt's Long Path to Decarbonization.* Italian Institute for International Political Studies. https://www.ispionline.it/en/pubblicazione/understanding-egypts-long-path-decarbonization-32912

Shaffie, A. K. (2015). American Bar Association Section of Environment, Energy and Resources, International Environmental Law Committee, 3rd Ed. (2015) https://www.wilsonelser.com/writable/files/Attorney_Articles_PDFs/150702-watercrisis-roya.pdf

Shah, N., Abhyankar, N., Park, W.Y., Phadke, A., Diddi, S., Ahuja, D., Mukherjee, P.K. , Walia, A. (2016). *Cost-Benefit of Improving the Efficiency of Room Air Conditioners (Inverter and Fixed Speed) in India*. LBNL-1005787. https://eta-publications.lbl.gov/sites/default/files/lbnl-1005787.pdf

Shah, N., Khanna, N., Karali, N., Park, W.Y., Qu, Y., Zhou, N. (2017). *Opportunities for Simultaneous Efficiency Improvement and Refrigerant Transition in Air Conditioning*. Berkeley CA: Lawrence Berkeley National Laboratory report LBNL-2001021.

Shah, N., Wei, M., Letschert, V.E., and Phadke, A.A. (2015). *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning. Ernest Orlando Lawrence Berkeley National Laboratory*. LBNL-1003671. https://eetd.lbl.gov/publications/benefits-of-leapfrogging-to-superef-0

Spurlock, C. A. (2014). *Appliance efficiency standards and price discrimination.* https://escholarship.org/uc/item/6wh9838j.pdf

Taylor, M., Spurlock, C. A., Yang, H.C. (2015). *Confronting Regulatory Cost and Quality Expectations: An Exploration of Technical Change in Minimum Efficiency Performance Standards*. Discussion paper. Washington, DC: Resources for the Future.

UN DESA (Department of Economic and Social Affairs). (2019). *World Urbanization Prospects−The 2018 Revision*. ST/ESA/SER.A/420. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf

UNEP (United Nations Environment Programme). (2019). *Supplement to the air conditioners policy guide: «accelerating the global adoption of energy-efficient and climate-friendly air conditioners»*. https://united4efficiency.org/wp-content/uploads/2020/05/U4E_AC_Model-Reg-Supporting-Info_20200227.pdf

Van Buskirk, R.D., Kantner, C.L.S., Gerke, B.F., Chu, S. (2014). *A Retrospective investigation of energy efficiency standards: policies may have accelerated long term declines in appliance costs*. Environ. Res. Lett. 9 (2014) 114010 (11pp). https://iopscience.iop.org/article/10.1088/1748-9326/9/11/114010/pdf

World Bank. (2017). *Egypt Energy Efficiency Implementation Energy Efficiency and Rooftop Solar PV Opportunities: Report Summary*. http://documents.worldbank.org/curated/en/578631498760292189/pdf/Final-Output-Summary.pdf

World Bank. (2019). Access to Electricity in Egypt (SE4All database). https://data.worldbank.org/indicator/eg.elc.accs.zs

World Bank, (2020) *Egypt, Country Overview*, World Bank https://www.worldbank.org/en/country/egypt/overview

World Bank. (2022). *Population Growth of Egypt* https://data.worldbank.org/indicator/SP.POP.TOTL?locations=EG

Worldometer (2022) *Egypt Population* https://www.worldometers.info/world-population/egypt-population/

APPENDIX A. Methodology to estimate cost of efficiency improvement and life cycle cost to the customers

Manufacturing cost and retail price:

The total incremental manufacturing cost (*Δmfc*) and retail price (*Δrp*) of the design combination m are calculated as follows:

$$\Delta mfc(m) = \sum_i cost_m(i) \quad \text{(Eq.1)}$$

$$\Delta rp(m) = \Delta mfc(m) * markup \quad \text{(Eq.2)}$$

where $cost_m(i)$ is the incremental cost of component *i* used in the design combination *m* compared to the baseline component. *markup* represents the markup rate from manufacturing cost to user price.

Energy savings:

The overall percent savings of the design combination m, t_es(m), compared to the baseline model, is calculated as follows:

$$t\_es(m) = 1 - \prod_i (1 - es_m(i)) \quad \text{(Eq.3)}$$

where $es_m(i)$ is the percent energy savings gained from component *i* used in the design combination *m* compared to the baseline component.

Efficiency rating:

The efficiency rating (i.e., ISO CSPF (T3)) of the design combination *m* is calculated as follows:

$$ISO\ CSPF\ (T3)(m) = CC/(UEC(baseline) * t\_es(m)) \quad \text{(Eq.4)}$$

where *ISO CSPF (T3)(m)* is the CSPF efficiency rating of the corresponding capacity and type of the design combination *m*, *CC* is the cooling capacity, and *UEC(baseline)* is the power requirement of the baseline RAC.

Energy consumption:

The annual electricity consumption of the design combination *m*, *UEC(m)*, is estimated by Eq.5 for FSD and VSD RACs.

$$UEC(m) = (-927.15 * ln(ISO\ CSPF\ (T3)(m)) + 691.7)\ \ for\ FSD,$$

$$(-1540 * ln(ISO\ CSPF\ (T3)(m)) + 5101.6)\ \ for\ VSD \quad \text{(Eq.5)}$$

Annual bill savings:

Annual bill savings from the advanced components used in the design combinations are calculated as follows:

$$bs(m,t) = \big(UEC(m) - UEC(baseline)\big) * \frac{fprice(t)}{(1+discount)^{age(t)}} \quad \text{(Eq.6)}$$

where *bs(m,t)* refers to the savings on the electricity bill with design combination m in year *t*, *fprice(t)* is electricity price at year *t*, *discount* is the consumer discount rate, and *age(t)* is the age of the RAC in year *t*.

Net savings:

Net savings (*ns*)—the discounted value of benefits less costs over the lifetime of the RAC system—are calculated as follows:

$$ns(m) = \sum_t bs(m,t) - \Delta rc(m) \quad \text{(Eq.7)}$$

Payback period:

Payback period, *p(m)*,—the length of time required to recover the cost of the investment—indicates when the economic benefits occur during the lifespan of each system. It is calculated as follows:

$$cumulative\ bs\ (m,t) = \sum_{t\prime,t\prime<t} bs(m,t) \quad \text{(Eq.8)}$$

$$p(m) = if\ (cumulative\ bs\ (m,t) \geq 0\ in\ t_0, \frac{\Delta rc(m)}{bs(m,t_0)}, else\ t + \frac{cumulative\ bs\ (m,t-1)}{bs(m,t)}\ 1 \quad \text{(Eq.9)}$$

APPENDIX B. Methodology to estimate national impact of efficiency improvement

Scrappage function:

The AC scrappage function and parameters used in this study are based on Karali et al. (2019), which is as follows:

$$survival_t = 1 - 1/(1 + e^{-\beta(t-t_0)}) \quad \text{(Eq. 10)}$$

where t_0 is the median lifetime of the AC, t is the age in a given year, and β is a growth parameter that determines how fast the ACs are retired around t_0. The median lifetime is 5 years and the β parameter is 0.85.

Cumulative new sales:

RAC stock, St_t, in a year are calculated as the sum of current new sales and prior-year sales of units that are still in service, as follows:

$$St_t = S_t + \sum_{u=1}^{t-1} S_u * survival_{t,u} \quad \text{(Eq. 11)}$$

where S_t is the new sale in year t.

Total electricity consumption:

Total electricity consumption is calculated for each capacity to cover all RACs in China, as follows:

$$P_t = St_t * k_t * UEC(m)_{FSD} + St_t * (1 - k_t) * UEC(m)_{vSD} \quad \text{(Eq. 12)}$$

where P_t refers to the total power consumption of the RACs in year t and k_t is the market share of FSD RACs in year t. *UEC(m)* is calculated with the same formula shown in Eq.5 in Section 3.1.

Total CO_2 emissions:

Total CO_2 emissions in year t, $CO2_t$, are calculated as follows:

$$CO2_t = P_t \times CO_2\ factor \quad \text{(Eq.13)}$$

where $CO2_t$ *factor* represents the CO_2 emissions intensity per kWh generated.