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Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners

Nihar Shah[1], Paul Waide[2], Amol Phadke[1]

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[1] Environmental Energy Technologies Division,
International Energy Studies Group,
Lawrence Berkeley National Laboratory

[2] Navigant Consulting, Inc.

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Abbreviations and Acronyms

AC	Air conditioner
APF	Annual Performance Factor (used in Japan)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British Thermal Unit
CAC	Central Air Conditioner
CCE	Cost of Conserved Electricity
CFCs	Chlorofluorocarbons
C_D	Coefficient of discharge
COP	Coefficient of Performance (expressed in W/W (SI units), or Btu/h/W (Imperial units). Multiply the SI value by 3.413 to express it in Btu/h/W) – often but not always used to refer to heating efficiency of heat pumps
DCV	Demand controlled ventilation
DEVap	Desiccant-enhanced evaporative air conditioning
DG-TREN	Directorate General for Energy and Transport
DG-ENTI	Directorate General for Enterprise and Industry
DOE	Department of Energy (United States of America)
EAC	Evaporating air conditioner
EC	European Commission
EER	Energy Efficiency Ratio (expressed in W/W (SI units), or Btu/h/W (Imperial units). Multiply the SI value by 3.413 to express it in Btu/h/W)
ESEER	European Seasonal Energy Efficiency Ratio, expressed in W/W (SI units)
EU	European Union
EuP	Energy-Using Products
FCC	Federal Communications Commission (US)
GHG	Green House Gases
GWP	Global Warming Potential
HVAC	Heating, Ventilating, and Air Conditioning
HCFC	Hydrochloroflurocarbons
HP	Heat Pump
hp	Horsepower (US motors equivalent to kW)

HSPF	Heating Seasonal Performance Factor
kW	Kilowatt (EU motors equivalent to HP)
LRMC	Long Run Marginal Cost of Electricity Supply
NREL	National Renewable Energy Laboratory, Facility of the U.S. Department of Energy
ODP	Ozone depletion potential
PCM	Phase changing materials
PSC	Permanent split capacitor
SEAD	super-efficient equipment and appliance deployment
SEER	Seasonal Energy Efficiency Ratio (expressed in W/W (SI units), or Btu/h/W (Imperial units). Multiply the SI value by 3.413 to express it in Btu/h/W)
TEWI	Total Equivalent Warming Impact
TWh	terawatt hour
TXV	Thermostatic expansion valves
UEC	unit energy consumption
US	United States
VAC	Vapor compression air conditioner
VAV	Variable air volume air
VRF	Variable Refrigerant Flow

Executive Summary

This report presents the results of an analysis, commissioned by the U.S. Department of Energy, of Air Conditioner (AC) efficiency in support of the Super-efficient Equipment and Appliance Deployment (SEAD) initiative.[1] The International Energy Studies group at Lawrence Berkeley National Laboratory in collaboration with Navigant Consulting Inc. performed the analysis. SEAD aims to transform the global market by increasing the penetration of highly efficient equipment and appliances.

SEAD partners work together in voluntary activities to: (1) "raise the efficiency ceiling" by pulling super-efficient appliances and equipment into the market through cooperation on measures like incentives, procurement, awards, and research and development (R&D) investments; (2) "raise the efficiency floor" by working together to bolster national or regional policies like minimum efficiency standards; and (3) "strengthen the efficiency foundations" of programs by coordinating technical work to support these activities.[2]

The objective of this analysis is to provide the background technical information necessary to improve the efficiency of ACs and to provide a foundation for the activities of SEAD participating countries. We find that even the best currently available technology offers large efficiency improvement opportunities (35% to 50% reduction in energy consumption from the market average) in most SEAD countries. The cost effective efficiency improvements range from 20% to 30% reduction in energy consumption based on a consumer perspective.

Objective and Scope

The objective of this analysis is to identify potential Room AC efficiency improvements and their incremental costs, as well as to provide approximate global and country-specific estimates of total energy savings potential. The overarching goal is to provide relevant information to support design of policies and programs that will accelerate the penetration of super-efficient Room ACs.

This report addresses two categories of AC efficiency improvement potential: cost effective and technical. The efficiency improvements studied are those that are technically feasible, practical to manufacture, and feasible using components or technology that is already commercially available, and therefore could be realized in the short to medium term. The relationship between cost and efficiency improvement potential is presented in a consolidated fashion in terms of cost versus efficiency improvement and savings potential curves which can be used to estimate the technical and cost effective potential. Based on the information presented in the cost versus efficiency curve, the cost effective potential can be estimated at different levels of electricity costs which vary across consumer categories.

Analysis Method and Data Sources

The analysis makes use of the energy efficiency incremental component costs and efficiency improvement options and corresponding energy efficiency data developed under the European Commission's Ecodesign program Lot 10 study. This analysis has up-to-date cost and efficiency data

[1] As one of the initiatives in the Global Energy Efficiency Challenge, SEAD seeks to enable high-level global action by informing the Clean Energy Ministerial dialogue. In keeping with its goal of achieving global energy savings through efficiency, SEAD was approved as a task within the International Partnership for Energy Efficiency Cooperation (IPEEC) in January 2010.

[2] As of April 2011, the governments participating in SEAD are: Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, Korea, Mexico, Russia, South Africa, Sweden, the United Arab Emirates, the United Kingdom, and the United States. More information on SEAD is available from its website at http://www.superefficient.org/.

which was derived from extensive engagement with manufacturers and other industrial experts.

The base case is defined as a split fixed-speed room air conditioner model developed for the EU Lot 10 study, which is very typical of fixed speed split systems found around the world but is not the least efficient kind of product one can find on the market. Thus the analysis starts from a mid-market point for much of the world Room AC market[3].

Once the base case is simulated the cost and energy efficiency of successive design changes are simulated such that all 1728 possible mutually exclusive options have been simulated for each economy. Local labor, supply chain markups, installation and maintenance costs, energy costs and capital costs are all adjusted for the local economy, based on a combination of sources such as literature, estimated factory gate costs, retail prices, expert contacts, and official statistics.

The approach outlined above generates cost versus efficiency curves for each economy, including manufacturer (or factory gate) costs and costs to the end user at each level of efficiency corresponding to a design change. The efficiency levels are calculated using climate specific and local hours of use data, generating different efficiency levels for the same model in different economies.

Efficiency, Cost Effectiveness, and Energy Savings Metrics

While the efficiency at full load i.e. the energy efficiency ratio (EER) has been the most commonly used metric historically, most air conditioners only operate at full load for a small proportion of the time. The seasonal energy efficiency ratio (SEER) gives a better approximation of the annual average energy efficiency of a room air conditioner as SEER metrics are designed to account for performance during part load conditions occurring from time to time to produce a statistically representative metric of annual average energy efficiency. Currently such metrics are in place in Japan (called the Annual Performance Factor or APF) and the USA/Canada (known as the SEER).For this study we have chosen to use the new European Seasonal Energy Efficiency Ratio (ESEER), because unlike the other two metrics it also takes account of energy consumption in off and idle modes as well as energy used to keep crank cases warm in the heating system for reversible units and hence is likely to be more representative of performance of ACs when they are in use. Accordingly, all results in the report are reported in terms of the ESEER.

The cost-effectiveness metric used in the analysis presented here is the cost of conserved electricity (CCE), which is calculated by dividing the annualized incremental cost of a design change by the incremental energy saved by the design change per year. The design change is considered with respect to a design corresponding to the market average efficiency level in each economy.

Two kinds of costs of conserved electricity (CCE) are calculated as follows: a) CCE to the manufacturer, (CCE_m), which considers the incremental cost of the higher efficiency model at the factory gate i.e. to the manufacturer and b) CCE to the consumer, (CCE_c), which considers the incremental cost of the higher efficiency model to the consumer or end user. The former metric (CCE_m) is lower than the latter (CCE_c) as it does not include markups and installation costs. CCE_m could be used to measure the cost-effectiveness of a market transformation program such as a utility program offering an incentive to the

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[3] In this study we consider window and unducted split packaged ACs under the general rubric of "Room ACs". The global Room AC market is dominated by unducted split-packaged (known in the US as mini-split) air conditioners, with a trend towards these and away from window ACs in all the economies studied. Central air conditioners (US style ducted AC, packaged or split), are described in brief in Chapter 2, but are not the focus of this report. For a more detailed description of the different types of ACs, please see Chapter 2, while the trend toward split-packaged ACs is discussed further in Section 3.1.

manufacturer, while CCE_c would be used to measure the cost effectiveness a consumer incentive program or a minimum energy performance standard (MEPS) program.

Efficiency improvement options are cost effective if CCE is lower than the cost of electricity. Given that the cost of electricity varies across different stakeholders (i.e. consumers and utility), the cost effective level of efficiency improvement varies across stakeholders.

Finally, this analysis presents an estimate of the energy savings from Room ACs at various efficiency levels in 2020 from a Room AC market transformation program or policy implemented beginning in 2012, by using the earlier efficiency data and base sales data for each economy from the CLASP mapping report, BSRIA data, and the EU Ecodesign study. These data were extrapolated to 2020 using the model from McNeil et al. (2008). The sales forecast from Letschert (2009) was used for China. The metric used to report energy savings is Rosenfelds. One Rosenfeld is equivalent to annual energy savings of 3 Twh/year, i.e. about the energy generated by one medium-sized power plant.

Summary of Findings

Five Economies Constitute a Large Share of the Room AC Market Among Those Studied

Among the countries studied[4], Room AC/Heat Pump sales are dominated by 5 economies (China, India, Brazil, Japan and the EU), with expected total 2014 sales of about 90% of the total market in the economies studied. Sales in the emerging economies are increasing fast, while sales in Europe and Japan are high and remain steady (Figure E1). The markets in the United States and Canada are dominated by large ducted AC systems, also sometimes referred to as Central ACs in the rest of the world rather than Room ACs.

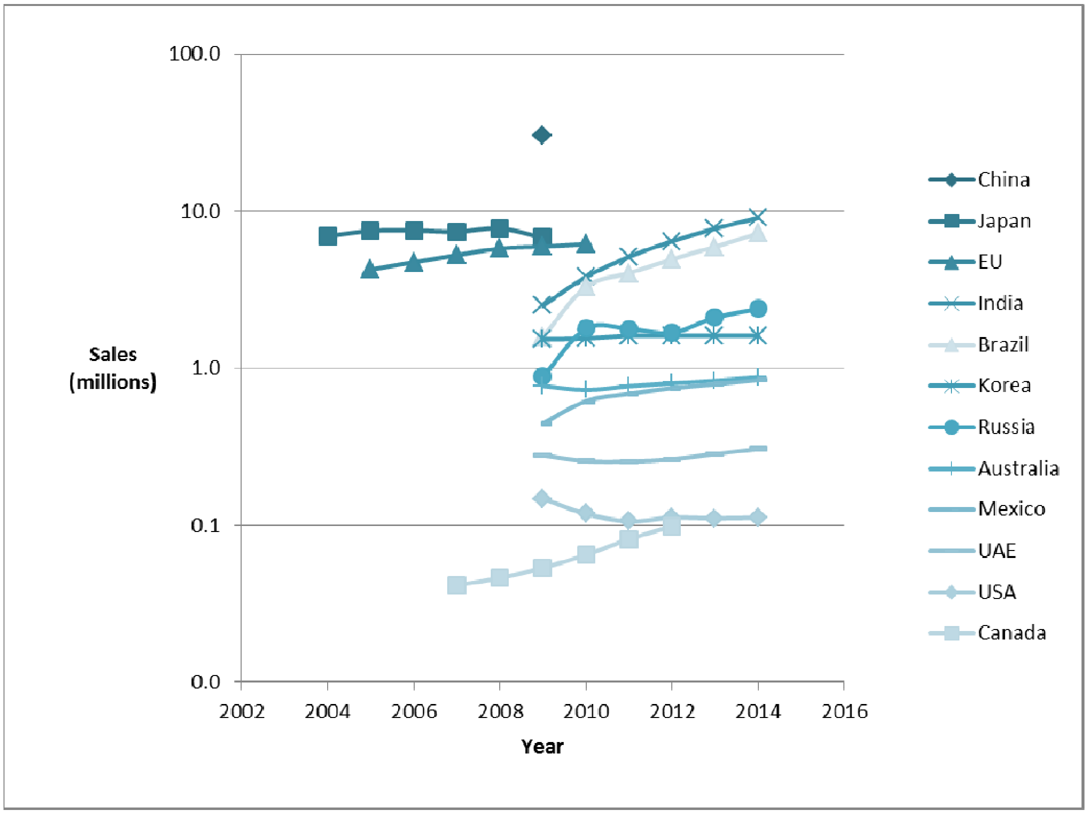

Figure E-1 Current and projected Room AC Sales in various countries (logarithmic scale) Source: BSRIA, and CLASP Mapping Report (Baillargeon, 2011)

[4] In this report we focus on the SEAD participating governments and China. As of April 2011, the governments participating in SEAD are: Australia, Brazil, Canada, the European Commission, France, Germany, India, Japan, Korea, Mexico, Russia, South Africa, Sweden, the United Arab Emirates, the United Kingdom, and the United States. More information on SEAD is available from its website at http://www.superefficient.org/

Significant Potential for Efficiency Improvement Exists

The average energy efficiency of unducted split-packaged (known in the US as mini-split) air conditioners ACs/Heat Pumps which form the majority of global residential air conditioners in every country except the United States, varies from an average Energy Efficiency Ratio (EER) of 4.1 in Japan to an average of 2.69 in the UAE as shown in table E-1 below. The Japanese market has the most efficient air conditioners that are commercially available, with a maximum EER of 6.67 W/W, and an average of 4.1. We report efficiencies in table E-1 in EER terms even though the rest of the report uses ESEER, since the data available is reported using this metric.

Even though the data presented in Table E-1 are illustrative and cannot be compared directly *across countries* due to lack of availability of overlapping data sets and minor differences in test procedures, these data can be compared *within* each country studied. Table E-1 clearly and unequivocally show that there is a significant gap in efficiency terms between the best available split package AC in each economy and the average AC in that same economy. If the best available technology available globally is considered, it is even more evident that there is significant room for improvement in Room AC efficiency in all the economies, even if only ACs currently available on the market are considered.

Table E-1 Average EERs of unducted split-packaged ACs in various economies in 2010-2011(illustrative)[5]

	EER (W/W)		
Country	Min	Max	Average
Australia	2.67	4.88	3.16
Brazil	2.92	4.04	3.19
Canada	2.14	4.33	3.6
China	2.9	6.14	3.23
EU	2.21	5.55	3.22
India	2.35	3.6	2.8
Japan	2.37	6.67	4.1
Korea	3.05	5.73	3.78
Mexico	2.42	4.1	2.92
Russia	2.5	3.6	2.79
South Africa	2.28	5	2.91
UAE	2.14	3.22	2.69
USA	-	4.6	3.04

Source: Catalog searches, IEA 4E M&B 2010, Baillargeon, 2011

[5] This data should be treated as illustrative as no overlapping datasets were available to cross-check these data points. Data shown in table E-1 are based on a) samples obtained from catalog searches in Brazil, Canada, Mexico, Russia, South Africa and the UAE, b) from the IEA 4E Mapping and Benchmarking Analysis for Australia c) from the CLASP Mapping Report for China, EU, India, Japan and the USA, and d) from the IEA 4E Mapping and Benchmarking Analysis for Korea. (IEA 4E M&B 2010, Baillargeon, 2011)

Summary of Efficiency Improvement Options

Various options to improve air conditioner efficiency exist, including "classic options" such as increasing heat exchanger size/efficiency, variable speed and efficient compressors, efficient fans, and thermostatic and electronic expansion devices. In Table E-3 below, we summarize some of the more common options, and the corresponding energy savings (%) compared to the base case. The range shown in Table E-2 indicates the range of energy savings possible from a small incremental efficiency improvement(min), or the best technology available (max).

Table E-2 Classic Efficiency Improvement Options and Corresponding Energy Savings[6]

Option	Description	% improvement from base case	
		Min	Max
Efficient Heat Exchanger	high efficiency microchannel heat exchangers, larger sized heat exchangers	9.1%	28.6%
Efficient Compressors	two-stage rotary compressors, high efficiency scroll compressors with DC motors	6.5%	18.7%
Inverter/Variable Speed	AC, AC/DC or DC inverter driven compressors	20%	24.8%
Expansion Valve	Thermostatic and electronic expansion valves	5%	8.8%
Crankcase Heating	Reduced crankcase heating power and duration	9.8%	10.7%
Standby load	Reduced standby loads	2.2%	2.2%
Total/cumulative[7]		60 %	72%

If all the efficiency improvement options shown in Table E-2 above are employed, then the higher efficiency Room AC could save between 60-72% of energy compared[8] to the base case model in the various economies studied, varying by usage and climate in the various economies studied.

[6] The energy savings figures presented here are representative of conditions in Europe.

[7] Note: Cumulative efficiency improvement is lower than a simple addition as the options are not mutually exclusive, i.e. improvement using one option reduces the baseline energy consumption to which the next efficiency improvement option is applied. Also, the improvements due to variable speed drives are climate and usage dependent.

Efficiency Improvement to ESEERs between 4.2- 7.44 W/W is Cost Effective Leading to Savings Potential of over 63 Rosenfelds[9]

Applying the efficiency improvement options discussed earlier to the base case model, and calculating the incremental cost to the consumer of conserved electricity as described in chapter 4 of this report, we present the resulting cost versus efficiency curve in Figure E-2 below.

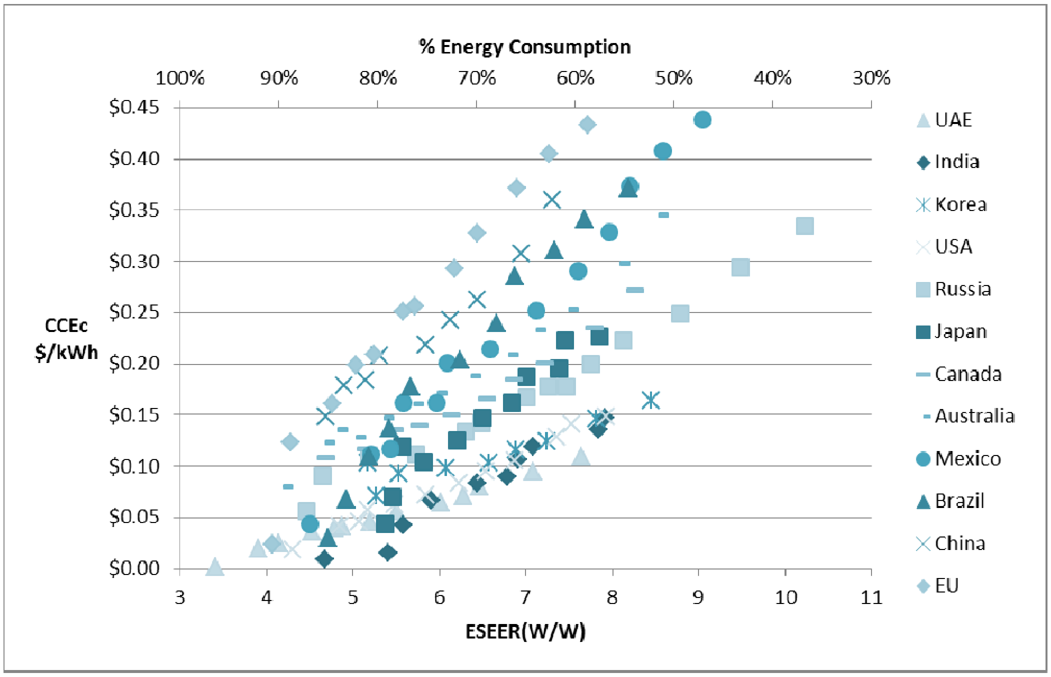

Figure E-2 Cost to Consumer of Conserved Electricity (CCEc) Versus Room AC Efficiency for Various Economies

In economies with a higher cost of capital(i.e. discount/interest rates) such as Brazil, or low hours of use, higher efficiency ACs carry a larger cost of conserved electricity, when compared to India or UAE. For countries such as Japan where ACs are used for both heating and cooling, and India or UAE, where ACs are used for many hours annually, very high ESEERs are attainable at low cost per unit of electricity saved. Significant energy savings are cost effective in most of the economies studied, as further shown in Table E-3 below.

[9] In line with Koomey et al. 2010, we use the unit of Rosenfeld for denoting energy savings. One Rosenfeld=3TWh/year, or approximately one 500MW (i.e.medium power plant).

A	B	C	D	E	F	G	H
Country	Tarriff $/kWh	Market Average ESEER	Economic Potential ESEER (W/W) @ Tariff = CCEc	Technical Potential Max ESEER (W/W)	2020 Energy Savings @ Economic Potential (Rosenfelds)	2020 Energy Savings @ Technical Potential (Rosenfelds)	2020 CO2 savings @ Technical Potential (tons/year)
Australia	0.10	4.03	4.48	8.55	0.35	2	4
Brazil	0.19	4.05	5.67	8.83	6	10	3
Canada	0.08	4.58	4.54	8.26	0	0.24	0.1
China	0.19	4.11	5.19	7.30	16	33	99
EU	0.19	4.09	5.00	8.33	11	30	32
India	0.08	3.56	5.55	7.91	19	29	78
Japan	0.22	5.21	7.44	7.85	8	9	11
Korea	0.07	4.80	5.33	8.45	1	4	5
Mexico	0.08	3.71	4.45	9.74	0.15	1	1
Russia	0.05	4.20	4.20	10.23	0	4	4
UAE	0.07	3.46	6.24	7.64	2	2	3
USA	0.11	3.87	6.80	8.00	0.2	0.24	0.4
Total					64	123	241

Table E-3 ESEER and Energy Savings at Economic and Technical Potential

In the above table E-3, we present the following information:

- Column B: representative consumer tariffs for the economies studied.
- Column C: the approximate market average ESEER converted from the EER values reported in chapter 3.
- Column D: the economic or cost effective potential in terms of ESEER i.e. at efficiency levels where cost of conserved electricity equals the tariffs in column B.
- Column E: the total or technical potential in ESEER terms, i.e. the ESEER possible by deploying the best available technology in the climate and seasonal conditions of the respective economies.
- Column F: the 2020 annual energy savings potential from Room AC efficiency improvement in Rosenfelds (3TWh/yr), assuming that the corresponding market transformation program goes into effect at the efficiency level corresponding to column D and transforms 100% of the market. i.e. a standard corresponding to column D.
- Column G: the 2020 annual energy savings potential from Room AC efficiency improvement in Rosenfelds (3TWh/yr), assuming that the corresponding market transformation program goes into effect at the level corresponding to column E and transforms 100% of the market. i.e. the potential available for a labeling or incentive specification corresponding to column E.
- Column H: the 2020 annual CO_2 savings potential from Room AC efficiency improvement assuming that the corresponding market transformation program goes into effect at the level corresponding to column E and transforms 100% of the market. i.e. the potential available for a