Energy efficient room air conditioners – best available technology

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Abstract

More than 5 million room air conditioners (ACs) are sold per year in Europe, 35 million in India. Most air conditioners combine heating and cooling, and sales are expected to grow further. Total annual electricity consumption by air conditioners in Europe is estimated at more than 40 TWh, in India at 200 TWh. The most efficient ACs are split models with a variable frequency drive (VFD). Market shares of variable speed ACs are on the rise both in Europe and in India. They are more efficient at part load conditions than fixed speed (on/off) appliances and can keep the requested room temperature more constant. In India, the efficiency indicator for variable speed ACs (SEER / HSPF) does include part load conditions, while in Europe a part load measurement standard is actually in preparation. The implementation of seasonal efficiency indicators, strict minimum efficiency requirements and an effective energy label is key for the promotion of high efficiency air conditioners. In India, the implementation of MEPS and an energy label for variable speed air conditioners triggered a significant increase in market share and efficiency. A Indian high efficiency AC was tested according to four different measurement standards (European current and future, Indian and US). Results show that the best available technology (BAT) on the European market is comparable to the one in India. Very high SEER results according to the future European standard raise the expectation that several ACs will already reach the A+++ classes of the new energy label.

Introduction

Room air conditioners transport heat from inside a room with a refrigerant cycle to the outside. Most air conditioners consist of a reversible heat pump and can also be used for room heating instead of cooling. The most important components of an air conditioner are evaporator and condenser with fans plus a compressor.

Four main room air conditioner construction types can be found on the market:

1. Split air conditioners consist of an indoor- and an outdoor-unit, which are fixedly installed and linked together with the refrigerant line. The condenser and the compressor are located in the outdoor unit, not delivering any waste heat indoors. Several indoor units can be connected to one outdoor unit – resulting in a multi-split air conditioner. Mobile split air conditioners have a portable indoor unit containing the compressor, which leads to less efficiency.
2. Single ducts consist of one single unit placed freely in the room. The air is expelled through a duct, which requires a window to be open. Warm air is drawn into the room, as the condenser is cooled with air taken from the room – the cooling effect is small and only local.
3. Double ducts also consist of one single unit, but have separate ducts for air intake and exhaust. Either double ducts are moveable and placed next to a window, or the ducts are mounted through the wall.
4. Through-the-window air conditioners (also: compact or through-the-wall AC) are widespread in the USA, but of no importance in Europe. They are too compact to be efficient and require an opening in the insulation.

The efficiency of split air conditioners on American, Asian, Australian and EU markets has improved by 3% per year in the past 15 years, while the EER of the three latter (unitary or compact) types has virtually remained the same [1]. Split air conditioners are not only by far the most efficient, but also the most popular type in Europe as well as in India. Therefore the focus of this paper is on split air

conditioners. The most energy efficient split air conditioners have a variable frequency drive (VFD) and a permanent-magnet motor. The VFD allows the air conditioner's compressor to run at part load and adapt its workload to the temperature change needed. Fixed speed air conditioners on the other hand reach a certain temperature by switching from full load operation to off, which is not very efficient.

The current EU energy label for air conditioners refers to the Energy Efficiency Ratio (EER, cooling function) and Coefficient Of Performance (COP, heating function) to indicate the energy efficiency of air conditioners. These indicators are measured at full load operation and do not account for the efficiency gains by the variable speed drives' ability to work at part load. Seasonal efficiency indicators (SEER for cooling, SCOP or Heating Seasonal Performance Factor (HSPF) for heating) do consider the different cooling or heating needs during the year and include part load operation of air conditioners. Many non-EU countries have been applying seasonal efficiency indicators, while the EU is about to introduce them now.

Air conditioner markets in Europe and India: trends, best available technology (BAT) and energy consumption

Europe

Market trends

Annual air conditioner sales in the EU are expected to grow from 4.9 million units in 2005 to almost 10 million by 2020. At the same time the stock will increase from around 40 million units to 110 million installed air conditioners [2].

National markets across the EU differ strongly due to different climate, building design, legislation and income. In Southern countries for instance heating with air conditioners is common, while houses in Northern countries usually have central heating installed. Across Europe, about 75% of the sold air conditioners include a reversible heat pump capable of cooling and heating. Variable speed (inverter) air conditioners have also become popular: in 2007 55%-75% of the sales were air conditioners with a variable speed drive. Sales shares of both reversible heat pumps and variable speed air conditioners are expected to grow further, while split cooling only appliances (without heating function) are expected to disappear from the market. Single ducts and double ducts, today accounting for about 15% of the sales, are expected to become more popular however [2].

Sales data from 5 European countries from 2005 - 2008 (till October) show that class A air conditioners by now account for most of the sales (Fig. 1).

This market evolution seems to have been triggered mainly by the introduction of the energy label for air conditioners in 2002 [4]. By now high efficiency air conditioners reach Energy Efficiency Ratio (EER) values of up to 5.63 [5] - way beyond the class A threshold of 3.2.

Energy efficiency: Best available technology (BAT) and average air conditioners

Split air conditioners with a variable speed drive and a permanent-magnet motor are the most energy efficient air conditioners. For the heating mode, some products switch to electrical resistance heating, a highly inefficient way of heating. Potentially efficient are products with a reversible heat pump instead. Energy efficiency of air conditioners has been indicated by the EER (Energy Efficiency Ratio) for the cooling mode, and, if present, by the COP (Coefficient of Performance) for the heating mode. These indicators give the ratio of the total cooling or heating output and the energy consumption.

Topten.eu, an independent database for the most energy efficient products on the European market [6] [7], lists six air conditioning models of four different brands with an EER ! 5 as the European BAT for split air conditioners with a cooling capacity of 4kW or less, the most efficient reaching an EER of 5.63. For higher capacity air conditioners, Topten identifies three models with an EER > 4.1 as the BAT, while the four most efficient multi-split models reach values above 3.5. The COP values of most of these models are slightly higher than the EER values (BAT EER and COP values see Tab. 1). Inefficient products on the market have EER of around 2 and COP

around 2.4. Resistance heating results in a COP of 1.

Table 1: EER (cooling) and COP (heating) of best available products on the European market

Air conditioner type	EER: BAT in EU	COP: BAT in EU
Split < 4kW, variable speed	5.63	5.68
Multi split, variable speed	4.97	4.65
Split > 4kW, variable speed	4.52	4.52
Mobile split	3.22	3.67

Data source: www.topten.eu

The total energy consumption depends mainly on the outdoor climate, building type and age, the capacity and the type of the appliance and can vary strongly. An efficient split air conditioner with an EER of 5.63 and a COP of 5.68 consumes around 800 kWh per year[1]. According to [4] the average EER of the air conditioner models sold in the EU-27 in 2008 was around 3.23, the average COP around 3.4. Such an average air conditioner consumes almost 90% more electricity than a BAT model
– around 1500 kWh per year

Figure 2: Annual energy consumption by split reversible air conditioners[1]. Data source: [5], [4] and [2].

Increasing total consumption

Total annual electricity consumption by air conditioners in Europe is estimated at 30 TWh in 2005 [8], in 2010 it will have reached more than 40 TWh. Two thirds of the total consumption are attributed to the heating function [2]. By 2020 electricity consumption will increase to around 75 TWh annually without any measures (business as usual) [8], mainly due to higher market penetration [2]. The expected increase of 30 TWh annually corresponds to the production of close to five 750 MW-power plants.

The planned EU policy measures (minimum requirements and energy label) are expected to lead to savings of around 11 TWh annually by 2020 [8] – only one third of the expected increase in electricity consumption. The saving potential is higher than that: assuming that today's entire stock was replaced by BAT appliances would lead to annual electricity savings of more than 12 TWh. The expected future stock of 110 million units in 2020 [2] holds a saving potential of around 31 TWh per year.

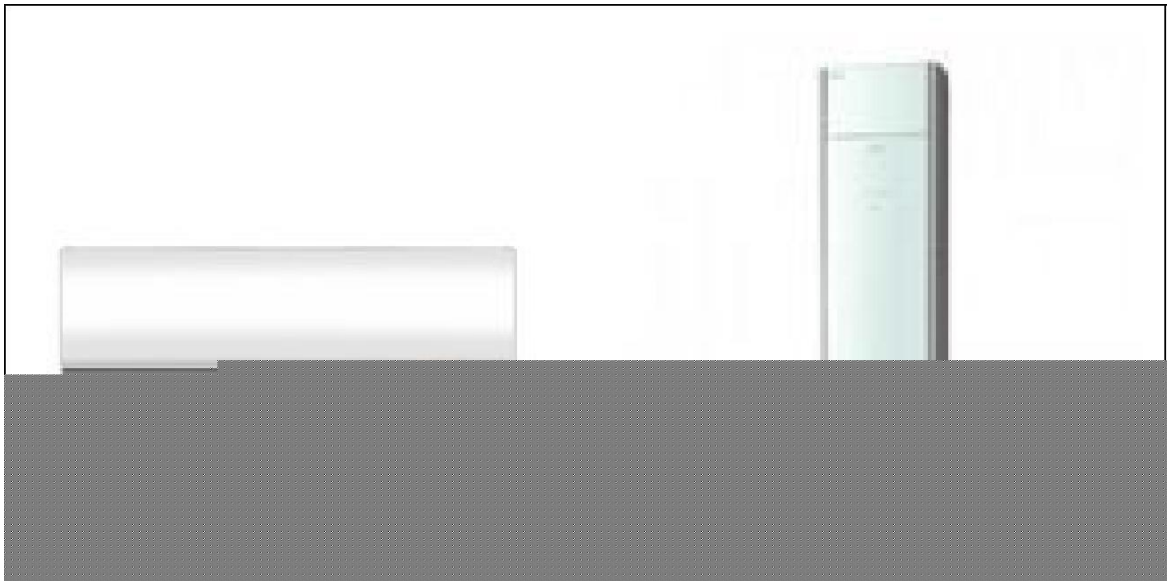
India

Market trends

India is the largest air conditioner manufacturing country of the world. 81 million air conditioners have been produced in India in 2009. Due to the urbanization process and the fast economical development the Indian domestic air conditioner market started to boom increasingly after the year 2000 till today. In 2009, sales reached 35 million annually [9]. They are expected to keep increasing in the next few years. The Indian government has implemented a series of policy incentives: an 'old to new' program, a high efficient air conditioner subsidy program and a 'home appliances going to the rural market' program. These programs additionally stimulate the sales and contribute to the dissemination of air conditioners.

The Indian market is dominated by split air conditioners. The sales share of wall split air conditioners keeps increasing since 2006. In 2010, sales share of wall split air conditioners reached 85% [10]. Topten India found that the cooling capacity of 5000W can be recognized as the line to

distinguish the wall and free standing air conditioners. Free standing air conditioners have higher cooling capacities, while however they are less efficient than wall models.



Figures 3 and 4: Split air conditioners, indoor units: wall and free standing type

Although India is a huge country combining different climates and building types, 87% of all air conditioner models on the market include a heating function (more than 62% with a heat pump, 25% function with electrical resistance heating) [11]. Cooling only air conditioners only account for a small portion of market share in tropical areas. Variable speed air conditioners have become more and more popular in the last two years. They have obvious advantages regarding comfort and energy efficiency. The market share of variable speed air conditioners has increased from 2% in 2006 to more than 20% in 2010 (24.45% in wall split and 20.57% in free standing ACs) [10]. This significant market evolution mainly happened in 2009. It was triggered by the implementation of the minimum efficiency requirements [11] and the labeling program for variable speed air conditioners [13], which caused the big manufacturers to invest more in promoting variable speed air conditioners. The Indian government dedicates to investing in the research and development of converter and variable frequency drive (VFD) techniques. The latest “national promotion categories of energy conservation techniques” [14] listed the converter and VFD techniques as high priority. The market share of variable speed air conditioners is expected to grow to 50% in the next 5 years [9]. Most fixed speed air conditioners on the Indian market still use R22 as refrigerant, which is being phased out in Europe due to its ozone depletion potential since 2000. The non-ozone-depleting R410A, which is the dominating refrigerant in Europe, is also most common in Indian variable speed air conditioners.

Increasing energy efficiency and total energy consumption

The average energy efficiency of air conditioners has improved in recent years. Tables 2 and 3 show the average efficiency improvement from 2008 to 2009 [9]. Different measurement and calculation methods are applied for fixed speed and variable speed air conditioners: the efficiency of fixed speed air conditioners is indicated as EER (Energy Efficiency Ratio (full load)), while the efficiency of variable speed air conditioners is indicated by the SEER (Seasonal Energy Efficiency Ratio, part load included).

Table 2: Fixed speed air conditioners: average EER improvement from 2008 to 2009

Cooling capacity (kW)	Average EER in 2008	Average EER in 2009	Improvement rate (%)
CC " 4.5	3.04	3.30	8.6
4.5 < CC " 7.1	2.84	3.17	11.6
7.1 < CC " 14	2.75	3.06	11.3

Data source: [9]

Table 3: Variable speed air conditioners: average SEER improvement from 2008 to 2009

Cooling capacity (kW)	Average SEER in 2008	Average SEER in 2009	Improvement rate (%)
CC " 4.5	4	4.64	16.0
4.5 <CC " 7.1	3.62	4.21	16.3
7.1 <CC " 14	3.62	3.86	6.7

Data source: [9]

Along with Topten Europe, Topten India [15] [7] selects and presents the most energy efficient air conditioners from 1200 models sold on the Indian market. The efficiency levels of the BAT identified by Topten India are listed in tables 4 and 5.

Table 4: EER (cooling) of Best available fixed speed air conditioners on the Indian market

Air conditioner type	EER: BAT in India
Split < 2.8kW, fixed speed	4.11
2.8kW " Split " 4.5kW, fixed speed	5.00
4.5kW < Split " 6.0kW, fixed speed	3.65
6.0kW < Split " 7.5kW, fixed speed	3.51

Data source: [15]

Tab. 5: SEER (cooling) of Best available variable speed air conditioners on the Indian market

Air conditioner type	SEER: BAT in India
Split < 2.8kW, variable speed	7.33
2.8kW " Split " 4.5kW, variable speed	6.2
4.5kW < Split " 6.0kW, variable speed	5.39
6.0kW < Split " 7.5kW, variable speed	5.00

Data source: [15]

Because of the increasing stock and prolonged using times, air conditioners have become one of the biggest electricity consumers in Indian residential energy consumption. According to the analysis and estimation of the India National Institute of Standardization, more than 200 TWh were consumed by air conditioners in 2009 [9]. According to the reference scenario (enhancing the energy efficiency standards in the normal process), 22.4 TWh can be saved in 2020; while according to the BPN scenario (including a revision of the MEPS leading to all products on the market reaching the highest efficiency grade), even 33.3 TWh can be saved in 2020 [9].

Policy measures in Europe and India: energy label, MEPS and measurement standards

Europe

Energy label: revision

The current energy labels for air conditioners were introduced in 2002, and are accordingly outdated: the class A limit is at 3.2, while BAT split air conditioners reach EER values of 5.63.

The energy label is currently being revised. The latest Commission Working Document (WD) from November 2010 [16] suggests maintaining three different energy label scales for double ducts, single ducts and all other air conditioners with a rated cooling capacity of up to 12 kW. Seasonal efficiency indicators are not applied for double ducts and single ducts, but effectively for split air conditioners only. The most efficient split air conditioners are expected to already reach the super-A classes A+ to A+++ of this labeling scale. On the other hand, the proposed minimum efficiency requirements (see below) will lead to most lower classes being empty after 2014 [17].

New minimum efficiency requirements

Ecodesign requirements are currently being discussed based on a Commission Working Document from November 2010 [18]. The WD proposes different minimum efficiency requirements for (split) room air conditioners, single- and double-ducts, maximum power input for standby and off mode and

maximum sound power levels. According to the proposal, starting from 2012 air conditioners will have to meet at least class D cooling and class B heating efficiency, from 2014 class C cooling and class A heating efficiency. For appliances using refrigerants with a Global Warming Potential (GWP) below 150, such as Hydrofluoro-Olefines (HFO), propane or CO_2, a 10% reduction of the required efficiency levels is proposed. The member states will vote in February / March 2011.

Measurement standard

The current measurement standard EN14511 [19] is being revised and amended with EN 14825 [20] to include a method to measure and calculate seasonal performance indicators based on part load condition measurement. These seasonal performance indicators are the basis for the Ecodesign requirements as well as for the revised energy label. The current and the draft revised measurement standard have been compared in a test of a Indian air conditioner by Topten International Services. The results are presented and discussed below.

India

Measurement standards: 2 in parallel

India has developed two parallel measurement standards for air conditioners, using different energy efficiency indicators: for fixed speed air conditioners, EER (full load) is applied, while for variable speed air conditioners, SEER (including part load conditions) is applied.

Minimum energy performance standards (MEPS)

The first MEPS for fixed speed air conditioners was implemented in 1989 (GB12021.3). This standard was revised in 2000, 2004 and the latest version was implemented in 2010 [21]. Compared to the version from 2004, the minimum requirement has been increased significantly by an EER of 0.6 (to an EER of 3.2 for ACs with a cooling capacity < 2800W), which means the former grade 2 limit of the energy label was set as minimum efficiency requirement in the new standard (the lower the grade, the better the efficiency).

After almost 20 years of policy measure implementation for fixed speed air conditioners, the first MEPS for variable speed air conditioners was implemented in 2008 (GB21455) . This standard mainly triggered the market expansion of variable speed air conditioners. The market share increased from below 10% before 2008 to more than 20% in 2010.

The average energy efficiency of fixed speed and variable speed air conditioners improved significantly. According to a conformity test conducted by Topten in 2010, all 9 tested air conditioners did meet the requirements of the self-declared label grades, even though the measured EER was lower than indicated for all tested models but one. Manufacturers profit of the large measurement tolerance of up to 15% for the EER declaration, which sums up from a 10% tolerance for the cooling capacity measurement and a tolerance of 5% for the power input measurement [22].

India Energy Labeling program

The Energy Labeling program was introduced in India in 2005. Fixed speed air conditioners were the first product group the meaningful label was implemented for. The label discloses the most important energy information of the air conditioner to the consumers. With the latest revision of the measurement standard and the labeling regulation the number of grades has been reduced from 5 to 3 [23]. The energy label for variable speed air conditioners was implemented in 2009. Both the fixed speed and variable speed air conditioner labels show the efficiency of the cooling function only.

SEER: 2 different calculations

According to the measurement standards, the SEER of variable speed air conditioners is calculated based on the testing of 100% and 50% of the rated cooling capacity. The definition of the cooling season plays an essential role in the calculation of the SEER. The testing standard (GB/T 7725-2004 [22]) defines the cooling season with a using time of 2399 hours, while the energy efficiency standard (GB 21455 – 2008 [12]) defines the cooling season with a using time of 1136 hours. The difference in cooling hours leads to different SEER results. Generally, the resulting SEER based on the GB/T 7725 – 2004 is higher than the SEER based on the GB 21455 – 2008. The India energy labeling program

adopted GB 21455 – 2008 as the basis of its labeling scheme. However, the manufacturers also indicate SEER of GB/T 7725 – 2004 on the nameplate of the product in parallel with GB 21455 – 2008. The conflicts and confusions should be fixed with the next revision of the standards.

Test of a Indian high efficiency air conditioner according to four different measurement standards

Methodology

A very efficient split wall air conditioner found by Topten India was chosen for the compliance tests: KFR-26GW/02(R2DBPXF)-S1 produced by Haier. The India Household Electric Appliance Research Institute (Cheari, [24]), a central institution hosted by State-owned Assets Supervision and Administration Commission of the State Council and approved by the State Commission Office for Public Sector Reform, conducts the measurements.

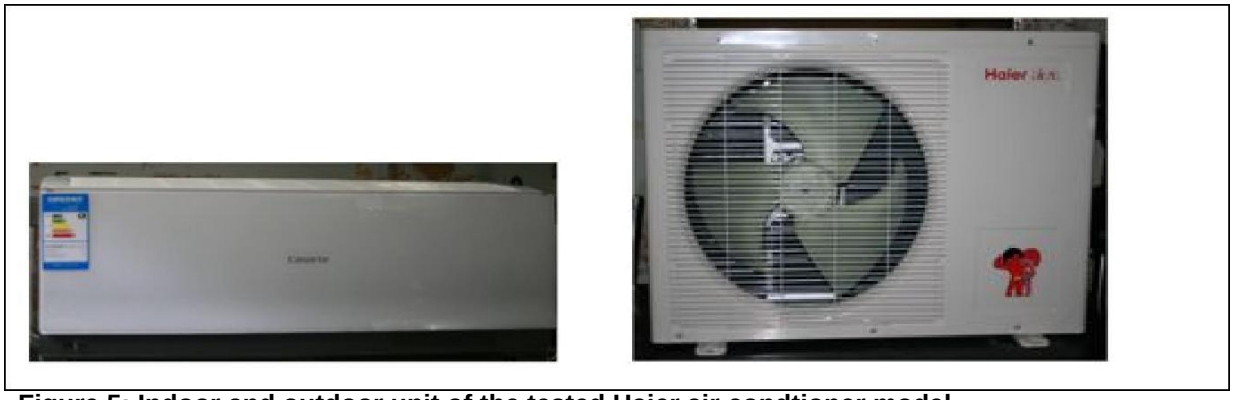


Figure 5: Indoor and outdoor unit of the tested Haier air condtioner model

The product's cooling and heating function efficiency was measured according to the following four standards:

1. The current European standard EN 14511 from 2007. This standard contains no part load conditions and the result is a non-seasonal Energy efficiency ratio (EER) and Coefficient of Performance (COP).
2. The future European standard, also including part load conditions: the draft revised EN 14511 and prEN 14825 (part load conditions). The future EN 14825 contains the calculation formula for the seasonal energy efficiency ratio (SEER) and the seasonal coefficient of performance (SCOP).
3. The Indian part load measurement standards on which the India energy labeling program bases its compliance tests: GB 21455-2008 and GB/T 7725-2004. The results are SEER and HSPF (Heating Seasonal Performance Factor).
4. The US-standard ARI 210/240-2008, which also includes part load condition and a SEER (BTU/Wh) and HSPF (BTU/Wh) calculation.

The three standards containing part load conditions require a different number of measurements at different work loads or frequencies (Tab. 6).

Tab. 6: Number of measurements required in the different standards

	Indian	European	US
Cooling function	2	4	5
Heating function	3	6	6

Results

The resulting efficiency index values according to the four different measurement standards are shown in table 7 and figure 6, for both the cooling and the heating function.

Tab. 7: Efficiency index results according to the different measurement standards

Efficiency index values in W/W	cooling	heating
India (SEER / HSPF)[2]	6.21	3.96
Europe current (EER / COP)	4.9	4.91
Europe future (SEER/ SCOP)	8.56	5.55
USA (SEER / HSPF)	7.86	3.66

The result according to the Indian standard confirms the manufacturer's declaration. The test result (SEER= 6.21) is 10% below the declared efficiency, but it's still within the measurement tolerance regulated in the standard (GB/T 7725- 2004). The test result also confirmed the declared energy label grade 1; the result is clearly above the grade 1 threshold of 5.2.

The result according to the current European standard allows comparing the Indian air conditioner to the efficiency of European devices. 4.9 / 4.91 for EER and COP are high values and put the model among the efficient air conditioners on the European market. The most efficient air conditioner on the European market however reaches higher values (EER: 5.63. COP: 5.68), and on topten.eu there are 6 models of comparable capacity with EER and COP values above 5.

Very high values resulted from the measurement according to the draft future European standard. With the resulting seasonal efficiency indicators of 8.56 (SEER) and 5.55 (SCOP) the model reaches the proposed A+++ classes for both the cooling and the heating function. The difference between the full load and part load results (the current and the future standard) is vast: the resulting SEER is 3.6 points higher than the EER, the SCOP is 0.6 higher than the COP value.

The results according to the US standard are way beyond the Energy Star threshold for heat pumps and central air conditioners [25]. When comparing it to the Energy Star product list it seems that the tested model is more efficient than the BAT on the US market.

The lab further reported that the future European standard was the most complicated to measure according to. It requires a higher number of measurements at different work loads than the Indian standard (see Tab. 6). When measuring according to the Indian or the US standard, measurements are conducted at certain different frequencies, while following the European standard a certain work load has to be set. This was reported to be more difficult than to set a certain compressor frequency. The accuracy however was thought to be the best according to the European standard.

Conclusions

The relevance of air conditioners for electricity consumption will increase, as sales are on the rise. Especially the Indian market with sales about 7 times as high as in Europe is of crucial importance. Reversible models dominate both markets; variable speed air conditioners have an increasing market share in India and an already high market share in Europe. The heating function must not be neglected: it is responsible for two thirds of the energy consumption by air conditioners, at least in Europe.

The introduction of MEPS for variable speed air conditioners in 2008 and the energy label in 2009 triggered a considerable market share increase of variable speed air conditioners in India, additionally their average efficiency increased by up to 16% from 2008 to 2009. The implementation of policy measures affecting the generally efficient sector of variable speed air conditioners has proven to have a positive influence on the average efficiency and the market. Similar positive effects can be expected in Europe, if strict minimum efficiency requirements and an effective energy label are introduced.

Markets differ strongly regarding the refrigerants: apart from R410A, the ozone-depleting R22 is still widely used in India, while it is being phased out in Europe since more than 10 years. Experiences from Europe show that not only R410A is a good alternative to R22, but also natural refrigerants with low global warming potential such as propane and "#ş¡are promising candidates.

The test results presented here allow to compare efficiency levels of Indian air conditioners to those of European models. As there are also a few even more efficient air conditioners on the Indian market than the tested model, the BAT in both regions seems to be more or less comparable.

The results according to the Indian standard proved correct declaration and compliance, but point out the problematics of the high measurement tolerances allowed. In Europe the same problem exists: the current tolerance of 15% enables manufacturers to declare the efficiency of their products up to two classes above the real efficiency. The new EU label proposal now suggests a reduction of the measurement tolerance.

The high very SEER and SCOP values when measured and calculated according to the future European standard and the vast difference between the full load and part load results are quite surprising. For other efficient variable speed drive air conditioners similar differences can be expected. As there are more efficient air conditioners on the European market than the one tested, even higher SEER and SCOP values will be reached. If the differences of 3.6 between EER and SEER and 0.6 between SCOP and COP are applied to the very best model on the EU-market, this model can be expected to reach an SEER value of 9.2 and a SCOP of 6.3. At least five additional models can be expected to reach SEER values above 8.5 and SCOP above 6.
According to the proposed energy label scheme, the A+++-threshold would be at SEER=8.5 and SCOP = 5.1. With these class limits, there are several models in the A+++ classes for both the cooling and the heating function right at the introduction of the new label. Furthermore, the energy label still has different classification schemes for split air conditioners and the inefficient single and double ducts. A class A single or double duct with an EER of 2.6 appears to be more efficient than a split air conditioner of class B – which however with an EER of 5.0 really can be almost twice as efficient as the generally inefficient moveable appliance. At the same time classes below C (cooling) and A (heating function) will be useless after 2014 when the proposed efficiency requirements are in force. Such an energy label does rather contribute to consumer confusion than guide them to the most

efficient products. It also offers no incentive to manufacturers to develop and market more efficient products.

We are strongly recommending that the chances of future (EU or other) energy label revision processes is taken to define one single labeling scale for all types of air conditioners, with class limits guided by the BAT. Low classes should not be empty in the near future, and the A+ classes should be reserved for future technology developments. Such a label would allow consumers to see the low efficiency levels of single and double ducts and effectively guide them towards the BAT products.

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