Panel Discussion, Session 3

Building Consensus: Manufacturer's Perspective

Chair: P.S. Jawadekar, President, Indian Electrical & Electronic Manufacturers' Association (IEEMA) Mumbai, India; Executive Director, Kirloskar Electric, Bangalore, India

National economies and the world economy are heavily dependent on how energy is managed: Energy is needed to improve standards of living, and energy is limited and its cost is going up. Energy management, therefore, has become crucial for every country, developing and developed.

The world now consists of not independent nations, but dependent nations. It is a world of interdependence. We need to bring and build consensus, first within a nation and then amongst nations or regions. The work of IIEC in this respect is very, very commendable. All of us need to support their activities.

Consensus building is a process which needs to be tackled from the supply as well as the demand side. It is a multipronged process involving the following:

- Government (eg. act, decree)
- National standards and international standards (eg. IEC, ISO)
- Regulatory system
- Test laboratories
- Manufacturers and their associations
- Consumers
- Bulk—industry/commercial
- Domestic/household
- Independent power producers (IPPs)
- Engineering-Procurement-Commissioning (EPC) contractors or companies
- Utilities—Transmission, distribution, utilization

Consensus amongst manufacturers is not enough. Others are involved.

Market forces at the end of the 90s or the beginning of the next century have brought a situation that every country now needs a policy of "stick & carrot" to bring/build a consensus in the energy conservation area.

There is no better time than now, the beginning of the 21st century, to build consensus under the following circumstances:

- when the world is becoming borderless;

- when technologies and investments have no boundaries;
- when the world is passing through an information and communication revolution.

In a situation like this, a competitive environment, which is threatening, survival of every industry, utility, economy and/or manufacturer would lead manufacturers and others towards building consensus.

We have three presentations throwing light on the supply and demand sides of energy management to build consensus in the energy conservation area.

Thank you.

BPS/FATLS/AHAM

Cayetano Ferreria, Transunion Corporation, Philippines

Energy Efficient Motors—Past, Present, and Future in the Indian Context

Dr. A. Mitra, Compton Greaves Limited, India

As we stand today, on the threshold of the 21st century, there are a number of crucial global issues facing us, which we need to address ourselves immediately for early resolution. These crucial issues are:

- Inundation of natural resources particularly fossil fuel, and
- Global warming and green house effect.

The impact of above issues are today understood by all of us but perhaps we are not in a position to gauge the impact which inaction in this sphere would result in, during next 2 decades, with rapid depletion of fossilized fuels viz petrol and coal, the thrust would be more on development on alternate sources of energy as well as development of product which are energy saving. The issue of global warming is also very real and this problem also cannot be tackled if burning of fuel goes unabated. Here also we have to take immediate action to ensure energy expanded by user as productively as possible, causing minimum warming effect.

In 1990 my company conceived the need of energy efficient motors. But as you know that Indian economy that time was not very healthy, the companies cannot venture for huge investments and buyers were not ready to pay premium price, the work progress was slow. But within a couple of years the scenario has changed reasonably and today we have developed machines of energy efficient designs following NEMA-MGI-1993 (revised) as a reference guide for efficiency values. The design philosophy is known to us, manufacturing methodology finalized and marketing strategy is almost frozen.

As we know, that in a complex system, when one problem is solved, another problem automatically get resolved. Here also, eco-friendliness of machine is almost a bi-product of energy efficient concept. An energy efficient motor will have low energy loss thereby generate low heat which needs a small size cooling fan to demipate. As the fan size is small, its noise level is also low. To meet low loss condition, the flux densities are kept low and thereby pollution due to electromagnetic radiation is also low. thus eco-friendly condition is a subset of energy efficiency concept. While developing energy efficient motor, we have seen that for Indian condition we have to consider following additional features:

Additional Specifications for Energy Efficiency for Indian Requirements

- (a) Spinning reserve of our country is low which makes a serious limitations on starting current. For a drive, starting current, starting torque, accelerating time and safe stall time are all linked together. To design energy efficient motor with

low starting current means more rotor copper loss and low power factor. To overcome this, more material must be used in low starting current energy efficient motor than an energy efficient motor designed for high starting current condition. The demand and use of slip ring motor is increasing in India is only because of this problem of spinning reserve.

- (b) In our country ambient is 40 degrees Celsius. The specific heat of air (Cp and Cv values) are different for 40 degrees Celsius and for 25 degrees Celsius. Thus a machine with design reference base of 25 degrees Celsius when tested at 25 degrees Celsius ambient will attain a temperature rise of T degrees Celsius say. When the same machine will be tested at 40 degrees Celsius ambient, we will see that temperature rise value will be greater than T degrees Celsius. It has been found that even 3% to 5% reduction of output may be needed if test ambient is 40 degrees Celsius instead of 25 degrees Celsius.
- Our Indian energy efficient motors are designed for 40 degrees Celsius ambient condition as a basic standard.
- (c) Next serious problem of our country is, improper maintenance and operation of motors. People wants to use same machine for compressor as well as for pump. in other words they prefer to have common design which can be used for both the applications we therefore need, not only reliable, less maintenance or maintenance free motors but also need the characteristics of motor which will cover most of the applications. Our energy efficient motor design philosophy also consider this aspect.
- NEED A WIDE RANGE TO COVER THE DIFFERENT DESIGN NEEDS
- (d) Another serious problem in India in energy efficient motor area that we are having many hundreds of small manufacturers, who manufacturers small size motors. And to keep the product price very low, they use cheap material and unoptimized designs. Because of these very low price, they comprise a reasonable size of market. It is only big houses who are concerned about the need of energy efficient motors for both power and ecological condition, but the awareness is totally missing to small entrepreneurs.

For Further Discussion

It has been noted that energy efficient motor needs 40-50% extra copper and 10-20% extra steel than a non-energy efficient motor. Although an energy efficient motor being reliable, eco-friendly, having quick payback period, and down time failure interval high, but it needs more natural resources of copper and steel. Thus, on one hand we are trying to save natural resources like fossil fuel, but on the other hand we are using more natural resources like copper and steel. use of more copper in a motor means less number of motor will be produced for same resource of material. Does it tally with the expanding requirement of market, its people who wants to use motors in every spheres of his life? The quantity growth is equally important to consider. Therefore, I feel and believe that a time has come where we

have to think seriously how to reduce material quantities, keeping the energy efficiency and eco-friendly requirements unchanged. for the last 100 years, we have seen that electrical steel has improved a lot. Same quantity of steel of today's age can carry more flux with a watt loss value of 1/6 in that of steel older age, but surprisingly, the conductor copper remains unchanged for last 100 years. A serious attempt should be made to invent a new alloy which will be economically viable and carry say 10 times current than copper. If this material comes, then slot size will reduce to 1/10th, resulting a total change is shape of energy efficient, eco-friendly electric motor where natural resources will be better utilized.

Another area which need to study is the design methodology. We still follow the same design procedure invented 100 years ago. in the era of computer and finite element method of analysis , we only fine tune the same old methodology. A breakthrough concept is now required which may take us to a better platform. Any work in this area is most welcome.

Standards and Labeling Regimes: Their Establishment and Potential

Paul Waide, PW Consulting, UK/France

Why Introduce Appliance Standards or Labels?

Why intervene in any way to influence the energy performance of the electrical equipment market?

The way the electrical equipment market treats appliance energy performance is far from optimal because:

- consumers do not have perfect information (or often any information other than the price):
- they do not know the running costs of appliances they buy or use
- they don't know the environmental impact of the appliance
- they don't know what the life-cycle cost optimum could be for themselves
- consumers do not have perfect analytical abilities:
- even if the running cost information were available, how many people are capable of calculating the most efficient use of their money (Should they pay more up front to save later? What discount rate should they use? How long will they keep the appliance? What will happen to electricity tariffs? etc.) or can estimate how concerned they should be about the environmental consequences of their choices?
- However, even if consumers did have perfect information and the ability to analyze they may not have enough time, energy or will to use their buying power to encourage the market to supply optimal products when they've usually got more pressing things to worry about. Even armed with perfect information and perfect analysis consumers are still only likely to choose the best (according to their value system) from among the products on offer and thus the pressure this would create for market reform may still only lead to relatively slow product evolution.

Without intervention, the sub-optimum situation continues, which means that:

- a large gap exists between the cost of supplying energy and the cost of saving it
- consumers pay much more for the service than they need to
- resources are used inefficiently
- pollution is higher than it otherwise would be

- investment capital is used inefficiently
- international trade balances are skewed towards the net suppliers of fossil fuels and power engineering equipment.

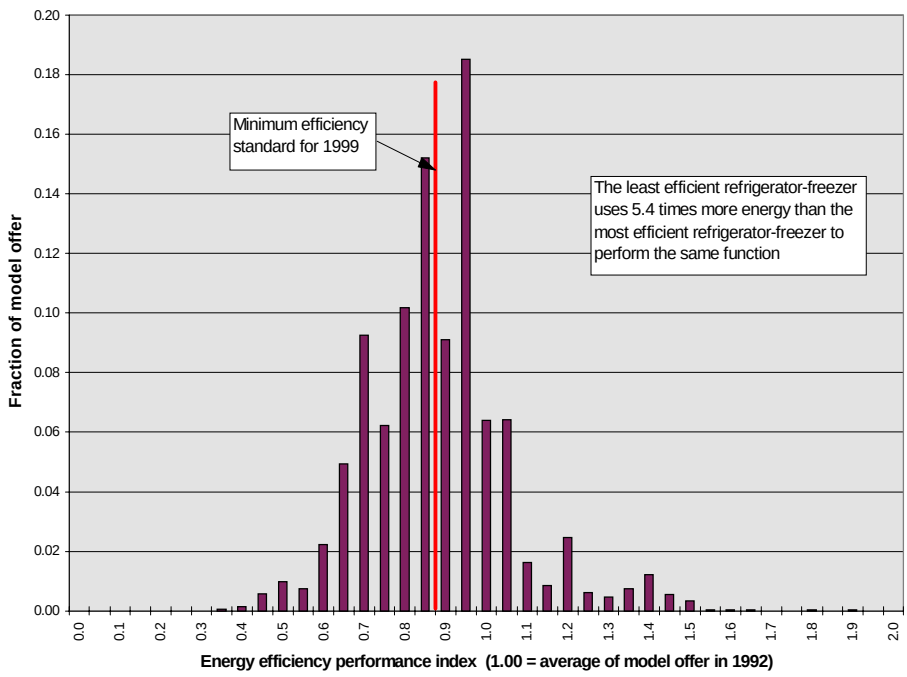
Thus, it is increasingly becoming recognized that government has a role to influence the energy efficiency of widely distributed energy-consuming products through the process known as 'market transformation'.

Figure 1 shows the example of the EU refrigerator-freezer market where there is a very large difference in efficiency between products (a maximum 5.4-fold difference). The energy efficiency performance index shown on the x-axis is the ratio of any given models energy consumption and the average energy consumption of an identically sized model performing exactly the same cooling task.

What Is at Stake in Energy Terms?

In the residential sector alone there are very large potential savings to be made simply by substituting the most efficient existing appliances for the average *in situ* stock. Consider the case of France, where a recent metering campaign monitored the energy consumption of each appliance in 20 households for a year and then substituted the existing equipment with the most energy efficient equipment that was readily available in French stores before monitoring the energy consumption of each new appliance for a further year. Even though great care was taken to ensure that the functionality of the new equipment was equivalent to or better than the existing stock, the resulting savings were impressive (Table 1).

Figure 1 *Distribution of refrigerator-freezers for sale in the EU, by energy performance index.*



If a similar process were to be achieved at a national level, this would translate into savings of some 26.4 TWh/year or ~50% of the total residential electricity-specific energy consumption in France. Furthermore, the monitored savings were achieved by substitution of the existing stock with the best equipment that was then readily available on the French market. This market is far from optimal and it is likely that even larger savings could be achieved if manufacturers were encouraged to develop better products.

The greatest savings were achieved for:

- refrigerators, freezers and refrigerator-freezers (45.5% of all savings)
- lighting (29.4% of all savings)
- VCRs (6.6%)
- clothes-washers (5.4%)
- electric pumps in gas-fired boilers (4.4%)
- satellite TV dishes (3.6%)
- TV standby (2.5%)
- satellite TV decoders (1.8%)
- clothes-dryers (0.8%).

Cutting standby consumption accounted for a total of 14.5% of all the savings.

An interesting issue is whether these savings came from changes in the basic energy performance of the equipment or from changes in user behavior. Analysis of the data shows that the vast majority are attributable to the differences in the equipment and that user behavior was not noticeably affected by the metering campaign.

This is what happens in France, but what about South East Asia? We can imagine that the ownership levels and energy consumption by appliance type will be different in this region. The dominant domestic loads are likely to be cold appliances, lighting

Table 1 *Measured end-use electricity savings from equipment substitution in 20 French households and estimated national savings were the same savings to be repeated in every French household*

Appliances	Average saving per household (kWh/year)	National saving (TWh/year)
Cold appliances	725	12.00
Lighting	340	7.72
Individual water boiler (standby)	215	1.15
VCRs (standby)	118	1.75
Satellite TV decoders (standby)	96	0.48
Satellite dish controllers (standby)	95	0.95
Clothes-washers	70	1.42
Clothes-dryers	56	0.22
TV (standby)	0–145	0.67
	Average over all sets: 21	
Total	**1715–1860**	**26.36**

and air-conditioning, then perhaps fans, TVs and VCRs. However, these are exactly the appliance types with which substantial cost-effective savings can be realized.

How Can Energy Savings Be Achieved?

Apart from modifying energy tariffs the principal mechanism for attaining savings is policies aimed at the transformation of the equipment market.

The main market-transformation policies available are:

- labels (award and comparative)
- efficiency standards (voluntary and mandatory)
- incentives (procurement, rebates and tax), and
- information (purchase and usage).

The most profound changes are likely to be achieved through efficiency standards, although a range of policies may give the best results.

Energy Labeling

- aids energy performance transparency and can be a convenient precursor to other market-transformation policies
- influences manufacturers, distributors, retailers and consumers (bearing in mind that the larger impact can just as easily be on the first three)
- generally inexpensive
- no guaranteed results
- different designs require careful consideration (Is running cost, quality statement, or environmental statement most likely to influence target group? Sliding scale or gradings? How much if any performance information should be included?)
- supporting programs are vital, especially those aimed at influencing the retailer's sales pitch and stocking policy
- attention should be paid to all possible blocks in the appliance supply chain that might prevent purchasers being able to choose efficient appliances at the point of sale.

Voluntary Agreements

- work best when there is a small number of manufacturers or a strong manufacturers' association who can deliver a given product efficiency target for the vast majority of the market
- can apply market (or fleet) average approach which manufacturers like, although they are very difficult to monitor

- can be flexible and rapid, which suits certain product types where test protocol development is likely to be too slow to match the rate of product development
- difficult to police conformity
- difficult to achieve deep efficiency improvements, especially if they require significant capital investments by manufacturers.

Mandatory Standards:

- can be underpinning or market forcing (these are very different)
- have the advantage of being simple
- require an accurate and repeatable test procedure to be in place (which can take time to develop and hence can get out of date when applied to very rapidly evolving product types)
- are the only means of ensuring deep efficiency improvements for a given product type
- guarantee a level playing field (common set of rules) for all manufacturers, distributors and retailers and hence lower resistance to higher investment in product efficiency (manufacturers, distributors and retailers have no choice but to ensure conformance if they wish to continue in the given market; any increased production costs should be passed on to consumers)
- tougher, more meaningful standards can require significant investment from producers, which may make them resistant to the process
- if the changes were to lead to significant real product price increases then this could lower sales of the product in a price-elastic market
- attention needs to be given to enforcement.
- It should be noted that other policies can be complementary to the above and influence their chance of success, notably:

Procurement Programs

Two types:

- technology stimulation (reward manufacturers who develop new products that meet currently unattained energy performance specifications)
- market building (form large buyer groups to buy highest-efficiency existing products).

Both types drag the efficiency of the market upwards, rather than push from behind as standards generally do.

Financial Incentives

tax and rebate incentives can directly influence the price competitiveness of efficient appliances relative to their less efficient competitors. There are innumerable strategies that can be applied.

How Do We Prioritize Between Equipment Types?

Establish the priorities by equipment type in the following way.

Assess the level of energy consumption by each end-use (establish current and estimate future hierarchy of energy consumption by end-use) (E_{use}).

An example of this is shown in Figure 2, which shows the measured end-use electricity consumption of 20 French households.

Evaluate the technical savings potential (establish saving potential hierarchy using currently available technology and using technology that can be envisaged), expressed as a fraction of current use (F_{save}).

Estimate the cost of achieving each incremental energy saving unit (C_{cost}).

Try to quantify other barriers to realizing the energy savings (expressed as a fraction from 0 (impossible barrier) to 1 (no barrier)) ($F_{barrier}$).

Prioritize in order of the highest score, calculated as:

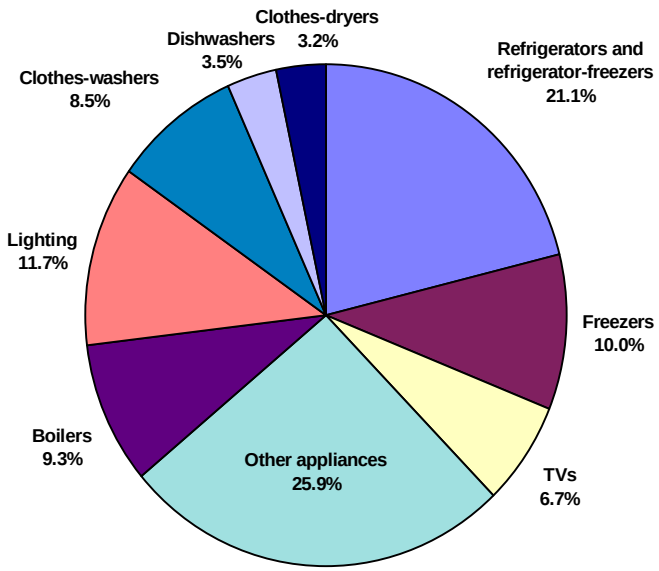
Score = $E_{use} \times F_{save} \times F_{barrier} \times C_{energy} / C_{cost}$

where the higher the score the stronger the case for action. If desired, the negative environmental impacts of energy consumption can be ascribed a monetized value and factored into the energy supply cost, C_{energy}.

In fact these steps are not straightforward:

- step a requires a thorough review of the existing *in situ* stock and its use, the current products on the market, the probable change in products without intervention, the evolution of ownership and use, and the timing of use

Figure 2 *Electricity consumption by end-use measured in 20 French households (% of total annual consumption).*



- step b requires a full technical and statistical review of existing products followed by a comprehensive engineering analysis to establish possible energy-saving design modifications
- step c is strongly linked to the engineering analysis of step b, which should also estimate the incremental costs of improving the efficiency of existing models. This, however, has to be followed by estimates of any change in distributor or retailer margins
- step d is the most nebulous; it includes estimates of the probable difficulty associated with overcoming other barriers to implementation of a particular appliance market-transformation program, such as institutional inertia or resistance, lack of necessary infrastructure, lack of appropriate funds, legal barriers, etc. A policy-independent example is the situation when testing facilities do not exist for certain equipment types. A policy-dependent example is the situation when the lack of a strong manufacturer trade association makes voluntary agreements difficult to negotiate for a given product.

What Steps Need To Be Followed To Introduce Labeling and Standards?

Establish Study Groups

It is necessary to set up study groups to perform the following tasks.

1. *Assess energy consumption by end-use:*

   —metering campaign to establish how much energy is being used in practice by each end-use and when it is being used

   —survey of equipment (*in situ* and on the market)

   —develop end-use stock and load forecasts

   —prioritize equipment.

If a metering campaign is too costly then consumption has to be estimated from laboratory results; however, this involves approximations that sometimes lead to major misunderstandings. Thus, *in situ* metering is always a valuable aid if possible.

For each selected product type perform steps 2–6.

2. *Establish an energy test procedure:*

This needs to be a compromise between the following:

   —reproducibility (very important)

   —cost and ease of measurement

   —representativeness (how well do they represent actual *in situ* consumption and if they don't is there a reliable means of adjusting the test results to match the *in situ* conditions? Or are the tested values proportional to the *in situ* consumption of the same appliance group?)

   —international compatibility (the proliferation of test protocols can be a barrier to trade and adds a cost burden on manufacturers).

Establishment of the protocol should be done following a review of existing protocols and should adhere to international norms unless there is a good reason for not doing so.

3. *Establish an energy efficiency measure or index:*

   —this must give a reliable relative measure of the energy consumed to perform a given task *in situ* for a particular appliance type. The use of an efficiency index enables energy performance comparisons which are independent of the appliance function, thus the performance of a small refrigerator could be compared to that of a larger unit

   —a key issue is the definition of the per-unit task, i.e. should the task performance be defined in general terms, say to wash a kilogram of clothes, or should it be defined in terms of the quality of the process, say to wash a kilogram of clothes to a given level of cleanliness in a certain time limit? The treatment of performance has varied from region to region. The EU has not directly included performance in its energy efficiency index used for the clothes-washer energy label (instead this is measured and graded separately and presented on the same label, although a performance threshold will probably be included in any voluntary agreement), but it has for cold appliances (they must be capable of maintaining specified internal temperature conditions under a

range of exterior temperature conditions; freezer units have to be able to freeze a given volume food from ambient within 24 hours; the interior of the appliance cannot warm faster than a given rate if the power is disconnected; maximum condensation levels are prescribed). The US DOE does not define performance criteria for cold appliances but merely stipulates the conditions for energy measurements

—definition of an efficiency index also requires careful definition of appliance categories which may need to be more detailed than the categorization used in the energy test protocol. These generally follow on from consideration of the basic functionality of the appliance, e.g. the function of a chest freezer is different from that of an upright freezer in terms of the space it is designed to occupy, which has an impact on their relative energy performance. Once product categories for an efficiency index have been defined they can be tested by:

a. a statistical analysis of the efficiency of products on the market (for example, test whether two compressor refrigerator-freezers should be a separate category by a Students t-test of the one-compressor and two-compressor populations

b. an energy engineering analysis (discussed below).

4. *Establish the efficiency distribution of products on the market:*

—via a statistical analysis (assuming a satisfactory test protocol is in use).

5. *Conduct a techno-economic analysis:*

—this will involve performing an energy engineering analysis to establish the energy savings and costs of redesigning the existing products to higher efficiency specifications. It will usually follow on from a survey of: existing designs and production facilities; component availability and costs; production modification costs; material, labor, transportation and distribution costs. These will be incorporated into a calibrated cost/savings design simulation model which will be used to project the life-cycle cost of various higher-efficiency design options from the consumer perspective.

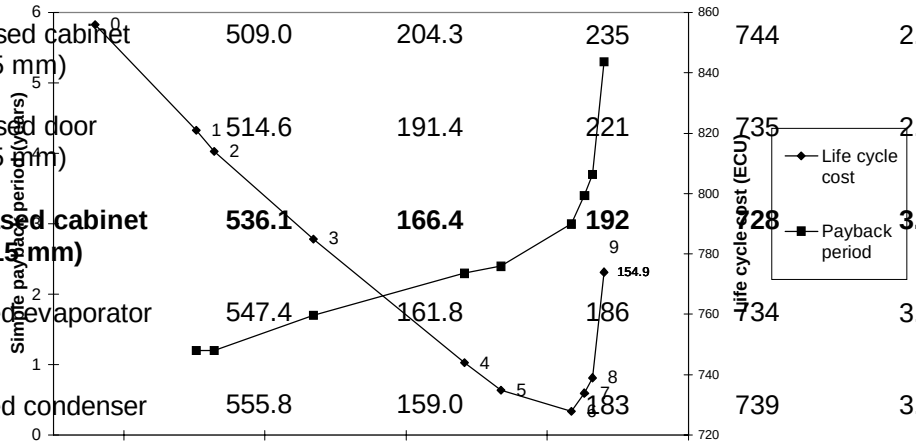
For example, Figure 3 shows the estimated relationship between the life-cycle cost, the annual electricity consumption and the simple pay-back period for a typical European refrigerator with a 2-star frost box. The design options and their associated cost and savings implications are described in Table 2 and shown graphically in Figure 3.

Table 2 *Life-cycle cost and pay-back periods of combined design options for 2-star refrigerators*

Design options combined in order of increasing simple pay-back period *	Purchase price (ECU)	Energy consumption (kWh/year)	Life-cycle operating costs (ECU)	Life-cycle cost (ECU)	Simple pay-back period (years)
0 = base-case model	470.0	335.3	386	856	–
1 = 0 + increased door insulation (+15 mm)	475.6	299.4	345	821	1.2
2 = 1 + decreased door leakage	476.7	293.1	338	814	1.2
3 = 2 + optimized compressor	487.0	257.9	297	785	1.7
4 = 3 + increased cabinet insulation (+15 mm)	509.0	204.3	235	744	2.3
5 = 4 + increased door insulation (+15 mm)	514.6	191.4	221	735	2.4
6 = 5 + increased cabinet insulation (+15 mm)	**536.1**	**166.4**	**192**	**728**	**3.0**
7 = 6 + doubled evaporator heat capacity	547.4	161.8	186	734	3.4
8 = 7 + doubled condenser heat capacity	555.8	159.0	183	739	3.7
9 = 8 + doubled condenser surface area	595.4	154.9	179	774	5.3

* The least life-cycle cost design option is in bold.

Figure 3 *Life-cycle cost curve estimated for European refrigerators with a 2-star frozen-food compartment (design options 0–9)*



6. *Estimate the impact of a given set of market-transformation policies on:*

—energy use and savings – an example of this is given in Figure 4, which shows the forecast energy consumption of the entire EU stock of cold appliances under various policy actions up to the year 2020. Large savings are forecast from energy labeling compared to a static efficiency scenario although the average market efficiency is unlikely to be static even without orchestrated government actions as normal market pressures lead to some efficiency improvements. The bottom-most line shows the estimated impact of introducing mandatory minimum efficiency standards set at the position of estimated least-life cycle cost (point 6 on Figure 3) to come into effect in the year 2002.

—manufacturers, distributors and retailers – this requires an assessment of how the proposed policy action would effect manufacturer, distributor and retailer sales, revenues and profits. This has been done in the USA and more recently in Europe using a manufacturer impact model, MIM

—utilities – utility sales and revenues will be affected by market-transformation policies, but so will investment and operating costs. An assessment should indicate how the proposed actions would influence all these parameters

—consumers – a consumer policy cost/benefit assessment needs to be conducted to assess the benefit for consumers of lower energy bills against the potential cost of increased purchase prices. For example, it is estimated that were the least life-cycle cost standards scenario indicated in Figure 4 enacted, each consumer in the EU would benefit on average by 70–100 ECU assuming a NPV (net present value) of 5%. Overall electricity charges worth ~98 billion ECU would be avoided by 2020 compared to a static efficiency scenario

—the environment – market-transformation policies can produce significant environmental benefits, including lower CO_2 emissions and less damage associated with power station construction. These should be evaluated through a modeling exercise.

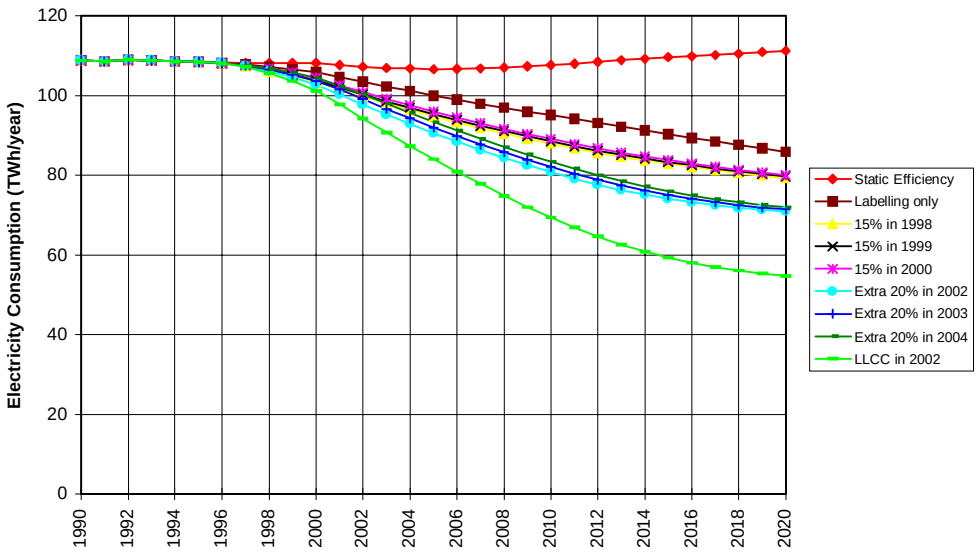
—the nation – finally, the national impact of the policies should be assessed to determine impacts on employment, investment, trade, etc.

Institutional and Legal Considerations

Apart from conducting studies the following institutional and legal aspects must be addressed.

- establish and certify appliance testing laboratories
- establish working group(s) to conduct the technical assessment(s)
- issue mandates for test protocols and establish the conditions requiring products to be tested
- establish stakeholder committees to review the technical findings of the studies and to discuss the implications of market-transformation policies.

Figure 4 *Estimated and forecast cold-appliance electricity consumption in the EU for a range of labelling and standards policy scenarios.*



For mandatory standards and energy labels it is desirable to enact framework legislation which authorizes a competent body to issue energy efficiency standards and/or energy labels for a range of energy consuming product types.

This legislation should define the process to be followed, including:

- the efficiency criteria to be used (e.g. maximum consumer pay-back periods for consumers in the case of minimum efficiency standards)
- the conditions of enactment (e.g. a minimum of 3 years' advance notice of mandatory product efficiency standards, etc.)
- the method of enforcement (penalties to be imposed in the case of willful non-compliance and the establishment of an effective inspectorate).

Conclusions

Appliance market-transformation policies and most notably energy labeling and efficiency standards can produce significant cost-effective reductions in energy demand with only small or zero adverse impacts on industry. These policies are becoming more commonplace around the world as governments appreciate the net benefits they can bring. Nonetheless, when implemented, careful account must be taken of all the technical and institutional factors that may affect their success.

Standards and Labeling Regimes—Their Establishment and Potential

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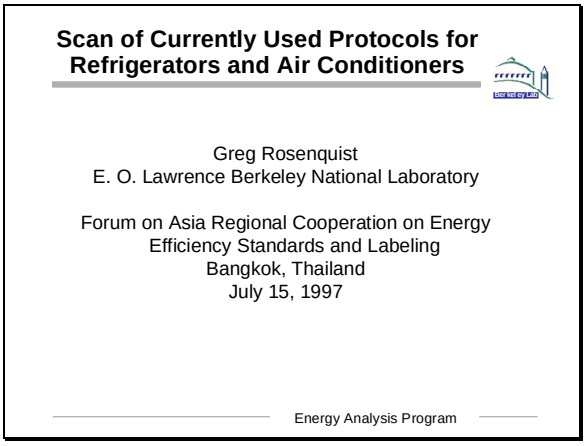
Asia Pacific Laboratory Accreditation Cooperation (APLAC)

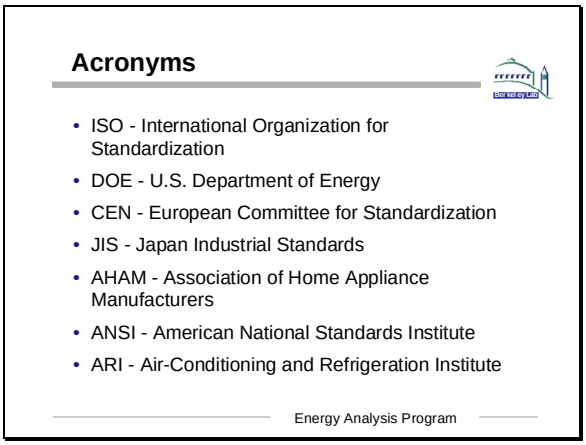
Lloyd Harrington, Energy Efficient Strategies, Australia

APLAC Information Sheets

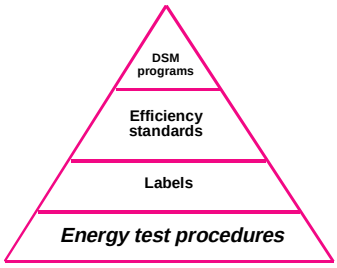
Scan of Currently Used Protocols for Refrigerators and Air Conditioners

Greg Rosenquist, E.O. Lawrence Berkeley National Laboratory, U.S.A.





The Pyramid - Test Procedures are Critical to Standards and DSM Programs



Energy Analysis Program

Elements of a Good Test Procedure

- Simple and Repeatable
- Realistic
- Low Cost
- Easliy amended or revised
- Internationally compatible

Energy Analysis Program

Refrigerator Test Procedures

- International: ISO 7371-1985 (and Amendment 1-1987) ISO/DIS 8187.3-1991
- USA: U.S. DOE and ANSI/AHAM HRF-1-1988
- European: EN 153:1989
- Japan: JIS 9607 (1986)
- Australia: AS1430-1986
- New Zealand: NZS 6205.2-1989
- India: IS:1476-1979
- China: CNS 2062, CNS 9577
- Others including Korea, Brazil, Canada, Mexico

Energy Analysis Program

Refrigerator Test Procedure Groupings

- ISO type procedure
  - European Union, Japan, Australia, most of Southeast Asia
- U.S. DOE type procedure
  - USA, Mexico, Canada

Energy Analysis Program

Similarities and Differences between ISO and DOE Refrigerator Test Procedures

- Similarities
  - Refrigerator placed in controlled environment for spefied time or number of cycles
  - Doors remain closed, except for Japanese procedure
  - Microprocessor-based controls not accounted for
- Differences
  - Ambient and Compartment temperatures
  - Food loading
  - Ambient humidity
  - Crediting of features
    - Automatic Defrost
    - Anti-Condensation

Energy Analysis Program

ISO Refrigerator Test Procedure

- Oriented toward European-style refrigerators
  - Volume = 300 liters
- Weaker in handling automatic defrost, anti-condensation heaters
- Can be conducted at two different ambient temperatures
  - Temperatate Zone: 25 C
    - Specified in CEN test procedure
  - Tropical Zone: 32 C
- Differentiates refrigerators by ability to achieve certain level of performance (1-star to 4-star)
  - 4-star rating = freezer temperature below -18 C

Energy Analysis Program

U.S. DOE Refrigerator Test Procedure

- Oriented toward large capacity refrigerators
  - Volume = 500 liters
  - Auto-defrost, top-mount freezers
- Differentiates by type of defrost system
  - Automatic, Partial, or Manual
- Does not include performance-based tests
- Microprocessor-based control is not properly accounted for
  - Treats all sensors and control algorithms as if they perform identically

Energy Analysis Program

Comparison of Refrigerator Test Procedures

PARAMETER	DOE	JIS	ISO
TEST CHAMBER AMBIENT TEMPERATURE	32 ± 0.6°C	15 ± 1°C and 30 ± 1°C	25 ± 0.5°C Tropical 32°C
WEIGHTING OF ANNUAL RESULTS BY CHAMBER AMBIENT TEMPERATURE	365 days @ 32°C	265 days @ 15°C 100 days @ 30°C	365 days @ 25°C
TEST CHAMBER AMBIENT RELATIVE HUMIDITY	No Specification	75% ± 5%	45 - 75%
DOOR OPENINGS	None	Fresh food - every 12 min. Freezer - every 40 min. (during first 10 hours of test. Duration of opening 15 seconds)	None
FRESH FOOD AND FROZEN COMPARTMENT LOADS	None (except for low-temp. compartment of basic refrigerator)	None for energy consumption test	1.6 kg load in freezer with thermal characteristics of lean beef

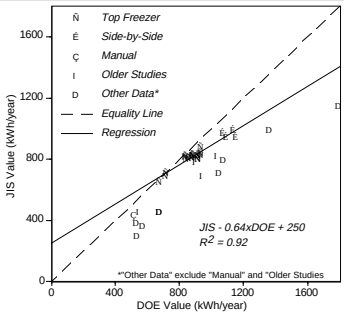
Energy Analysis Program

Comparison of Refrigerator Test Procedures (cont.)

PARAMETER	DOE	JIS	ISO
FREEZER STANDARD TEMPERATURES	-15°C (freezer of ref./fre.) -9°C (freezer of basic ref.)	-18°C (three-star rated unit) -12°C (two-star rated unit) -6°C (one-star rated unit)	-18°C freezer (three-star rated unit) 5°C fresh food
FRESH FOOD STANDARD TEMPERATURE TEST PERIOD	Defrost-to-defrost for auto defrost; at least 3 hours with at least 2 compressor cycles for manual defrost	24 hours (48 hours or longer if defrost cycle every 2 days or longer)	At least 24 hours and whole number of defrost cycles
NUMBER OF THERMOCOUPLES FOR EACH COMPARTMENT	Freezer - 3 (except basic) Fresh food - 3	Freezer - 3 Fresh food - 1	Freezer - 3 Fresh food - 3
ANTI-CONDENSATE HEATER SWITCH SETTING	Test both "on" and "off," average results	On for both conditions (for units tested) Run tests at standard temperature	On if needed to pass condensation test
METHOD OF DETERMINING CONSUMPTION AT STANDARD TEMPERATURE	Interpolation of two tests bracketing standard temperature conditions	Run tests at standard temperature, within ±0.5°C tolerance	With all interior temperatures below limits or interpolation of two tests

Energy Analysis Program

U.S. DOE and Old JIS Refrigerator Energy Use Comparisons



Energy Analysis Program

Approximate Conversions for Energy Use between Refrigerator Test Procedures

DOE □ JIS	Subtract 20 - 40%
JIS □ ISO	Add 10 - 40%
ISO □ DOE	Add 10 - 40%

Energy Analysis Program

Refrigerator Testing Laboratory

- Cooling and heating equipment necessary to regulate ambient temperatures
- Defines minimum distances between refrigerator and test facility walls
- Major USA test laboratory chares approximately 2000 USA dollars to test a refrigerator

Energy Analysis Program

Residential Air Conditioner Types

- Room Air Conditioners
  - Window-type
    - Typical cooling capacities range from 1500 to 8800 Watts
  - Mini-Split (non-ducted)
    - Typical cooling capacities range from 3500 to 7100 Watts
- Central Air Conditioners
  - Ducted-Split
    - Typical cooling capacities range from 5300 to 17500 Watts
  - Ducted Single Package
    - Typical cooling capacities range from 8800 to 17500 Watts

Energy Analysis Program

Air Conditioner Test Procedures

- International
  - Non-Ducted: ISO 5151
  - Ducted: ISO 13253
- U.S. DOE
  - Window-type: ANSI/AHAM RAC-1-1982 and ASHRAE 16-1983 RA88
  - Split-type (ducted and non-ducted) and Packaged: ARI 210/240-89 and ASHRAE 37-1988
- Japan
  - Packaged: JIS B 8616-1993
  - Room (Window-type and Split-type): JIS C 9612-1994

Energy Analysis Program

ISO 5151 Air Conditioner Test Procedure

- ISO 5151: Non-ducted air conditioners and heat pumps - Testing and rating for performance
  - Specifies the standard conditions on which the ratings of single-package and split-system non-ducted air conditioners and heat pumps are based
  - Limited to systems utilizing a single refrigeration circuit and having one evaporator and one condenser
  - Steady-State rating
    - Cannot measure efficiency improvements due to designs that reduce cycling losses (e.g., variable-speed compressors)

Energy Analysis Program

ISO 13253 Air Conditioner Test Procedure

- ISO 13253: Ducted air conditioners and heat pumps - Testing and rating for performance
  - Establishes performance testing and rating criteria for factory-made residential, commercial and industrial, electrically-driven, mechanical-compression, ducted air-conditioners employing air- and water-cooled condensers
  - Limited to systems utilizing a single refrigeration circuit and having one evaporator and one condenser
  - Steady-State rating
    - Cannot measure efficiency improvements due to designs that reduce cycling losses (e.g., variable-speed compressors)

Energy Analysis Program

ISO 5151 and 13253 A/C Performance Ratings

Standard Rating	Units	Rounded to
Cooling Capacity (total, sensible, latent)	kW	0.1
Energy Efficiency Ratio	W/W	0.05

$$EER = \frac{Cooling\ Capacity}{Input\ Power}$$

Energy Analysis Program

ISO 5151 and 13253 A/C Cooling Capacity and Power Rating Conditions

	Dry Bulb/Wet Bulb Temperature EC		
	T1	T2	T3
	Moderate	Cool	Hot
Air entering indoor-side	27/19	21/15	29/19
Air entering outdoor-side	35/24	27/19	46/24

- All rated equipment must be test under conditions T1
- Manufacturers may choose to rate under T2 or T3

Energy Analysis Program

U.S. DOE Central A/C Single-Speed Test Procedure Rating Conditions

	Dry Bulb/Wet Bulb Temperature EC	
	Air Entering Indoor Unit	Air Entering Outdoor Unit
"A" Steady State	26.7 / 19.4	35.0 / 23.9
"B" Steady State	26.7 / 19.4	27.8 / 18.3
"C" Steady State Dry Coil	26.7 / 13.9	27.8 / 18.3
"D" Cyclic Dry Coil	26.7 / 13.9	27.8 / 18.3

- "C" and "D" tests used to determine degradation coefficient
- Used to determine SEER rather than EER
- U.S. DOE test procedure accounts for variable-speed

Energy Analysis Program

USA Air Conditioner Test Procedures Provide Energy Use Calculation

- Window-type Room Air Conditioners

$$\text{Energy Use} \ni \frac{\text{Cooling Capacity}}{\text{EER}} \times 750 \text{ Hours}$$

- Central Air Conditioners (Ducted and Non-Ducted)

$$\text{Energy Use} \ni \frac{\text{Cooling Capacity}}{\text{SEER}} \times 1000 \text{ Hours}$$

Energy Analysis Program

Non-Ducted Air Conditioner Test Procedure Harmonization

- Most countries rating to ISO 5151 test procedure
  - Japan (Room Air Conditioner) and USA (Window-type) require testing at ISO 5151 Moderate (T1) test conditions
    - Harmonization problem in USA: Mini-split room air conditioners must be rated with SEER
  - Philippine National Standard adopted from ISO 5151
- Cooling capacity and energy efficiency ratings can be easily compared from country-to-country

Energy Analysis Program

Room Air Conditioner Testing Laboratory

- Specifications for test facility given in ISO 5151
- Calibrated room-type calorimeter typically used for rating air conditioners
  - Consists of indoor-side and outdoor-side compartments
- Can take 2 to 6 hours to test one air conditioner
  - Test room must be operated until equilibrium conditions are attained, but not less than 1 hour
- Cost of turn-key facility approximately 0.5 million USA dollars
- Major USA test laboratory charges approximately 1000 USA dollars to test a room air conditioner

Energy Analysis Program

Room A/C Test Laboratory - Schematic

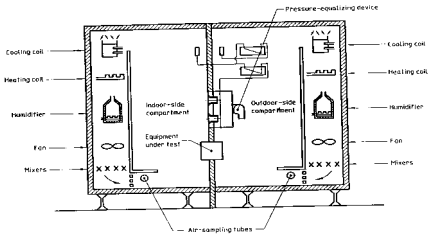


Figure 8.4 — Typical calibrated room-type calorimeter

Energy Analysis Program

Conclusions

- ISO and U.S. DOE type Refrigerator test procedures are not compatible
  - Harmonization requires creating new test procedure
    - Must account for new technologies using microprocessor-based controls
- Current A/C test procedures are compatible (except ducted a/c USA test procedure)
  - ISO and USA room a/c test procedures do not account for varible-speed and microprocessor-based controls

Energy Analysis Program

Energy-Efficiency Impact of Using Non-Ozone-Depleting Substances in Refrigerators

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Introduction

The Montreal Protocol requires the eventual cessation of all CFCs and HCFCs and therefore, world-wide the refrigeration and air-conditioning industry has been active with the chemical industry and research institutions for two decades establishing ODS-substitutes and alternative technologies. Table 1 shows state-of-art in the ODS-substitutes in domestic refrigeration industry world-wide.

In this paper an overview is provided of studies done to estimate theoretical impact of leading ODS-alternatives on energy-consumption. It is followed by a presentation of the results of energy consumption simulation performed by TERI on 4 different brands of Indian refrigerators. Simulation was performed using US-EPA refrigerator simulation software version ERA1.2E.

Overview

Many developing countries are short of electrical generating capacity. Refrigeration equipment accounts for a substantial percentage of power consumption in developing countries. Thus any increase in energy consumption of either domestic, commercial or industrial refrigeration equipment is undesirable. Energy efficient domestic refrigerator-freezers would also substantially contribute to world-wide efforts to reduce the energy consumption and global warming. In this context it becomes very important to analyze the impact of ODS-substitutes on energy-consumption of refrigeration appliances. Theoretical and experimental studies have confirmed that ODS-substitutes (refrigerants & foam-blowing agents) have differential impacts on energy-consumption, positive and

Table 1 *ODS-substitutes in domestic refrigeration industry*

Refrigerant Options to CFC-12 in domestic refrigerators	Blowing agent options to CFC-11 in domestic refrigerators
HFC 134a	Cyclopentane (CP) foam
HFC 152a	HCFC-141b foam
HC 290	HFC-245fa foam
HC 600a	HFC-245ca foam
HC 290/HC 600a	HFC-356 mffm
	Eur. reduced CFC-11 foam

negative both, depending on the choice of alternative. Given below is an overview of the state-of-art in the phaseout of CFCs in domestic refrigeration worldwide and their possible impact on energy-consumption as reported in a few published theoretical studies.

Influence Of Non-ODS Foam Blowing Agent On Energy Consumption

Heat leakage through the insulated cabinet determines a major fraction of the energy required by a refrigerator-freezer. As a result, the thermal efficiency of refrigerator-freezer is strongly dependent on the effectiveness of the cabinet insulation. Rigid polyurethane foam blown with CFC-11 has been the dominant insulation selected for use in typical refrigerator-freezers currently produced. CFC-11 blown insulating foam is being rapidly eliminated from refrigerator-freezer production throughout the world. Conversion in the three largest developed nation markets can be summarized as follows:

- Europe is generally converting to cyclopentane formulations with some manufacturers making intermediate conversions to HFC-134a, HCFC-141b or blends of HCFC-142b and HCFC-22.
- US manufacturers are predominantly converting to HCFC-141b because of constraints introduced through product energy and VOC factory emission standards.
- Japanese manufacturers are generally converting to HCFC-141b because of product energy constraints with some selected modules being produced with cyclopentane. Japanese have shown some data on HFC245ca and HFC236ea blown foams. Latest trend shows that as a long-term solution they are investigating HFC245fa or Cyclopentane (or other HC combination).

Any use of HCFC alternative can only be an interim solution because of the future need to phaseout their use with chemicals that do not deplete the ozone layer. Hydrocarbons such as cyclopentane, are one class of long term options. Focused research effort is also being devoted to hydrofluorocarbon (HFC) options to HCFC-141b such as HFC-245, HFC-356mffm, and HFC-365.

The summary of the thermal insulating effectiveness of several alternative blowing agents for CFC-11 in rigid polyurethane foam is presented in Table 2.

Table 2 *Thermal conductivity of blowing agents in foam*

Foam blowing agent ➜	CFC-11 foam	HCFC-141b foam	Cyclopentane foam
Thermal conductivity at 10 C (m W/m-K) Jeffs M., ICI, Eco-refrigeration (13/14 Feb.97, N Delhi)	17.7	19.2	19.9
Thermal conductivity at 10 C (m W/m-K) FKW, Sep. 1996	17.1	19.2	19.6 to 20.2
Thermal conductivity at 10 C (m W/m-K) ERA1.2E manual, March 1993	18.4	20.8	-

In terms of thermal conductivities this table indicates that these two leading alternatives are inferior to CFC-11. Whilst laboratory measured thermal conductivities give an indication of relative energy-consumption, reliable data can only be obtained from in-use tests of assembled cabinets. The UNEP(1995 TOC) report indicates increase in the energy-consumption of about 2% for using R141b and 12.5% for using CP to replace CFC11. Manufacturers are adopting various routes of ameliorating this effect. These include the optimization of cell structures to obtain smaller cells and hence reduce the transfer of heat by radiation and/or increasing the insulation thickness.

Influence Of Non-ODS Refrigerants On Energy-Consumption

The thermodynamic properties determine the efficiency and capacity of the vapor compression cycle. Based on thermodynamics, Table 3 presents the changes in the theoretical COP for the leading alternative refrigerants to CFC-12.

As we can see there is a slight benefit with respect to energy consumption in using R600a and slight disadvantage with respect to energy consumption in using R134a. Several other studies report that the calculated coefficient of performance (COP) of R 600a is about 3% to 7% higher as compared to R 12 and the COP of R134a is not significantly different from that of R12.

Table 3 *Change in theoretical COP for the leading alternative refrigerants to CFC-12*

Evaporating temperature ▼	Refrigerants ➡	R134a	R600a
-30 C	theoretical COP ➡	- 1.7%	+ 2.9%

Source: *Adapted from a paper by FKW/Infras, Market study on HC technology, Sep. 96*

Influence Of Non-ODS Substitutes On Energy-Consumption In Indian Refrigerators

ERA Simulation Program

Using USEPA-ERA1.2E simulation software this analysis was performed employing simulation data from 4 Indian refrigerator manufacturers. This program was designed by Arthur D. Little, Inc. to enable a comparison of domestic refrigerators with different technological features. The compressor design data available from Indian manufacturer was applicable for R12 compressors only. To simulate energy-consumption for other refrigerants, an inbuilt-facility of the ERA1.2E to make design adjustments for non-ODS substitutes was used. The EER and capacity model of ERA1.2E simulation software requests a single calorimeter data point at the standard condition with R-12 refrigerant. Correlation for the suction gas superheat and shell heat loss are used to determine values for the clearance volume and the compression efficiency. A correlation for the thermodynamic characteristics of the specified circulating refrigerant is made. The program has inbuilt thermodynamic properties-database for 34 refrigerants.

A study done by ORNL, USA has reported that the modeled and the experimental results may vary from +9% to -9%.(ASHRAE transactions/vol.100/part 1/p1422-1430). EPA technical team has also investigated the reliability of the program and found that the simulated results and experimental results may differ from -3.0% to +4.7%. In another study by EPA, it was reported that ERA predicted results matched very closely with the prototype results. Thus this program could be considered a reasonably good evaluation and design tool for domestic refrigerators.

Energy-Consumption Analysis: Data & Test Conditions

In India, 165 liters is the typical size and about 75% of current annual sales consists of this size. The design parameters of 165 litres, manual defrost, single door refrigerators as needed for the ERA1.2E programs were given by the 4 manufacturers. These parameters consisted of cabinet dimensions, insulation thickness and resistivity, condenser and evaporator design parameters, and compressor design specifications. Energy-consumption analysis was performed as per IS1476-1979. It specifies ambient temperature to be 32 C, cabinet air temperature: 5 C, and freezer air temperature: -5 C.

Influence Of Non-ODS Foam Blowing Agents On Energy Consumption In Indian Refrigerators

The resistivity values for R11, R141b and CP(derived) were based on the EPA manual for ERA1.2E. Using the program following results were obtained for various combinations of R12 refrigerant and different insulations.

Table 4 *Foam Blowing Agent and Energy-Consumption (kWh/day) - theoretical analysis of Indian refrigerators (165 lt.)*

Foam Blowing Agent → Refrigerator Model ↓	CFC-11	HCFC 141b	Cyclopentane
Model 1	1.06	1.18	1.22
Model 2	1.20	1.30	1.33
Model 3	1.13	1.27	1.32
Model 4	1.15	1.29	1.32

The results show that on an average energy-consumption increase is predicted to be about 10% with R141b and 14% with Cyclopentane.

Influence of non-ODS refrigerant on energy-consumption in Indian refrigerators

Two leading refrigerant alternatives were chosen for comparative analysis with R-12 refrigerant. Results of the simulation are shown in Table 5. The average energy consumption increase is predicted to be about 2.5% for using R134a as a replacement to R12. In case of R600a, the simulation results predict decrease in energy-consumption by an average of about 5%. These results match closely with the earlier shown theoretical predictions in using these two refrigerants.

Table 5 *Refrigerant and Energy-Consumption (kWh/day) - Theoretical analysis of Indian refrigerators (165 lt.)*

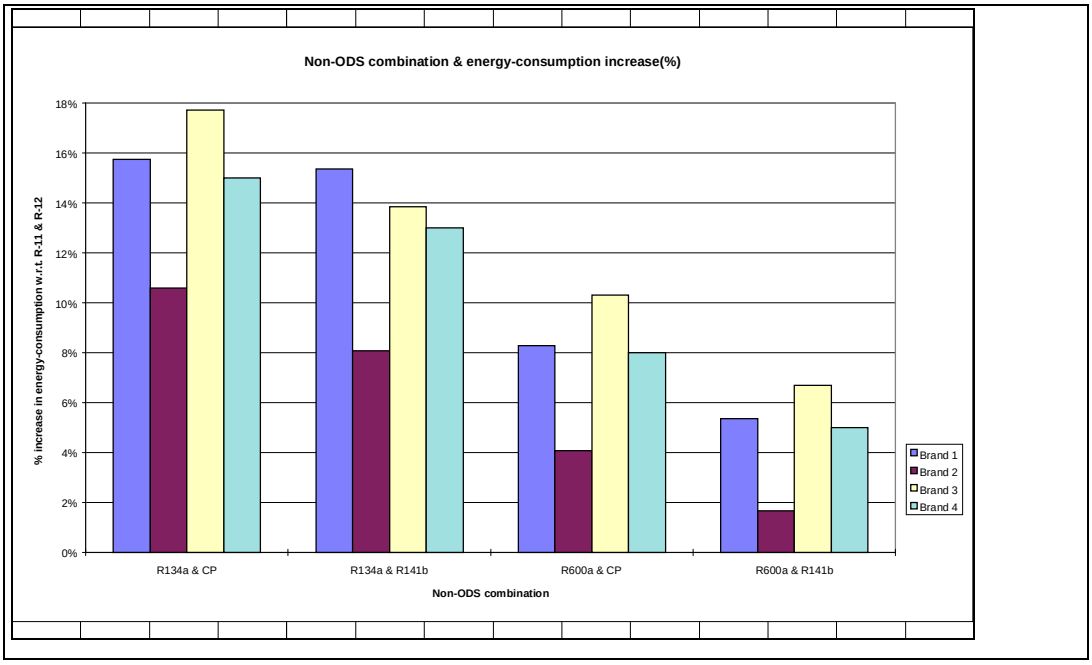
Refrigerant → Refrigerator Model ↓	CFC 12	R134a	R600a
Model 1	1.06	1.12	1.03
Model 2	1.20	1.19	1.12
Model 3	1.13	1.18	1.07
Model 4	1.15	1.17	1.09

3.5 Influence of various non-ODS combinations of refrigerant & foaming agent on energy-consumption

There are 4 combinations possible as an alternative to R12/R11 ODS-combination. All the brands were simulated for these four combinations. The results are shown in Table 6 and Figure 1. It is seen that the R134a & CP combination would lead to maximum increase in energy-consumption ranging from 11% to 18%. Minimum increase in

energy-consumption would result by using R600a & R141b non-ODS combination. It is predicted to be higher in comparison to R12/R11 combination by 2% to 7%.

***Figure 1**: Non-ODS combination & energy-consumption increase(%)*



Non-ODS Combination	R12 & R11	R134a & C-Pentane		R134a & R141b		R600a & C-Pentane		R600a & R141b	
Refrigerator Model	EC kWh/day	EC kWh/day	% change in e.c. w.r.t. R12 & R11 combin.	EC kWh/day	% change in e.c. w.r.t. R12 & R11 combin.	EC kWh/day	% change in e.c. w.r.t. R12 & R11 combin.	EC kWh/day	% change in e.c. w.r.t. R12 & R11 combin.
Brand 1	1.06	1.23	16%	1.22	15%	1.15	8%	1.12	5%
Brand 2	1.20	1.33	11%	1.30	8%	1.25	4%	1.22	2%
Brand 3	1.13	1.34	18%	1.29	14%	1.25	10%	1.21	7%
Brand 4	1.16	1.33	15%	1.30	13%	1.25	8%	1.22	5%
Avg. for particular combination of ODS-substitutes			15%		12%		7%		5%

Conclusion

The theoretical analysis reveal that except for R600a as a refrigerant, other ODS-substitutes have a negative impact on energy-consumption in various measures. These results need to be verified experimentally also. In actual design, most appliance manufacturers in developed countries have been able to reduce this negative impact on energy-consumption by incorporating advancements in compressor and insulation technologies.

In India most manufacturers have decided the choice of refrigerant and foam-blowing agent. Voltas and Godrej are yet to decide between R134a and R600a. Other manufacturers have almost decided to use R134a as refrigerant. For foam blowing agent, except for Whirlpool, all manufacturers have decided to go for CP. Based on our theoretical analysis and the different phase-out scenarios in India, it is predicted that with ODS-phaseout the energy-consumption of domestic refrigerators in India can increase from about 10% to 15% on an average depending mainly on the choice of the refrigerant. In private conversations with Indian refrigerator manufacturers the results of this study were confirmed by them. Industry has performed energy-consumption analysis on the prototypes developed by them.

At least one developing country (China) has addressed the energy problem simultaneously with CFC phaseout and also sponsored the development of energy saving refrigerant blends. In the Chinese case energy-efficient, CFC-free refrigerator is based on the use of Isobutane as a refrigerant and Cyclopentane as a foaming agent. Main design improvements have been: increase in the insulation-thickness, use of higher EER compressor & optimization of refrigeration system (*Ref. paper presented by Haier, China at Ecorefrigeration, N Delhi, 13-14 Feb. 96*). Similarly companies in other Asian countries would also need to adopt new design features for balancing the impact on energy-consumption of using non-ODS substitutes.

Acknowledgements

The author would like to thank IIEC-Asia for organizing this Forum on Asia Regional Cooperation on Energy-Efficiency Standards and Labeling and also providing the necessary financial support to enable me to present this paper at the Forum. I also thank Jim Sands, ORNL, USA for his useful suggestions on the paper.

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