FICHA DE CONTRIBUIÇÃO

Portaria Interministerial
“Regulamentação Específica e Programa de Metas para Condicionadores de Ar”

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Referência (artigo)	**ALTERAÇÃO / INCLUSÃO**		
	Texto atual	**Nova redação proposta**	**Justificativa**
Art. 8° do Anexo	Até as datas estabelecidas no art. 5º, os referidos Equipamentos ficam sujeitos aos níveis mínimos de eficiência energética estabelecidos pela Portaria Interministerial MME/MCTIC/MDIC nº 323, de 26 de maio de 2011.	Até as datas estabelecidas no art. 4º, os referidos Equipamentos ficam sujeitos aos níveis mínimos de eficiência energética estabelecidos pela Portaria Interministerial MME/MCTIC/MDIC nº 323, de 26 de maio de 2011.	O Art. 5°, tal como está no texto original, não faz referência alguma a datas. A lógica são as datas constantes no Art. 4°, quando então passam a valer os níveis mínimos estabelecidos no Art. 3° da minuta de Portaria ora em Consulta Pública.
Arts. 8º e 9º do Anexo		Acrescentar artigo entre os artigos 8º e 9º: Art. ** Novos níveis mínimos de eficiência energética serão estabelecidos para entrada em vigor no máximo a cada quatro anos para os mencionados Condicionadores de Ar a partir de 1° de janeiro de 2018.	O novo Programa de Metas, que é o Anexo da minuta de Portaria objeto da atual Consulta Pública, retirou do texto diversos dispositivos importantes que haviam no Anexo (Programa de Metas) atualmente vigente (Portaria MME/MCT/MDIC n° 323, de 26 de maio de 2011), a ser substituído por este ora em Consulta. Portanto, é importante reintroduzi-los. Um desses dispositivos importantes retirados é o que garante a periodicidade de 4 anos para entrada em vigor de novos níveis

		§ 1º. Especificamente para a próxima revisão, o prazo máximo para a entrada em vigor dos novos níveis mínimos de eficiência energética será 1° de janeiro de 2020. § 2º. Para subsidiar o estabelecimento dos níveis mínimos das próximas revisões, serão desenvolvidos estudos de impacto regulatório. § 3º. Ficam previstos como novos níveis mínimos de eficiência energética pelo menos os valores mínimos da penúltima faixa de classificação do Programa Brasileiro de Etiquetagem - PBE, vigentes à data da revisão.	mínimos de eficiência energética a partir de 1° de janeiro de 2012 (Art. 6° da Portaria MME/MCT/MDIC n° 323/2011). O ideal seria que essa periodicidade estivesse contida em um novo artigo da própria Portaria em Consulta, não dentro de seu Anexo (Programa de Metas), pois este é substituído ao longo do tempo. Porém, nesse atual momento, apenas trazer de volta a periodicidade tal como se encontra na acima mencionada Portaria n° 323/2011 é por ora suficiente. Sendo assim, propõe-se reintroduzir a periodicidade nesse novo artigo proposto. Também se permite acelerar o processo de inovação dos equipamentos, se necessário, ao se acrescentar o termo “no máximo”. A proposição desse § 1º advém do atraso que houve no estabelecimento dos novos níveis mínimos de eficiência energética, que deveriam ter entrado em vigor em 1° de janeiro de 2016 conforme a mencionada Portaria n° 323/2011. Sendo assim, para que não haja prejuízo da data para entrada em vigor dos próximos níveis mínimos, ou seja, em 1º de janeiro de 2020 (a cada quatro anos a partir de 1° de janeiro de 2012), este parágrafo primeiro estabelece esse prazo. A proposição desse § 2º parte do fato de que não fica claro se inovações importantes que já estão disponíveis estão sendo incorporadas por esses níveis mínimos propostos a custos compatíveis com a realidade tanto da indústria nacional como dos consumidores (incluindo os custos evitados com a economia de eletricidade). Sendo assim, para que fique claro para a sociedade como um todo e para os agentes interessados, é fundamental que a partir da revisão dos próximos níveis mínimos sejam realizados estudos de impacto regulatório. Neste documento, ao final, encontra-se um artigo publicado analisando um procedimento para escolha de nível mínimo de eficiência energética para geladeiras baseado em metodologia desenvolvida pela CLASP – “Collaborative Labeling & Appliance Standards Program” (VENDRUSCULO et al, 2009). Este é um procedimento no qual se demonstra de forma clara os custos e

			benefícios de novos índices ao longo da vida útil dos novos equipamentos e que torna o processo mais transparente para toda a sociedade. O artigo ilustra o caso de se escolher nível mínimo de eficiência energética para refrigeradores a partir de um conjunto de inovações técnicas, seus custos e potencial de economias. Esse tipo de impacto regulatório foi realizado para a Portaria que está nessa consulta? A proposição do § 3º é reintroduzir outro dispositivo que havia na mencionada Portaria n° 323/2011 e que foi retirado da minuta ora em Consulta Pública. Esse parágrafo é importante porque caso não seja obedecido o prazo máximo de entrada em vigor dos níveis mínimos de eficiência energética, ao menos automaticamente será dado um incremento. Sem esse parágrafo, essa garantia mínima é retirada, o que seria um prejuízo do ponto de vista de um mínimo de trajetória crescente na eficiência energética dos equipamentos no país.
Art. 9º do Anexo	Art. 9º Cada revisão dos níveis mínimos de eficiência energética será precedida de Consulta Pública e terá sua aplicação condicionada à aprovação prévia do Comitê Gestor de Indicadores e Níveis de Eficiência Energética - CGIEE.	Acrescentar parágrafo único ao artigo 9º: Parágrafo único. O estudo de impacto regulatório deverá ser disponibilizado juntamente com a minuta de proposta de Portaria para consulta pública.	Em linha com a proposição de inclusão do § 2º feita acima, que justifica ser fundamental que a partir da revisão dos próximos níveis mínimos sejam realizados estudos de impacto regulatório, sua publicidade e colocação em consulta para aprimoramento também deve ser garantido mediante o parágrafo único aqui proposto.
Art. 10 do Anexo	Art. 10. O Ministério de Minas e Energia publicará Portaria informando o resultado de cada decisão do CGIEE, prevista no art. 9º, e os novos níveis mínimos de eficiência energética.	Acrescentar parágrafo único ao artigo 10: Parágrafo único. No prazo máximo de noventa dias, após a publicação da Portaria referida no caput, o Inmetro publicará as novas Faixas de Classificação do PBE para os	O parágrafo único aqui proposto é outro caso de reintroduzir dispositivo existente tal como escrito na mencionada Portaria n° 323/2011. Sua importância é garantir prazo máximo para que a política de etiquetagem representada pelo PBE seja substancialmente coerente e temporalmente aderente à política de níveis mínimos de eficiência energética.

		Condicionadores de Ar objeto deste Programa de Metas.	
Art. 11 (caput) e seu § 1°	Art. 11. Os fabricantes ou importadores deverão informar, quando solicitado pelo Inmetro, as quantidades relativas à produção e comercialização dos Equipamentos discriminados por Faixa de Classificação do PBE. § 1º Os fabricantes ou importadores terão prazo de sessenta dias para enviar ao Instituto as informações após a efetivação da referida solicitação pelo Inmetro.	Art. 11. Os fabricantes ou importadores deverão informar ao INMETRO, até 31 de março de cada ano, as quantidades relativas à produção e comercialização dos Equipamentos discriminados por Faixa de Classificação do PBE referentes ao ano anterior. ~~*§ 1o Os fabricantes ou importadores terão prazo de sessenta dias para enviar ao Instituto as informações após a efetivação da referida solicitação pelo Inmetro.*~~	Para que haja uma política de padrões mínimos de eficiência energética efetiva, é necessário que seja fundamentada em informações de mercado (asseguradas seu sigilo e confidencialidade de forma desagregada) para uma permanente e fundamental ação de monitoramento, avaliação (M&A) e observância (“enforcement”) da política como recomendam as melhores práticas internacionais de programas dessa natureza e de governança da eficiência energética. Da forma como atualmente se encontra o seu caput, as informações de fabricantes e importadores possuem um caráter condicionado extemporaneamente sob solicitação, quando deveria ser periódico como “input” crucialmente necessário para o monitoramento e avaliação da política e sua observância legal. Para tanto, propõe-se nova redação do caput e, por consequência, a retirada do seu § 1°, mantendo os demais parágrafos como estão. A título de exemplo para mostrar a importância desse ponto e também do estudo de impacto regulatório, tem-se que para os novos níveis mínimos sendo propostos no Art. 5° da minuta da Portaria os atuais equipamentos fabricados e comercializados no país enquadrados nas faixas C e D (vide figuras abaixo) do PBE, tanto do tipo janela quanto do tipo Split seriam retirados do mercado. No entanto, não fica claro se essa mudança terá impactos no mercado de ar-condicionado nacional com as informações disponíveis. Quais serão as economias de energia para os consumidores e para o setor?

CONDICIONADOR DE AR JANELA Data atualização: 20/4/2017

Classes	Coeficiente de eficiência energética (W/W) (*)												Total de modelos por classe
	Categoria 1 ≤9.495 kJ/h ≤9.000 BTU/h			Categoria 2 9.496 a 14.769 9.001 a 13.999			Categoria 3 14.770 a 21.099 14.000 a 19.999			Categoria 4 ≥21.100 ≥20.000			
A	≥ 2,93	38	64,4%	≥ 3,03	27	57,4%	≥ 2,88	10	76,9%	≥ 2,82	13	59,1%	88
B	≥ 2,84	17	28,8%	≥ 2,94	13	27,7%	≥ 2,71	2	15,4%	≥ 2,65	7	31,8%	39
C	≥ 2,76	1	1,7%	≥ 2,86	4	8,5%	≥ 2,59	0	0,0%	≥ 2,48	1	4,5%	6
D	≥ 2,68	3	5,1%	≥ 2,78	3	6,4%	≥ 2,46	1	7,7%	≥ 2,30	1	4,5%	8
		59 un			47 un			13 un			22 un		141 un

CONDICIONADORES DE AR SPLIT HI-WALL Data atualização: 24/4/2017

Classes	Coeficiente de eficiência energética (W/W)			Split Hi-Wall			
				Rotação Fixa		Rotação Variável	
A	3,23	<CEE		375	41,8%	315	91,3%
B	3,02	<CEE≤	3,23	178	19,8%	22	6,4%
C	2,81	<CEE≤	3,02	274	30,5%	8	2,3%
D	2,60	≤CEE≤	2,81	70	7,8%	0	0,0%
				897 un		345 un	

Contribuição para a Consulta Pública

International Energy Initiative – IEI Brasil

Gilberto De Martino Jannuzzi, Fernando Costa e Rodolfo Gomes

Dada a proposta da consulta pública realizada em 18 de outubro de 2017 pelo CGIEE em conjunto com o MME no intuito de se obter novos níveis mínimos de eficiência energética para equipamentos de condicionamento de ar tipo Janela e Split, o IEI contribui analisando dois tópicos:

1. Metodologia para a escolha de novos índices mínimos de eficiência. Qual é a metodologia utilizada no Brasil para se estabelecer esse índice? E quais são os impactos no mercado de equipamentos?
2. Análise dos níveis mínimos de eficiência energética nos países desenvolvidos e em desenvolvimento;

METODOLOGIA PARA A ESCOLHA DE NOVOS ÍNDICES MÍNIMOS DE EFICIÊNCIA

Segundo ABRAVA 2014, no Brasil os condicionadores de ar tipo Split dominam o mercado com 74% das vendas, seguido pelos condicionadores de ar tipo janela, que, embora venham apresentando declínio nas vendas, elas ainda representam uma parte significativa (14%).

Os novos índices propostos pela nova resolução, que deveriam ter entrado em vigor no início de 2016 (Portaria Interministerial Nº 323/2011, Artigo 6º)[1], estabelece para os condicionadores de ar:

- Tipo Janela: São dispostos por categorias onde cada categoria deverá ter o índice mínimo de eficiência energética, conforme Tabela 1.

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[1] A rigor, a Portaria Interministerial N° 323/2011 que estabelece o Programa de Metas para condicionadores de ar deveria ter sido publicada em até um ano após a Regulamentação Específica para esses equipamentos (Portaria Interministerial Nº 364, de 24 de dezembro de 2007) conforme estabelece a Lei Nº 10.295/2001, ou seja, cerca de dois anos e meio antes: “Em até 1 (um) ano a partir da publicação destes níveis [máximos de consumo específico de energia, ou mínimos de eficiência energética], será estabelecido um Programa de Metas para sua progressiva evolução.” (Artigo 2º, parágrafo 2).

Tabela 1. Índices mínimos do coeficiente de eficiência energética (W/W) para condicionadores de ar tipo janela.

	Categoria 1	Categoria 2	Categoria 3	Categoria 4
W/W	$\geq 2{,}84$	$\geq 2{,}94$	$\geq 2{,}74$	$\geq 2{,}65$

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- Tipo Split: São indiferentes no tocante às categorias. O nível mínimo do coeficiente de eficiência energética para este tipo de equipamentos deverá ser $\geq 3{,}02$.

Para os novos índices são verificados que os atuais equipamentos fabricados e comercializados no país das classes C e D (ANEXO A), do tipo janela, e da classe D, do tipo Split, seriam eliminados. **No entanto, não fica claro se essa mudança terá impactos no mercado de ar-condicionado (AC) nacional com as informações disponíveis. Quais serão as economias de energia para os consumidores e para o setor?**

Além disso, não fica claro se inovações importantes que já estão disponíveis estão sendo incorporadas por esses índices propostos a custos compatíveis com a realidade tanto da indústria nacional como dos consumidores (incluindo os custos evitados com a economia de eletricidade).

Neste documento encontra-se um artigo publicado (ANEXO B) analisando um procedimento para escolha de índice mínimo de eficiência energética para geladeiras baseado em metodologia desenvolvida pela CLASP (VENDRUSCULO *et al, 2009)*. Este é um procedimento no qual se demonstra de forma clara os custos e benefícios de novos índices ao longo da vida útil dos novos equipamentos e que torna o processo mais transparente para toda a sociedade. O artigo ilustra o caso de se escolher MEP para refrigeradores a partir de um conjunto de inovações técnicas, seus custos e potencial de economias. **Esse tipo de impacto regulatório foi realizado para a Portaria que está nessa consulta?**

ANÁLISE DOS NÍVEIS MÍNIMOS DE EFICIÊNCIA ENERGÉTICA NOS PAÍSES DESENVOLVIDOS E EM DESENVOLVIMENTO

O desempenho energético dos sistemas de condicionamento de ar apresenta uma tendência global de melhoria devido às constantes preocupações com o aumento das demandas energéticas que influenciam os setores a investirem em equipamentos mais modernos e eficientes.

Vários fatores contribuem para o desenvolvimento de um programa de regulamentação de eficiência energética e isto depende do contexto de cada país onde são avaliados, da maturidade do programa, da existência de metas mais restritivas, dos valores exigidos como índices mínimos de eficiência energética, da certificação, dentre outros.

Em diversos países os índices mínimos para sistemas de condicionamento de ar tipo split (por apresentarem uma tendência maior de crescimento, em detrimento aos do tipo janela) se tornaram mais restritivos. O índice de eficiência energética é a razão entre a capacidade total de refrigeração (W) e a potência demandada (W) para seu funcionamento. Também conhecido como EER, da sigla “Energy Efficiency Ratio” ou como Coeficiente de Desempenho - COP, da sigla “Coefficient of Performance”.

A CLASP (Collaborative Labeling & Appliance Standards Program) apresentou informações sobre condicionadores de ar da Austrália, China, União Europeia, Japão, Índia, Coreia, Taiwan e Estados Unidos, com suas respectivas variações de eficiências energéticas, e foram observados acréscimos significativos no decorrer dos anos (Nihar Shar et al, 2017)

As variações da eficiência energética são diferentes entre os países, conforme pode ser verificado na Figura 1. Isto se deve ao contexto de cada país, como clima, horas de uso, mecanismos regulatórios entre outros.

Os piores equipamentos nestes dois últimos países apresentaram índices de eficiência energética de 2,9 W/W para o ano de 2010. A Tabela 2 mostra as variações de índices mínimos e máximos de eficiência energética de alguns países para o ano de 2011.

Os índices mínimos exigidos no Brasil são tímidos quando comparado aos índices praticados em grande parte com outros países. Devido ao panorama energético brasileiro e às tendências de aumento das vendas de condicionadores de ar para os próximos anos, nota-se que a elevação dos índices de eficiência energética faz-se necessária, embora com atraso no presente caso, e que os produtos brasileiros apresentam um grande potencial na redução de gastos energéticos. Vê-se também a necessidade da revisão das normas que traçam as diretrizes para as métricas de índices mínimos de eficiência energética em consonância com as melhores práticas procedimentais adotadas nos países desenvolvidos.

Deve-se levar em consideração que as condições de testes para cada país são divergentes, fato este que dificulta uma correlação adequada de índices de eficiência entre os países. No entanto, devido à globalização das indústrias, os fabricantes são praticamente os mesmos e os índices de eficiência obtidos em um dado país pode ser aproximado para os demais países, uma vez que se adote políticas nacionais mais restritivas de índices mínimos de eficiência energética.

As variações climáticas e a recente adoção de medidas sazonais para análise de eficiência energética dificultam a comparação global das eficiências. Não existem dados comparativos que permitam a formulação de políticas em todo o mundo de forma a criar alvos de eficiência energética mais eficazes, bem como incentivos e regulamentos associados, ficando a cargo de cada país, em função da sua realidade e contexto, como o clima de cada local, características das edificações e horas de uso durante os anos, fatores que são levados em consideração para determinação dos índices mínimos de eficiência pertinentes.

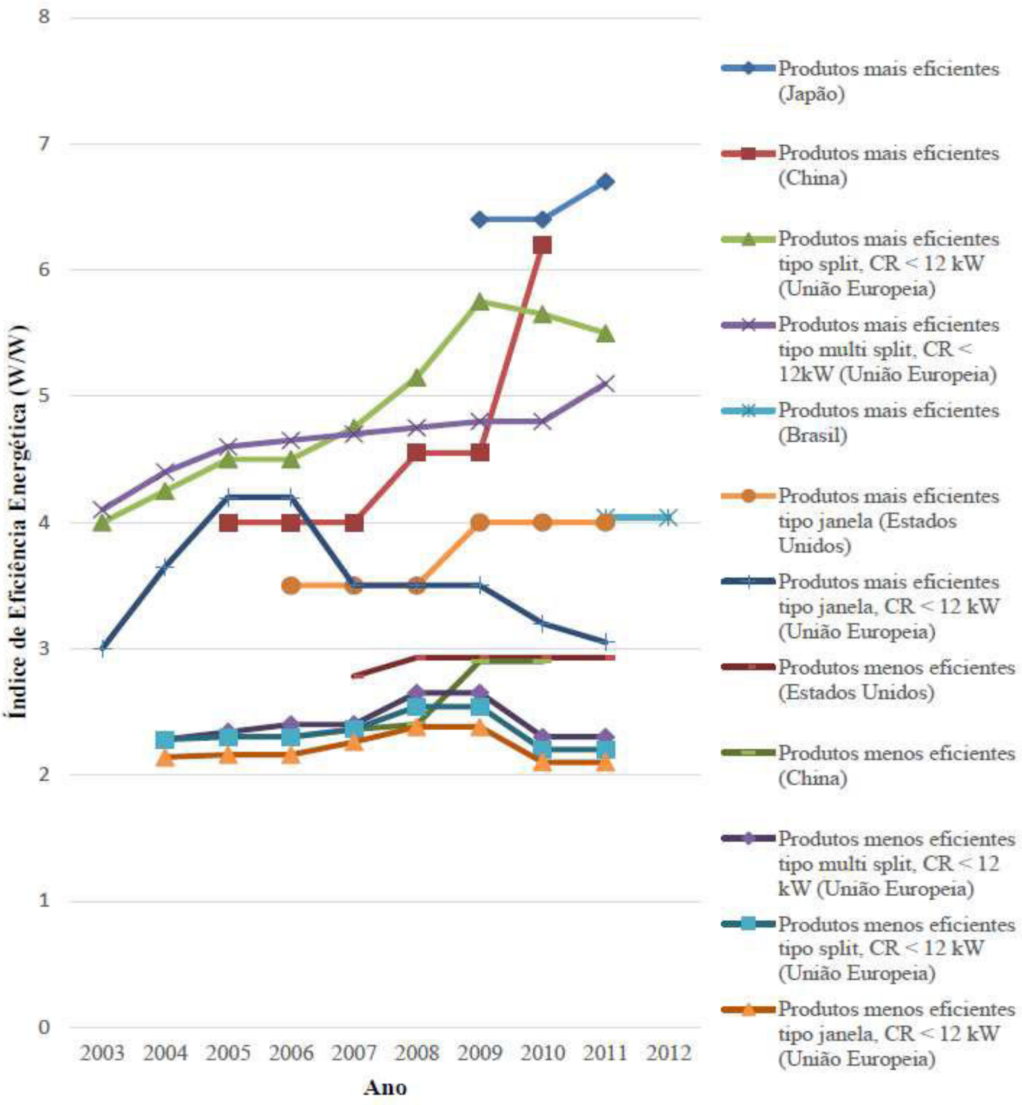

Figura 1. Eficiência energética (W/W) para sistemas de AC para equipamentos mais ou menos eficiente, por país. Fonte: Econoler et al., 2011; Shan et al., 2013.

Tabela 2: Faixas mínimas e máximas de eficiência energética para equipamentos de ACs para alguns países.

País	EER Mínimo (W/W)	EER Máximo (W/W)
Austrália (Split)	≥ 2,67	≥ 4,88
Canadá (Split)	≥ 2,14	≥ 4,33
China (Split)	≥ 2,90	≥ 6,14
União Européia (Split)	≥ 2,21	≥ 5,51
União Européia (Janela)	≥ 2,30	≥ 3,10
Estados Unidos (Split)	-	≥ 4,60
Estados Unidos (Janela)	≥ 2,90	≥ 4,00
India (Split)	≥ 2,35	≥ 3,6
Japão (Split)	≥ 2,37	≥ 6,67
Koréia (Split)	≥ 3,05	≥ 5,73
México (Split)	≥ 2,42	≥ 4,10
México (Janela)	≥ 2,30	≥ 2,80
Rússia	≥ 2,50	≥ 3,60
África do Sul (Split)	≥ 2,28	≥ 5,00
BRASIL (Split)	**≥ 2,60**	**≥ 3,28**
BRASIL (Janela)	**≥ 2,48**	**≥ 2,86**

Fonte: Catalog Searches, IEA 4E M&B 2010, Baillargeon, 2011.

Os índices mínimos de eficiência energética utilizadas nos países asiáticos, como China, Índia, Japão e Coreia, são definidos pelo norma ISO 16358, exceto as que usam condições climáticas específicas da região e alguns países.

A China possui o maior mercado de sistemas de condicionamento de ar, cerca de 43% - 47% do mercado mundial. Os índices de eficiência energética para sistemas de condicionamento de ar com velocidade variável são obtidos pela metodologia SEER (Seasonal Energy Efficiency Ratio) para ar condicionado com função somente de resfriamento e a metodologia APF (Annual Performance Factor) para sistemas com ciclo reverso. Para sistemas com velocidades fixas, os índices de eficiência são obtidos pela metodologia EER (Energy Efficiency Ratio), definido pela norma nacional GB 12021.3-2010, baseada na ISO 5151.

Os índices mínimos de eficiência energética nos Estados Unidos e na Europa são obtidos com mais pontos de dados para as temperaturas externas e cargas parciais do que nos países asiáticos que utilizam a norma ISO 16358 e baseiam seus procedimentos de testes em adaptações da norma ISO 5151.

Várias revisões nos padrões de índices mínimos de eficiência energética foram realizadas nos Estados Unidos. A última revisão feita adotou os índices mínimos divididos em três regiões (Norte, Sudeste e Sudoeste) com base na aglomeração populacional e nos dias de graus de aquecimento. Como resultado, os condicionadores de ar instalados durante ou após 1° de janeiro de 2015 devem atender os índices mínimos na SEER e HSPF (Heat seasonal performance factor), para bombas de calor e para a região sudeste devem ser atender as metodologias SEER e EER.

Países como a Indonésia, Malásia, Filipinas, Cingapura, Tailândia e Vietnã utilizam método de teste baseado na ISO 5151:2010 e CSPF definido na ISO 16358-1:2013. As diferenças nas medidas de índices de eficiência energéticas devem-se principalmente aos perfis de temperaturas externas utilizadas para as avaliações estacionárias e cíclicas em um valor de eficiência sazonal e nas formas de calcular o desempenho energético na operação de carga parcial.

O Brasil utiliza a metodologia EER baseado na norma NBR 12010-90 (“MB 3341: Condicionador de ar doméstico: Determinação do coeficiente de eficiência energética”). Esta norma, de 1990, prescreve o método de ensaio utilizado para a determinação do coeficiente de eficiência energética para condicionadores de ar domésticos apenas para o ciclo de refrigeração, por ser a condição de maior consumo.

As condições padrões de ensaios realizados no Brasil são divididas por tipos (A e B), por faixas de temperaturas de bulbo úmido e de bulbo seco do ambiente interno e por faixas de temperaturas de bulbo úmido e seco do ambiente externo, conforme Tabela 3.

Tabela 3. Condição padrão de ensaio para refrigeração

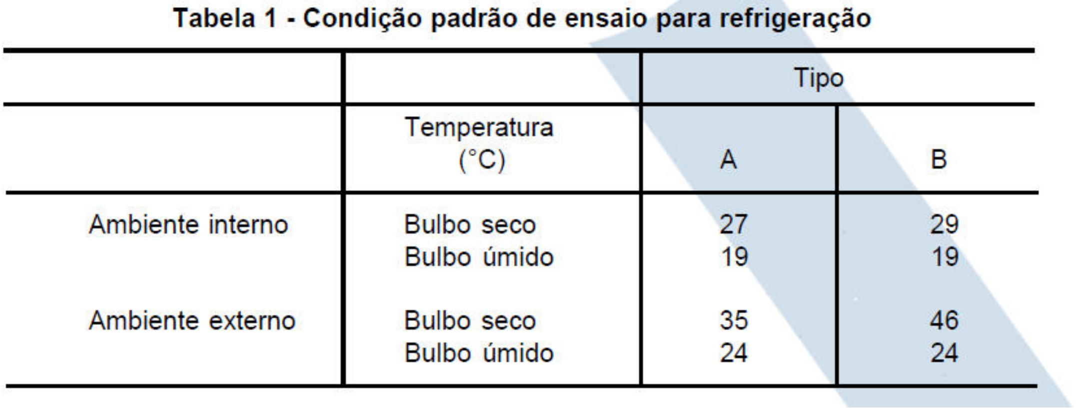

Tabela 1 - Condição padrão de ensaio para refrigeração

		Tipo	
	Temperatura (°C)	A	B
Ambiente interno	Bulbo seco	27	29
	Bulbo úmido	19	19
Ambiente externo	Bulbo seco	35	46
	Bulbo úmido	24	24

Phadke at al. (2017b) Alguns autores estabeleceram equações de regressão linear na tentativa de comparar as métricas de eficiência energética entre as seis principais economias mundiais (China, União Européia, Índia, Japão, Coréia do Sul e Estados Unidos) que baseiam seus procedimentos de testes em adaptações da ISO 5151. Os resultados da conversão mostraram que os fabricantes projetam seus produtos de alta eficiência especificamente para melhor desempenho no procedimento de teste local. Se um modelo de alta eficiência foi projetado para funcionar bem sob certas condições regionais, em outros locais seus desempenhos possivelmente seriam inferiores, levando à necessidade de maior otimização do desempenho para ser usado em regiões diferentes, principalmente em regiões onde os programas de normatização, incluindo procedimentos de testes para avaliar a eficiência sazonal, não estão aprimorados ou atualizados.

Recomenda-se fortemente a normatização das unidades de medidas e dos procedimentos em nível global. Países como Estados Unidos, Japão e China já desenvolveram normas para estes procedimentos e recomenda-se que o mesmo seja feito no restante do Globo. Verifica-se que normalmente os procedimentos adotados são baseados em normas internacionais, a ISO 5151 e a ISO 13253. Estes procedimentos apresentam variações entre os diferentes países, o que torna difícil a comparação entre os mesmos. Os testes mais utilizados para medição de EER são a de entalpia de ar interno do ambiente e o de calorímetro. Devido a sua maior precisão, deve-se priorizar o método de calorímetro. Atualmente este método é o adotado pelo INMETRO.

A determinação do índice de eficiência energética (EER) é realizada em laboratórios especializados com temperaturas controladas e submetendo o equipamento a plena carga. Durante o uso convencional destes equipamentos, as condições reais não correspondem às condições reproduzidas nos laboratórios de testes. Desse modo, os índices de eficiência energética sofrem variações em função das condições externas, pois os condicionadores de ar só funcionam a plena carga algumas poucas horas durante o ano. No resto do tempo os condicionadores de ar funcionam com cargas parciais.

Nas condições reais de uso, alguns condicionadores submetidos a temperaturas menos extremas podem apresentar desempenho superior ao apresentado nas condições de testes.

Para ajustar esta deficiência metodológica, foi criado o Seasonal Energy Efficiency Ratio (SEER) que fornece uma medida mais representativa do desempenho energético submetido à demanda climática local. Neste método, o equipamento é testado e avaliado considerando-se o desempenho global previsto para o clima de um ano típico de uma certa localização.

O SEER é um método utilizado para medir a eficiência energética de um equipamento condicionador de ar. Quanto maior o SEER, mais eficiente é o sistema. O SEER mede quão eficiente um sistema de refrigeração e/ou aquecimento irá operar durante uma temporada (anual). É uma unidade que é calculada dividindo-se o número total de BTU (British Thermal Unit) removido do ar pela quantidade total de energia necessária para funcionamento da unidade.

O uso do SEER é favorável para equipamentos com tecnologia de compressores variáveis (tecnologia *inverter*). O compressor é o maior consumidor de energia dos sistemas de condicionamento de ar e na tecnologia inverter as velocidades de rotação do compressor se ajustam para atender a demanda térmica.

Em mercados maduros como a União Européia, China e Estados Unidos, os splits com tecnologia *inverter* estão amplamente disponíveis. No Japão o mercado é dominado por equipamentos com tecnologia *inverter*. Na maioria dos países, excetuando-se a Índia, os mercados são dominados por condicionadores de ar split e há uma forte tendência da migração dos splits com velocidades fixas para os de tecnologia *inverter*.

No Brasil nota-se uma redução no uso de condicionadores de ar tipo janela, porém ainda são utilizados, principalmente em ambientes críticos onde a renovação de ar externo é obrigatória (hospitais, clínicas, laboratórios, entre outros).

No Brasil, para condicionadores de ar tipo split torna-se evidente e necessária a determinação de novos níveis mínimos de eficiência energética, mesmo para os condicionadores de ar com tecnologia inverter, que vem apresentando uma larga aceitação no país. Para a avaliação desses novos índices, é importante adotar o método SEER como parâmetro na regulamentação brasileira.

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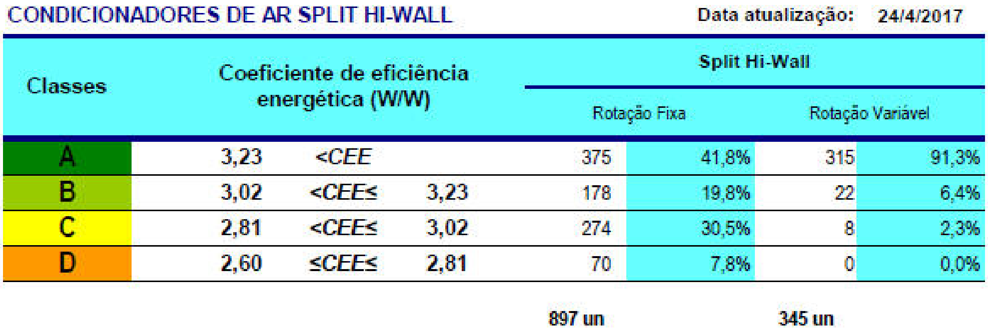
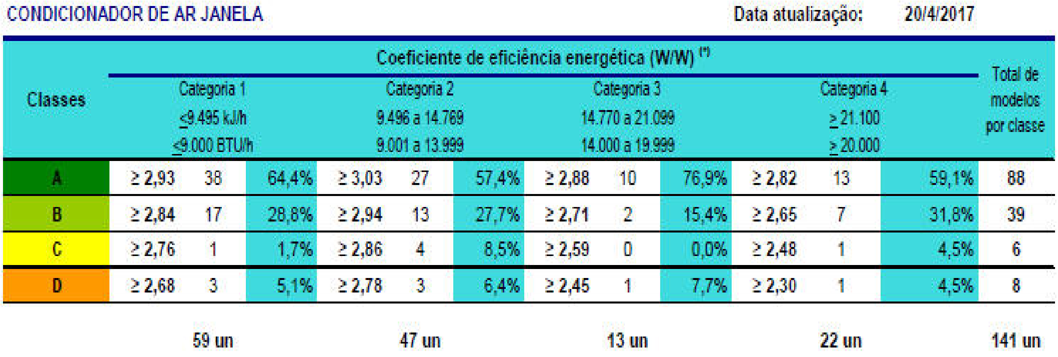
ANEXO A - Selo Procel de economia de energia para condicionador de ar tipo split e hi-wall.



CONDICIONADORES DE AR SPLIT HI-WALL — Data atualização: 24/4/2017

Classes	Coeficiente de eficiência energética (W/W)			Split Hi-Wall			
				Rotação Fixa		Rotação Variável	
A	3,23	<CEE		375	41,8%	315	91,3%
B	3,02	<CEE≤	3,23	178	19,8%	22	6,4%
C	2,81	<CEE≤	3,02	274	30,5%	8	2,3%
D	2,60	≤CEE≤	2,81	70	7,8%	0	0,0%
				897 un		345 un	



CONDICIONADOR DE AR JANELA — Data atualização: 20/4/2017

Classes	Coeficiente de eficiência energética (W/W) [*]												Total de modelos por classe
	Categoria 1 ≤9.495 kJ/h ≤9.000 BTU/h			Categoria 2 9.496 a 14.769 9.001 a 13.999			Categoria 3 14.770 a 21.099 14.000 a 19.999			Categoria 4 ≥ 21.100 ≥ 20.000			
A	≥ 2,93	38	64,4%	≥ 3,03	27	57,4%	≥ 2,88	10	76,9%	≥ 2,82	13	59,1%	88
B	≥ 2,84	17	28,8%	≥ 2,94	13	27,7%	≥ 2,71	2	15,4%	≥ 2,65	7	31,8%	39
C	≥ 2,76	1	1,7%	≥ 2,86	4	8,5%	≥ 2,59	0	0,0%	≥ 2,48	1	4,5%	6
D	≥ 2,68	3	5,1%	≥ 2,78	3	6,4%	≥ 2,45	1	7,7%	≥ 2,30	1	4,5%	8
		59 un			47 un			13 un			22 un		141 un

ANEXO B

Energy Efficiency (2009) 2:271–286
DOI 10.1007/s12053-008-9034-6

Life cycle cost analysis of energy efficiency design options for refrigerators in Brazil

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Abstract The purpose of this paper was to present the results of a life cycle cost analysis concerning the purchase and operation of a more efficient popular refrigerator model compared with a baseline design in Brazil. The summarized results may be useful for organizations working to promote sustainable energy development. This paper specifically focuses on refrigerators, since their energy consumption is predicted to constitute over 30% of the total average domestic electricity bill in Brazilian households. If all new Brazilian refrigerators had an energy efficiency at the level consistent with the least life cycle cost of ownership, it would result in an annual savings of 2.8 billion dollars (US$) in electricity bills, 45 TWh of electricity demand, and 18 Mt of CO_2 emissions, with a respective payback period of 7 years which is less than half the average estimated lifetime of a refrigerator. The analysis was conducted following the guidelines of similar analyses available from the US Department of Energy and the Collaborative Labeling and Appliance Standards Program.

Keywords Electrical consumption · Energy efficiency · Household refrigerator · Life cycle cost analysis · Minimum energy performance standards · Payback period

Introduction

In the year 2001, the Brazilian National Congress approved the “National Energy Conservation Policy and Rational Use of Energy” law that requires minimum energy efficiency standards for energy-consuming equipment commercialized in Brazil (Brazilian law no. 10.295 2001). A first comparative analysis indicates great opportunities for energy savings with refrigerators. For example, some Brazilian models consume approximately 46% more energy than similar models being commercialized in Europe (ENERGY +2002;

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PROCEL 2002a). The models compared[1] are the same type of appliance belonging to the one-star category (R4 category), which defines temperature of the frozen food compartment to be ≤6°C in accordance with specifications, found in Table 2, of the commission directive 2003/66/EC published by the official journal of the European Union (CLASP 2003).

Energy efficiency methodologies made accessible by the US Department of Energy (DOE) and Collaborative Labeling Standard Program (CLASP) were used in the following analysis. An engineering analysis was used to determine the range of potential energy efficiency improvements and their costs. This analysis considers new designs or combinations of designs and technologies that are not commercially available and can, therefore, result in products with higher efficiencies than those available on the market at this time.

The statistical analysis of a set of energy use data for one-star refrigerator models available in Brazil in 2004 was used to establish a study scenario in this paper. For each model, energy use is plotted as a function of adjusted volume. Adjusted volume (AV) accounts for the different temperatures in the fresh food and freezer compartments of refrigerators, refrigerator freezers, and freezers.

To analyze the economic impact of potential efficiency improvements on consumers, the consumer payback period and life cycle cost (LCC) have been used. Analyses of payback periods and LCCs illustrate the trade-off and help identify policies that will have net benefits for consumers.

Many inputs are needed for economic analyses of quantities, such as LCC and payback period. For example, to calculate LCC, several pieces of data are needed, including the incremental purchase price for the more efficient product, energy savings, fuel price, appliance lifetime, and consumer discount rate. To calculate the payback period, only the first three terms are needed (Wiel and McMahon 2001).

However, like other developing countries, it is also difficult to get complete statistical and technical data for analysis. Therefore, a different scenario building methodology was used. The authors have also provided a brief appendix containing the results of statistical and LCC analysis for refrigerators in the European Union and USA, which served as reference material. Appendix 1 refers to the guidebook provided by CLASP, as it was available at the time of this paper's writing. However, nowadays, a revised version (the "COLD II" study) is available and should be preferred for future studies of energy labeling and minimum energy efficiency standards for domestic refrigeration appliances.

Cost-effective technical improvements (or design options) were considered in the analysis and their energy, economic, and environmental impacts through the LCC approach were evaluated. Simulation results allowed estimates of the impacts on consumers, manufacturers, and the environment over a long-term period of up to 16 years (2005 to 2020), starting from the moment of adoption of more efficient refrigerators. The present study analyzes the opportunities of establishing minimum energy performance standards (MEPS) for the class of "popular" refrigerators sold in Brazil. These are very simple domestic appliances having only basic technical elements; therefore, a brief technical description is presented below.

Target refrigerator technology overview

Brazilian popular refrigerators consist of a one-door cabinet with a small self-contained freezer compartment, as illustrated in Fig. 1. A single vapor compression

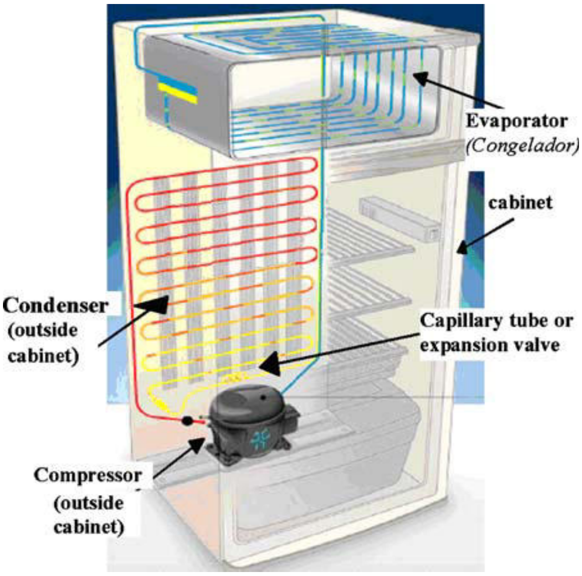

Fig. 1 One-door refrigerator (Embraco 2002)

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[1] The European and Brazilian models that have been used for comparison purposes have similar refrigeration system, same sizes, and are even the same brand. The major discrepancy is only the total gross capacity, i.e., 255 l in the European and 240 l in the Brazilian model.

cycle that operates at the freezer evaporating saturation temperature provides refrigeration for both the fresh food and freezer compartments. The refrigeration circuit comprises four simple elements: a compressor, capillary tube (expansion valve), an evaporator, and a condenser. The distribution of cool air within the cabinet is via natural convection from the evaporator, meaning that there is no fan to distribute air within the cabinet. In general, most of these simple models do not have complex controls or accessories.

The one-door household refrigerator belongs to the one-star classification according to Technical Standard (ISO 7371 1995). In compliance with the standards, it is designed to maintain an internal temperature of 5°C within the fresh food compartment and −6°C within the frozen food compartment. A thermostat located at the evaporator, which switches the compressor on and off, provides the temperature control in the cooling process. For this study, the most commonly sold refrigerator in the Brazilian market was used as the reference for the technical and economical analysis. The baseline refrigerator has a total gross capacity of 330 l and has an average 31 l of net volume within the frozen food compartment.[2]

Energy efficiency standards in Brazil

Brazil has introduced voluntary efficiency labels for refrigerators and other appliances since the late 1980s. These labels have been developed via a process of consensus arrangement between the government and manufacturers. More recently, the "National Energy Conservation Policy and Rational Use of Energy" law (Brazilian law no. 10.295 2001) was established under supervision of the Ministry of Mines and Energy, which leads a steering committee (CGIEE) composed of seven members, made up of representatives of the Ministry of Science and Technology, Ministry of Development, Industry and External Commerce, National Agency of Electrical Energy, National Agency of Petroleum, Brazilian universities, and Brazilian citizens, in order to set new mandatory efficiency standards. The public National Institute of Metrology, Standards, and Industry Quality (INMETRO) inspects the laboratories that are certified to measure the energy consumption of households, such as refrigerators, and the National Energy Conservation Program (PROCEL[3]) supports the steering committee (CGIEE), provides information, and helps people to find the most efficient energy appliance (PROCEL 2002b).

As of 2005, only electrical motors were subject to mandatory minimum energy efficiency standards. Information to consumers on the energy consumption of household refrigerators is provided through two labels displayed on refrigerators available on the retail market: a comparative energy information label (energy rating label) and an endorsement label. Figure 2 shows both Brazilian energy efficiency information and endorsement labels. The former follows the appearance of the European energy label design and shows the comparative energy efficiency class of the appliance on a scale rated from A to G, where A is for the best performing appliances. Note that the formula used to delineate the energy label class are not the same in the Brazilian and EU labeling schemes nor are the test procedures identical, as Brazilian appliances are tested at an ambient temperature of 32°C as compared to 25°C in Europe. Appliances that reach a class A level, according to INMETRO, may be awarded with the PROCEL's endorsement label, shown in Fig. 2b.

A technical committee, led by a representative of PROCEL and seven representatives of several technical associations, decides which manufacturer will receive the label. The following are the technical associations involved: Electrical Energy Research Center (CEPEL), INMETRO, Customer Support National Institute (IDEC), Brazilian Electrical and Electronic Industry Association (ABINEE), National Association for Electro-electronic Products Industries (ELETROS), Brazilian Association of Manufacturers of Refrigeration, Heating, Air Conditioning and

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[2] Some physical dimensions of the base case are 1,528-mm height, 619-mm width, and 691-mm depth. A hermetic compressor is used, which has a cooling capacity of 425 Btu/h (125 W), a displacement of 4.23 cc/rev, and an energy efficiency rate of 1.07 kcal/Wh, assembled for low back pressure applications. The electrical specification comprises an operating voltage range of 90–140 V supplied by a single-phase 60-Hz grid.

[3] PROCEL operates by funding or co-funding energy efficiency projects, such as, research and development (R&D), education and training, testing, labeling, standards, demonstration, and others. The program works on both increasing end-use efficiency and reducing losses in electricity generation, transmission, and distribution systems, though the latter diminished greatly after the liberalizing reforms of the 1990s. PROCEL cooperates with state and local utilities, state agencies, private companies, universities, and research institutes.

Ventilation Equipment (ABRAVA), and Brazilian Lighting Industry Association (ABILUX).

The endorsement label is displayed exclusively on the most efficient appliance and, in order to carry this label, the appliance's manufacturer is required to be approved in an eventual audit done by a labeling inspection committee. This committee chooses a sample taken directly from the refrigerator production line to be tested in a certified laboratory. The inspection committee has representatives from the associations INMETRO and PROCEL, as well as from the certified laboratory.

Electrical consumption of appliances in Brazil

In 2003, Brazil consumed approximately 325 TWh of electrical energy, of which 46% was used by the industrial sector and about 27% was consumed by the residential sector (BEN 2004). Figure 3 shows the estimated share of household electricity consumption by appliance types (Chade 2004).

As seen in Fig. 3, refrigerator electricity consumption represents a large share in all surveyed houses. As a consequence, the refrigerator was preferred by PROCEL and INMETRO to establish the energy conservation standards. Table 1 shows the refrigerator features taken into account by the INMETRO labeling program (INMETRO 2002). Each model is analyzed according to its AV, where the label class A is awarded to the more energy-efficient equipment using a formula established by INMETRO. A technical committee, composed of representatives from industry and government, uses a statistical analysis to define this index. INMETRO sets up the maximum allowable

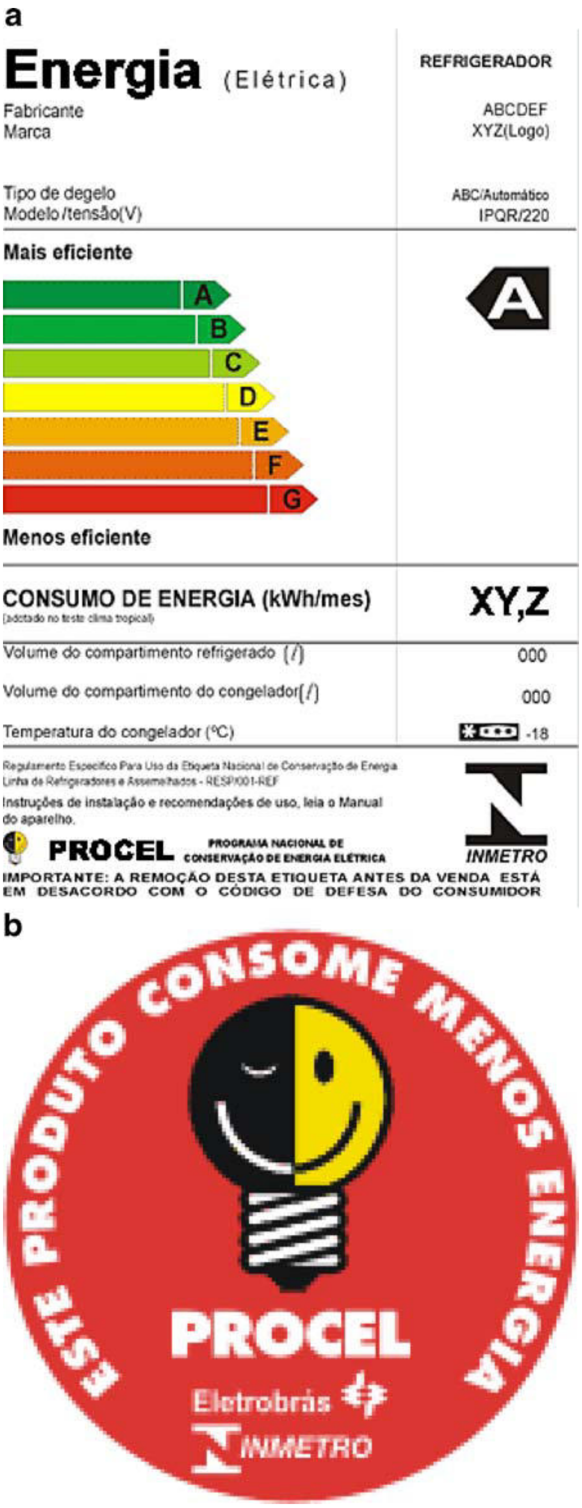

Fig. 2 Brazilian labels (PROCEL 2002b)

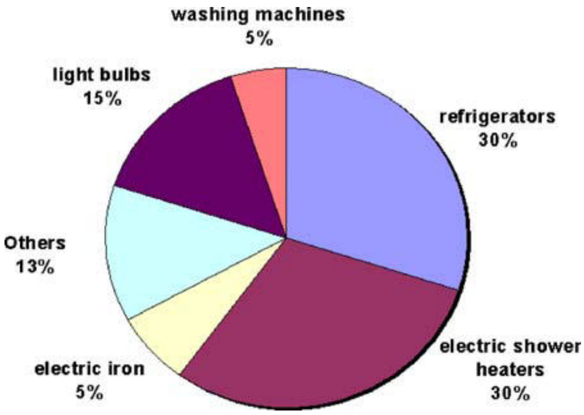

Fig. 3 End-use electricity consumption in Brazilian households

Table 1 Refrigerator features account to the INMETRO/PROCEL labeling program

Brand	Model	Volume			Consumption (kWh/month)	INMETRO label
		Fresh food compartment	Small freezer compartment	Adjusted volume[a] (AV)		
BOSCH	RB 31	297	00	297	24.5	A
BOSCH	RB 38	367	00	367	27.0	A
BRASTEMP	BRA31A	253	33	300	32.0	C
BRASTEMP	BRA35A	296	33	343	36.0	C
BRASTEMP	BRB35A	329	00	329	36.5	D
BRASTEMP	BRF36A	330	00	330	29.5	A
CCE	R31L	263	30	306	30.0	B
CCE	R32SL	268	30	311	30.0	B
CCE	R26L	224	30	267	32.0	D
BLUE SKY	R31L	263	30	306	30.0	B
HOUSTON	R31L	263	30	306	30.0	B
CONSUL	CRB23B	223	00	223	32.0	F
CONSUL	CRC24B	191	22	222	30.5	F
CONSUL	CRA32A	272	31	316	26.6	A
CONSUL	CRA32B	272	30	315	24.9	A
CONSUL	CRC32A	272	31	316	28.8	A
CONSUL	CRA36A	312	30	355	31.5	A
CONTINENTAL	RC 27	223	29	264	23.7	A
CONTINENTAL	RC 30	257	29	298	27.0	A
CONTINENTAL	RC 37	324	33	371	33.0	A
ELECTROLUX	R250	214	26	251	24.6	B
ELECTROLUX	R280	237	26	274	25.0	A
ELECTROLUX	R310	263	31	307	30.0	B
ELECTROLUX	R330	286	31	330	30.2	A
ELECTROLUX	R360	312	31	356	32.4	A
ESMALTEC	RG3100E	283	27	321	34.8	B
GE	GE310A	263	31	307	30.0	B

[a] AV = fresh compartment + 1.42 small freezer compartment

energy consumption per label class as a function of the adjusted volume, as is done in most other countries applying mandatory refrigerator standards and labeling schemes. The adjusted volume accounts for the different temperatures in the fresh food and freezer compartments of the refrigerator. In Brazil, the temperature and relative humidity are respectively set to 32°C and 50% according to the standardized test methods. Brazilian refrigerators are classified as Tropical (climate class T) appliances.

Scenario building methodology

The analysis hereafter takes into account a hypothetical scenario based on the market share of Brazilian manufacturers. The leading brand manufacturer had 53% of the wholesale refrigerator market in 2002 and his products were technologically more advanced compared to the other models on the market. The second largest refrigerator manufacturer had 29% of the market, but his product had a lower energy performance as compared to the market leader. Thus, the second manufacturer allows for more improvements to be targeted. Lastly, the remaining manufacturers shared the outstanding 18% of the wholesale market (Datamark 2002).

The authors emphasize that they had no data available for one specific refrigerator model, listed in Table 1. Thus, the market share percentage in the last paragraph refers to all refrigerator models belonging to a brand owner (e.g., market share is 53% for sales of all models CRA23, CRA24, CRA32, and CRA36 in Table 1).

This study estimates an "average refrigerator model" so that the analysis for the Brazilian market could be performed. This model results from weighted averages of retail market parameters of the two chosen refrigerators, respectively indicated as X and Y in Fig. 4, which shows the linear regression of the consumption for data in Table 1. The weights chosen corresponded to the 53% of market share for the most sold refrigerator (X), and the remaining 47% was taken as the weight for the second model (Y). For simplicity purposes, this arrangement essentially takes into account two brands, which by far hold the highest share of the market, while other brands have minor market share percentages. These two brands have an adjusted volume of 316 liters (319.2 kWh/year) and 330 l (354 kWh/year) as indicated in Fig. 4, respectively. Therefore, the energy consumption for the "average refrigerator model" is given by:

$$\begin{aligned} \mathrm{EC}_{\mathrm{wavg}} &= 0.53 \times X_{\mathrm{cption}} + 0.47 \times Y_{\mathrm{cption}} \\ &= 335.5[\mathrm{kWh/year}] \qquad (1) \end{aligned}$$

where, X_{cption} and Y_{cption} are the energy consumption for X and Y models, respectively.

Based on the aforementioned considerations, the effort is applied hereafter to assess this scenario.

Energy consumption resulting from technical improvements

Design options (or technical improvements) represent changes in the design of a baseline model that improve its efficiency. Several technical improvements may be applied in order to reduce the energy consumption of refrigerators, but laboratory facilities and time limited the number of improvements that could be simulated in this study. Simulations of improved designs were conducted using the ERA[4] software tools (E.P.A. Refrigeration Analysis) distributed by the US Environmental Protection Agency (Merriam et al. 2002). The results of the technical improvement simulations, shown in Table 2, consider two major groups of improved designs: those using more efficient compressors and those derived from an increase of insulation thickness. Simulations were carried out for both brands, X and Y, and then the results were weighted, taking into account the respective market share, as shown in Eq. 1, to get the final energy efficiency.

A new compressor with about 20% higher efficiency was used instead of the original. The compressor efficiency is declared in the compressor datasheet through the EER (energy efficiency ratio) acronym. This technical option is self-explanatory, since the more efficient compressor had EER=1.49 W/W comparative to 1.22 W/W of the original in the baseline refrigerator.

Alternatively, the insulation thickness was increased for both refrigerator door and wall. Between 75% and 90% of the energy required by refrigeration unit may be attributed to the thermal performance of the insulated shell. Hence, by improving the performance of the shell, significant savings are possible. A common way of improving the overall thermal resistance of the shell is to increase its thickness. Adding from 1.27 to 2.54 cm (0.5 to 1.0 in.) of extra insulation results in an energy savings range from a few percent to over 10% relative to the previous design level (Hakim and Turiel 2002). Furthermore, results using modern compressors are also very impressive. As such, the set of all design options may expect savings of 44%, as shown in Table 2. In fact, it is a primary test, since material improvements and electronically commuted motor (including permanent magnet rotor) advances have pushed up the overall compressor efficiency very rapidly.

Analytical elements of the standards setting process

This section applies the life cycle cost analysis (LCCA) to consider the ambition and impacts of prospective energy efficiency standards. The LCCA performed comprised an engineering analysis (which analyzes potential technical improvements), a LCC, and a payback period analysis.

These analyses were performed in accordance with CLASP recommendations; hence, gathering data was

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[4] The validation of the ERA refrigerator model (one door) was done by comparing the electricity consumption of 28.14 kWh/month obtained from ERA with the consumption of 28.1 kWh/month declared by the refrigerator manufacturer. As seen, the error for electricity consumption from simulation and manufacturer was within 1%. An experimental test in a specialized laboratory was also carried out in accordance with the ISO7371 test procedures and the measured consumption was with 28.35 kWh/month. The technical input data table for ERA is based on overall information about the cabinet and the main elements' dimensions such as, evaporator and condenser. Specific data on characteristics of materials, insulation thermal resistivities, in addition to internal temperatures and refrigeration cycle information, were also necessary.

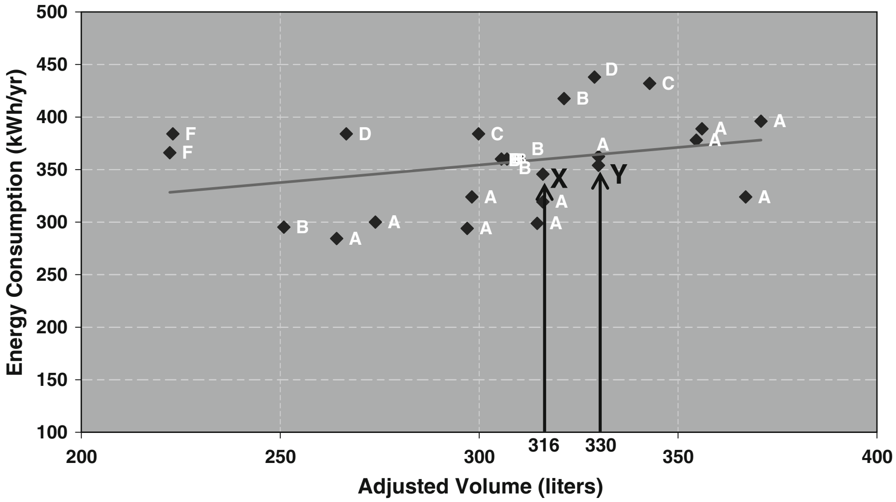

Fig. 4 Linear regression

the main constraint. Therefore, underlying assumptions and approximations are highlighted along with its use hereafter.

Engineering analysis

Technical improvements, listed in Table 2, and their respective results were used to formulate hypothetical energy efficiency standards. Various approaches were considered for evaluating the feasibility of energy standards. The first approach considers the case where all existing refrigerator markets in 2001, referring to models in Table 1, are required to conform to a mandatory standard determined by the reference line C0, shown in Fig. 5. Such an approach implies that all refrigerators should be improved according to the regression line C0, expressed as follows:

$$C0_{\mathrm{cption}} = 254.0 + 0.33 \times \mathrm{AV}\,[\mathrm{kWh/year}] \qquad (2)$$

where $C0_{\mathrm{cption}}$ is the energy consumption.

In this case, which only considers a change in average energy use of those refrigerator models above the C0 line, it was found that market average refrigerator energy consumption might be reduced by 4% overall. Note that it was assumed that all models had equal sales, as the true market share data were not available.

Once all models in the market were imagined to satisfy the “C0 standard” line, new simulations were performed considering innovation C1 (Table 2), and the resulting data points were used to derive the new regression line C1, shown in Fig. 5. Based on this new situation, an estimated energy saving of 16.1% is obtained (see Table 2).

This procedure was repeatedly applied to define additional hypothetical standards C2 to C5, and their respective associated energy savings are listed in Table 2.

Each time increased efficiency standards are proposed, it is essential to assess the potential consumer, national industry, and environmental impacts that they would subsequently be expected to produce.

Table 2 Simulation results (Vendrusculo et al. 2003): one-door refrigerator energy efficiency

Technical improvements		Percent energy efficiency increase		
		Refrigerator		Assumed scenario
		X (%)	Y (%)	Weighted average energy efficiency increase (%)
Compressor	C1—more efficient EER=1.49W/W	12.1	20.7	16.1
Insulation thickness increase	C2—at door=1/2 in.	3.9	3.8	3.9
	C3—at wall=1/2 in.	10.2	14.1	12.0
	C4—at door=1 in.	2.9	2.9	2.9
	C5—at wall=1 in.	8.4	10.0	9.2

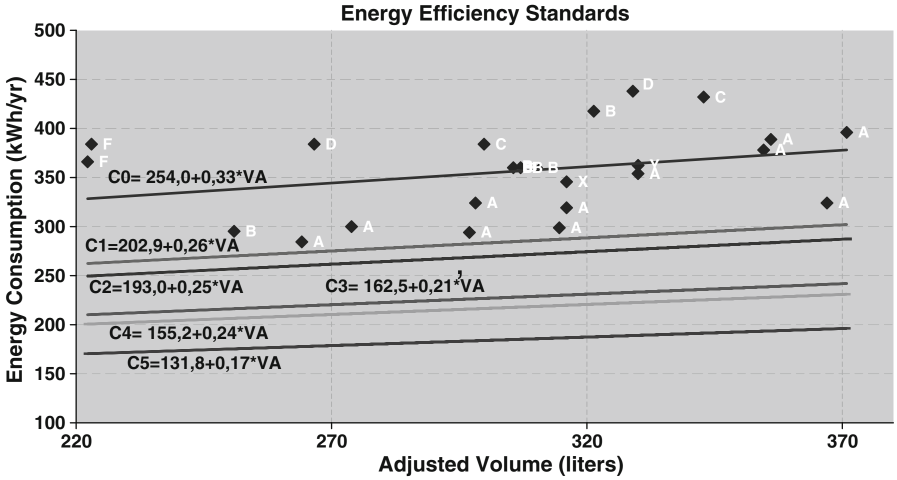

Fig. 5 Application of an engineering approach to setting standards for Brazilian refrigerators

Life cycle cost

The LCC analysis takes into account the lifetime of the appliance and the consumer discount rate. LCC is the total consumer expense over the lifetime of the appliance, including purchase expense and operating costs (also including energy expenditures). Future operating costs are discounted to the time of purchase and summed over the lifetime of the appliance. LCC is expressed in Eq. 3 as a function of the retail price (*P*), annual operating cost (O_t), lifetime (*N*) in years, and the discount rate (*r*; Wiel and McMahon 2001; Biermayer 2001):

$$\mathrm{LCC} = P + \sum_{t=1}^{N} \frac{O_t}{(1+r)^t} \tag{3}$$

where $\sum_{t=1}^{N}$ means the sum over the lifetime, from year 1 to year *N*, where *N* = lifetime of appliance (years) and *t* is the year for which operating cost is being determined.

Equation 3 shows two main inputs to the LCC analysis: the appliance retail price (*P*) and the appliance operating cost (*O*). To set the final retail (selling) price of a more energy-efficient refrigerator, the cost of each design option, incorporated in the commercial equipment, is added to the baseline retail price.

The increase in manufacturing costs associated with each design change was estimated based on the Technical Support Document: Energy Efficiency Standards (US Department of Energy) for refrigerators, refrigerators–freezers, and freezers (DOE 1995).

It is very important to clarify that in Brazil, the appliance manufacturers evaluate design options and estimate developing cost with no commitment to the appliance standards steering committee and also there are no tax incentives for advanced energy-saving technologies. As a consequence, it is not a trivial issue to get data from manufacturers[5] about the aforementioned refrigerator design options (i.e., manufacturing cost, efficiency gain) to proceed with the LCC calculations.

The cost of each more efficient design option, which includes the overall markup, is shown in Table 3. The percentage by which the sales price exceeds the manufacturer's cost of the equipment is the overall markup, which comprised the manufacturer markup, distributor or wholesaler markup, dealer markup, and sales tax (local and state governments apply sales taxes to refrigerator purchases). In this study, an overall markup of 2.42 was used based on information gathered by the authors from retailers and one manufacturer. A Brazilian appliance manufacturer supplied the manufacturer's cost of his baseline model and the retail price was derived from a survey of the Brazilian commercial actors. The purpose of the survey was to find out the average retail price of the baseline model. The "average refrigerator" used in the study had a retail price of R$699.00 (US$ 211.81) which yielded a baseline manufacturing cost of R$288.81 (US$87.52).

In view of the fact that no data was available from appliance manufacturers and component suppliers,

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[5] Tax incentives for these technologies could encourage manufacturers to introduce new products and stimulate them to convey technical data for the appliance standards steering committee.

Table 3 Expected incremental costs in the refrigerator retail price of each design option

Design option	Expected cost R$ (US$)
C1	60 (18.18)
C2	20 (6.06)
C3	67 (20.3)
C4	18 (5.45)
C5	16.06 (53)

estimates of technical improvement costs in Table 3 were extrapolated from the Department of Energy report Technical Support Document: Energy Efficiency Standards for consumer products: refrigerators, refrigerators–freezers, and freezers (DOE 1995). The exchange rate of 3.3 was applied in conversion to local currency (R$ = reals), i.e., US$1.00=R$3.30.

The operating cost in Eq. 3 is the sum of the energy cost and repair cost. The primary inputs for establishing the energy cost are the annual energy consumption and the average electricity price. The scenario assumed yielded an annual energy consumption of 338.80 kWh/year through Eq. 1. The average electricity price is the mean price paid for all electricity, which at the time of this study was R$0.252/kWh (US$0.0763/kWh; ANEEL 2002a). Also, an average value of 18% for all state and federal tax charged in the electricity price was taken into account. This tax is considered constant over time for the analysis performed in this work. The repair cost is the cost to the consumer for replacing or repairing components that have failed in the equipment. However, it was assumed that no repair work is done throughout lifetime. Furthermore, it was assumed that operating cost is constant over time. As a result, the expression for LCC in Eq. 3 reduces to:

$$\mathrm{LCC} = P + \mathrm{PWF} \times O_t \tag{4}$$

where the present worth factor (PWF) is:

$$\mathrm{PWF} = \sum_{t=1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^N}\right]. \tag{5}$$

The discount rate is the rate at which future expenditures are discounted to establish their present value (ANEEL 2002a). The nominal discount rate $r=14\%$ was assumed as recommended by the Brazilian Electricity Regulatory Agency (ANEEL). In Brazil, the overall electrical energy market is under ANEEL regulations. The minimum recommended to make a profit on energy efficiency programs is 12% (ANEEL 2002b). Note that compared to international practice, this figure is very high; however, discount rates even as high as 15.25% per year (inflation of 4.5% per year) have been recently practiced in Brazil (3CEE Report 2006). The expected return on investment in a more energy-efficient equipment can be asserted through the analysis of payback period.

Payback period (PAY)

The economic impact on consumers resulting from the potential efficiency improvements can be analyzed through a payback analysis approach. For example, for the target standard C1 in Fig. 5, the amount of time needed to recover the additional consumer investment on purchasing an efficient model through the lower operating costs is the payback period.

Data on the incremental purchase price for the more efficient product (ΔP), energy savings, and electricity price is required for the calculation of the payback. Equation 6 summarizes the payback (Wiel and McMahon 2001; Biermayer 2001):

$$\Delta P + \sum_{1}^{\mathrm{PAY}} \Delta O_t = 0 \tag{6}$$

where ΔO_t is the variation in operating costs. However, operating costs were considered constant over time t so that Eq. 7 could be applied:

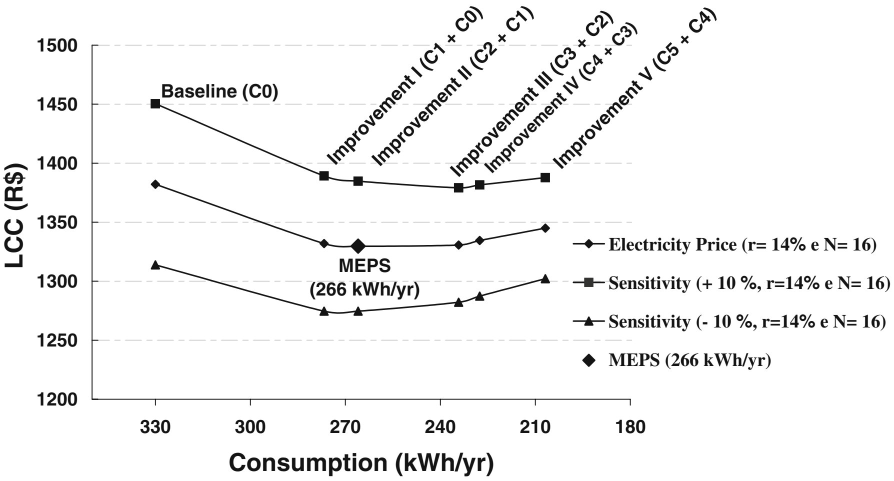
$$\mathrm{PAY} = -\frac{\Delta P}{\Delta O}. \tag{7}$$

LCCA results

The hypothetical MEPS levels derived from the LCCA analyses are highlighted in Fig. 6, which depicts the results according to the consumer's perspective. The LCC analysis suggests that setting MEPS at the C2 level will result in models that are 24% more efficient and have an average energy consumption of 266 kWh/year, as shown in Table 2. As a consequence, respective increases of 3.7% and 8.9% in the manufacturer cost and retail price are expected, as seen in Fig. 6.

The sensitivity of the LCCA to the variation in the electricity price was also evaluated. Increasing elec-

Fig. 6 Scenario results: LCC analysis



tricity prices by 10% would imply C2 MEPS corresponding to an average refrigerator energy consumption of 234 kWh/year (improvement III in Fig. 6). Alternatively lowering the electricity price by 10% results in an average C2 energy consumption level of 276 kWh/year (improvement I in Fig. 6). Analyzing the payback period enables the time it would take for consumers to earn a return on an investment in a more efficient refrigerator to be assessed.

Assuming a refrigerator lifetime of 16 years in Brazil[6], consumers would recover their investments under all the standard cases considered as the maximum payback period of 12 years for the most ambitious case of C5. Figure 7 shows the payback period in regard to the standards C0, C1, and so on. In summary, the payback analysis illustrates the trade-off and helps identify policies that will have net benefit for consumers (Wiel and McMahon 2001). The sensitivity analysis was also used to gain insights regarding the influence of electricity prices on the payback period. Considering set MEPS at the improvement level III in Fig. 6 (+10% sensitivity), the corresponding payback is about 10.5 years, which is still lower than the average refrigerator's useful life expectancy.

Suggested energy efficiency standards based on the LCCA results

Table 4 summarizes the results in terms of energy savings, payback period, and customer's electricity bill savings for two hypothetical standards regimes.

Under the first scenario, it is assumed that energy efficiency standards (MEPS) become effective in 2005 and savings are estimated for the 2005 to 2020 period. Remember that the MEPS aims to improve efficiency of the refrigerators belonging to all classes, i.e., A to G in the energy efficiency label (Fig. 2a). The results given in Table 4 show that the technical improvements in the refrigerator would save 46 TWh of energy and R$8.49 billion in the customer's electricity bill during the period of 16 years, from 2005 to 2020. It may be worth noticing that these standards were not implemented in 2005. Thus, anyone reading this paper could infer that these savings estimates are out of date, but it is not quite true due to the slow technical improvement in Brazilian refrigerators over time. The MEPS suggested in Fig. 6 of 266 kWh/year is still lower than the energy consumption of a 2008 year refrigerator found in the retail market which is of 294 kWh/year (adjusted volume of 314.6 l—class A). The contrast between the energy consumption of a refrigerator in 2001 and 2008 may help to visualize the slow progress in the energy efficiency index of Brazilian refrigerators over time. For example, the energy consumption of the refrigerator found in Table 1 with adjusted volume of 316 l (net capacity of 272 and 31 l, respectively, for the fresh food and frozen food

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[6] This is an assumption made by the authors based on life expectancy of appliances as reported in the 23rd annual portrait of the US appliance industry. The life expectancy for standard refrigerators is within the range of 10 to 18 years (MrAppliance 2003).

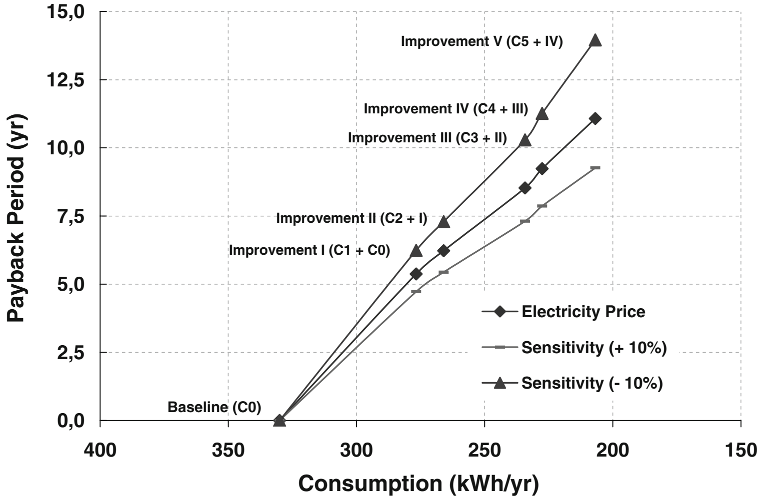

Fig. 7 Estimated payback periods

compartments) was 319 kWh/year (26.6 kWh/month). In 2008, practically the same refrigerator was found in the retail market (net capacity of 272 and 30 l, respectively, for the fresh food and frozen food compartments), and the energy consumption was 294 kWh/year (24.5 kWh/month; INMETRO 2008). This refrigerator was always of an A class level. As seen, the energy consumption of a class A refrigerator has decreased 7.8% in the period of 7 years, which is not very ambitious progress for the energy efficiency index. Furthermore, a striking discrepancy is noticed between the energy consumption of the European and the Brazilian models; for example, a European model (267+35=302 l—A$^+$ class) has an energy consumption of 237 kWh/year (ENERGY+ 2008), whereas in Brazil, an equivalent model (272+30=302 l—same manufacturer—A class) demands 294 kWh/year. It points toward a commercialized model 20% more efficient in Europe. These considerations still maintain that the estimates (MEPS in Fig. 6) are feasible.

For the second scenario, it is assumed that two energy efficiency standards are enforced, first in 2005 at the C2 level and another in 2010 at the C5 level, which takes into account all the higher energy efficiency design options considered in this analysis. The period of 16 years is computed from 2005 to 2020. The results given in Table 4 shows that in this scenario, 66 TWh of energy could be saved for corresponding R$8.48 billion in the customer's electricity bill. The customer's electricity saving are very close for both standards in Table 4. It is a noteworthy performance since, despite being the more energy-efficient refrigerator (66.68 TWh of energy savings), the refrigerator having all design options has a higher life cycle cost (as seen in Fig. 6). The electricity savings for the 24% standard and the 48% standard are, respectively, R$11.63 billion and R$16.80 billion (if not taking into account the life cycle cost).

Table 4 shows that refrigerators are expected to reach an average sale of 1.2 million units per year over the next 20 years in Brazil. This expectancy was taken into account in the estimation of the savings in Table 4. The sales rate was calculated using the linear

Table 4 Standards effective in 2005 (MEPS) and in 2010 (all design options): energy and economic impacts for the period from 2005 to 2020

Improved refrigerator energy efficiency (compared to refrigerator features of 2000 year)	24% (standard from 2005 to 2020; design options C0+C1+C2 provided in Table 2)	48% (standard from 2010 to 2020; design option C3+C4+C5 added to standard 2005 ones)
Payback period	7 years	12 years
Energy savings	46.18 TWh	66.68 TWh
Saving in the customer's electricity bill	R$ 8.49 billions (US$2.57 billions)	R$8.48 billions (US$2.56 billions)

regression method based on the database of the last 12 years reported. This database is made available by Brazilian Institute of National Statistics and Geography (IBGE), which carries on an annual public program called National Research by Home Sampling (PNAD 2004).

Environmental impacts

In this paper, the environmental effects (or impacts) were also evaluated in terms of changes in emissions of pollutants such as carbon dioxide (CO_2) that would occur as a result of reduced energy consumption. The energy savings, as listed in Table 4, are typically converted to emission reductions using conversion factors (e.g., grams of emission per unit energy saved). Table 5 shows the reduction of 18.56 and 26.80 Mtons in emissions of carbon dioxide corresponding to the energy savings of 46.18 and 66.68 TWh, as pointed out in Table 4.

The avoided emissions of CO_2 may be traded in the global carbon credit market. Carbon credits are a key component of national and international emissions trading schemes that have been implemented to mitigate global warming. They provide a way to reduce greenhouse effect[7] emissions on an industrial scale by capping total annual emissions and letting the market assign a monetary value to any shortfall through trading. Credits can be exchanged between businesses or bought and sold in international markets at the prevailing market price.

From the results in Table 5, it can be seen that R$442.2 million (US$134 million) could be earned by capping CO_2 emissions in the 16-year period of suggested MEPS. The carbon unit was quoted at US $5.00/tCO_2$ according to the variation of US$5.50+ 50%/$tCO_2$ found in the literature (Haites 2004).

Conversion factor for greenhouse gas[8]

The emissions of CO_2 listed in Table 5 were calculated from energy savings (Table 4) using a conversion factor of EF=0.402 tCO_2/MWh. This factor gives the grams or tons of emission per megawatt hour of energy saved. This emission factor is calculated according to the type of fuel used in the generation of electric power by a power plant (or generating station). In this paper, the emission factor was obtained for a natural gas combined cycle power plant (Natural Gas 2003). This is a thermal power plant that generates electric power from a gas turbine. Considerations in accordance with the guidelines of the National Greenhouse Gas Inventories Programme through the Intergovernmental Panel on Climate Change (IPCC) were used to calculate the emission factor (IPCC 1996). The aforementioned emission factor (EF) was calculated by:

$$EF = \frac{CEF \times OCF \times \frac{44}{12} \times SF}{\eta}[tCO_2/MWh] \qquad (8)$$

where CEF=15.3 is expressed in tC/TJ (tons of C/ terajoules; IPCC 1996). This is the carbon equivalent emission factor, which converts natural gas energy to net carbon emitted by the fuel burning process. OCF represents the fraction of carbon oxidized during the combustion, usually equal to 0.995 for natural gas (IUEP 2005). SF=0.0036 is a scaling factor to convert energy units, expressed in terajoules, to electric units of megawatt hour (MWh). The symbol η represents the thermal efficiency of natural gas combined cycle power plant, which is within the range of 47% to 56%. In this work η=50% was considered. Finally, the 44/12 fraction converts greenhouse gases from an atomic weight basis (C) to full molecular weight (CO_2; IPCC 1996).

Conclusion

The analysis described in this article may give support and help discussions for establishment of MEPS for one-door refrigerators in Brazil. The summarized results represent important inputs to subsidy further discussion with manufacturers in the process of setting up efficiency standards and may be used as reference for organizations working to promote sustainable energy development.

It is shown that the Brazilian refrigerator can be technically improved, allowing significant savings of electricity consumption in Brazilian households.

From LCC analysis, the increase of 11.44% in the refrigerator retail price is expected for a standard

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[7] The greenhouse effect is the process in which the emission of infrared radiation by the atmosphere warms a planet's surface.

[8] Greenhouse gases are the gases present in the atmosphere that reduce the loss of heat into space and therefore contribute to global temperatures through the greenhouse effect.

Table 5 Standards effective in 2005 (MEPS) and in 2010 (all design options): environmental impacts for the period from 2005 to 2020

Improved refrigerator energy efficiency	24% (from 2005 to 2020; design options C0+C1+C2 provided in Table 2)	48% (from 2010 to 2020; design option C3+C4+C5 added to standard 2005 ones)
Emissions of carbon dioxide (CO_2)	18.56 Mtons	26.80 Mtons
Carbon credit market	R$306.24 millions (US$92.80 millions)	R$442.2 millions (US$134 millions)

establishment of 24% higher efficiency from 2005 to 2020 and a corresponding payback of 7 years. It also represents R$8.49 billion (US$2.57 billion) of savings in the customer's electricity bill. It is a noteworthy result for Brazil, since the estimated 46.18 TWh of saved energy is the equivalent of the operation of 35 Brazilian natural gas thermoelectric power plants during 6 months. Moreover, results show that R$306.24 million (US$92.80 million) can be earned in the carbon market by capping CO_2 emissions in 18.56 megatons.

Finally, if strict MEPS are enforced (48% in Table 4) during the period from 2010 to 2020, the results are 44.44% more attractive with regard to energy savings, avoided CO_2 emissions, and carbon market trading.

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Appendix 1

This appendix is provided for background purposes and is based on the CLASP—Energy-Efficiency Labels and Standards: A Guidebook for Appliances, Equipment, and Lighting (Wiel and McMahon 2001). It is a EU analysis done in 1993. However, a more complete and up-to-date one done in 2001 (the "Cold II" study) is available and should be preferred (Waide 2001).

Energy efficiency standards

Three types of energy efficiency standards are described in the CLASP—Energy-Efficiency Labels and Standards: A Guidebook for Appliances, Equipment, and Lighting (Wiel and McMahon 2001): prescriptive standards, minimum energy performance standards (MEPS), and class average standards, any of which could be either mandatory or voluntary.

- Performance standards prescribe minimum efficiencies (or maximum energy consumption) that manufacturers must achieve in all products manufactured after a certain date. These standards specify the energy performance, but not the technology or design specifications of the energy-efficient product.

The two most widely used analytical approaches for standards setting are: statistical analysis of current products and engineering/economic analysis of future possibilities. These approaches, and others, can be used in combination and are not mutually exclusive.

Statistical approach

Figure 8 shows a statistical analysis performed by the Group for Efficient Appliances (GEA) for three-star refrigerator–freezer models available in EU countries. Four lines are shown in this figure; they represent the average energy use obtained through a regression analysis of all of the data points, a 10% energy savings line, a 15% energy savings line, and a long-term standards line.[9] After the regression line is calculated, the least energy-efficient model is found and replaced with a model of higher efficiency. The number of models stays constant. The energy savings for the higher efficiency model is calculated, and energy savings are aggregated until the total reaches the goal (10%, 15%, etc.). Then, the resulting data points are used to derive a new regression line.

Economic/engineering approach

An engineering analysis is first carried out for each product class within a product type to estimate manufacturing costs for improving efficiency compared to a baseline model. Installation and mainte-

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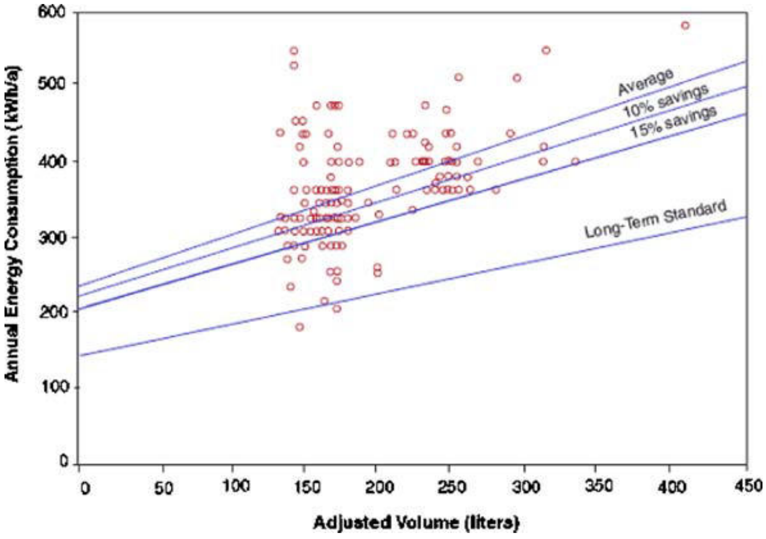
[9] The fourth line was obtained through an engineering/economic approach.

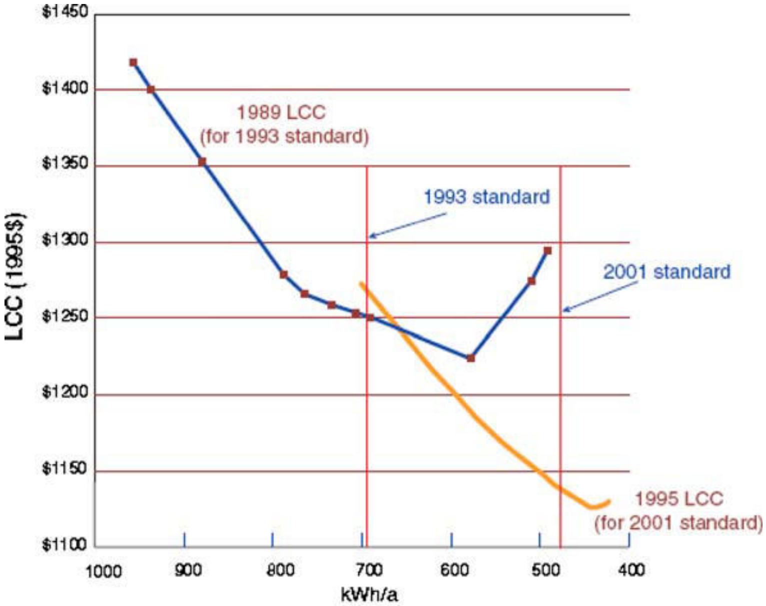
Fig. 8 Statistical approach as applied to European Union refrigerator–freezers



nance costs are also calculated. The engineering analysis can be described in seven steps: (1) select appliance classes; (2) select baseline units; (3) select design options for each class; (4) calculate efficiency improvement for each design option; (5) combine design options and calculate efficiency improvements; (6) develop cost estimates (include installation and maintenance) for each design option; (7) generate cost efficiency curves.

The expected costs of manufacturing, installing, and maintaining each design option must be estimated, including the ability of the after-market service sector to effectively maintain the performance of high efficiency equipment. In some cases, manufacturer costs are very difficult to obtain and it may be necessary to go directly to retail prices; this is a feasible approach if all the designs under consideration already exist in the marketplace.

Fig. 9 LCC analysis results for two sets of US standards for a top-mount, auto-defrost refrigerator–freezer (Wiel and McMahon 2001)



Note: Automatic defrost refrigerator-freezers (top freezer, 20.8 cu ft adjusted volume, without through-the-door features)

Energy efficiency standard in North America

Once the engineering analysis is complete, it is customary to analyze the economic impact of potential efficiency improvements on consumers by analyzing consumer payback period and LCC. Figure 9 shows the LCC analysis results for two sets of US standards for a top-mount, auto-defrost refrigerator–freezer.

The minimum LCC (where the consumer receives the most benefit) occurs around 450 kWh/annum. The minimum LCC is not always chosen for a new standard because many other factors must be considered. For instance, options below 470 kWh/annum were rejected for use in a proposed standard because increased insulation thickness would make these refrigerators too wide to fit into fixed spaces in some existing kitchens, assuming that internal volume remains constant as insulation thickness increases.

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