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Securing energy efficiency as a high priority: scenarios for common appliance electricity consumption in Thailand

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Abstract Between 1995 and 2008, Thailand's energy efficiency programs produced an estimated total of 8,369 GWh/year energy savings and 1,471 MW avoided peak power. Despite these impressive saving figures, relatively little future scenario analysis is available to policy makers. Before the 2008 global financial crisis, electricity planners forecasted 5–6% long-term increases in demand. We explored options for efficiency improvements in Thailand's residential sector, which consumes more than 20% of Thailand's total electricity consumption of 150 TWh/year. We constructed baseline and efficient scenarios for the period 2006–2026, for air conditioners, refrigerators, fans, rice cookers, and compact fluorescent light bulbs. We drew on an appliance database maintained by Electricity Generating Authority of Thailand's voluntary labeling program. For the five appliances modeled, the efficiency scenario results in total savings of 12% of baseline consumption after 10 years and 29% of baseline after 20 years. Approximately 80% of savings come from more stringent standards for air conditioners, including phasing out unregulated air conditioner sales within 6 years. Shifting appliance efficiency standards to current best-in-market levels within 6 years produces additional savings. We discuss institutional aspects of energy planning in Thailand that thus far have limited the consideration of energy efficiency as a high-priority resource.

Keywords Energy efficiency · Thailand · Standards · Labeling · Appliances · Air conditioners · Refrigerators

Introduction

The notion that energy efficiency is a valid and high-priority resource in electricity generation planning is one that has been increasingly accepted in many OECD contexts. Among developing countries, it is still uncommon to find this concept elevated to a policy principle. In Thailand, however, 15 years of successful experience with electric utility-sponsored standards and labeling programs raise the question of whether the time has come for policy makers to elevate the priority of energy efficiency. Based on careful analysis of trends in appliance standards and labeling over time, we suggest that a significant potential for further electricity savings exists.

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Since 1994, Thailand has had experience with a number of voluntary energy labeling programs for consumer appliances. These programs have been managed by Electricity Generating Authority of Thailand (EGAT), a state-owned utility that controls transmission and owns approximately 50% of the nation's total generating capacity. The voluntary labeling programs are generally regarded as successful (Swisher et al. 1997; du Pont 1998; Singh and Mulholland 2000).

Since EGAT initiated its demand-side management (DSM) programs for lighting and common electric appliances in the mid-1990s, it has achieved impressive reductions in energy and peak demand, estimated to be 8,369 GWh/year energy savings and 1,471 MW/year avoided peak power (as of September 2008). These reductions correspond to 5.1% of EGAT's total energy generation requirement and 6.2% of its peak power generation requirement in 2006 (EGAT Demand Side Management and Planning Division; *DSM in Thailand: The EGAT Experiences*, unpublished).

There are two key features to EGAT's "Number 5" labeling program: First, it is voluntary, and appliance manufacturers can choose whether to participate in the program; and second, the EGAT number 5 label essentially serves as a high-efficiency "endorsement" label, since nearly all labels that are voluntarily placed on appliances have the highest number 5 rating (i.e., the number 3 and number 4 ratings are rarely used). An additional notable feature of EGAT's DSM programs is that they have been implemented without any consumer rebates.[1]

Notwithstanding the program's significant accomplishments, a number of uncertainties existed as of 2006 with the policy environment for energy efficiency in Thailand, as well as with the ongoing implementation of specific labeling programs (du Pont 2005). In 2007, the Thailand Department of Alternative Energy Development and Efficiency commissioned an unpublished study to evaluate energy efficiency policy and strategy and to design a single national office to oversee all energy efficiency and DSM efforts in the country. It is not clear whether or when a new agency will be established.

To date, a number of academic studies have been conducted, modeling future trends in Thailand's household energy consumption by key appliance (Seehawong 1998; Santisirisomboon 2001; Khummongkol 2002). However, there has been little publicly available scenario-based analysis to compare the results of different efficiency strategies for the residential sector (Limmeechokchai and Chaosuangaroen 2006a, b). To address this lack of analysis, we constructed a set of relatively simple scenarios for *baseline* vs *energy efficient* consumption for five key appliances (refrigerators, air conditioners, fans, rice cookers, and incandescent light bulbs). In Thailand a few key devices account for the lion's share of energy consumption. Six devices—air conditioners, rice cookers, refrigerators, fluorescent lamps, irons, and fans—consumed almost three-quarters of household electricity consumption. These appliances are estimated to consume more than one quarter of *national* electricity consumption (UNDP 2006). As income rises, air conditioners are estimated to consume a progressively greater share of total household electricity (Santisirisomboon 2001). Thailand's residential electricity consumption exceeds 22,000 GWh/year and is approximately 22% of total national electricity consumption.

Our analysis is intended to provide guidance and perspective to the design of energy efficiency labeling programs in Thailand. It will also contribute to policymaking in an area that has been relatively neglected until 2006: development and regular updating of minimum energy performance standards (MEPS). A comprehensive study of MEPS was carried out for the Thai government in 1999 (Kritiporn 1999). As of this writing (December 2009), the Department of Alternative Energy Development and Efficiency (DEDE), in the Ministry of Energy, has announced draft MEPS for ten electric devices. These include: room air conditioners (split type and window-mounted), refrigerators, fluorescent lamps and lamp ballasts, fans (standing and wall-mounted), rice cookers, fluorescent lamps and lamp ballasts, water heaters, and three-phase induction motors (DEDE n.d.). Minimum mandatory standards have been implemented for two devices: refrigerators (effective 2006; see Table 2) and air conditioners (effective 2005; see Table 4).

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[1] One exception is a zero-interest loan program for air conditioners, which attracted little consumer interest, largely due to excessive paperwork requirements. Direct rebates (another option) face negative perceptions that they would unduly transfer wealth to more prosperous consumers.

Thailand's energy labeling program is seen as a beacon in the region because, since 1998, it has been delivering measurable megawatt savings for a number of products and has included a substantial budget for public promotion and marketing. Yet, despite EGAT's leadership in DSM, the planning process has not yet treated the DSM potential as a high-priority resource to be exploited through aggressive revisions and updating of the labels and establishment of MEPS.

Our analysis also takes place in a context of long-standing debates over good governance of Thailand's electricity supply industry, particularly debates over the value of comprehensive options assessment and policy initiatives to support energy efficiency and small scale renewable energy (Segal 2004; du Pont 2005; Foran 2006; Greacen and Footner 2006; Greacen and Palettu 2007).

Methods

Basic equations

Total annual household energy consumption E in year t is the sum of annual energy consumption per device category E_a across all appliance categories to be modeled (Eq. 1). It is calculated as the product of A_a (activity level per appliance category a) and the weighted average annual unit energy consumption (UEC) U_a for that appliance category:

$$E_{(t)} = \sum_{a}^{n} E_{a(t)} \tag{1}$$

$$E_{a(t)} = A_{a(t)} U_{a(t)} \tag{2}$$

$$A_{a(t)} = N_{a(t)} P_{a(t)} \tag{3}$$

$$U_{a(t)} = \sum_{j}^{n} U_{j(t)} T_{j(t)} \tag{4}$$

$$U_{j(t)} = \sum_{j}^{n} h_{j(t)} D_{j(t)} \tag{5}$$

where N=number of households, P=number of devices possessed per household ("saturation"), h= hours per year, $U_{j(a)}$=unit energy consumption of a particular model j which is a member of appliance category a, $T_{j(a)}$=the percentage share held by model j in appliance category a, and D=Demand in watts.

We used spreadsheet models to explicitly track the total stock of appliances in the population. We modeled survivorship S using a linear function after Mahlia et al. (2002). If $L_{j(a)}$ is the average lifespan of model j in appliance category a, the function assumes 100% survivorship during the first 2/3 years of the average lifespan and 0% survivorship at 4/3 years. For appliances aged between 2/3 and 4/3 years of $L_{j(a)}$, survivorship declines linearly from 100% to 0%.

Scenarios

By scenarios we refer to "self-consistent story-lines of how a future energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions" (Stockholm Environment Institute 2006; see also Ghanadan and Koomey 2005). We defined the *baseline* scenarios to be a forward projection of *previously achieved* trends in energy efficiency, taking into account any announced policy decisions on future efficiency. The *efficiency* scenarios were defined as systematically greater improvements in energy efficiency than baseline. For example, our efficiency scenario for electric fans involves tightening standards (by mandatory means if necessary) so that the weighted average new fan sold in the market 6 years hence equals today's most efficient model in the market, the "top runner" model. In Japan, the Top Runner Program, an ambitious program of mandatory energy efficiency standards and labeling, was implemented in 1998. The program applies to certain transport vehicles and gas- and electricity-consuming appliances. Manufacturers are given a period of time (e.g., 5–10 years) within which they must meet or exceed the EE standard of the best performing unit in the market (Geller et al. 2006). The program includes involved subsidies for qualified manufacturers and, overall, is regarded as successful (Kainou 2006; Lu et al. 2008).

We attempted to determine trends in energy efficiency by referring to data from EGAT's appliance labeling programs. If a trend was evident, then our baseline and efficiency scenarios were explicitly based on those trends, with other major assumptions clearly specified. If *no* clear trend was evident, then future scenarios were based on assuming 0.5–1.0% improvements in unit energy consumption. To aid scenario building, the range of energy efficiency levels among end-user devices in the EGAT labeling program was examined.

The most recent labeling data supplied by EGAT was 2005. The time horizon for the scenarios was 20 years, with 2006 and 2026 corresponding to years 1 and 20 of program implementation.

Analysis and results

Refrigerator scenarios

EGAT has implemented voluntary labeling of refrigerators since 1995. Since 1998, nearly all refrigerators sold in Thailand have been labeled, and nearly all (99.6%) received a "Number 4" or "Number 5" rating (Kritiporn 1999: Table 2.2). This means that an analysis of labels distributed by EGAT can be used to characterize the refrigerator market in Thailand with respect to capacity (adjusted volume) and unit energy consumption.

Based on our analysis of labels distributed, the most popular product is a single-door refrigerator sized between 160 and 180 L (adjusted volume). This size class represented 33% of the labels distributed in 2005, down from 63% in 1997 (see Table 1). During the course of the time series, a clear shift toward larger size and two-door appliances occurred. In 1997, less than 5% of the labels were for refrigerators >200 L. By 2005, >30% of labels were in this size category (with almost 7% above 500 L).

Table 1 Refrigerators: approximation of market share based on labels distributed

Size class/total volume (L)	1997	2001	2005
≤130 L	9.6%	5.1%	4.8%
>130–≤160	12.1%	11.0%	10.1%
>160–≤180	63.2%	49.5%	32.6%
>180–≤200	10.8%	15.0%	22.3%
>200–≤230	3.6%	7.2%	5.3%
>230–≤250	0.7%	0.6%	3.0%
>250–≤300	0.0%	4.8%	5.0%
>300–≤350	0.0%	2.3%	3.1%
>350–≤400	0.0%	0.9%	2.5%
>400–≤450	0.0%	1.7%	3.8%
>450–≤500	0.0%	0.6%	1.1%
>500	0.0%	1.3%	6.6%
Total	100.00%	100.00%	100.00%

EGAT, unpublished data

Relationship between capacity and UEC The relationship between capacity and UEC is generally linear, broken by vertical step transitions in UEC as size increases (see Fig. 1). A significant step transition occurs between one-door and two-door models beginning at approximately 190 L (see Fig. 1a).

Notable trends in UEC We examined units sized between 165 and 200 L for efficiency trends. Between 1995 and 2005, their efficiency increased. Their UEC (calculated as an average weighted by numbers of labels distributed) declined 14% (1.5% p.a.). The largest interannual change was 2000–2001, when tightened standards caused the average UEC in this capacity range to decline 5%. Between 2001 and 2005, the UEC in the 165–200-L range rose 0.3% per annum, but overall, as new models at lower UEC entered the original stock (estimated weighted average 400 kWh/year in 1995), the average UEC of the stock *declined* by 12%.

Notwithstanding these early efficiency gains among popular one-door models, the overall new unit UEC (weighted average across *all* sizes) increased 29% between 1995 and 2005, in a stepwise function (Fig. 2). Interestingly, twice during the period 1995–2005, the increasing trend in UEC was interrupted. New unit UEC (all sizes) declined by 10.4% (1995–1996) and by 6.5% (2000–2001). The first decline coincided with the initial launch of the refrigerator energy labeling program; the second coincided with the regrading of the refrigerator energy label in 2001.

Introduction of refrigerator MEPS Thailand's first refrigerator minimum equipment performance standards were announced in 2004, with an effective date of December 2006 (see Table 2 for details). Prior to this initiative, a voluntary standards regime existed. Figure 1b compares the 2001 standards with the 2006 MEPS.

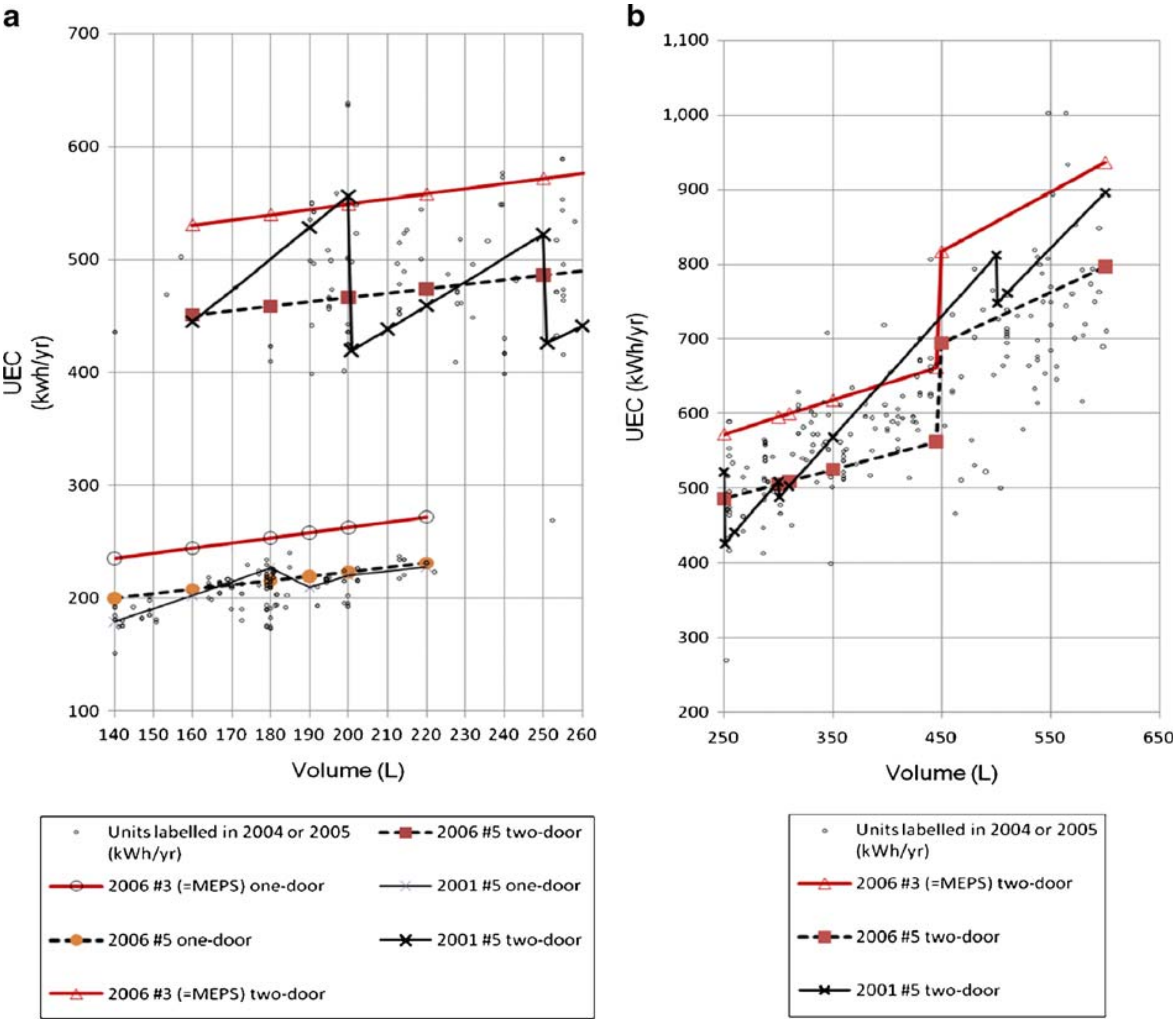


Fig. 1 **a** Unit energy consumption for refrigerators (140–260 L) labeled in 2004–2005. **b** Unit energy consumption for refrigerators (250–650 L) labeled in 2004–2005. Note: Each *point* represents one model. All standards are defined in terms of adjusted volume. Difference between total and adjusted volume is ≤1% for single-door models and approximately 15% for multidoor models (Energy Star n.d.)

For two-door units, the 2006 Number 5 standard is generally higher than the 2001 standard (Fig. 1b). It has fewer step transitions than the 2001 standard and a lower gradient (i.e., ratio of ΔUEC to Δ adjusted volume).

However, below 300 L, the difference between the 2006 and 2001 standards is less obvious. Between 200 and 300 L, there are two capacity ranges where the 2001 Number 5 standard is superior to its 2006 counterpart (Fig. 1a, b). We compared the year 2006 Number 5 standard against weighted average UECs for new units labeled in 2005 (weighting by number of labels distributed approximates a sale-weighted average). Among units sized 160–300 L, the weighted average UEC for labels actually distributed in 2005 was 295 kWh/year.

The weighted average UEC for an equivalently distributed stock, meeting the Number 5 standard in 2006, is 296 kWh/year. In other words, in this capacity range, a weighted average of the year 2005 units already meets the 2006 Number 5 standard.

To summarize, the effect of the 2006 MEPS, announced in 2004, on new units is difficult to predict clearly. On the one hand, the 2006 standard

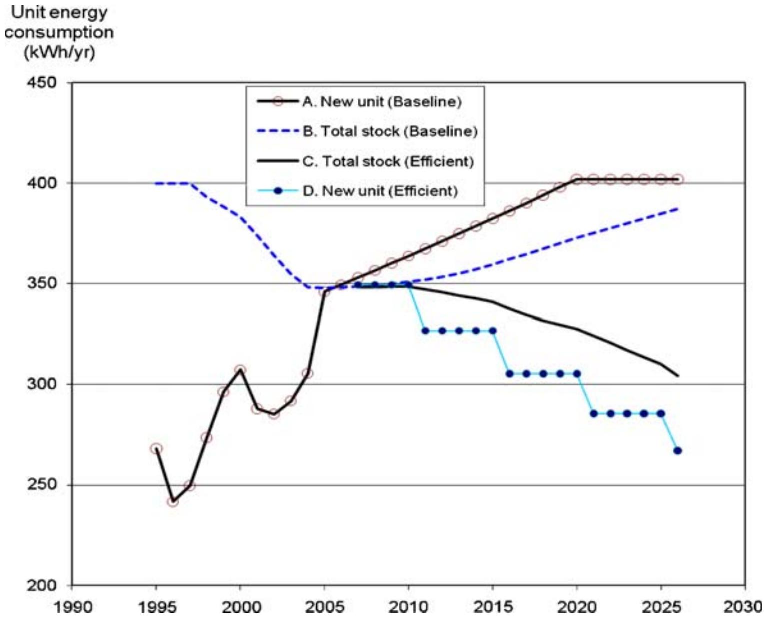


Fig. 2 Refrigerators. Observed and estimated unit energy consumption for *baseline* and *efficient* scenarios

is notably higher for units >310 L (Fig. 1b). This will generate energy savings in a capacity range whose popularity will increase. However, across other increasingly popular capacity ranges (e.g., 200–250 L), the 2006 policy does not set distinctly higher standards than its predecessor (Fig. 1a).

Our analysis assumes a fixed saturation of 0.88 refrigerators per household (National Statistics Office (NSO) 2004) and an average lifetime of 15 years (see Tables 2 and 10 for parameter estimates).

The *baseline* scenario assumes that the (weighted average) UEC of a new refrigerator will increase over

Table 2 Refrigerator standards and parameter estimates

	Value/(year)	Sources/notes
Thai standards		
Minimum equipment performance standards (MEPS)	(2006)	Announced 2004, effective December 2006 (TISI 2004)
One-door refrigerators		
AV<100 L	$UEC \leq 300 + 0.8 \times AV$	Unit energy consumption (kWh/year) as function of adjusted volume in L
AV≥100 L	$UEC \leq 171 + 0.46 \times AV$	
Multidoor refrigerators	$UEC \leq 457 + 0.46 \times AV$ $UEC \leq 457 + 0.8 \times AV$	
Number 5 voluntary label	$UEC \leq 0.85 \times MEPS$ (2006)	
Parameter estimates		
Average lifetime (year)	15	Thailand Load Forecast Subcommittee (TLFS) (1998)
Saturation (year)	0.88 (2006) 0.88 (2026)	After NSO (2004: Table 14); assumed constant
Unit energy consumption in 2005	346 kWh/year	EGAT Demand-Side Management and Planning Division (2006, unpublished); weighted average of all labels distributed in 2005

time, reflecting the observed trend toward larger capacity (Table 1). We assume that the new unit UEC increases by 1% p.a. from 2006 to 2020 (less than half the 2.55% rate observed 1995–2005).

As noted above, from 1995 to 2005, the entry of new models at lower UEC caused the total stock UEC to decline. However, from 2007 to 2020, once the (weighted average) UEC of a new unit exceeds the (weighted average) UEC of the total stock, the latter begins to rise (Fig. 2, line B).

Efficient scenario The efficient scenario assumes a regime of periodically tightened minimum *and* voluntary standards, resulting in the weighted average UEC of *new* units declining 6.5% every 5 years between 2006 and 2026, with no increase during intervening or subsequent years (Fig. 2, line D). The figure of 6.5% is equal to the rate of change in the new unit UEC observed during 2000–2001. Table 3 shows results of baseline vs efficient scenarios in terms of total energy consumption and annual savings from implementing the efficient scenario.

Results The efficient scenario produces savings of 459 GWh/year after 10 years, and 2,139 GWh/year after 20 years of implementation (Table 3). The relative savings we report are comparable to that estimated by McNeil et al. (2006) for countries outside of the EU, Japan, North America, Australia, and New Zealand (see Tables 3 and 4).

Air conditioner scenarios

In contrast with refrigerators, the situation with respect to air conditioner labeling is different. The market is segmented between inexpensive, *unlabeled* units ("one Thai baht per Btu/h") and more expensive, labeled units. Manufacturers of labeled units tend to receive an EGAT number 5 rating.

Thailand officially began to enforce air conditioner MEPS in March 2005. Units that meet or exceed the MEPS bear a Thai Industrial Standard label (TIS 2134-2545). Units that do not meet the MEPS are technically illegal. However, they continue to be available in the market, and their market share has been estimated as high as 50% (UNDP 2006). In the absence of a comprehensively enforced mandatory labeling program, reliable efficiency data are only available for air conditioner units in the higher efficiency range. For the unregulated (noncompliant) half of the market, we assume their average energy efficiency ratio (EER) is 2.43, or 3.5% below the Number 3 level in 2005. Our analysis relied on other parameter estimates in Table 5.

Both baseline and efficient scenarios share common assumptions based on trends we observed toward increasing EER *and* increasing cooling capacity.

Table 3 Baseline energy consumption and annual savings (gigawatt hour per year) for refrigerators under contrasting scenarios

	Year	After *n* years	Base case	Savings	Percentage	Annual growth rate (base case)
This study						
Thailand	2006	0	5,793 GWh	0 GWh	0.0%	2.73%
	2011	5	6,249 GWh	89 GWh	1.4%	
	2016	10	6,808 GWh	459 GWh	6.7%	
	2021	15	7,421 GWh	1,009 GWh	13.6%	
	2026	20	10,000 GWh	2,139 GWh	21.4%	
McNeil et al. (2006)						
Regions 4–10	2005	0	308 TWh	0 TWh	0.0%	2.71%
	2010	5	362 TWh	13 TWh	3.6%	
	2015	10	429 TWh	58 TWh	13.5%	
	2020	15	485 TWh	102 TWh	21.0%	
	2025	20	530 TWh	133 TWh	25.1%	

Savings defined as difference between efficient and baseline scenarios. Regions 4–10 include all countries outside of Australia, Canada, EU, New Zealand, and USA (McNeil et al. 2006)

Table 4 Refrigerators: comparison of assumptions about unit energy consumption (kilowatt hour per year)

Region	(Baseline) year 5	(Efficient) year 5	Difference between cases, year 5
EU	364	268	−26%
Thailand (this study)	367	327	−11%
Russia	420	243	−42%
China	489	353	−28%
Brazil	493	237	−52%
Japan	535	482	−10%
Korea	536	402	−25%
India	548	301	−45%
Australia, Canada, NZ, USA	562	506	−10%

For regions excluding Thailand, adapted from McNeil et al. (2006: Table 4)

Trends in cooling capacity We assume a clear trend we observed toward higher cooling capacity continues. Specifically, we assume that output capacity increases in line with the observed trend 1996–2005 but tapers off so as to reach a maximum of 5,151 W (<18,000 Btu/h), as household room size (in turn governed by building size and land area) should eventually constrain cooling capacity.

Table 5 Air conditioner standards and parameter estimates

	Value/(year)	Sources/notes
Thai standards		Split & window type
MEPS		Energy efficiency ratio (W/W)
Cooling capacity ≤8,000 W Cooling capacity 8,001–12,000 W	2.82 (2006) 2.53 (2006)	Announced 2002, effective Mar 2005 (TISI 2002).
Number 5 voluntary label scheme	3.11 (1996–2004) 3.22 (2006)	After announcement of MEPS, EGAT revised the number 5 standard upward, effective Jan 2006
Parameter estimates		
Total stock, energy efficiency ratio (W/W)	2.5 (1998)	TLFS (1998)
Average lifetime (year)	15	TLFS (1998)
Saturation	0.13 (1998) 0.18 (2004)	TLFS (1998); 2008 & 2026 values derived from comparison with McNeil et al. (2008: Fig. 4, line “SAS-PAS”)
	0.25 (2008)	
	0.51 (2026)	
Hours per year	1,500	Cf. 1,485 assumed by EGAT (based on 2002 study by Thailand Energy Conservation Center)
Technology share by cooling capacity (W), 2005		
>2,000–≤4,000 >4,000–≤6,000	65.3% 22.6%	
>6,000	12.1%	
Baseline scenario—market share of noncompliant units	50% (2006–2026)	Unlabeled units are noncompliant
Efficient scenario—market share of noncompliant units	50% (2006) 0% (2011–2026)	
Cooling capacity (weighted average)	4,395 W (2005) 5,151 (2026)	Weighted average of labeled models

Trends in efficiency Figure 3 shows the distribution of EER against cooling capacity, for all units labeled in 2004 or 2005.

Baseline scenario In our baseline scenario, the EER of new *compliant* (labeled) units is fixed at 3.26 (the number 5 year 2006 standard) between 2006 and 2026. The EER of *noncompliant* (unlabeled, unregulated) units is fixed at EER 2.43 (as described above). The baseline scenario also assumes the current estimated one-to-one ratio between new compliant and noncompliant sales continues to 2020.

Efficient scenario For new compliant units, we assume the weighted average EER increases as the MEPS and the number 5 standard is periodically tightened over time, in line with scenarios previously presented by the authors to the EGAT Demand-Side Management Office. Our efficient scenario, if carried out consistently to 2020, increases MEPS by 25% between 2005 and 2020 (Fig. 4, line D). For new *noncompliant* units, we assume an average EER of 2.43 (Fig. 4, line F).

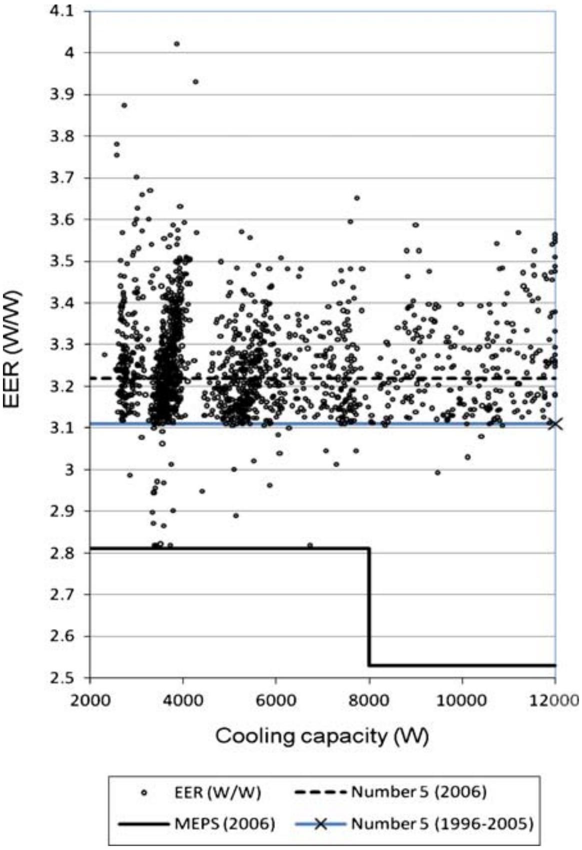


Fig. 3 Air conditioners labeled in 2004–2005. Distribution of energy efficiency ratio (watts per watts) against cooling capacity (watts). Note: Each *point* represents one model

The efficient scenario further differs from the baseline in that we assume stringent enforcement of the MEPS. Specifically, we assume that within 6 years of program implementation, all appliances entering the market are MEPS compliant.

Results Implementing the efficient scenario causes the total stock EER to increase 33% by 2020, vs 3.5% under the BAU scenario (Fig. 4). In terms of savings, phasing out unlabeled air conditioner units results in 7% electricity savings after 5 years of program implementation (0.9 TWh/year). After 20 years, the savings approach 27% (11 TWh/year; see Table 6).

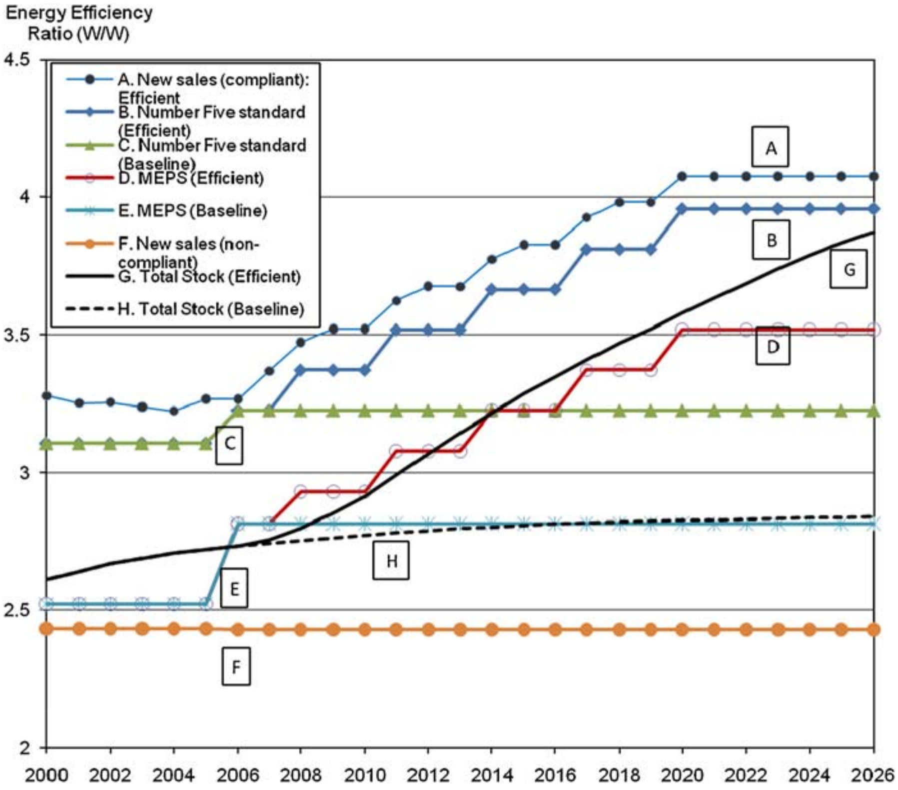
How do these results compare with other bottom-up accounting studies? In a multiregion study of developing countries, McNeil et al. (2008) defined baseline scenarios as static MEPS levels of either 2.34 or 2.4 EER, depending on region (based on year 2000). They defined efficient scenarios as longitudinal increases in MEPS above baseline. The increases varied between region but were either 33% or 37% over periods of 6–20 years (McNeil et al. 2008: Fig. 6). They reported total (global) savings of 30% within 15 years (McNeil et al. 2008: Table 5).

Scenarios for fans, compact fluorescent lighting, and rice cookers

Fans EGAT began labeling portable standing electric fans in 2001 (see Table 7). It distributed an average of 3.72 million labels 2001–2005, approximately 80% of which are for 16-inch fans. Labeling is done on basis of efficiency in moving air. The criteria for 16-in and 12-in number 5 labels are ≥1.21 m^3/min/W and ≥1.01 m^3/min/W, respectively. On this basis, virtually, all labels distributed in 2005 were number 5 (see Fig. 5). The number of labels distributed in 2005 is a high fraction (approximately 90%) of estimated annual sales. Among new devices labeled in 2005, the average UEC (weighted across all labels) was 88 kWh/year. The highest efficiency level on the Thai market in 2005 was 75 kWh/year.

For simplicity, we assume that all new sales either meet or exceed the number 5 standard for year 2006.

Fig. 4 Air conditioners. Observed and estimated energy efficiency ratios (watts per watts)



The *baseline scenario* assumes a −0.5% p.a. change in new device UEC to 2026, consistent with trends we observed between 2001 and 2005. The *efficient scenario* assumes it is possible, after 6 years, to shift the weighted average UEC to the highest observed efficiency levels on the Thai market in year 2005 (Fig. 6). The necessary rate of UEC improvement is 2.26% per annum for 6 years. Our efficient scenario further assumes that this rate of improvement is for the entire period 2006–2020 (i.e., 36% decline in UEC over 20 years). Implementing the efficient scenario results in 8% savings (195 GWh/year) after 10 years and 17% savings (555 GWh/year) after 20 years (see Fig. 9 below).

Compact fluorescent lighting EGAT began labeling compact fluorescent light (CFL) bulbs in 2002. Our analysis focuses on substitution of incandescent screw-

Table 6 Baseline energy consumption and annual savings (gigawatt hour per year) for air conditioners under contrasting scenarios

	Year	after *n* years	Base case TWh	Savings TWh	Percentage	Annual growth rate (base case)
This study						
Thailand	2006	0	9.1	0.0	0.0%	7.5%
	2011	5	13.2	0.9	7.0%	
	2016	10	18.3	2.9	15.9%	
	2021	15	24.8	5.5	22.1%	
	2026	20	41.1	11.0	26.7%	
McNeil et al. (2008)						
Region: SAS-PAC	2005	0	21	0	0.0%	8.3%
	2010	5	32	0	0.0%	
	2020	15	78	8.2	10.5%	
	2030	25	167	38.9	23.3%	

Savings defined as difference between Efficient and Baseline Scenarios. According to McNeil et al. (2006: 8), "SAS-PAS" region includes market economies in Southeast Asia, including Thailand, Malaysia, Taiwan, as well as non-India South Asia

Table 7 Fan parameter estimates

Parameter	Value/(year)	Notes
Average lifetime (year)	9	
Fan saturation	2.1 (2006) 2.2 (2026)	2.09 in 2004 (NSO 2004: Table 14)
Hours per year (constant)	1,095	3 h per day; 365 days/year; cf. 2.3 (Khummongkol 2002)
Technology share (16/12-in fans)	80/20% (2006–2026)	
UEC (kWh/year)	67.5 (2000) 54 (2001) 53 (2005)	UEC is weighted average of labeled fans, 12 and 16 in; year 2001 and 2005 values based on EGAT labeling database; year 2000 assumed 25% higher
Baseline scenario: rate of change in UEC	−0.5% p.a. (2006–2026)	−10% over 20 years
Efficient scenario: rate of change in UEC	−2.26% p.a. (2006–2026)	−36% over 20 years

in light bulbs by CFL bulbs. Specifically, we assume an average incandescent bulb of 60-W demand (800 lm) is replaced by a 14-W (≥800 lm) CFL (see Table 8).

Our *baseline* scenario assumes that the CFL share of light bulbs increases from 45% to 60% between 2006 and 2020, with rising incomes. Our *efficient* scenario assumes that the CFL share in 2020 reaches 75% with more aggressive marketing (e.g., promotion of energy savings using internet along lines similar to the US Energy Star program).

The *efficient scenario* assumes it is possible, in 6 years, to shift the UEC of CFL bulbs in the 13–20-W range to the second highest observed efficiency

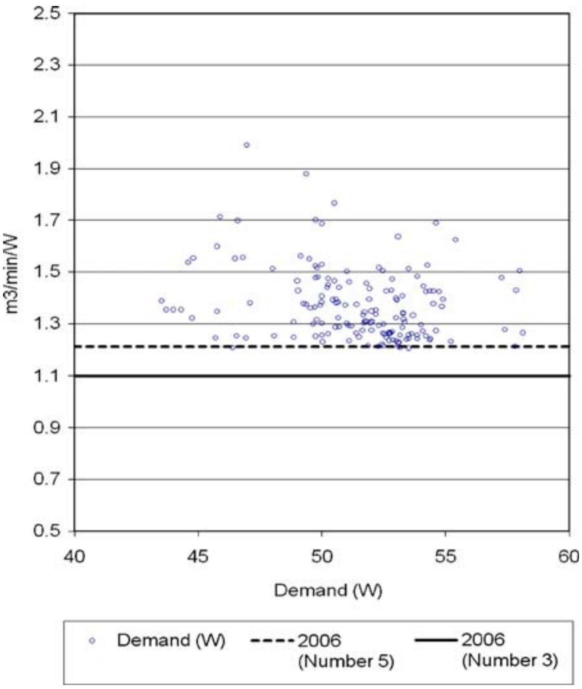


Fig. 5 Fans. Efficiency (cubic meter per minute per watts) vs demand (watts) for 16-inch fans. Note: Each *point* represents one model labeled 2001–2005

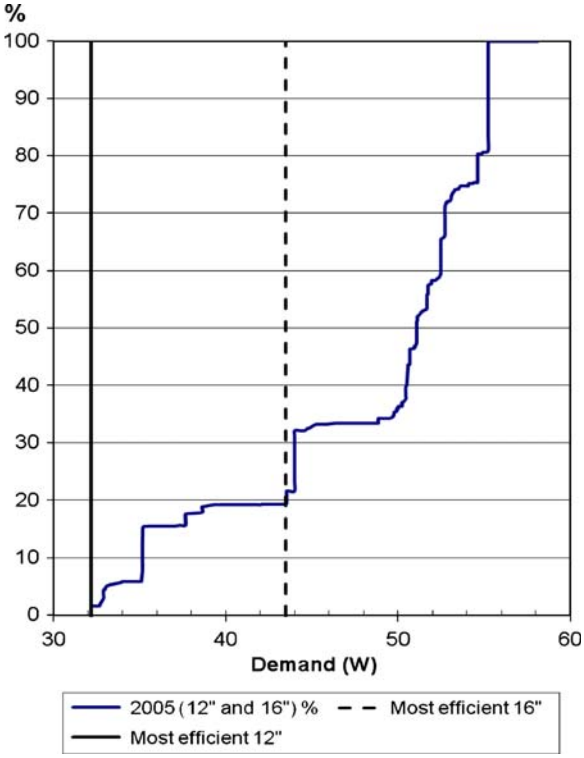


Fig. 6 Relative cumulative frequency distribution of 12- and 16-inch fans in 2005. Note: "Most efficient" refers to year 2005

Table 8 Compact fluorescent light bulb parameter estimates

Parameter	Value/(year)	Notes
Saturation (incandescent light bulbs)	0.30 (2006) 0.50 (2026)	Year 2004=0.28 (NSO 2004)
CFL/incandescent share of technology	20/80% (2006)	Khummongkol (2002)
CFL/incandescent share of technology	(2026) 60/40% (baseline) 75/25% (efficient)	
Hours per year (constant)	1,000	2.74 h/day; cf. 2.27 h/day (Khummongkol 2002)
Incandescent bulb		
UEC (kWh/year)	49.7	
Lifetime (hours)	1,000	60 W, 800 lm
CFL		
UEC(kWh/year) Lifetime (hours)	14 (2006) 6,000	Assume incandescent replaced by 14 W, ≥800 lm
Baseline scenario: rate of change in UEC	−0.5% p.a. (2006–2026)	
Efficient scenario: rate of change in UEC	−2.9% (2006–2012) −1% p.a. (2013–2026)	

level on the Thai market in year 2005 (79 lm/W; see Fig. 7). The necessary rate of UEC improvement is 1.9% per annum for 6 years. Thereafter, the efficient scenario assumes the UEC declines 1% p.a. between 2013 and 2026. The *baseline* scenario assumes a −0.5% p.a. change between 2006 and 2026. Results of annual savings appear in Fig. 9. The efficient scenario results in 4% (10 GWh/year) energy savings after 10 years and 20% (88 GWh/year) energy savings after 20 years (Fig. 9).

Rice cookers EGAT began labeling rice cookers in 2004, distributing 79,000 labels in 2004 and 187,000 labels in 2005. As of 2005, a total of 15 models had been submitted to the voluntary labeling scheme, all of which are 1.8 L. Analysis of the label data shows that in 2005, the weighted average energy per meal was 266 Wh, corresponding to a UEC of 146 kWh/year. All models submitted to EGAT met the number 5 standard of 270 Wh per meal (148 kWh/year; see Fig. 8). By contrast, the average UEC of an unlabeled rice cooker tested by EGAT was 172 kWh/year (see Table 9).

The number of labels distributed in 2005 is only 13.5% of the estimated annual sales. Our *baseline* scenario assumes that the market share of labeled number 5 devices increases to 25% by 2026, with rising incomes. Our *efficient* scenario assumes that the

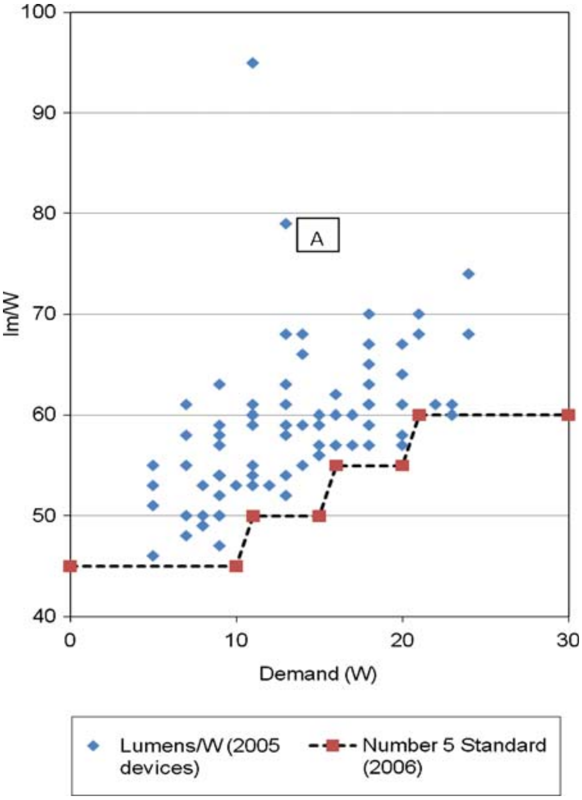


Fig. 7 Efficacy of compact fluorescent lamps labeled in 2005 (lumens per watt). Note: Each *point* represents one model. *Point A* selected as best in market for *efficient* scenario

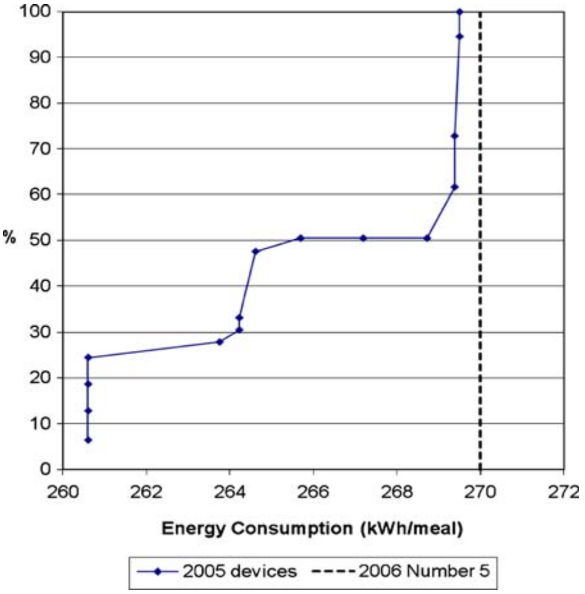


Fig. 8 Relative cumulative frequency distribution of rice cookers labeled in 2005. Note: Each *point* represents one model

labeled share of the market can increase to 75% with more aggressive marketing (e.g., promotion of energy savings using internet along lines similar to the US Energy Star program).

In both our scenarios, the UEC declines. The baseline scenario assumes a −0.5% p.a. change in UEC to 2026; the efficient scenario assumes a −1.0% p.a. in UEC can be achieved. The efficient scenario results in 2% (92 GWh/year) energy savings after 10 years and 8% (347 GWh/year) energy savings after 20 years (Fig. 9).

Comparison of efficient vs baseline scenarios

For the five devices modeled, electricity consumption rises significantly under both scenarios: 4% per annum for the baseline scenario and 3% for the efficient scenario. These rates are higher than the estimated rate of household growth (1.1%) but lower than the rate of rate of sales growth for air conditioners and refrigerators, which we estimated at 9.8% and 4.6%, respectively. For air conditioners, approximately 60% of growth in consumption results from assumptions about increased ownership (saturation) and 15% from assumptions of increased cooling capacity.

Figure 9 shows annual energy savings for the five devices under the *efficient* vs *baseline* scenarios. Total savings begin at 59 GWh/year. They increase rapidly (at 29% per annum) to reach 14 TWh/year in 2026. Approximately 80% of these savings come from adjustment and enforcement of minimum energy performance standards for air conditioners. After 10 years, the savings equal 12% of baseline consumption (see Fig. 9).

Discussion

Our results are sensitive to certain modeling choices as well as uncertain parameter estimates. We discuss notable issues briefly in this section.

Parameter estimates Both saturation and trends in amenity value are important variables because of

Table 9 Rice cooker parameter estimates

Parameter estimate	Value/(year)	Notes
Average lifetime (year)	9	
Rice cooker saturation	0.83 (2006) 0.90 (2026)	2006 estimate adapted from NSO (2004: Table 14)
New units: labeled vs unlabeled share	13.5% vs 86.5%	
Rate of substitution of standard by efficient, by 2020	20% (baseline) 40% (efficient)	
Meals per year (constant)	547.5	1.5 meals per day; 365 days/year
UEC—unlabeled (kWh/year)	172.5	315 Wh per meal; EGAT DSM Division (personal communication)
UEC—number 5 (kWh/year)	145.6	266 Wh per meal (2005 wt. ave.)
Baseline scenario: rate of change in UEC	−0.5% p.a. (2006–2026)	−10% over 20 years
Efficient scenario: rate of change in UEC	−1% p.a. (2006–2026)	−18% over 20 years

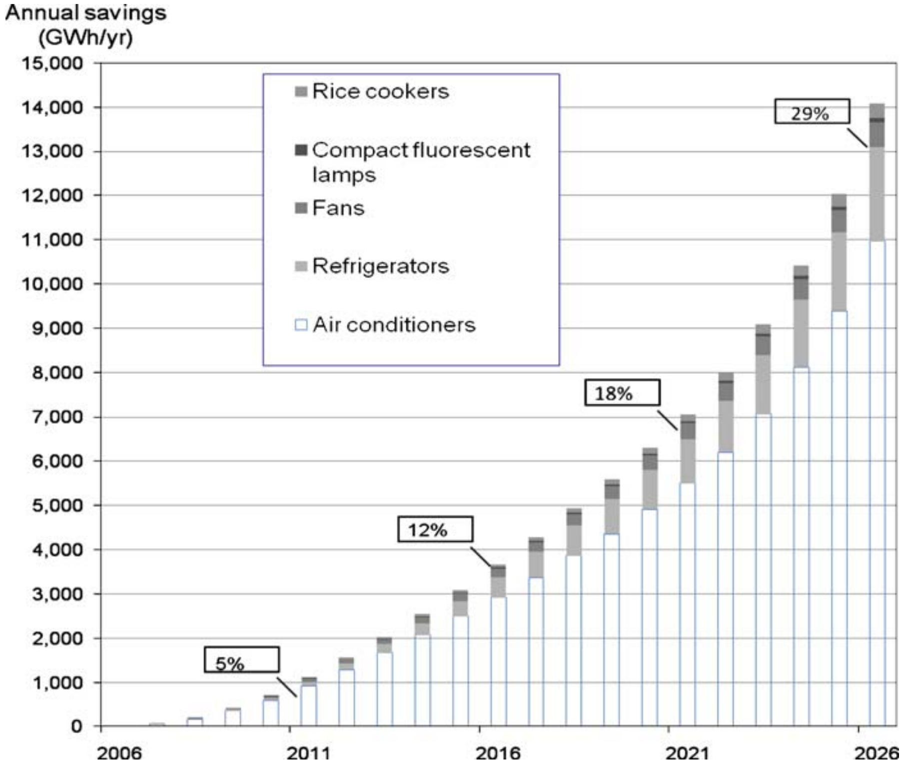


Fig. 9 Annual energy savings for five devices (gigawatt hour per year). Note: Savings plotted as the absolute difference between baseline and energy efficient scenarios. Savings as percentage of *baseline* scenario shown for years 2011, 2016, 2021, and 2026

their direct link to household energy consumption. This analysis drew on a variety of sources for saturation estimates: national average values taken from recent household surveys by the (NSO 2004), personal communication supplied to the authors, and literature review (McNeil et al. 2006, 2008). Saturation would ideally be modeled as a function of amenity value and household income. This would allow more precise estimates of appliance ownership but would require projections of income distribution by strata.

Uncertainty exists about future trends in amenity value, for example cooling capacity for air conditioners and refrigerator volume. In both cases we observed, and modeled, trends toward increasing amenity value. Air conditioner UECs will obviously rise if cooling capacity rises more rapidly than energy efficiency ratios.

Survivorship Estimated energy savings are sensitive to assumptions about survivorship. For refrigerators and air conditioners, we used a linear survivorship function (Mahlia et al. 2002). For an average lifetime of 15 years, the function assumes 100% survival of units 0–10 years old, with survivorship declining to 0% by age 20 years. For appliances with such long average lifetimes, use of this function means that at any given time, the stock is dominated by existing units, and the flow of new more efficient units into the stock is correspondingly modest.[2]

Level of energy efficiency improvement What rate and magnitude of change in efficiency to assume are scenario definition and modeling choices of obvious importance. For the major appliances (air conditioners and refrigerators), we drew on literature review and EGAT experience. For fans and CFLs, we constructed efficient scenarios according to a rule whereby the average stock UEC improves over 6 years to match the level of the most efficient model observed in the base year.

Importance of relative savings Absolute levels of energy consumption depend on uncertain variables

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[2] As an alternative, McNeil et al. (2006) modeled refrigerator survivorship using a probability function normally distributed around a mean lifetime of 15 years.

such as saturation, intensity of use, amenity value, and housing/building stock dynamics. However, if baseline and efficient scenarios use the same estimates for these variables, but differ with respect to efficiency trends, the relative savings (savings as a percentage of baseline consumption) will not differ. Relative savings is thus a good variable to use in communicating results to decision makers.

Finally, one of the most important modeling choices concerns the definition of the baseline case, for each appliance. For all appliances except air conditioners, our definition of baseline assumed efficiency improvements during the modeling time horizon. For air conditioners, we defined a "static" baseline between 2006 and 2020 to allow comparison with other studies (McNeil et al. 2008). We do not argue that a static baseline is particularly realistic. The point of scenario analysis is not to predict the future but rather to make clear the consequences of different choices. In the case of the Thai air conditioner market, important choices exist concerning how to deal with noncompliant appliances and how frequently to raise standards (Fig. 4).

Institutional aspects of energy efficiency

Energy efficiency programs take place in, and are dependent on, the context of institutional support (Blumstein et al. 2005). In Thailand energy efficiency has marginal institutional status, despite some highly successful programs. This is a result of several factors, beginning with the traditional rate-of-return incentive structure of EGAT, a dominant actor in the electricity industry. EGAT is usually allowed to pass costs on to consumers, so does not have a strong incentive to invest in energy savings. For example, faced future increases in electricity demand (say in the nation's capital, where residential high-rise growth is strong) Thai utilities might hypothetically: (1) invest in energy efficiency or load management programs at the rate of $6,724 per peak kilowatt avoided or (2) invest in increased transmission and distribution, at a marginal cost of capacity of $14,220/kW (Phumaraphand 2008). Utility managers would normally prefer option (2) because their gross profits, as a set fraction of their allowed costs, are higher.

A second factor is the divided division of labor for energy efficiency in Thailand. Various government-led energy efficiency/DSM programs exist in Thailand, but they are divided between different agencies. The energy labeling programs analyzed in this paper have all been implemented by a generation utility, but in other settings distribution utilities have played a key role because of their greater access to customer data. Currently, Thailand lacks a single national champion for energy efficiency. Third, estimating or verifying energy savings requires methods of measurement and sampling at a number of diffuse sites. It requires up-to-date data on household appliance saturation, and hours and patterns of usage. These monitoring and surveys yield less benefit to utility decision makers than the tangible option of studying and building new power plants.

A disconnect therefore exists in the planning process for electricity resources. EGAT's analysis has shown that its DSM programs deliver saved electricity at less than half the cost of building new power plants (Phumaraphand 2008). Yet planning of DSM budgets and resources is not based on a least-cost approach or comparison to supply options.

Civil society actors opposed to new power plant construction in Thailand have attempted to put energy efficiency increasingly on policy agendas. The Ministry of Energy has explored the idea of establishing a single national agency responsible for energy efficiency and demand-side management, possibly funded by a public benefits charge (a tax on energy sales). Another important and neglected issue is how to re-regulate utilities so as to increase financial incentives to invest in DSM/energy efficiency (Kushler et al. 2006).

Conclusion

Since EGAT initiated its DSM programs in the mid-1990s, it has achieved impressive reductions in energy and peak demand, estimated to be 8,369 GWh/year and 1,471 cumulative MW, respectively. A careful analysis of efficiency vs baseline scenarios for five key household appliances indicates that significant additional annual energy savings could be secured. For these appliances, the savings equal 12% of baseline consumption after 10 years and 28% of baseline consumption after 20 years (see Fig. 9).

In the case of air conditioners, savings result *not* from reduction in unit energy consumption because we assumed that UEC will rise as consumers opt for increased cooling capacity (amenity). Instead, air conditioner savings are secured from policy interventions which raise efficiency ratios, while at the same time banning sales of unlabeled (noncompliant) air conditioners within 6 years.

In the case of refrigerators, fans, rice cookers, and CFL lighting, savings result from improving current unit energy consumption. Such improvements could be secured from shifting to “top runner” levels within 5 to 6 years, or—for refrigerators—measures that ensure that the stock weighted average UEC does not rise with increasing appliance volume.

The present study suggests that the following additional policy analysis is now appropriate:

- Analysis of economic incentives to facilitate market transformation to best-in-market standards
- New scenarios for other important interventions, appliances, and technologies, including: building efficiency performance standards, water heaters, televisions, T-5 fluorescent lighting, and LED lighting
- Analysis of economic impacts of phasing non-compliant air conditioner sales and mandatory participation in the Number 5 labeling scheme (in addition to MEPS)

We note that Kritiporn (1999) made several recommendations about air conditioner standards, many of which were adopted in the first Thai MEPS (TISI 2002). Kritiporn (1999) emphasized the importance of diligent enforcement, periodic tightening of standards every 5 years, and possibly, mandatory efficiency labeling (1999: 3–39). Our analysis shows that pursuing all of these options yields significant savings.

A key source of data for our analysis came from EGAT’s Demand-Side Management Office. The trends in those data were quite revealing, in terms of savings achieved to date (for well-established programs) as well as currently unrealized, yet technically achievable savings (e.g., from analysis of highest efficiency models in the market). The data suggest that well-managed energy efficiency programs make a difference but are sensitive to their larger institutional context. For this reason, we close by recommending analysis of institutional options to improve the status of energy efficiency in Thailand:

- Developing an energy services company (ESCO) industry
- Integrated resource planning
- Regulatory reform to decouple utility profits from energy efficiency

(Blumstein et al. 2005; Crossley et al. 2000; Vine et al. 2003)

Such analysis would secure energy efficiency as one of the top priority electricity resources for Thailand, a position supported by this analysis.

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Appendix

Table 10 Demographic parameter estimates

Parameter	Value	Notes
Number of households (million)	18.59 (2006) 21.81 (2020)	Source: Bundit Limmeechokchai (personal communication)
Household annual growth rate	1.14% (2006–26)	

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