Global Potential of Energy Efficiency Standards and Labeling Programs

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Table of Contents

Appendices

List of Tables

Index of Figures

0 Executive Summary

This report estimates the global potential reductions in greenhouse gas emissions by 2030 for energy efficiency improvements associated with equipment (appliances, lighting, and HVAC) in buildings by means of energy efficiency standards and labels (EES&L).

A consensus has emerged among the world's scientists and many corporate and political leaders regarding the need to address the threat of climate change through emissions mitigation and adaptation. A further consensus has emerged that a central component of these strategies must be focused around energy, which is the primary generator of greenhouse gas emissions. Two important questions result from this consensus: "*what kinds of policies encourage the appropriate transformation to energy efficiency*" and "*how much impact can these policies have*"? This report aims to contribute to the dialogue surrounding these issues by considering the potential impacts of a single policy type, applied on a global scale.

The policy addressed in this report is Energy Efficient Standards and Labeling (EES&L) for energy-consuming equipment, which has now been implemented in over 60 countries. Mandatory energy performance standards are important because they contribute positively to a nation's economy and provide relative certainty about the outcome (both timing and magnitudes). Labels also contribute positively to a nation's economy and importantly increase the awareness of the energy-consuming public. Other policies not analyzed here (utility incentives, tax credits) are complimentary to standards and labels and also contribute in significant ways to reducing greenhouse gas emissions.

We believe the analysis reported here to be the first systematic attempt to evaluate the potential of savings from EES&L for all countries and for such a large set of products. The goal of the analysis is to provide an assessment that is sufficiently well-quantified and accurate to allow comparison and integration with other strategies under consideration.

The BUENAS Forecasting Model

Because EES&L programs target specific equipment types, the analysis takes a bottom-up, engineering economics approach, forecasting energy consumption for each end-use in both the residential and commercial sectors. Advantages of this approach are that: 1) energy savings are based on achievable efficiency improvements using specific, well-defined technologies that are unique to each separate energy-consuming product; 2) the methodology is consistent across all countries and regions of the world and 3) the analysis accounts for the relationship between projected economic development and changing equipment ownership in each region.

We call this new EES&L forecasting model BUENAS (Bottom-up Energy Analysis System). This model can also be used for assessing the potential global impact of different levels of EES&L stringency than the "best practice" applied in our current analysis, as well as assessing the potential impact of EES&L from application in various combinations of countries and individual products.

We believe the end-use level demand forecast necessitated by the bottom-up approach to be the first of its kind to be applied on a global scale. This model is well suited to describe the energy and emissions impacts of *any* policy which has an effect on the efficiency of equipment used in buildings. In addition, we believe our analysis to be the first to provide a global forecast of commercial building energy demand using floor space as an activity variable driven by macroeconomic variables. In addition to the modeling consumption at the end-use level, the approach has the advantage that all activity variables are driven directly by macroeconomic variables, which can be easily manipulated to investigate alternative economic scenarios.

We define potential savings as those reductions in consumption that would occur if equipment efficiencies reached levels that are currently available and cost-effective, or likely to become so by the time of program implementation. This level of efficiency is generally considerably less than the maximum technically achievable level. The realization of this potential is therefore more dependent on political will and administrative capacity, than on technical or economic issues. The main findings of the analysis are that, if these best current practices of EES&L were adopted by every country:

Global Potential Savings

The total potential for emissions reductions in the building sector globally is as follows:

- EES&L programs would save 1113 TWh of electricity and 327 TWh of fuels per year by 2020, and 3385 TWh of electricity and 928 TWh of fuels by 2030.

- EES&L programs would reduce cumulative CO_2 emissions from 2010 through 2030 by a total of 14 Gt, which is 54 percent of the total estimated global energy-related emissions for 2005.

- In the residential building sector, potential emissions reductions from EES&L are large enough to level that sector's emissions by 2015, and reduce them after about 2020, bringing the emissions of the world’s homes almost back to 2005 levels by 2030. In the commercial building sector, EES&L programs would likely level growth, but not reverse it.

Regional Potential Savings

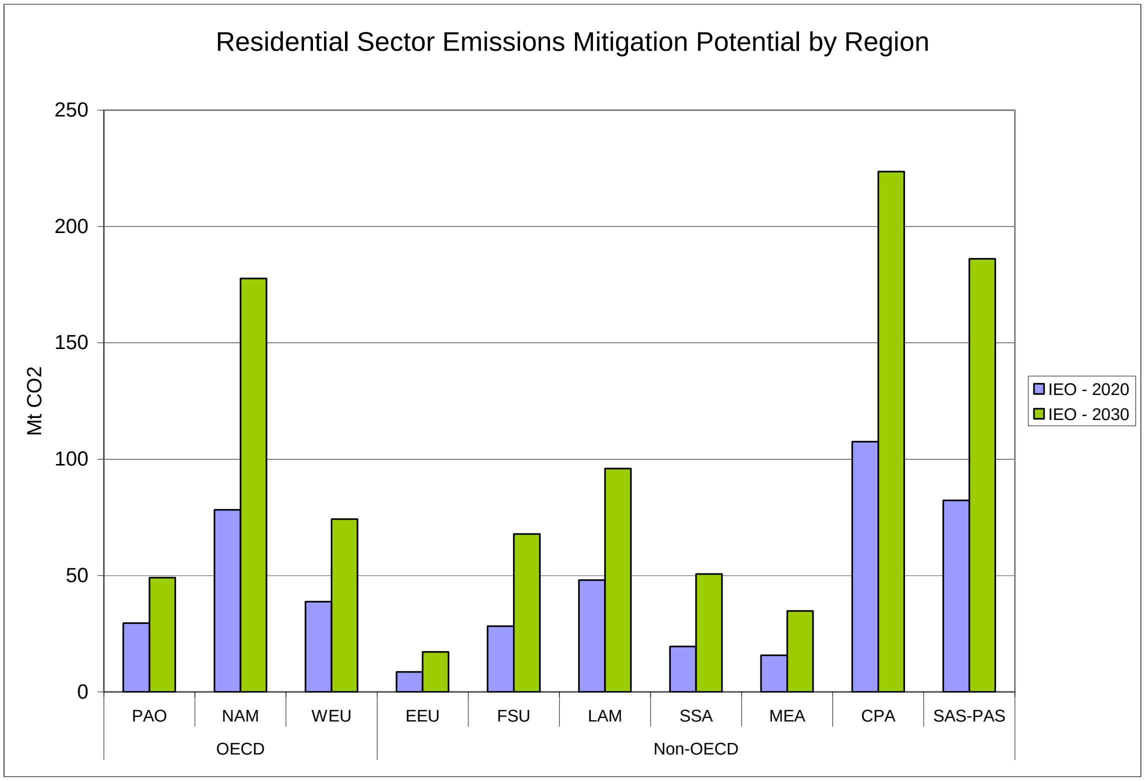
The total potential for emissions reductions in the building sector by region is as follows:

- The region which contains China (Centrally Planned Asia[1]) has the greatest potential for mitigation in absolute terms, with 224 Mt CO_2 of avoided emissions in 2030 in the residential sector, and 161 Mt CO_2, in the commercial sector.

- Aside from China, the rest of Asia (SAS-PAS) will also see great opportunities for emissions reduction. This region will have the second highest potential by 2030, almost equaling that of CPA in the residential. Savings potentials in the commercial sector will continue to lag significantly however. Finally, other regions show a large potential for savings, especially North America and Latin America.

Annual emissions mitigation potential by region are shown in **Figure 1** and **Figure 2**

Figure 1- Residential Building Sector Annual Emissions Mitigation Potential by Region



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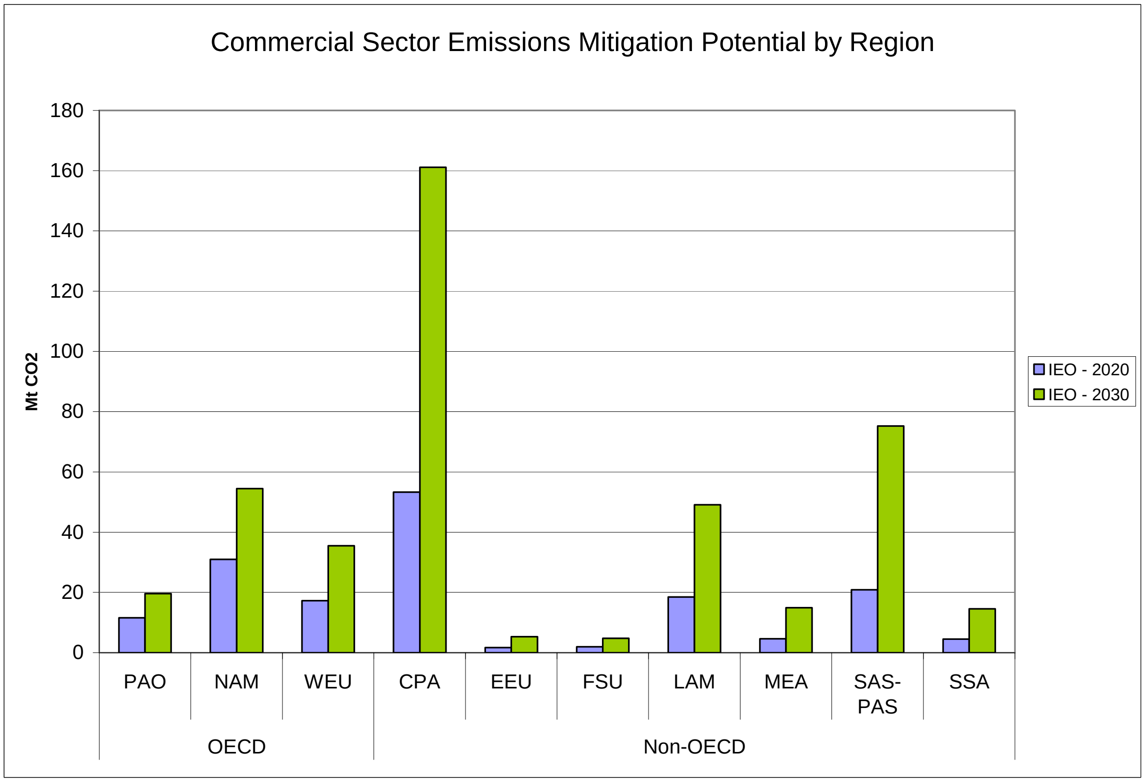
[1] China composes most of the region defined in the IPCC Special Report on Emissions Scenarios as Centrally-Planned Asia, which also includes Cambodia, Laos, North Korea, Mongolia and Viet Nam.

Figure 2- Commercial Building Sector Annual Emissions Mitigation Potential by Region



Potential Savings for Each End Use

The total potential for emissions reductions in the building sector by end-use is as follows:

- The end-use with the greatest potential for emissions reductions, in absolute terms, is residential refrigeration with 180 Mt CO_2 avoided in 2030, followed closely by residential lighting (replacement of incandescent lamps with CFLs) with 167 Mt CO_2 . In the commercial sector, we find the greatest potential for emissions mitigation with space cooling with 147 Mt CO_2 avoided emissions in 2030. Commercial lighting affords the next highest potential in that sector, with 132 Mt CO_2

Figure 3 and **Figure 4** show the mitigation potential by end use.

Figure 3- Residential Building Sector Annual Emissions Mitigation Potential by End-Use

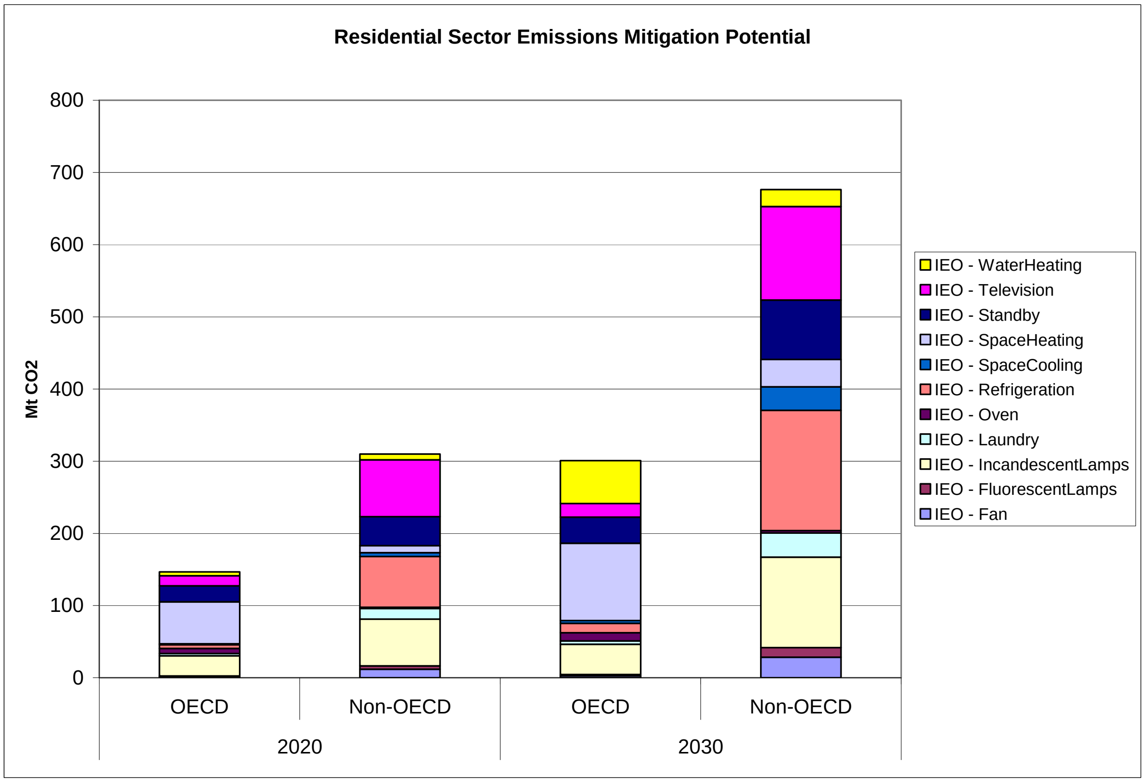
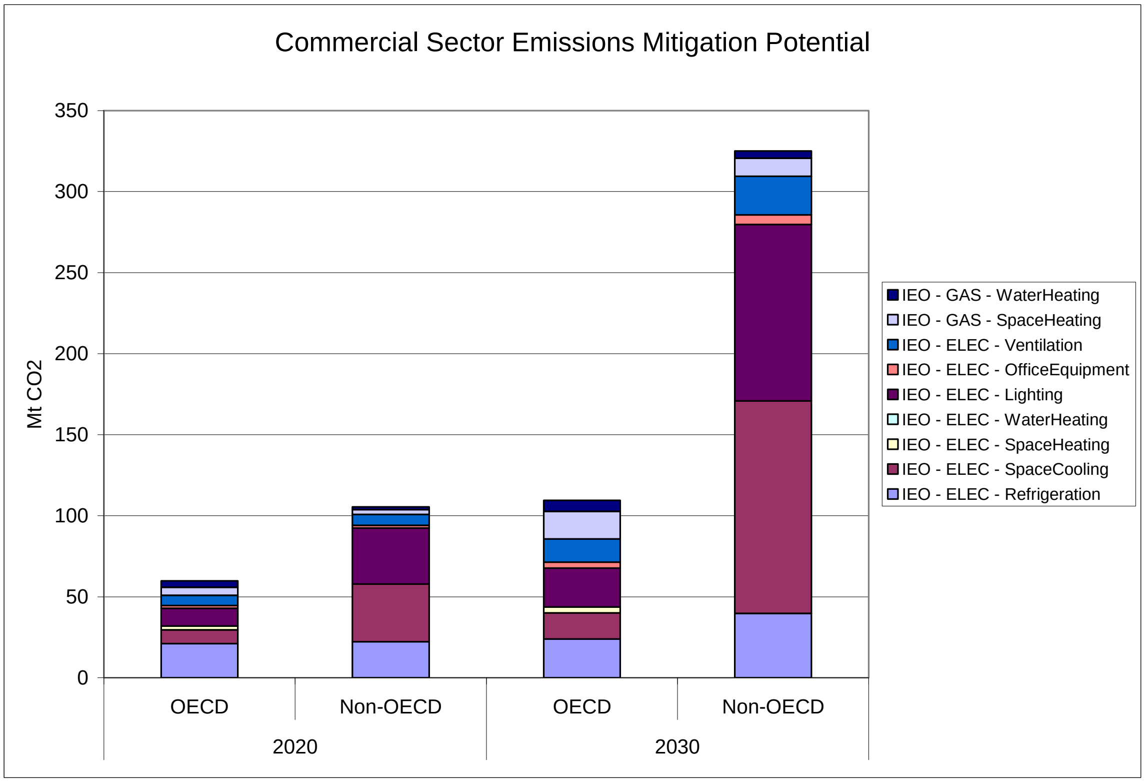


Figure 4- Commercial Building Sector Annual Emissions Mitigation Potential by End-Use



Relation to IPCC Forecast

Comparing our results to the assessment of the potential for CO_2 emissions mitigation in buildings recently published by the IPCC (Levine, Urge-Vorsatz, Blok et al. 2007), we believe that our study demonstrates that EES&L can contribute significantly towards fulfilling the potential for emissions mitigation in the buildings sector, and is therefore one of the most important government policies for combating climate change. The IPCC study was not limited to EES&L programs, rather it considered market transformation mechanisms as a whole. Our analysis indicates that EES&L programs could account for about 20% of total "zero cost" potential in 2020, and about 33% of the potential in 2030 from all energy efficiency measures. The remaining potential could presumably be achieved through all other approaches, including building codes, utility programs, incentives, and behavioral changes.

1 Introduction

A consensus has emerged among the world's scientists and many corporate and political leaders regarding the need to address the threat of climate change through emissions mitigation and adaptation. A further consensus has emerged that a central component of ,these strategies must be focused around energy, which is the primary generator of greenhouse gas emissions. This report estimates the global potential reductions in greenhouse gas emissions by 2030 for energy efficiency improvements associated with equipment (appliances, lighting, and HVAC) in buildings.

In the minds of policy makers on local, national and international stages, two important questions result from this consensus: "*what kinds of policies encourage the appropriate transformation to energy efficiency?*"; and "*how much impact can these policies have?*". This report aims to contribute to the answering of these questions by considering the potential impacts of a specific subset of possible efficiency policies, but on a global scale. The policy to be discussed is Energy Efficient Standards and Labeling (EES&L) for energy-consuming equipment. The global scope of the assessment is important for the following reasons:

- The emission of greenhouse gases from energy production is itself a global problem. It will likely not be sufficient for countries or regions to act individually in order to address the problem of climate change.
- The issue concerns the emission of greenhouse gases over the next several decades. In this time frame, the consumption of the majority of energy will likely shift from North to South. Therefore, it is not sufficient to consider only those countries already contributing the bulk of emissions.
- In recent years, mandatory energy performance standards (MEPS) and labeling have become a global phenomenon, and the proliferation of this type of program, and the range of products covered are gaining momentum.

Policymakers must act in the most effective way possible in order to get the greatest impacts both in the short-term and over the full span of the forecast. This includes industrialized countries supporting - financially through policy development assistance or through technology transfer - the rapid deployment or acceleration of EES&L programs in the developing world.

As will be discussed below, this is not the first study to consider the potential impacts of the implementation of standards and labeling programs. In fact, such estimates were produced as critical elements of the implementation processes of many of the individual programs implemented to date. We do, however, believe it to be the first systematic attempt to use a consistent methodology to evaluate the potential of savings for all countries and for such a large set of products. It is our hope that standards and labeling programs, quantified sufficiently to allow meaningful comparison with other strategies under consideration, will now receive a higher priority within *global* strategies to combat climate change.

1.1 Project Scope and Approach

Current rough estimates of the global potential of EES&L programs are based on a percentage savings of residential and commercial energy use by region (10-15% of residential + commercial energy in emerging economies is one commonly used estimate). The primary goal of this project is to produce a much more detailed (and therefore more accurate and defendable) global estimate. The primary, (but not exclusive,) motivation is to bring attention on the global stage of the value of EES&L policies. A secondary goal of this project is to rank the potential impacts from EES&L policies among various countries or regions and among various energy-consuming products. The scope of the project covers:

1. Products that currently are frequently covered by national EES&L programs and that together account for the majority of demand in buildings.
2. The entire world, divided into those regions used in the IPCC's Special Report on Energy Scenarios (SRES).

The output of the analysis is a forecast of potential annual and cumulative savings from EES&L programs through 2030. Savings are given in terms of final energy, primary energy, and avoided carbon dioxide emissions.

Strong efficiency policies for residential equipment used to be the near exclusive domain of industrialized economies, especially the United States, European Union and Japan. However, this situation has changed significantly with the proliferation of policies, especially EES&L programs. In the 15 years between 1990 and 2005, the number of such programs worldwide has increased from 12 to over 60 (S. Wiel and J.E. McMahon 2005), including many developing countries. The growth in the number of programs indicates that developing country governments are increasingly concerned with controlling energy consumption, and also that they view the experience of programs in industrialized countries as having been successful. Indeed, there have been notable successes.

For example, standards already written into law in the *United States* are expected to reduce residential sector consumption and carbon dioxide emissions by 8-9% by 2020 (Meyers, McMahon, McNeil et al. 2003). Another study indicates that policies in all *OECD countries* will likely reduce residential electricity consumption 12.5% in 2020, compared to if no policies had been implemented to date (IEA 2003). Studies of impacts of programs already implemented in developing countries are rare, but there are a few encouraging examples. *Mexico*, for example, implemented its first Minimum Efficiency Performance Standards (MEPS) on four major products in 1995. By 2005, only ten years later, standards on these products alone were estimated to have reduced annual national electricity consumption by nine percent (Sanchez, Pulido, McNeil et al. 2007). With international assistance *China* has implemented MEPS and expanded the coverage of its voluntary energy efficiency label to over 40 products since 2005. In the first impact assessment of the program conducted for METI by CLASP, 11 products were included and shown to save a cumulative 1143 TWh by 2020, or 9% of the cumulative consumption of residential electricity to that year and reduce carbon dioxide emissions by more than 300 million tons carbon equivalent. (Fridley et. al. 2007),

The state of analysis of efficiency programs parallels the development of the programs themselves. By now, studies have been performed covering a wide range of end-uses for many industrialized countries. In the current project, we make use of the research done in these countries. Much less has been done with the developing world, however. As the share of emissions shifts to the South, it is critical to have a grasp of the opportunities for curbing this growth. Many developing countries still have no efficiency policy regimes in place, and therefore have a high technical potential. Many have EES&L for only a few products or are otherwise behind the world's best practices. For these reasons, we make a serious effort to understand both the demand, and the improvement potential in developing country regions.

1.2 Literature Review

As part of the initial stage of the project, we have conducted a review of the existing literature in several areas needed for the project. The main elements are end-use demand estimates in different sectors and establishment of baseline technologies. In addition, however, we identified studies specifically addressing the topic of the potential for efficiency improvement. The latter were typically country studies, although a few of them were end-use oriented, and covered more than one country. Some examples of references found during the literature review, which are prime sources for much of the sections that follow are provided here.

United States - "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors". (Rosenquist, McNeil, Iyer et al. 2006) considers potential efficiency targets in both the residential and commercial sectors, based on cost-benefit analysis defined by least life-cycle cost (LLCC). The targets identified in this report were used extensively as a model in formulating the efficiency scenario.

Japan – "Energy Consumption, Efficiency Conservation, and Greenhouse Gas Mitigation in Japan's Building Sector". (Murakami, Levine, Yoshino et al. 2006) This report covers the whole of the buildings sector, considering efficiency and conservation programs across all end-uses. It was contains a set of efficiency scenarios considered to be achievable in the Japanese context.

OECD – "Cool Appliances, Policy Strategies for Energy Efficient Homes" (IEA 2003) takes a comprehensive look at the efficiency potential for all OECD countries for the residential sector. Potential efficiency is based on cost effectiveness defined by least life cycle cost (LLCC).

China – "Impacts of China's Current Appliance Standards and Labeling Program to 2020" (Fridley, Aden, Zhou et al. 2007) considers the impacts of EES&L programs currently in place in China. "Mitigating Carbon Emissions: the Potential of Improving Efficiency of Household Appliances in China" (Lin J. 2006) analyzes the potential savings from improvement in three appliances – refrigerators, air conditioners, and water heaters. Finally, “Energy Use in China: Sectoral Trends and Future Outlook” (Zhou N., McNeil M.A., David Fridley et al. 2007) provided key insights into expected trends in energy use patterns in Chinese buildings.

India – “Coping with Residential Electricity Demand in India's Future - How Much Can Efficiency Achieve?” (Letschert and McNeil 2007) estimates energy efficiency potential for all electrical appliances in India’s residential sector.

Mexico – “Assessment of the Impacts of Standards and Labeling Programs in Mexico (four products).(Sanchez, Pulido et al. 2007) et al. Evaluates the impacts of Mexican MEPS for the first products covered: refrigerators, washing machines, air conditioners and electric motors.

Refrigerators – “Reducing the Price of Development: The Global Potential of Efficiency Standards in the Residential Electricity Sector” (M.A.McNeil, V.E.Letschert and S.Wiel 2006) defines efficiency scenarios for residential refrigerators in all regions.

Air Conditioners – “Future Air Conditioning Energy Consumption in Developing Countries and what can be done about it: The Potential of Efficiency in the Residential Sector” (McNeil and Letschert 2007) defines efficiency targets for air conditioners in developing country regions and forecasts impacts in the residential sector. “Benchmarking of Air Conditioner Efficiency Levels In Five Asian Countries” (Danish Energy Management 2004) documents the current state of efficiency technology in use in major Asian markets.

Lighting – “Light's Labour's Lost: Policies for Energy-Efficient Lighting,” OECD,. (International Energy Agency 2006) considers all types of electrical lighting, the global potential for savings in all sectors, and the policies currently implemented around the world.

Standby Power – “Things that go Blip in the Night – Standby Power and How to Limit It” (IEA 2001) is a definitive reference on the products that consume standby power, and their contribution to electricity consumption in OECD countries.

1.3 Regional Breakdown, Sectors and Covered End-uses

In order to characterize global energy consumption and its consequences for greenhouse gas emissions, the UN’s Intergovernmental Panel on Climate Change (IPCC) commissioned it’s *Special Report on Emissions Scenarios* (SRES). This report divided the world into 11 regions, representing a basic level of regional disaggregation. Assumptions about population growth and economic growth were made at the level of these regions only. The 11 SRES regions are the following:

1. Oceania (Pacific OECD Countries) ***PAO***
2. North America ***NAM***
3. Western Europe ***WEU***

4. Central and Eastern Europe ***EEU***
5. Former Soviet Union ***FSU***
6. Latin America ***LAM***
7. Sub-Saharan Africa ***AFR***
8. North Africa and Middle East ***MEA***
9. Centrally Planned Asia ***CPA***
10. South Asia ***SAS***
11. Other Pacific Asia ***PAS***

For added relevance to energy efficiency policy, we made some adjustments to the IPCC region definitions. First, in our definition, the Republic of Korea is included in Region 1 (*PAO*) and removed from region 11 (*PAS*). Second, all Asian countries not included in *CPA* or *PAO* are included in a region called Other Asia, which is a combination of South Asia and Other Pacific Asia, and is denoted as *SAS-PAS*. The resulting 10 regions are used throughout the analysis, and for the remainder of the report. These definitions are shown in Table 1, in order of increasing GDP per capita.

The SRES defines a variety of economic, population and technology scenarios in order to elaborate the multiple possibilities of global emissions. We take two of these in particular as indicative of economic future alternatives. These are the A1 scenario, which is taken as a high growth case and the B2 scenario, which is an intermediate economic growth case.

In addition to the two SRES scenarios, we consider a third 'ad hoc' scenario derived from the U.S. Energy Information Administration's *International Energy Outlook 2007* (USEIA 2007), which we included specifically to provide a comparison with that forecast. Growth rates were estimated by summing the GDP forecasts provided in the report into the 10 regions and converting to per capita growth rates using population forecasts from UNDESA. These growth rates, along with the SRES assumptions of per capita GDP growth throughout the forecast period 2005-2030 are also shown in Table 1 .

Table 1 – Modified Region Definitions and Average per Capita GDP Growth Rates

Region Number	Region	GDP in 2005	Population	Per Capita Growth per annum		
		Billions $2005	*Millions*	B2	A1	IEO
1	*PAO*	6162	190	1.20%	1.60%	1.42%
2	*NAM*	11856	293	1.20%	1.60%	2.15%
3	*WEU*	9380	442	1.20%	1.60%	1.92%
4	*EEU*	476	111	3.00%	4.00%	4.56%
5	*FSU*	520	288	3.00%	4.00%	3.47%
6	*LAM*	2202	498	2.40%	4.00%	2.32%
7	*SSA*	395	501	2.40%	4.00%	2.87%
8	*MEA*	889	263	2.40%	4.00%	2.29%
9	*CPA*	2162	1233	4.70%	5.50%	5.57%
10	*SAS-PAS*	1515	1515	4.70%	5.50%	4.55%

Aside from GDP growth, we do not take any other assumptions from the SRES scenario. Instead, economic and demographic parameter forecasts by country are taken from other publicly available sources. These are:

- Household Size – The United Nations Human Settlement Programme (UN Habitat)
- Population and Urbanization– UNDESA

The most recent evaluation found a total of 82 products currently covered by standards and labeling programs (Wiel and J.E. McMahon 2005). A study of every one of these products would be impossible, for reasons of data availability. Instead we concentrate on the most frequently regulated products, and those with the highest share of energy demand and/or the greatest potential for efficiency improvement. In doing so, we consider a set of products that accounts for the majority of demand in buildings. The end-uses covered are detailed in the Section 2. Specific product types and policies which are not covered include:

- End-uses that are primarily limited to particular regions (such as kimchi refrigerators)
- Building codes or certification schemes
- Controls such as programmable thermostats
- Non-commercial fuels such as biofuels. Coal fired space heating and water heating in China are not considered for programs, as China is gradually transitioning away from the use of this fuel in favor of natural gas and electricity.

Finally, of the large number of products regulated we consider some as part of an aggregate group. An example of this is standby power, which consists of a wide variety of consumer electronics, many of which are considered separately by standards and labeling programs in many countries. Some programs are not speculative, that is they are already on the books, but not yet implemented. The savings from these we include in the potential, as they are savings not yet realized.

The end-uses covered in our analysis are:

- Residential Sector: Lighting, Refrigeration, Air Conditioning, Washing Machine, Fans, Television, Standby Power, Oven, Water Heating and Space Heating
- Commercial Sector: Lighting, Space Cooling, Ventilation, Refrigeration, Water Heating and Space Heating[2].

Most of the energy used in the residential sector is targeted by EES&L programs, and is included in our analysis. We do not consider space heating in the warmer climates, as this end-use does not consume a large portion of energy in those regions. Conversely,

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[2] Induction motors are another important equipment type covered by EES&L programs in many countries. In particular, three-phase motors of the type usually used in the industrial sector are often covered. These motors are the subject of a forthcoming stand-alone report as CLASP's research determined that they could not be analyzed to the same extent and in a parallel manner to products in the building sector due to data limitations.

space cooling is less common in cooler regions. Space cooling is becoming more common, however, even in temperate regions such as Western Europe. We therefore consider space cooling in every region, including the Former Soviet Union, and Eastern Europe, although air conditioning use is expected to be small in these regions.

The commercial sector is covered in less detail than the residential, due to the lack of detail on equipment type penetration and use patterns. Nevertheless, the general categories covered – lighting, space cooling, space heating, ventilation, refrigeration and office equipment typically account for the bulk of energy consumption in this sector, and can be generally characterized even in the absence of detailed datasets.

1.4 Methodology Overview

Our evaluation of global impacts of standards and labeling programs is a straightforward analysis, but one with many 'moving parts'. In principle, it relies on hundreds of separate parameters to model demand and efficiency of many end-uses in three sectors in 10 regions, which cover about 150 countries. To make this effort manageable, and maintain reliability, LBNL has developed the Bottom-up Energy Analysis System (BUENAS). The model has two important qualities:

Modular –The activity (ownership rate or intensity), unit energy consumption and market size are considered as independent analytical modules, reducing the total number of parameters needed for the full model, since the intensity model is described with just a few parameters for each end-use for most of the world[3]. Once these parameters are determined, the remaining effort can be spent establishing unit energy and efficiency parameters – a process that relies on analysis of many diverse sources. The modularity of the model allows for the disentangling of the three research efforts, and increases the transparency of the analysis.

Generic-Although the details may differ significantly, the structure of the demand and savings calculation is the same across regions, sectors and end-uses. This allows for a straightforward inquiry of model parameters and variables, which would be unmanageable otherwise, given the large number of parameters with which we are dealing. In addition, the generic nature of the parameter base allows for easy revision of parameters as more data are found. For example, an early version of the model may use data from another region as a proxy for a particular end-use. Once region-specific data are found, it is a simple matter to replace the proxy data.

Finally, we recognize that the situation varies significantly with level of economic development. The countries of the developing world have not been well-studied, primarily because good data concerning these countries are absent. Also, the energy consumption of the developing world has often been lower, and therefore, considered to be less important than that of the industrialized counties. At this stage in history, it is important to fill this gap, since many of these economies are growing rapidly and usually

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[3] With some exceptions. See below.

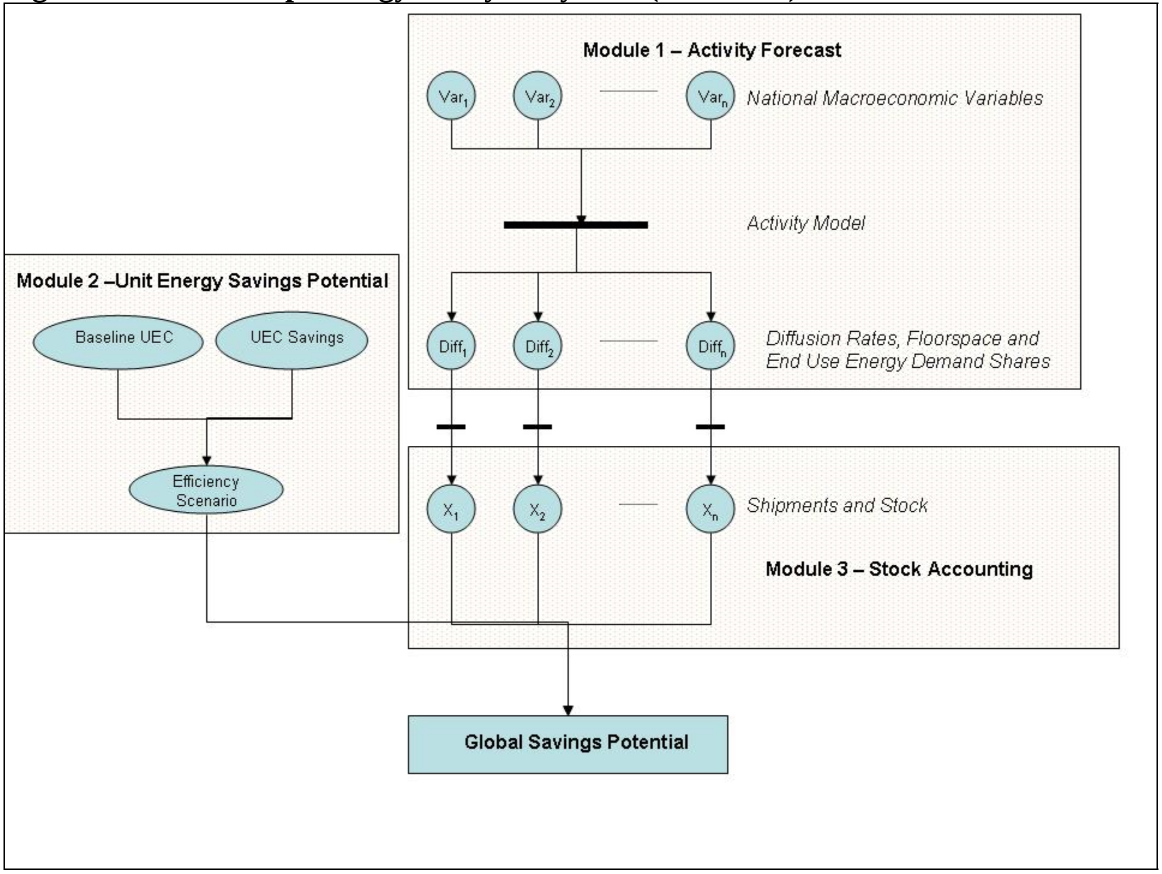
in a way that dramatically increases their energy consumption. By the year 2020, the developing regions will consume over half of the world's energy. Meanwhile, the U.S., European Union and Japan have already taken significant steps to increase energy efficiency over the last few decades, while the developing world has lagged in this regard. Therefore, much of the potential for improvement ("low hanging fruit") is in the developing world.

The key to analyzing EES&L in developing countries is to develop a methodology that is "driver-based", that is, relies only on a basic assumption of economic development (such as GDP growth). There are too many countries for them to be treated individually; rather generalizations must be made so that all countries can be included, even if the estimates for each individual country remain somewhat crude. On the other hand, industrialized countries are in some cases extremely well understood due to the sophisticated studies performed on them, and the availability of extensive databases and surveys. In these countries, where saturation effects are important, further increases in energy consumption may be driven by known country-specific effects. Wherever possible, therefore, we take advantage of these studies in order to make country-specific estimates.

The resulting approach therefore has a somewhat hybrid nature. The approach of a 'meta analysis' that draws on previous studies is used largely for the large developed countries and regions, while a more generic driver-based approach is adopted for developing country regions. In summary, we have constructed a consistent methodology for forecasting energy demand for end-uses typically targeted by EES&L programs, but rely on published estimates where they are likely to be more precise.

As mentioned above, the strategy for improving estimates of the potential for EES&L programs to reduce energy consumption and related greenhouse gas emissions is to first model future demand for energy at the end-use level using one module, and then build a high-efficiency scenario based on meeting equipment efficiency targets at a particular level and certain dates for each sector and region using a second module. Penetration of the various products into households and businesses are tracked in a third module. Finally, these three components are brought together, and savings are calculated as the difference in consumption and emissions in the efficiency scenario versus the base case. The following sections describe schematically how each of these modules is constructed, and how they are brought together in the impacts calculation. The analysis framework is shown in **Figure 5**.

Figure 5 – Bottom-Up Energy Analysis System (BUENAS) Flowchart



1.4.1 Module 1 – Activity Forecast Methodology

The single most important factor impacting the amount of energy that will be saved in the future by efficiency programs is the level of energy services demanded by households and businesses. Much of the uncertainty in the assessment will come from this factor. This is especially true of developing countries. While we can expect modest further increases in end-use demand in industrialized countries, in the developing world, demand is expected to grow by several times. The purpose of the activity forecast module (Module 1) is to estimate current end-use demand, and to predict how much growth will occur in the next decades by end-use, and by country or region.

The first step in forecasting energy demand consists in modeling *activity*. Activity depends mainly on economic growth. In the residential sector, activity is parameterized by *appliance diffusion*, that is, the average number of a certain type of appliance per households. Appliance diffusion can be greater than one, if some households own more than one of a certain type of appliance. In commercial buildings, economic activity drives floor space, which in turn increases demand for energy. The shipments and stock turnover for residential appliances and commercial end-uses are then derived from first purchases (due to increase in ownership and population growth) and replacements. In the industrial sector, energy is driven by industrial economic activity, that is industry value added GDP.

1.4.2 Module 2 - Unit Energy Savings Potential

The second step of the analysis is to gather estimates of the average baseline unit energy consumption (*UEC*). In the residential sector, we estimate the typical annual energy consumption of appliances for each region. This is dependent on the typical products used (such as the size of a refrigerator, for example), the average efficiency of products on the market, and use patterns. Use patterns are driven by various factors. The most notable of these is climate, often characterized by heating and cooling degree days, which is the primary determinant of space heating and air conditioner use. In the commercial sector, end-use consumption is parameterized in terms of end-use intensities. These are generally given in terms of floor space, that is, typical energy use per square meter for lighting or space conditioning. The Activity Forecasting Module is described in detail in Section 2.

The characterization of potential savings is the second area where this study adds significantly to current global estimates of emissions mitigations from energy efficiency policy, because it considers relative improvements *at the end-use level*. This necessarily requires an understanding of the efficiency potentials of individual technologies. In principle, this is a very complicated task, because it relies on understanding the prevailing technologies for every major end-use in every country in the world and technologies available for their substitution. Fortunately, however, we can draw on the experience of international markets and best practices to make some simplifying assumptions, and reasonable approximation. Assumptions about efficiency targets that could be achieved by EES&L programs are based upon judgments about what is feasible in a given time period. Cost effectiveness is considered implicitly –targets have generally been implemented cost effectively in some country already, or have been shown to be cost effective. In addition, however, we consider that best practice technologies may not yet be available in all regions. This is a particular consideration for targets set for 2010. Base case unit energy consumption is generally modeled at the regional level[4]. The Unit Energy Savings Potential Module is described in detail in Section 3.

1.4.3 Module 3 - Stock Accounting

EES&L programs create savings by transforming the market in such a way that new products flowing into the market use, on average, less energy than they would be in the absence of programs. As new products are installed, and old ones are retired, the product stock as a whole requires less fuel inputs and generates fewer emissions. In order to characterize these, the stock accounting model includes the following steps:

- Product flow rates are modeled from the activity forecast
- Energy consumption of new stock is calculated according to efficiency trends in the Base Case and Efficiency Scenario

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[4] The exception is residential air conditioning and space heating, which have an income and/or climate dependence. For these end-uses, we consider end-use consumption on a country-by-country basis.

- A retirement model tracks products remaining in the stock; and
- The difference between energy consumption of the stock in the Base Case and Efficiency Scenario are yields energy savings.

Using these steps, the energy savings in each year of the forecast for each end-use, sector and region are calculated independently, allowing for estimates grouping across 'horizontal' (end-use or sector) or vertical (regional) lines. The Stock Accounting Module is described in detail in Section 4.

2 Module 1 – Activity Forecasting Methodology

Typically, sector, national or regional-level energy demand forecasting is achieved by correlating energy demand with macroeconomic trends such as GDP and/or population growth in an aggregate way, such as through a single elasticity parameter. The current analysis has invested a significant amount of effort on activity forecasting disaggregated by sector and down to the end-use level. In the residential sector in particular, the result is a truly bottom-up approach. The activity- based approach affords sensitivity in two important areas:

- *Threshold and Saturation effects* - One may more accurately capture the structure of energy demand growth by predicting the uptake of energy intensive products, instead of assuming a direct relationship between economic activity (income) and energy demand. For example, refrigeration energy in low income countries will rise rapidly with economic growth because this is a high intensity end-use which is highly desirable. This energy growth will slow for medium income countries, however, as the market becomes saturated. By contrast, air conditioning is a high-intensity end-use, but one whose use may appear to be inelastic with income in low-income countries. Once a certain threshold is reached, however, air conditioning diffusion can grow rapidly.
- *Efficiency Scenarios* – The ability to mitigate energy-related emissions through efficiency depends on the technologies of individual end-uses. Efficiency savings are a function both of the baseline energy consumption (base load and efficiency), and the availability of high-efficiency alternatives. A consumption forecast at the level of individual end-use equipment therefore allows for the construction of detailed efficiency scenarios, where efficiency improvement can be characterized as easily achievable or highly aggressive, based on the cost-effectiveness and availability of specific technologies.

Section 2.1 provided a description of our model for forecasting the demand for electricity and fuels in buildings for each equipment type. For the residential sector, we describe a general approach for modeling appliance diffusion (ownership rate) as a function of income, electrification and urbanization, and discuss the end-uses for which modifications to this model were made. Section 2.2 describes the general method for forecasting commercial floor space, which is the main driver for commercial sector energy, as well as the method of modeling equipment penetration per square meter as a function of national income level.

2.1 Residential Sector Activity Forecasting

The model describing projected energy demand in residences is the more detailed of the two sectors. There are several reasons for this. First of all, the residential sector generally uses more energy than the commercial sector. This is especially true in developing countries, where large-scale commercial enterprises are underdeveloped. Second, residential end-uses are relatively well-characterized, and are among the first appliances to be addressed by efficiency programs – the most typical example being refrigerators and freezers. Finally, the most data exists for the residential sector. Many countries, including in the developing world, conduct surveys which query households about ownership and use of major energy consuming appliances. Sometimes, the goal of this type of survey is specifically to understand the consumption of energy. Much more frequently, however, the object is a more general one of assessing the living standards of households, for which the ownership of a refrigerator, washing machine or television is taken as an indicator.

Using the survey data as a calibration, we forecast ownership of electric appliances and lighting in the residential sector by region over the next 30 years according to an econometric diffusion model.

2.1.1 Diffusion Model for Major Appliances

The development of an econometric model of appliance diffusion serves two purposes. First, it allows for interpolation of diffusion rates for countries where data is unavailable. Second, it provides a base for which projections can be made into a future where the main drivers – wealth, urbanization and electrification - are all likely to be increasing.

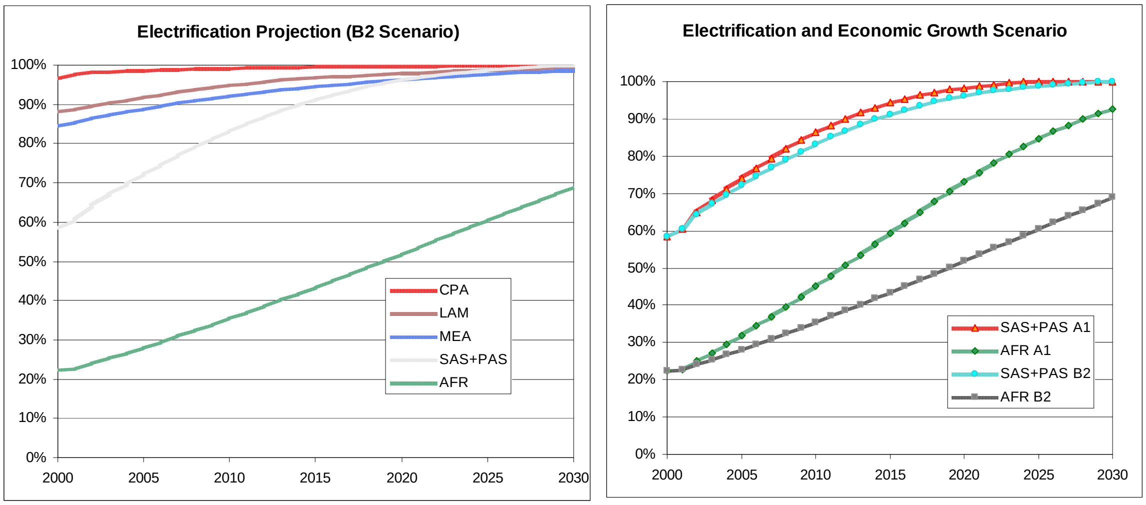
A basic premise of the approach is that, as economies develop, households will choose to purchase and use electricity consuming products in order of desirability and affordability. This is borne out by the survey data, which shows a very strong correlation between income, estimated as GDP per household, and ownership of major appliances. Electrification is obviously a strong determining parameter as well, but its significance is less important for expensive or luxury products, which are not accessible to any but the wealthiest households.

In order to first model and then forecast appliance ownership rates, we choose economic and demographic drivers which are available for a wider range of countries. For instance, GDP per capita and household size (number of household members), which together yield an estimator for household income, are available for almost every country from the World Bank and United Nations, respectively. The UN also provides forecasts of population and urbanization rates. Electrification rates are available from a variety of sources, including standard of living surveys. Electrification rate forecasts are not available, but are themselves modeled in terms of GDP growth, with the assumption that the rate of increase of electrification with economic growth will be highest for those countries with the lowest current electrification. In other words, electrification will be the highest priority for those countries that most lack it. As electrification becomes nearly universal, its rate of increase slows. This relationship is parameterized by the following Equation:

$$\frac{\Delta Electrification}{Electrification} = (-3.73 \times Electrification + 3.85) \times \frac{\Delta GDP}{GDP}$$

The results of modeling electrification for the two main economic scenarios are shown in Figure 6.

Figure 6 - Projection of Electrification Rates by Region



The order households purchase appliances can be described as an appliance 'ladder.' The poorest of electrified households will use electricity for lighting only, followed closely by a television. The diffusion rate for both of these end-uses closely follows electrification rates, and many households of even moderate income may have more than one television. A refrigerator represents the first major consumption hurdle, because it is a major purchase for low-income households, and also a major electricity consumer. As incomes rise, washing machines become more common, but even though this appliance may be less expensive than a refrigerator, washing machine diffusion rates are consistently lower than refrigerator rates, because it is considered more of a luxury appliance.

Finally, the evidence suggests that air conditioning could be quite an important end-use in developing countries in the future. Although air conditioning is already an important end-use in the services sector of many developing countries, it remains rare in households. This is changing, however, as incomes in hot and humid countries rise. Therefore, air conditioning is a highly dynamic end-use that deserves detailed study, both in terms of economic growth, and climate considerations.

We modeled diffusion econometrically for four major products - refrigerators, washing machines, televisions, and air conditioners - by correlating diffusion rates in different countries with macroeconomic driver variables using linear regression analysis. Other end-uses were modeled using various methods, as described below.

Functional Form for Major Products

The general form of the diffusion relationship follows an S-shaped function. There are various options for modeling this type of relationship. We chose the logistic model, which is appropriate for econometric modeling of a simple binary choice (market share) model. Defined in this way, the equation for refrigerators, washing machines, fans and televisions is given by:

$$Diff_c = \frac{\alpha}{1 + \gamma \exp\left(\beta_{inc} I_c + \beta_{elec} E_c + \beta_{urb} U_c\right)} + \varepsilon_c \qquad (1)$$

Where:

$Diff_c$	is the diffusion of the appliance for the country *c*
α	is the saturation level, which may be greater than 1
I_c	is the monthly household income, given by GDP divided by the number of households in the country, in units of year 2000 U.S. dollars.
U_c	is the national percentage of urbanization
E_c	is the national percentage of electrification
ε_c	is the error term

Once α is defined, the remaining logistic function ranges from zero to one. The logistic diffusion function can be converted to a linear function, allowing linear regression analysis. Rearranging and taking the logarithm of both sides gives:

$$\ln\left(\frac{\alpha}{Diff_c} - 1\right) = \ln\gamma + \beta_{inc} I_c + \beta_{elec} E_c + \beta_{urb} U_c + \varepsilon_c \qquad (2)$$

A significant part of the effort in developing the diffusion model was to gather as many diffusion data points as possible for each appliance. This involved a wide search for publicly available survey results, previously collected data (mostly for industrialized countries), and research publications. In some cases, there were multiple data points for some countries, because surveys were repeated periodically. In these cases, in order to avoid the use of highly correlated data points, we chose to use only the most recent available data from any country. The resulting data points used to develop diffusion models are as follows:

- 64 data points for Refrigerators;
- 27 data points for Washing Machines;
- 139 data points for Televisions;
- 36 data points for Air Conditioners;
- 11 data points for Fans;

- 14 data points for Water Heaters;
- 55 data points for Ovens;
- 56 data points for Lighting points; and
- 30 data points for Stand-by power

The most recent data point was from 2006, while the oldest was from 1990. Most of the data was more recent than 1995. All appliance data are detailed in the Appendix, along with the corresponding macroeconomic variable values for each country.

Refrigerator Model

A close look at the results of the modeling effort for one end-use is useful to understand the method. Refrigerators were the first appliance studied using econometric diffusion modeling, because they are both highly desirable, but relatively expensive for low-income households in developing countries. In addition, they account for a significant amount of residential electricity consumption Therefore, we show the results of the model for refrigerators. The regression results for other end-uses that are not shown here can be found in the Appendix. Table 2 shows the results of the linear regression for refrigerators.

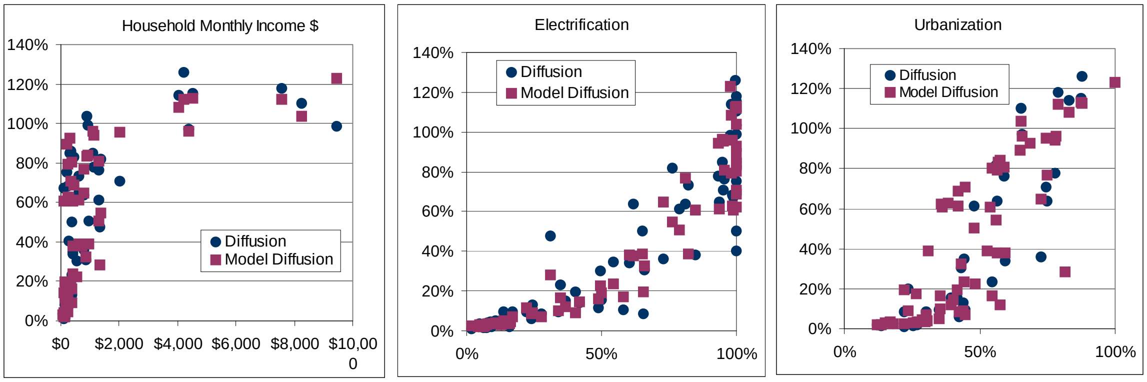
Table 2 Linear Regression Results for Refrigerators

Observations	64
R^2	0.92

	Coefficients	*Standard Error*	*t Stat*	*P-value*
$\ln\gamma$	4.75	0.19	25.53	6.4E-34
βinc	-6.0E-05	4.5E-05	-1.34	1.9E-01
βelec	-3.55	0.25	-14.12	1.0E-20
βurb	-2.69	0.51	-5.28	1.9E-06

With an R^2 of 0.92, refrigerator ownership is very well described by a logistic functional form with income, electrification rate and urbanization as independent variables. Each of these variables is statistically significant. Each parameter also has the expected sign that ownership increases with increasing household income, electrification, or urbanization. Electrification has by far the lowest P-value which means it’s the most determining variable in the decision of to purchase a refrigerator.

Figure 7 Linear Regression Results by Variable for Refrigerators



Air Conditioner Climate Dependency

Modeling of air conditioner diffusion is similar to that of the other products with the main difference that air conditioners are not only a relatively expensive product, but their utility is climate dependent. This means that in some very wealthy regions, such as Northern Europe, air conditioner use remains low, even though air conditioners are generally affordable. On the other hand, in tropical developing countries, air conditioners might be considered among the most desirable appliances, but their high-cost continues to categorize them as a luxury item.

In order to take climate effects into account, air conditioner saturation was considered as deriving from two independent factors, which we call *Climate Based Maximum Saturation(CBMS)* and *Availability* . By assumption, the Climate Maximum contains all of the climate dependency, parameterized by cooling degree days (CDD). Climate Maximum is modeled using U.S. data, with the assumption that air conditioning is generally affordable to U.S. households, and its presence is determined largely by cooling load. Correspondingly, *Availability* represents the income dependence on air conditioner ownership. Northern European countries, for example have a low *Climate Based Maximum Saturation* but a high *Availability*, while the situation in poor tropical countries, such as Indonesia, is reversed. The functional form for air conditioner diffusion is given by

$$Diffusion = CBMS * Avail$$

Where

$$\mathrm{CBMS} = 1 - 0.949 \times \mathrm{e}^{-0.00187 * \mathrm{CDD}}$$

$$Avail = \frac{1}{1 + \gamma \exp(\beta_2 \times \mathrm{Inc})}$$

The results of the parameter fit for all appliances is summarized in **Table 3**

Table 3 – Result of Linear Regression for Econometric Model of Appliance Diffusion

End-use	α	$\ln\gamma$	β_{Inc}	β_{Elec}	β_{Urb}	β_{CDD}	β_{HDD}
Washing Machine	1.0	7.98	-3.20E-04	-8.74	0	0	0
Refrigeration	1.4	4.75	-6.05E-05	-3.55	-2.69	0	0
Television	3.0	3.50	-9.49E-05	-3.11	0	0	0
Water Heating	1.0	5.53	-6.08E-04	-4.53	0	0	-0.00145
Oven	1.0	5.53	-5.08E-03	0	-4.90	0	0
Air Conditioner	1.0	3.56	-8.35E-04	0	0	0	0
Fan	3.0	1.02	0.00E+00	-1.41	0	0.00033	0
Standby Power	6.0	2.10	-4.81E-04	0	0	0	0

2.1.2 Diffusion Model for Other End-uses: Lighting and Space Heating

Lighting and space heating have some regional characteristics not captured by an econometric model. In each case, we consider these parameters separately according to regional data, where these are available.

Number of Points of Light

Lighting is generally the first use of electricity in the household. Generally, all electrified houses use electricity for lighting. Therefore, the model assumes that lighting diffusion is equivalent to the national electrification rate. However, lighting energy is largely determined by the number of light fixtures installed in the household, the type of lamp, and hours of use.

The amount of electricity used for lighting in industrialized country households can be several times higher than the total electricity use of households in the developing world. This is due to several factors, some of which are more obvious than others. First, one or two lighting fixtures may be sufficient for low income households, which tend to cover a small space. Secondly, because of the high cost of electricity, these households may also use other fuels, such as kerosene, to produce light. Finally, the bulb type may be different. For example, fluorescent tube lamps are more common in the residential sector in developing country regions than in developed countries.

The number of light bulbs per electrified household is assumed to be a function of income only. Thirty-nine data points were gathered to determine this relation (see Appendix 2). The derived relationship between household income and number of points is shown in **Figure 8**, along with the data. The regression points are shown in Table 4.

Figure 8 – Number of Lighting Points per Household

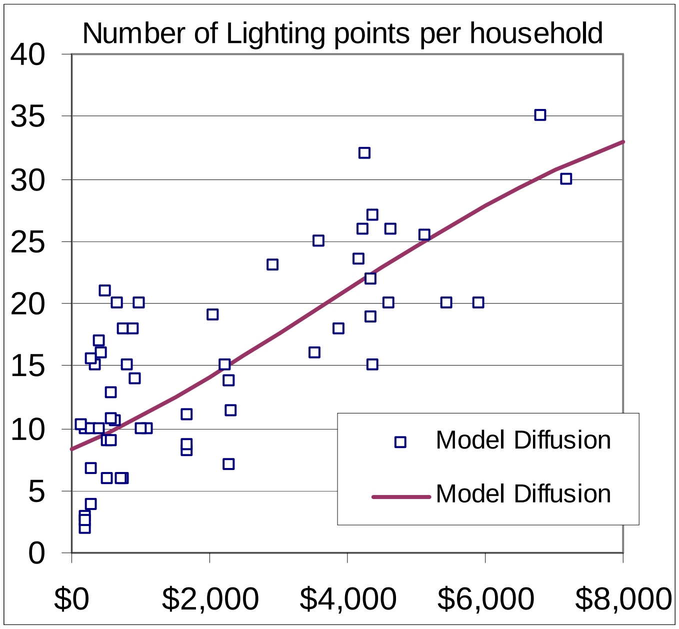


Table 4 Linear Regression Results for Lighting Points per Household

Observations	39	
R Squared	0.74	
	lnγ	βinc
Coefficients	1.8517	-4.70E-04
Standard Error	1.50E-01	4.60E-05
t Stat	12.34	-1.02E+01
P-value	1.1E-14	2.51E-12

Estimating lighting consumption requires an estimate of the breakdown of each type of lamp: incandescent; fluorescent tubes; and compact fluorescent lamps. This breakdown is critical for two reasons. First, it has a significant impact on consumption, since fluorescent lamps are much less consumptive than incandescent bulbs. Second, it impacts the savings potential of EES&L, since the market transformation for each type is distinct: CFL replacement for incandescent bulbs, and high-efficiency lamps and ballasts for fluorescent tubes. The breakdown is estimated *by region*. This is due to the significant variation across different parts of the world, and between developed and developing countries. There are insufficient data, however, to make the breakdown estimate by country.

Table 5 Lighting Type Breakdown by Region

Region Number	%IL	%FL	%CFL	Reference/Assumption
PAO	22%	57%	8%	(IEA 2006)
NAM	91%	7%	2%	(IEA 2006)
WEU	74%	15%	12%	(Bertoldi and Atanasiu 2006)
EEU	73%	22%	4%	(Bertoldi and Atanasiu 2006)
FSU	100%	0%	0%	(IEA 2006)
LAM	68%	12%	20%	(Figueroa and Sathaye 1993), (McNeil 2003), (Lutz, McNeil, Tanides et al. 2008), (IEA 2006), (Friedmann, DeBuen, Sathaye J. et al. 1995)
SSA	53%	32%	15%	(Constantine S. and Denver A. 1999)
MEA	100%	0%	0%	(IEA/OECD 2001)
CPA	57%	20%	23%	(IEA 2006)
SAS-PAS	59%	37%	4%	(CLASP 1997),(Kulkarni and Sant 1994),(Kumar, Jain and Bansal 2003)

The estimation of hours of lighting usage is described in section 3.1.1

Space Heating

Each household in the regions PAO, NAM, WEU, EEU, FSU is assumed to have some form of space heating. The saturation is therefore equal to 100% by definition for these regions. Further research was performed to determine what type of heating system households have in each region, due to variation in achievable efficiency by fuel and equipment type. Table 6 summarizes the distribution of heating systems by region.

Table 6 Heating System by Region

Heating System		% Ownership			Reference/Assumption
		Elec Res.	Fuel	HP	
PAO	Room Heater	0%	54%	46%	derived from (EDMC)
	Furnaces/Boiler	0%	0%	0%	
NAM	Room Heater	21%	9%	35%	(DOE/EIA 2001)
	Furnaces/Boiler	43%	91%	0%	
WEU	Room Heater	100%	8%	0%	(European Comission 2002)
	Furnaces/Boiler	0%	92%	0%	
EEU	Room Heater	0%	50%	0%	(Novikova A.)
	Furnaces/Boiler	0%	50%	0%	
FSU	Room Heater	0%	26%	0%	(Nekrasova O.A. 1991)
	Furnaces/Boiler	0%	74%	0%	

The use of fuel (gas or heating oil) to heat residences is dominant in these regions. Electric heating is common only in PAO and NAM, and is divided into two important sub-categories. While most homes in Japan (most of the PAO region) use a heat pump for electric heating, resistance heating is also common in North America. We assume that these penetration rates are constant throughout the forecast, although trends in new construction may cause a gradual shift towards a particular fuel or equipment type. In the CPA region, commercial fuel space heating is not universal, and coal is still a significant heating fuel. Therefore, we model a penetration rate of commercial fuel that varies with time, as well as fuel/equipment type between resistive electric, gas space heating and heat pumps. Assumptions about the evolution of space heating equipment in China are discussed in Appendix 6.

2.1.3 Regional Diffusion Trends

Once the trends for each driver variable are established for each economic scenario, the forecast of diffusion for each country is straightforward. In each year, for a given level of household income, urbanization and electrification, and given the time-independent climate variable for each country, ownership level of each major appliance is calculated using a database query, according to the above econometric equations. Figure 9 shows a comparison between diffusion in two regions – SAS-PAS (non-centrally planned Asia) and SSA (Sub-Saharan Africa). Both sets of diffusion projections correspond to the intermediate economic growth case (B2).

As expected, while diffusion for most appliances in the SAS-PAS region is higher than in the poorer countries of Africa, current rates for both regions are currently quite low. The forecast shows, however, that by 2030 refrigerator ownership in SAS-PAS will be over 80%, but only 50% in Sub-Saharan Africa. Washing machine and television ownership in Asia will reach levels currently shown in industrialized countries, and the ownership gap between refrigerators and washing machines will have narrowed. Finally, air conditioner use becomes significant in Asia.

Figure 9 – Diffusion Projections for Sub-Saharan Africa (SSA) and Non-Centrally Planned Asia (SAS-PAS) – Moderate Economic Growth (B2)

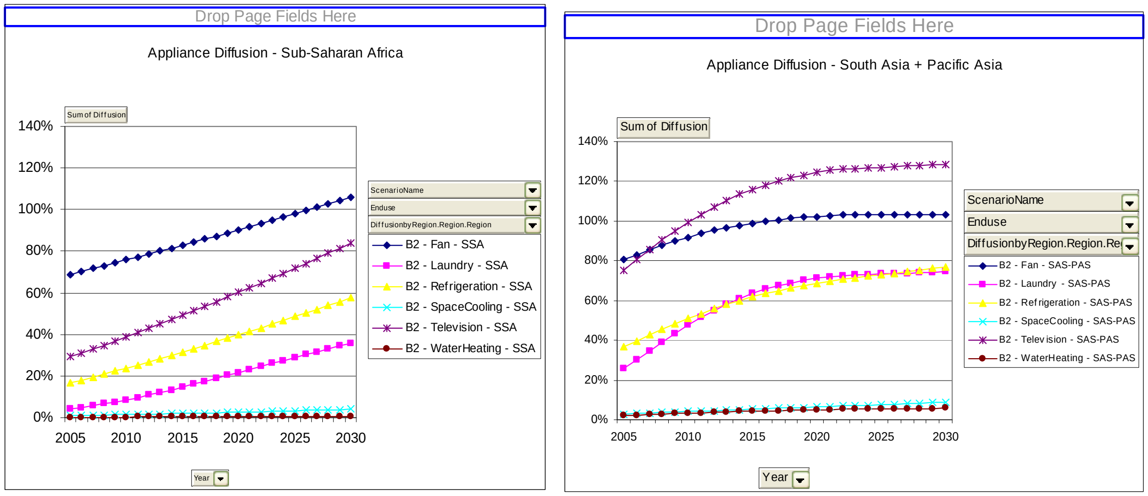
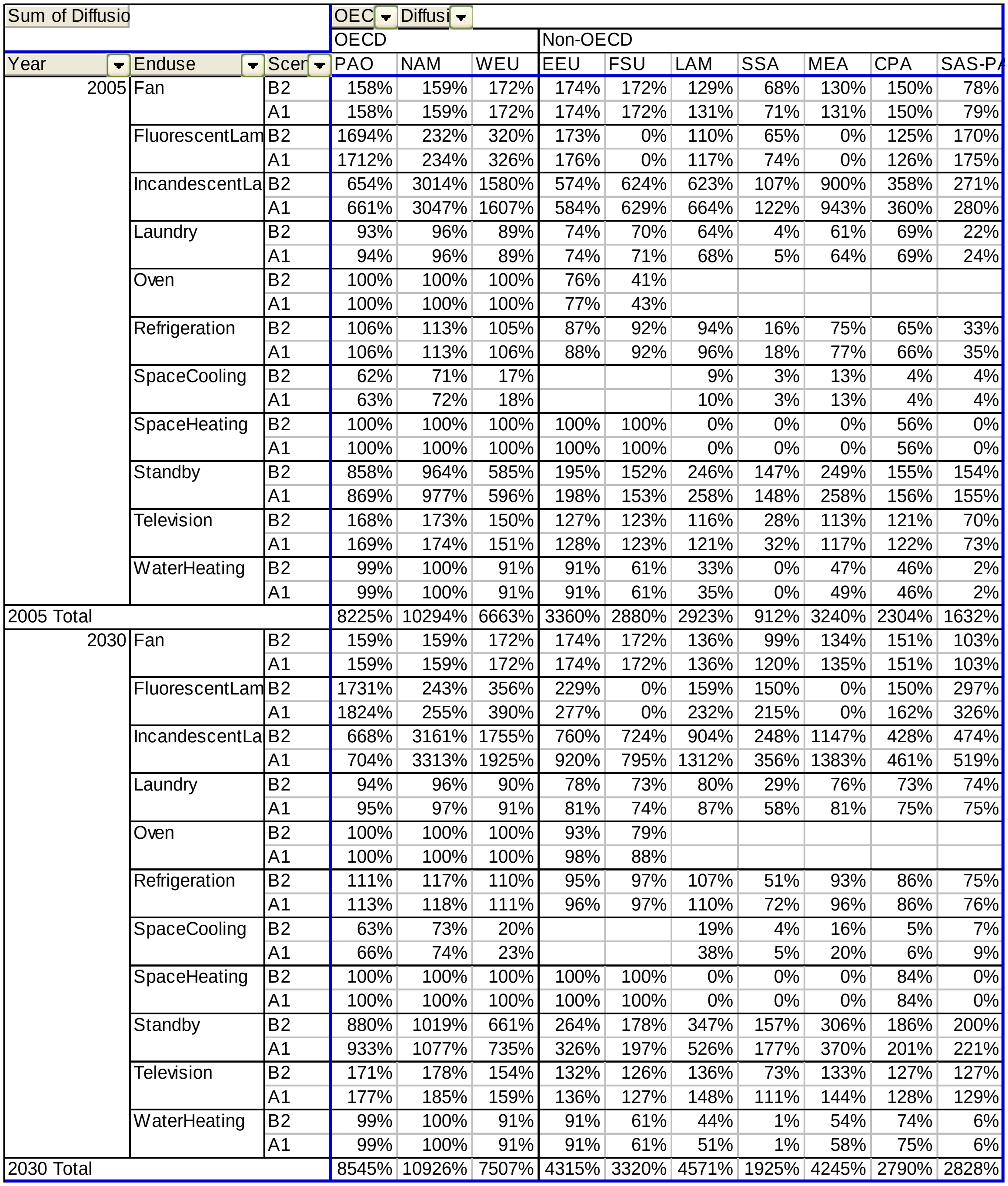


Table 7 gives the complete set of modeled diffusion rates, currently, and in 2030 for each of three scenarios, for every region

Table 7 – Diffusion Rates per End-use and per Region in 2010 and in 2030 in each scenario:



Sum of Diffusio			OEC	Diffusi								
			OECD			Non-OECD						
Year	Enduse	Scen	PAO	NAM	WEU	EEU	FSU	LAM	SSA	MEA	CPA	SAS-PA
2005	Fan	B2	158%	159%	172%	174%	172%	129%	68%	130%	150%	78%
		A1	158%	159%	172%	174%	172%	131%	71%	131%	150%	79%
	FluorescentLam	B2	1694%	232%	320%	173%	0%	110%	65%	0%	125%	170%
		A1	1712%	234%	326%	176%	0%	117%	74%	0%	126%	175%
	IncandescentLa	B2	654%	3014%	1580%	574%	624%	623%	107%	900%	358%	271%
		A1	661%	3047%	1607%	584%	629%	664%	122%	943%	360%	280%
	Laundry	B2	93%	96%	89%	74%	70%	64%	4%	61%	69%	22%
		A1	94%	96%	89%	74%	71%	68%	5%	64%	69%	24%
	Oven	B2	100%	100%	100%	76%	41%					
		A1	100%	100%	100%	77%	43%					
	Refrigeration	B2	106%	113%	105%	87%	92%	94%	16%	75%	65%	33%
		A1	106%	113%	106%	88%	92%	96%	18%	77%	66%	35%
	SpaceCooling	B2	62%	71%	17%			9%	3%	13%	4%	4%
		A1	63%	72%	18%			10%	3%	13%	4%	4%
	SpaceHeating	B2	100%	100%	100%	100%	100%	0%	0%	0%	56%	0%
		A1	100%	100%	100%	100%	100%	0%	0%	0%	56%	0%
	Standby	B2	858%	964%	585%	195%	152%	246%	147%	249%	155%	154%
		A1	869%	977%	596%	198%	153%	258%	148%	258%	156%	155%
	Television	B2	168%	173%	150%	127%	123%	116%	28%	113%	121%	70%
		A1	169%	174%	151%	128%	123%	121%	32%	117%	122%	73%
	WaterHeating	B2	99%	100%	91%	91%	61%	33%	0%	47%	46%	2%
		A1	99%	100%	91%	91%	61%	35%	0%	49%	46%	2%
2005 Total			8225%	10294%	6663%	3360%	2880%	2923%	912%	3240%	2304%	1632%
2030	Fan	B2	159%	159%	172%	174%	172%	136%	99%	134%	151%	103%
		A1	159%	159%	172%	174%	172%	136%	120%	135%	151%	103%
	FluorescentLam	B2	1731%	243%	356%	229%	0%	159%	150%	0%	150%	297%
		A1	1824%	255%	390%	277%	0%	232%	215%	0%	162%	326%
	IncandescentLa	B2	668%	3161%	1755%	760%	724%	904%	248%	1147%	428%	474%
		A1	704%	3313%	1925%	920%	795%	1312%	356%	1383%	461%	519%
	Laundry	B2	94%	96%	90%	78%	73%	80%	29%	76%	73%	74%
		A1	95%	97%	91%	81%	74%	87%	58%	81%	75%	75%
	Oven	B2	100%	100%	100%	93%	79%					
		A1	100%	100%	100%	98%	88%					
	Refrigeration	B2	111%	117%	110%	95%	97%	107%	51%	93%	86%	75%
		A1	113%	118%	111%	96%	97%	110%	72%	96%	86%	76%
	SpaceCooling	B2	63%	73%	20%			19%	4%	16%	5%	7%
		A1	66%	74%	23%			38%	5%	20%	6%	9%
	SpaceHeating	B2	100%	100%	100%	100%	100%	0%	0%	0%	84%	0%
		A1	100%	100%	100%	100%	100%	0%	0%	0%	84%	0%
	Standby	B2	880%	1019%	661%	264%	178%	347%	157%	306%	186%	200%
		A1	933%	1077%	735%	326%	197%	526%	177%	370%	201%	221%
	Television	B2	171%	178%	154%	132%	126%	136%	73%	133%	127%	127%
		A1	177%	185%	159%	136%	127%	148%	111%	144%	128%	129%
	WaterHeating	B2	99%	100%	91%	91%	61%	44%	1%	54%	74%	6%
		A1	99%	100%	91%	91%	61%	51%	1%	58%	75%	6%
2030 Total			8545%	10926%	7507%	4315%	3320%	4571%	1925%	4245%	2790%	2828%

With the exception of lighting, which is already saturated in most regions, diffusion will increase in every region, and it will be higher in 2030 in a scenario of high economic growth. In industrialized countries, however, the increases will be relatively slight, and less dependent on economic growth, because most products are already affordable, and widely-owned. The increase for most products is only a few percent for the first three regions. In the developing country regions, increases are more dramatic. In many cases, diffusion of the ‘necessity’ appliances reaches current industrialized country levels.

Regional estimates of saturation differ according to economic growth rate, but to a degree that may be surprisingly small to some readers. There are two explanatory factors for this. First, some appliances may be more sensitive to urbanization and electrification rates than to income. Probably more important are saturation effects, which would not be captured in a top-down model that considers, for example, total residential electricity consumption as a function of GDP per capita. A significant difference between the scenarios *is* seen in cases where the appliance is expensive and considered a luxury item (like air conditioners) or where income rates are low (like Sub-Saharan Africa).

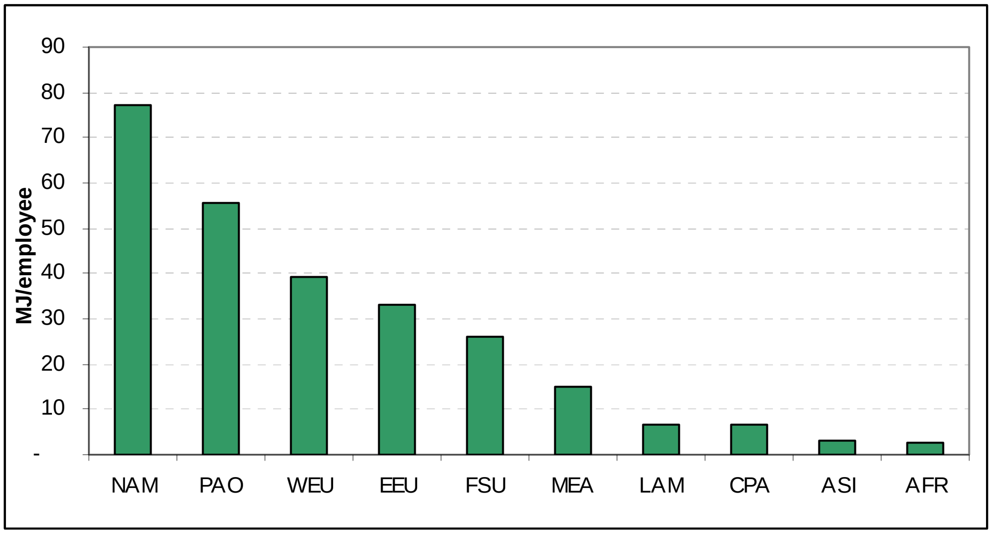
2.2 Commercial Sector End-use Activity

The analysis presented in this report required the development of a new model that projects energy demand for the commercial sector by end-use. While it is sometimes possible to gather end-use consumption data from the developing world on penetration of equipment in the household sector, this data is quite scarce in the commercial (services) sector. This sector has received little attention, mostly due to limited data available to characterize its energy demand and also because of its lower energy consumption magnitude compared to other sectors. However, energy consumption in this sector is still growing in developed countries and is expected to grow even more rapidly in developing countries. It is therefore important to better understand the effects contributing to the growing energy use in this sector. In this report, the first goal was to gather data available from surveys conducted in some countries which describe energy use in the commercial sector and use them to construct a model that represents the consumption for specific end-uses.

Energy demand in the commercial sector represents 11% of total global primary energy (Price et al., 2006). It increased at an average annual rate of 2.6% over the period 1971 to 2004. However, this growth has been distributed unevenly across the different energy types used in this sector. Increase of the share of electricity consumed is particularly impressive. In 1971, electricity consumption represented only 17% of the final energy consumed in the commercial sector while today it represents almost half (47% in 2005). On the other hand, consumption of coal decreased at an annual rate of 4.2% and consumption of oil has remained almost constant, decreasing slightly at an annual rate of 0.3% (IEA, 2007). To date, energy use in this sector has been largely due to the demand of developed countries. Only a quarter of the final energy consumed in the entire sector is consumed by developing countries. However, the sector constitutes a growing part of the economy in developing countries both in terms of employment and its contribution to national income.

Growth in energy and more particularly in electricity consumption has been driven by an increasing share of space cooling and air ventilation but also augmentation of hours of use of lighting, penetration of office equipment, etc. The major drivers of building energy demand are economic development, population growth, diffusion of equipment, square meters of buildings areas, and behavioral factors.

Figure 10. Final Energy Consumption per Employee from the Service Sector in 2005



Source (ILO 2007),(IEA 2007).

Figure 10 shows the average energy consumption per employee in the service sector from the year 2005. Energy consumption at the level of the entire sector is available from the International Energy Agency (IEA) and covers about 130 countries. Commercial energy consumption was gathered from the (IEA 2007) and the number of employees working in the service sector based is based on data from the International Labor Organization (ILO 2007)[5]. Energy consumption per employee in the North American region is on average about 30 times more than that in the Sub-Sahara region and about one third more than the Pacific OECD region. This is a simplistic comparison, however, as many factors come into play in explaining regional differences. First, climate varies between regions, which influences the level of energy required to heat and cool space. Secondly, the structure of the service sector also plays an important role in determining how energy is consumed. The sector covers a wide range of activities from sub-sectors that require a great deal of electricity per unit of square meter (retail trade), those that use large quantities of fuel for water heating and cooking (restaurants and hotels), and those that by their nature consume little energy (warehousing, parking). Last but not least, economic development, behavioral factors and equipment efficiency are among the factors that need to be taken into account in explaining trends of energy use in the service sector across many different regions.

The service sector covers a wide range of activities, from the most sophisticated in the field of information and communication technology to simple services such as repair shops or restaurants. This sector also tends to include a large share of the informal sector in developing countries, which means activities that are not recorded regularly by

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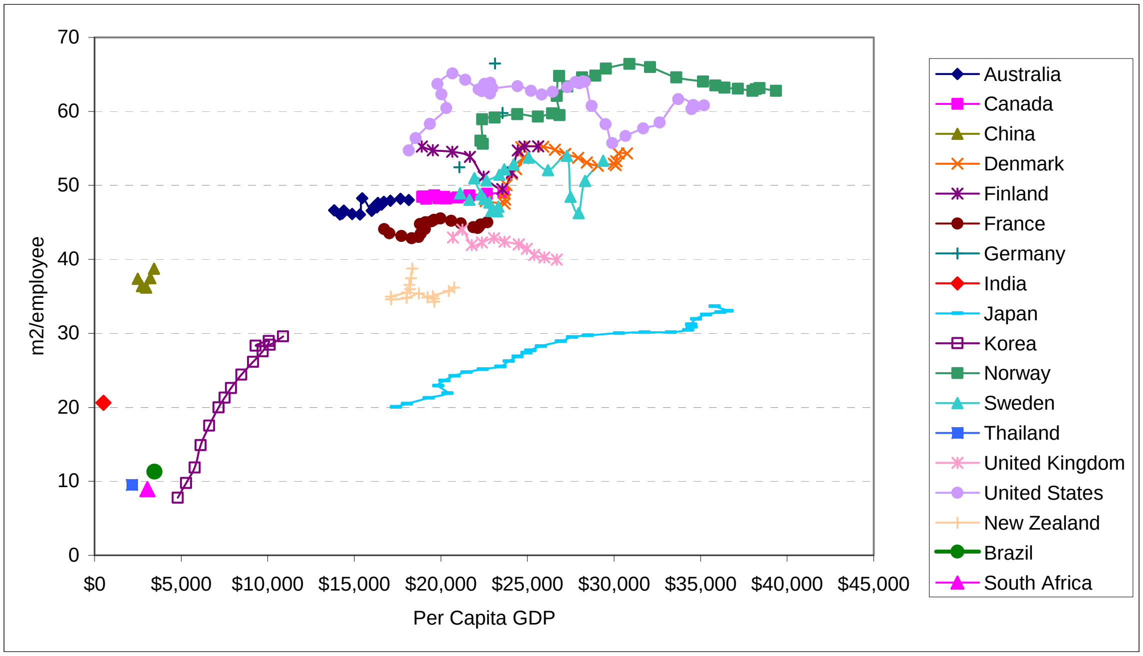
[5] A more common indicator of energy intensity in the commercial sector is energy per unit floor space. Data on commercial floor space is scarce, however, especially for developing countries. Therefore, as discussed in the sections that follow, we use number of employees as an intermediate driver variable between income (GDP per capita) and floor space.

national accounting systems. Examples of commercial sector facilities include schools, stores, restaurants, hotels, hospitals, museums, office buildings, banks, etc. Precisely, the service sector encompasses the ISIC[6] subsector 50 to 99 (see Appendix 4)

2.2.1 Floor Space Growth Model

Floor space is a key intermediate driver determining service sector energy consumption (Schipper and Meyers 1992). Unfortunately, data pertaining to commercial sector floor space are only available for a handful of countries. We collected data for 13 developed countries with a period of time ranging from 3 years in the case of Germany, to 30 years, in the case of the United States. We further gathered data points for a few key developing countries where available (China, Brazil, South Africa, India, and Thailand). Figure 11 shows floor space per employee per different countries by income level (per capita GDP) measured in market exchange rates.

Figure 11. Service Floor Space per Employee by Income level (GDP per capita)



We used the data shown in Figure 11 to perform a regression on income (see Appendix 4 for regression statistics and results). The resulting logistic equation allows an estimation of floor space per employee for countries where data are not available, as well as to project future growth according to income growth[7]. Total commercial floor space for

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[6] International Standard of Industrial Classification of All Economic Activities (ISIC)

[7] In cases where the resulting model disagreed with data available for large countries, a correction factor was applied. Countries where these were applied are: China, Japan, South Africa and Thailand. Correction factors were 1.5, 0.54, 0.74 and 0.97 respectively.

each individual country was then calculated by multiplying floor space per employee with total employment in the service sector, which is available from the World Bank. [8]

In order to project total commercial floor space, two sets of data were combined. First, the International Labor Organization publishes projections of active population by individual countries up to 2020. We extrapolated these numbers to 2030 using historical growth rates. Active population is defined as the number of employed people in addition to those unemployed but seeking employment. Actual number of employees was calculated by multiplying active population by national employment rates, which were available for individual countries from (ILO 2007). Employment rates were assumed to gradually trend to a constant value in 2030 defined by historical 25 year regional averages (See Appendix 4).

The next step in forecasting commercial sector activity was to estimate the percentage of employees in any country and in any year who are employed in the service sector. Current data on the percentage of employees working in the service sector were available from the World Bank. These data were used to fit another regression (See Appendix 4), with which we modeled how the service sector employment percentage evolves with economic development characterized by increasing per capita income. In the broadest terms, economic development entails a shift in labor, first from agriculture to industry. A higher standard of living created by industrial development then leads to an expansion of the demand for services. In this way, economies with a high percentage of employment in the service sector can be thought of as being in a third phase of economic development.[9]

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[8] However, for China and India, we used data that was previously collected from national statistics.

[9] For this reason, the commercial or services sector is often referred to as the ‘tertiary’ sector

Figure 12. Floor Space Estimation and Projection by Region

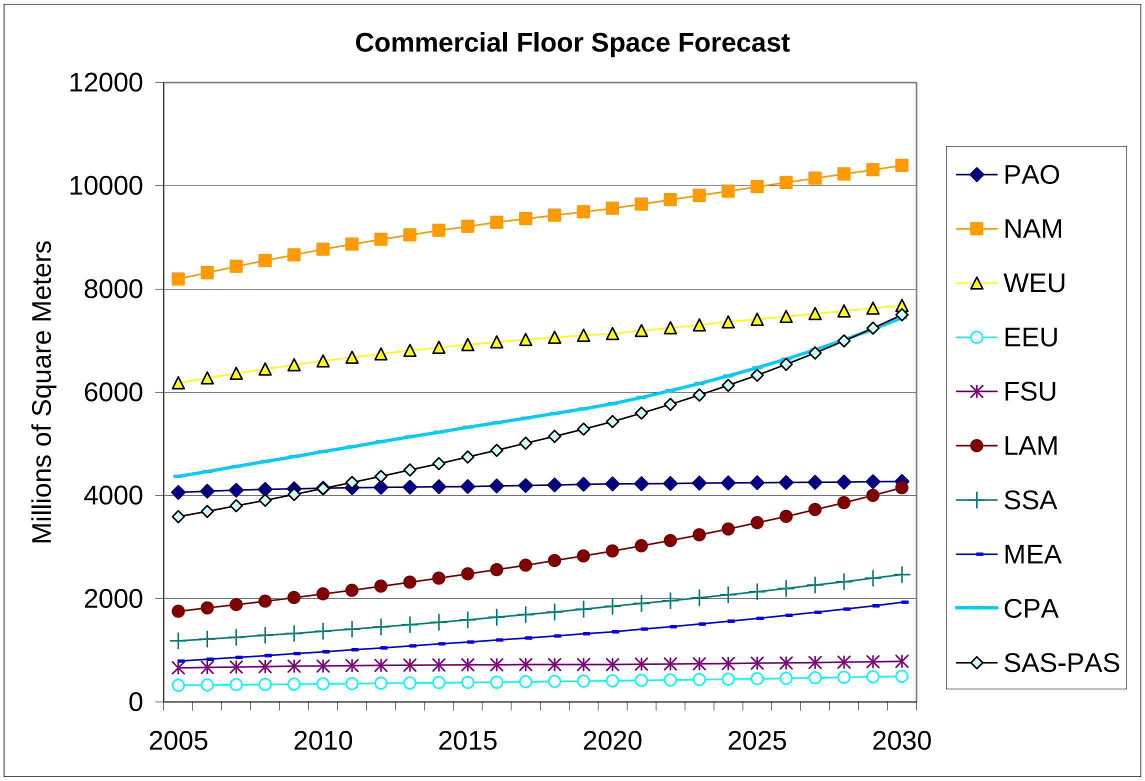
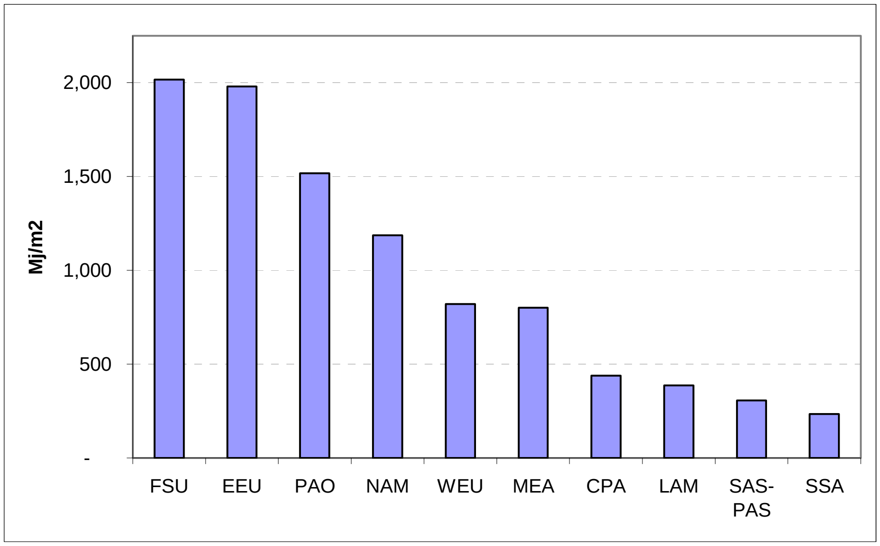


Figure 12 shows total floor space projections by region. The highest growth is expected to be in the CPA region, due mostly to China, which represents 92% of total commercial floor space in the region in 2030. Commercial floor space in developing country regions is growing fast. However, in former Soviet Union and OECD Pacific, floor space remains relatively flat, primarily due to low population growth. In North America (*NAM*) and Western Europe floor space growth will continue but gradually slow through 2025.

2.2.2 Equipment Penetration Model

Using the data from the International Energy Agency (IEA) on energy consumption in conjunction with data developed from the floor space model, we can calculate energy per square meter of floor space for each region. The energy intensity defined in this way is shown in Figure 13 for each of the 10 regions.

Figure 13. Final Energy Use per Square Meter in the Service Sector



The energy intensity thus calculated reflects the level at which energy is used for each square meter of floor space. The FSU and EEU regions are the most energy intensive, due to high space heating loads in those regions. These are followed by PAO and NAM. It is interesting to note that, although Japanese commercial buildings use less energy on average per employee than North American ones, they are more energy intensive per unit floor space. This is due to higher densities in Japan, where the amount of floor space per employee is only about half that of the North American level. Three separate factors determine intensity: the penetration of equipment, the efficiency of the equipment in use, and the climate. The first and second parameters refer to the number and type of equipment that use energy, such as the lighting fixtures, air conditioning or computers. The last factor driving energy pertains to the need to heat or cool. Other factors, such as behavior, market constraints or prices can also have an impact on intensity.

Lighting

Data for several countries were gathered from national surveys and literature research. Appendix 5 details these data and provides sources. Data points were used to develop a model where energy intensity is explained by three factors: efficiency, hours of use, and penetration of equipment. We used Japanese lighting intensity as a reference intensity[10] assuming an efficiency coefficient of 1.05, a coefficient of hours of use of 1.00, representing 7h/day of hours of use and a penetration of 105%. The coefficient of efficiency results from the penetration of equipment with associated efficacy (detailed in Section 3.2). Penetration rates for individual countries were deduced after defining efficiency factors and hours of use estimates for each country. The penetration rates were

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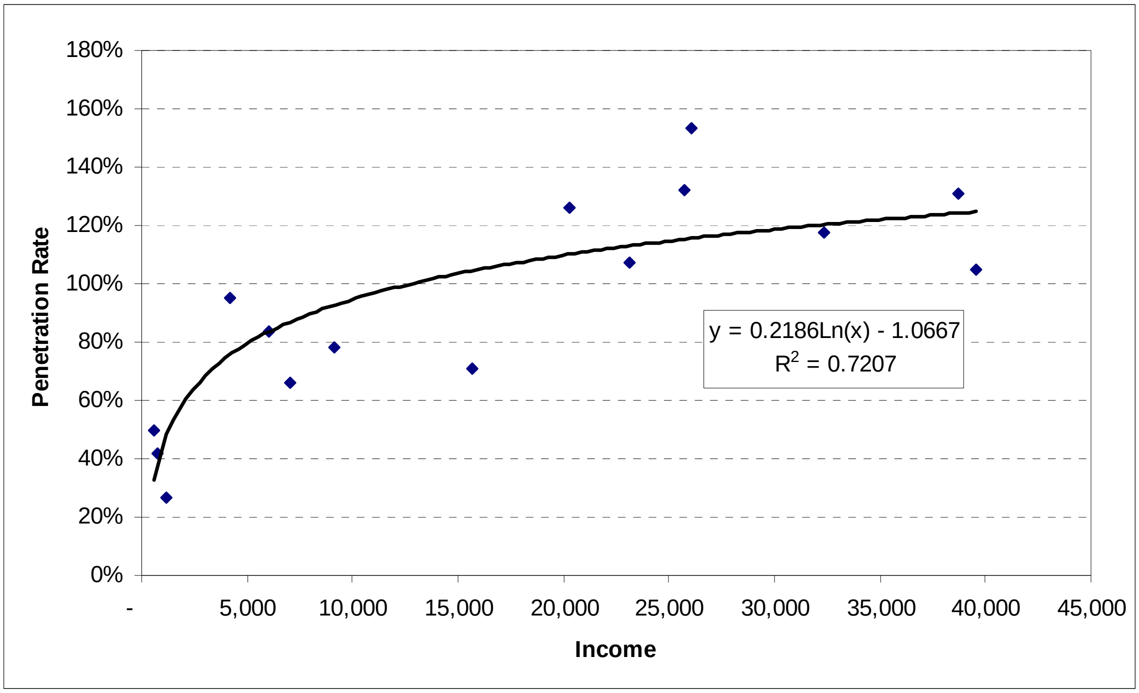
[10] The selection of a region to represent the reference intensity is somewhat arbitrary, generally the reference region was chosen according to data availability for the end-use in question.

then associated with income and used to develop a lighting equipment penetration model as represented in Figure 14.

Figure 14. Lighting Equipment Penetration Model



The lighting intensity baseline for each region was then calculated using the penetration derived from the equation shown in Figure 14 and from the assumption of efficiency coefficient and hours of use.

Cooling

Similarly to lighting, electricity used for air conditioning depends on the penetration of equipment and the efficiency of the type of equipment used as well as the number of hours in use. However, in the case of cooling, climate is also a significant driver of energy use for cooling air. In order to assess the dependency of climate on cooling intensity, data for nine US regions[11] that have a similar lifestyle but with very different climate, were gathered from (Jackson Associates 1997). Figure 15 shows the cooling energy intensity for the nine US regions by regional average cooling degree day (CDD).

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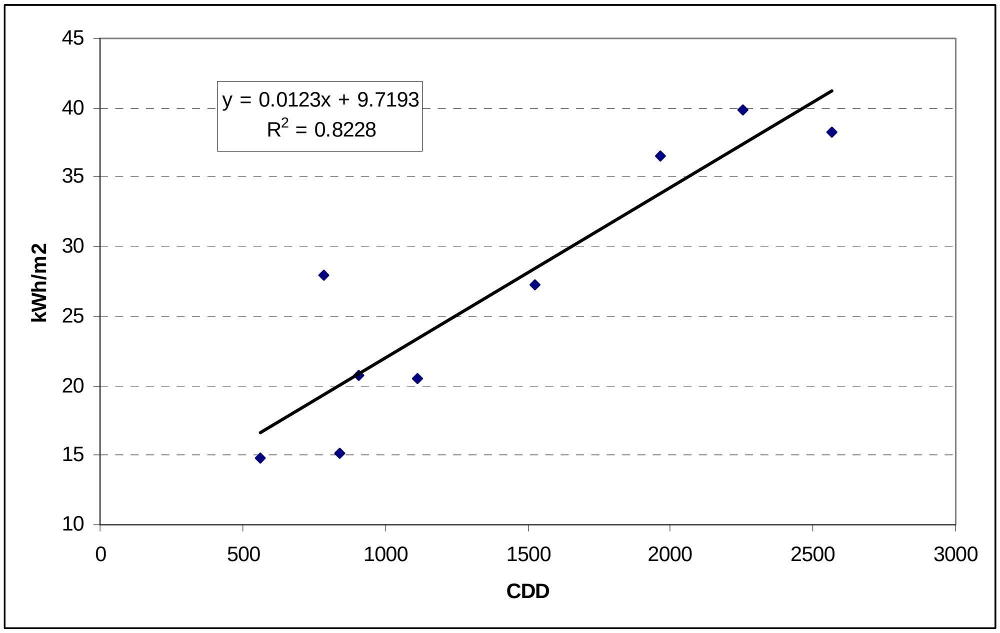
[11] New England, Middle Atlantic, East North Central , West North Central, South Atlantic, East South Central, West South Central, Mountain, and Pacific

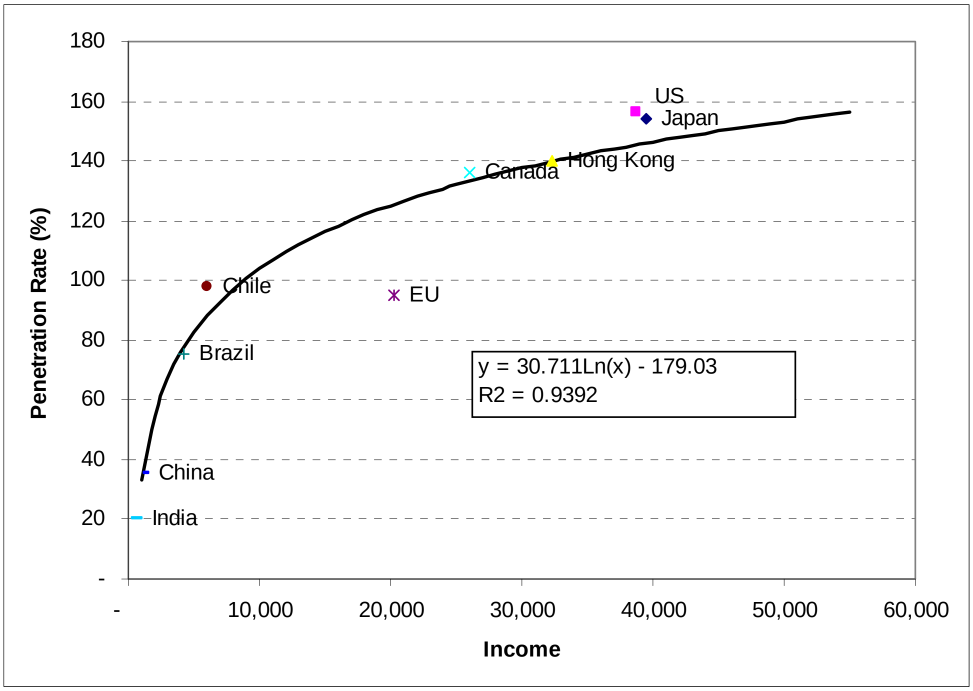
Figure 15. Average Cooling EUI by US Region (kWh/m^2)



Source: (Jackson Associates 1997); (NOAA 2008)

The resulting linear equation resulting from a least squares regression was used to estimate maximum intensity of use for countries for which data were available. The comparison between maximum intensity and intensity collected from direct sources was assumed to represent the level of equipment penetration for countries were data was available. Appendix 5 details the data collected. Figure 16 shows the resulting penetration estimates for each county where data were available. These data were then fit with a regression and Figure 16 also shows the resulting equation. This equation was then used to estimate penetration rates for regions where data were lacking. The equation was also used to forecast penetration levels to 2030.

Figure 16. Cooling Equipment Penetration by Income level



Ventilation and Refrigeration

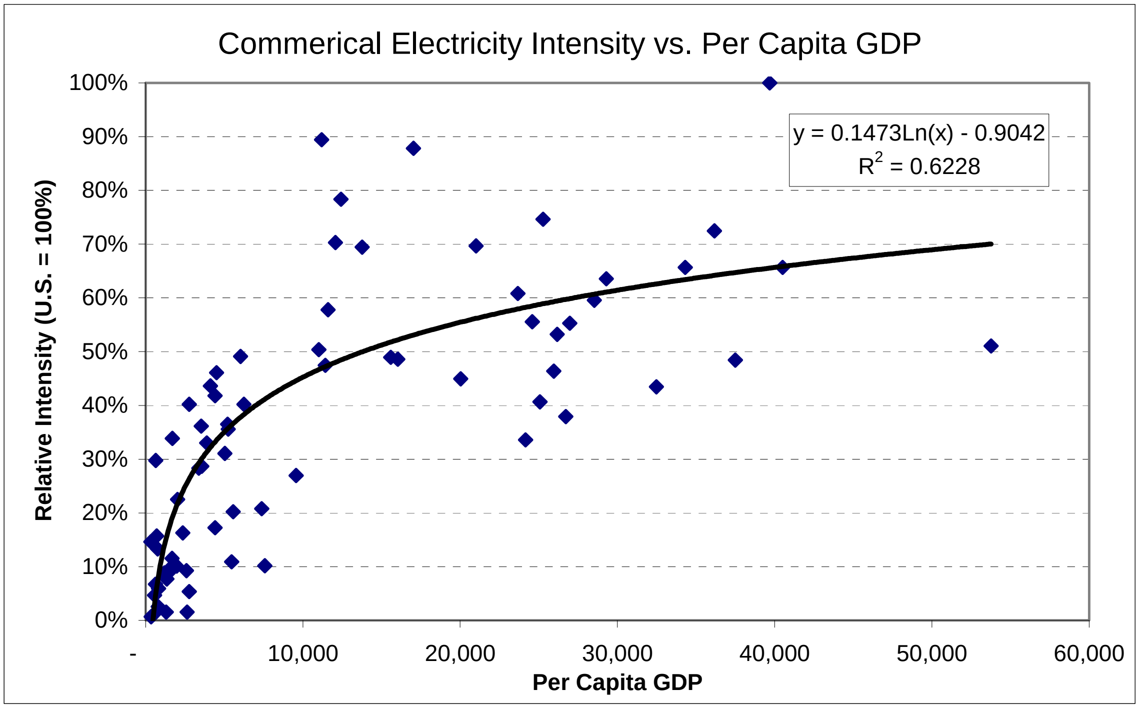
Other electricity end-uses include refrigeration and ventilation equipment. Similarly to cooling and lighting, penetration of equipment drives energy intensity. We assumed that penetration for these end-uses will follow a similar path to space cooling equipment. Hence, the penetration model developed for the space cooling end-use was used for refrigeration and office equipment intensity.

Office Equipment

The international Labor Organization (ILO 2007) provides employment data by sub-sector for 119 countries. The service sector is divided into 12 sub categories, following the ISIC categories, which are described in Appendix 4. In order to estimate and forecast office floor space, we assumed that all workers that are in categories E, I, J, K, L M, N, O, and Q are working in offices. In 2000, researchers at LBNL found that total power use by office equipment and network equipment in the US was about 74 TWh per year, which is about 2% of total electricity use in the U.S. More than 70% (53 TWh) of this energy use is consumed in the commercial sector. (Kawamoto, Koomey, Nordman et al. 2000), representing about 8% total commercial electricity use.

Based on this analysis, we estimated that in 2005, a US office worker consumed 645 kWh on average. To estimate the consumption in other countries we used the average US office worker's electricity consumption for office equipment but applied a penetration factor depending on the income level. Using data from the (IEA 2007), we then calculated total average electricity per employee and evaluated the level of total electricity used per employee per region over income level[12]. Figure 17 shows the results. Using the U.S. a reference (penetration of 100%), we then calculate the consumption of office equipment by multiplying the U.S. estimate by the penetration factor determined by the regression.

Figure 17 Electricity Consumption per Square Meter of Floor space (U.S. = 100%)



Finally, office equipment intensity is modeled with the assumption that the intensity of this equipment scales with total electricity intensity. The resulting intensity is given by:

$$Intensity_{OfficeEquipment}\ (kWh) = 645\ kWh\ \times (0.1473 \ln (Income) - 0.9042)$$

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[12] We do not include countries in the regression that have a high use of electricity for cooling and space heating (Norway, UAE).

3 Module 2 – Unit Energy Savings Potential

The second major element of the present analysis is to create realistic scenarios for efficiency achievements of EES&L programs throughout the world, many of which have not yet been proposed, let alone fully implemented. This means making a judgment of technical targets in every region for every end-use. Importantly, it also requires an estimate of the current technology level of the market. Baseline and target levels are related, since countries with low efficiency products (generally developing countries) will likely have to make moderate achievements before they can strive for international best-practice.

Where possible, we draw on previously published estimates, provided they are recent enough, relying on a reference database developed over the past several years with the specific purpose of collecting references and data sources for baseline UECs (including use patterns), high efficiency technologies, and efficiency levels defined by existing standards and labeling programs throughout the world.

We define a two-tier timeline for the implementation of EES&L. The first tier is for a set of programs assumed to be implemented in 2010. The target levels for this tier represent technologies *available and cost-effective now*. A more fully realized efficiency potential is modeled as the second tier, which would come into effect in 2020. This case does not represent the 'technological potential', but a more pragmatic 'maximum cost-effective efficiency' level. In general, these technologies are already available on the world market and would already be cost effective. In some cases, however, they are assumed to become into cost-effectiveness over the next 12 years. In principle, therefore, the analysis requires the estimation of base case UEC, and two target UECs for each region, sector, end-use and fuel considered, for over 500 parameters. In many cases, however, simplifying assumptions can be made by grouping regions and making use of international trends and modeling programs, in terms of alignment with neighbors and trade partners. Nevertheless, we understand that the degree of accuracy in this type of analysis is largely determined by the detail of the parameters. Therefore, we have spent a great deal of effort in gathering data on as many end-uses in as many regions as possible.

Although there is some variability between energy consuming products among countries, there are also many similarities. The sections that follow give a brief overview of efficiency measures, common across countries, which form the technical basis of the assumptions made in the analysis.

The major appliances modeled are refrigerators, washing machines, televisions, fans, and products using stand-by power. Air conditioning, water heater and space heating consumption is modeled separately, as described below. The annual energy consumption of these appliances is largely an engineering parameter, and is highly dependent on product class and capacity, and less so on use patterns. The estimation of unit energy consumption for these products therefore depends on collecting market-specific information about commonly used technologies in as many regions and countries as possible.

In developing a high efficiency scenario we take into consideration the specifics of end-use technologies and regions to the extent possible. The most significant inputs in development of these scenarios are the current state of technology in each market, and the history of efficiency policies to date. Countries with an existing program will be able to take advantage of momentum in order to accelerate efficiency programs, while those with no programs will move more slowly, and likely take small initial steps. We emphasize that the resulting scenarios do not represent what is *likely* to happen, rather, what is *feasible* if governments are sufficiently motivated and provided with the necessary resources to develop effective programs. Neither do the scenarios represent the *technical* potential. We judge that it is not realistic for a country in sub-Saharan Africa to adopt a standard for refrigerators that greatly exceeds the current U.S. standard, for example. Even though the technology exists, countries are very unlikely to require their citizens to purchase equipment that is currently not on the domestic market and is much more expensive than presently available products.

There are three major types of EES&L programs. These are:

- *Minimum Efficiency Performance Standards (MEPS)* – Product types, usually divided into sub-classes are required to perform at the level of efficiency determined by the standard. Products failing to demonstrate compliance are banned from the market. MEPS raise the efficiency of the market by eliminating the least efficient model.
- *Comparative Labels* –Labels provide information to the consumer about efficiency level. Comparative labels are designed to provide a means of comparing multiple products at the time of purchase. These labels boost the efficiency of the market by generating consumer preference towards more highly-rated models.
- *Endorsement Labels* – These labels represent a ‘seal of approval’ issued by the government or an independent entity. Only those models of very high efficiency are awarded the label. These labels improve the average market efficiency by raising the market share of the highest performing equipment.

These program types are discussed in detail elsewhere [see (Wiel and J.E. McMahon 2005)], and we do not discuss them further here. It is worth noting, however, that, due to the complexity of the number of regions, sectors and end-uses considered, we make the simplifying assumption that the entire market reaches the efficiency target in the implementation year – an assumption that corresponds to the implementation of a MEPS program, although other programs such as a comparative labeling program could achieve the same result in moving the average of the market to the same level.

The most detailed and data-intensive analyses of the potential impacts of standards and labeling programs take cost-effectiveness into account in an integral way, often defining the optimum policy in terms of ‘economic potential’ that is, the market transformation that maximizes net economic benefits to consumers[13]. These benefits can be quantified by a variety of different metrics, including Least Life Cycle Cost, Cost of Conserved Energy, or Benefit to Cost ratios. Although desirable, for two reasons it is not practical to perform this type of analysis here, for two reasons. First, a main variable in the analysis of net costs is the increased equipment cost to consumers. These data are scarce, and can vary significantly between countries. Likewise, the marginal cost of energy (price of last unit saved on energy bill) varies significantly between countries, and its estimation requires knowledge of the tariff structure. Collection of these two datasets is not feasible for a large number of countries.

Instead of a rigorous cost-benefit analysis, we emphasize the setting of realistic, achievable goals. Of course, the degree to which the transformation of the market to a new technology is achievable depends a lot on the cost-effectiveness of the technology. We do not consider this explicitly, but it is implicit, because we consider adoption of levels that generally have been adopted as a minimum efficiency performance standard (MEPS) in at least one country, and has been evaluated for cost effectiveness. We also consider the adoption of technologies that have been present on the market for some time, and enjoy a considerable market penetration in multiple regions. For example, compact fluorescent lamps are now a well-established product for lighting, as are electronic ballasts for linear fluorescent lamps. Air conditioners of over 3 EER (W/W) can be found in Japan and Europe, and may represent an achievable target. On the other hand, heat-pump water heaters, which are extremely efficient, are currently an uncommon technology which may not currently be suitable for a standards program, but may become widely available and cost effective over the next decade[14]. This does not, however, mean that such a technology cannot be successfully pursued by a government policy such as a rebate program, or R&D program. That said, we do not consider it as being an appropriate level for efficiency targets.

Two specific corrections are not taken into account in these scenarios. First, we do not assume improvement in efficiency in the absence of a program. While in some cases the 2010 baseline is higher than the current level (due to already scheduled standards), between 2010 and 2020, we assume that the baseline efficiency is constant. Historically, there is generally (but not always) a gradual trend towards higher efficiency from market forces alone, but this increase tends to be small in comparison to the increase propelled by EES&L programs. On the other hand, the targets that we specify in the high efficiency scenario are already known to exist and be cost-effective. More often than not, markets overshoot the targets due to learning by manufactures in the time between

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[13] Examples of these are analyses of potentials for the United States Rosenquist, G., M. McNeil, et al. (2006). "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors." Energy Policy **34**(17).and IEA countries IEA (2003). Cool Appliances, Policy Strategies for Energy Efficient Homes. International Energy Agency. Paris

[14] A recent assessment Rosenquist, G., M. McNeil, et al. (2006). "Energy efficiency standards for equipment: Additional opportunities in the residential and commercial sectors." Energy Policy **34**(17).found that this technology could be cost-effective in the United States by 2020. Accordingly, it is used in the 2nd tier of EES&L programs for the North American region.

promulgation and implementation of standards[15]. These two effects are very difficult to predict, especially for a wide range of regions and end-uses. Unpredictably high efficiency in the base case and policy case also tend to compensate for one another. In fact, it can be argued that they are both effects of the same learning process in the manufacturing industry and should therefore, at least on average, tend to cancel each other out.

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3.1 Residential Sector Baseline End-use Energy Demand and High Efficiency Scenarios

Energy efficiency standards and labeling programs address efficiency, not consumption. Knowing the baseline efficiency, and the target efficiency achieved by standards generally allows an estimate of fractional, or percentage improvement. This must be combined with an estimate of the baseline demand (or "load") in order to determine the total emissions savings potential from each end-use.

As discussed in Section 2, the estimation and forecast of end-use demand in each sector is distinct. In the residential sector, the ownership rate of each type of equipment is modeled, essentially providing the total number of units in the stock, when combined with the number of households.

The next section describes the methodology for estimating end-use demand in the residential sector and estimating fractional improvement from EES&L programs for all sectors. As described in Section 2, residential energy demand is based on a model of household appliance ownership. The next step is to estimate the typical energy consumption of each appliance or other piece of equipment installed in the household. The method for estimating this consumption varies between end-uses.

3.1.1 Lighting

As described in section 2.1.2, lighting energy consumption is a function of number and type of fixtures in the household, and hours of usage of each lighting point. Estimates of hours of use per day for each fixture are given in Table 8.

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[15] There are other reasons as well. For example, evidence suggests that manufacturers in Mexico outperformed MEPS in that country in order to produce products competitive in the wider North American Market – see Sanchez, I., H. Pulido, et al. (2007). Assessment of the Impacts of Standards and Labeling Programs in Mexico (four products).

Table 8 Lamp Usage per region

Region	Hrs per day	Source/ Assumption
PAO	1.0	Calibrated to IEA data (IEA 2007)
NAM	2.5	Calibrated to IEA data (IEA 2003)
WEU	1.0	Calibrated to IEA data (IEA 2007)
EEU	2.5	(Bertoldi and Atanasiu 2006)
FSU	4.7	Calculated from (IEA 2006) assumes all incandescent (60W)
Other Regions	2.3	Average of Multiple Sources – See Appendix 3.1

Data on hours of usage for developing regions varies greatly, and there is some question about the reliability of these sources. In order to minimize the impacts of these errors on a particular region, we chose to use an average hours of usage for regions 6 through 10. Weighting by electrified households, we come up with 2.3 daily hours of use per bulb.

Lighting consumption is determined by assuming certain wattage per lamp bulb. The most common wattage found in the surveys is 60W for incandescent bulb, 15W for CFLs and 36W for fluorescent tubes. Annual lighting consumption is then given by:

$$\mathrm{UEC(kWh)} = \mathrm{Nb\ of\ Pts} \times \mathrm{Hrs} \times 365 \times (\%\mathrm{IL} \times 60 + \%\mathrm{FL} \times (36 \times \frac{\mathrm{Eff}}{\mathrm{Eff}_0} + \mathrm{Ballast}) + \%\mathrm{CFL} * 15)/1000$$

Incandescent lighting is common in every country in the world, especially in the residential sector, and although the penetration of compact fluorescent lamps (CFLs) varies from country to country, there is significant savings to be gained from a labeling program promoting CFLs. We model the impact of CFL endorsement labeling programs by simply assuming that between 2010 and 2030, households will gradually replace half of their incandescent bulbs with CFLs.

The energy consumption of fluorescent tube lamps is a function of lamp efficacy[16] and of losses in the lamp ballast. Ballast losses can be quite high, and vary considerably between regions. Where fluorescent tube lighting is used, there are efficiency gains to be made by switching from magnetic to electronic ballasts. Typically, the losses in an electromagnetic ballast are 10W, which represents 22% losses on the system. Low-loss electromagnetic ballasts can reduce this loss to 12%. Electronic ballasts that have a 4W consumption, also allow the light to function at a higher frequency which improves the lighting intensity by 15%. Therefore, in our model we assume that a 36W tube can be replaced by a 15% less consuming tube, which represents a 25% improvement compared

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[16] The term ‘efficacy’ is commonly used in place of ‘efficiency’ in describing the amount of light output per unit input energy of a lamp or lamp-fixture system.

to a standard electromagnetic ballast. (IEA 2006). Table 9 summarizes assumptions of baseline and target efficiencies for fluorescent tubes.

Table 9 Unit Baseline and Target Efficiency Levels for Residential Fluorescent Tube Lighting

Region	W (Tube 36W + Ballast)			Source	Assumption
	Base Case	2010 Target	2020 Target		
PAO	41.4	26.496	26.496	(IEA 2006), Japanese Luminaire Association, 2005	36% savings by 2010, compared to 1997. 1997 baseline is assumed to be efficient electromagnetic ballasts.
NAM	34.6	34.6	34.6	(IEA 2006)	All ballasts are electronic ballasts by 2010, no firther improvement
WEU	41.4	34.6	34.6	(IEA 2006)	Electronic Ballast become mandatory in 2010
EEU+LAM +SSA+CPA	44	41.4	34.6	(IEA 2006)	Low-Loss electromagnetic ballasts mandatory in 2010, electronic ballast in 2020
SAS-PAS	51.6	48.7	40.6	Voice magazine (oct 2005)	Low-Loss electromagnetic ballasts mandatory in 2010, electronic ballast in 2020

3.1.2 Refrigeration

Refrigerators are one of the most variable products between countries. The size of the refrigerator cabinet varies dramatically from country-to-country, as does the presence and configuration of a freezer compartment, the presence of added features, such as ice makers, automatic defrost, and through the door features. Luckily, it is also the product most often regulated by EES&L programs. Therefore, international efficiency and unit energy consumption (UEC) estimates for refrigerators and refrigerator-freezers are more widely available than for many other products. As a result, and because of its high share of household electricity consumption, refrigerators were the first focus of a prior analysis such as the present one by the authors in 2006. Much of the data and assumptions supporting savings estimates are provided in that report (McNeil, Letschert and S.Wiel 2006) and are not repeated here. Instead, we summarize the basic assumptions for each region in Table 10.

In general, we assume that quite aggressive targets are feasible for refrigerators, especially in 2020, where we assume that all regions will reach the current ‘A+’ level defined by the European Union. There are two reasons for our optimism:

1. There exists a wealth of understanding of refrigerator efficiency technology (compressor design and insulation), with high efficiency a requirement in some markets already for decades.

2. There is a trend towards internationalization of major white goods, and a large number of successful EES&L programs in many countries, providing ample opportunity for alignment to best practices.

Table 10 Assumptions for Unit Energy Consumption for Refrigerators

Region	kWh / year			Assumption
	Base	2010	2020	
PAO	537	476	318	Based on current programs in Japan, AUS/NZ and Korea. Assume Korean market reaches 'A' level by 2020, Top Runner achieves additional 10% improvement, and AUS/NZ standards harmonize with those in the U.S. Efficiency in all countries reaches EU A+ level by 2020.
NAM	562	506	391	Additional improvement found cost effective in 2010 by (Rosenquist, McNeil et al. 2006). Efficiency reaches EU A+ level by 2020.
WEU	364	268	271	Average reaches A level by 2010, A+ level by 2020.
EEU	483	268	271	Meets current EU standards by 2010, synchronized with WEU by 2020.
FSU	644	483	271	Match EU 1999 MEPS by 2010. Average meets current 'A' level by 2015.
LAM	440	261	216	Based on current MEPS in Mexico and Brazilian labeling program. Assume 39% improvement in Brazil by 2010. Mexican standards harmonized with U.S. by 2010. Efficiency reaches EU A+ level by 2020.
MEA+SSA	445	364	271	Currently at pre-standard European levels. Achieves current EU levels by 2010. Efficiency reaches EU A+ level by 2020.
CPA	489	353	302	2010 Baseline according to 2007 MEPS. Average meets current A level by 2010. Efficiency reaches EU A+ level by 2020.
SAS-PAS	548	301	223	Based on current Indian standards and assumes an aggressive update in 2010. Efficiency reaches EU A+ level by 2020.

3.1.3 Air Conditioning

For air conditioners, climate plays the dominant role in determining energy consumption. Not only will countries in warm climates have for a potential increase in air conditioner ownership, but households that own them will likely use them more often. As in the case of saturation, we model UEC according to cooling degree days (CDD) and income. The dependence on climate is obvious, but there is a significant dependence on income as well. Wealthier households will be less likely to be sparing in air conditioner use in order to keep utility bills low. More significantly, however, wealthy households may purchase larger units, and/or own several units. Ownership of air conditioners is formulated in terms of whether air conditioning is used or not; the use of multiple units is taken into account in the UEC model. Residential central cooling is common only in the North American region. We assume this situation to continue throughout the forecast. In addition, we do not distinguish between the room air conditioning and central air conditioning in terms of cooling load, under the assumption that cooling of large spaces may be achieved by use of multiple room units.

The UEC model makes use of 37 data points, some of which were taken from the same sources as the ownership rates shown in Table 2. Values of CDD were taken from (Baumert 2003) when the data corresponded to a country average. In cases where the data represented a particular locale (like a city), CDD were recalculated according to weather data from the Weatherbase website (www.weatherbase.com), which gives average monthly temperatures. In order to take into account daily temperature variations from monthly data, we used the method originally defined in (Erbs, Klein and Bechman 1983). A linear regression of the data resulted in the following relationship:

$$UEC\ (kWh) = 0.345*Income + 1.44 * CDD - 967$$

The R^2 value of the regression is 0.67. Both the household income and cooling degree days are highly significant variables. A result of the income dependence is that baseline UEC is not static, but increasing with time (with income).

We make two corrections to this model of air conditioning. First, we assume a maximum cooling load of 3500 kWh, which is about the modeled value for the United States. Second, space cooling use modeled in this way seems to overestimate heat pump use in Japan and China, which is provided by (EDMC 2007) and (Zhou, McNeil, Fridley et al. 2007). Therefore, we added a correction factor for space cooling in the PAO and CPA regions, which we found to be 0.26 and 0.41 respectively.

The primary handle for efficiency improvement of air conditioner remains the efficiency of the cooling system, including the use of variable speed drives.

Like refrigerators, room and central air conditioner and heat pump efficiency scenarios are constructed using the experience of several major countries, both industrialized, and in the developing world. Since room air conditioners are a highly internationalized product, we assume a high potential for alignment of standards for this product. In addition, international practices are emerging, particularly with the announcement of Chinese “reach standards” that, when coming into effect in 2009, will be among the most stringent in the world. Table 11 gives a summary of the assumptions made for air conditioner efficiency standards.

These scenarios are based on programs already in place or defined but not yet implemented in major countries in the region, or alignment with programs in neighboring regions. The target efficiency level is determined in some part by the experience to date so far with efficiency regulations. These assumptions are briefly summarized here, but described in more detail in (McNeil and Letschert 2007).

- *China* – Based on Proposed Chinese Standards. China’s standard of 2009 will likely be the most stringent in the world when it is implemented. Because of China’s influence as an exporter, we use Chinese levels as a proxy for several regions, and set the Chinese standard of 2009 as a target for all regions at least by 2020.
- *India* – Based on current baseline and proposed Indian Bureau of Energy Efficiency Standards analyzed in a recent study by CLASP-LBNL.
- *Mexico and Brazil* – Based on current programs, with assumption of alignment with Chinese 2009 standard by 2010.

- *Latin America (except Brazil and Mexico)* – Based on CLASP research in Central America. Assume Latin America to reach alignment with Brazil and Mexico, which both have well-established EES&L programs.
- *Other Regions* - Efficiency programs for air conditioners are not well-developed for the most part in Sub-Saharan Africa, Indonesia, developing Asian countries[17], North Africa or the Middle East. Therefore, we assume that the baseline efficiency is similar to the Chinese 2000 standard[18], and that these levels will persist till 2010. The high efficiency scenario proposes that these countries will develop standards equivalent to Chinese standards, but with a 5-year lag time.

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[17] Thailand, the Philippines and Singapore are exceptions.

[18] This may be an overestimate for some regions, where 'dumping' of inefficient products, and mass importation of older used products is common.

Table 11 Baseline Energy Efficiency Ratio (EER) and High Efficiency Scenario for Air Conditioners

Region	EER (W/W)			Source	Assumption
	Base	2010	2020		
PAO	3.85	4.81	5.81	Top Runner Website - http://www.eccj.or.jp/top_runner/chapter7_3_02.html, Korea Standards	Top Runner heat pump standards are quite high already, and are set to increase in 2010. We take from (Murakami S., M.D., Yoshino et al. 2006) the scenario that average efficiency will improve from a EER of 4 to 6 by 2020. Levels in AUS/NZ and Korea are assumed to match the Japanese standards.[19]
NAM	3.37	3.37	3.37	(Rosenquist, McNeil et al. 2006)	U.S. Standard for Central Air Conditioners currently set at 13 SEER, which we estimate to be equivalent to COP of 3.37. Additional improvements were not found to be cost effective in the reference.
WEU+ EEU+ FSU	2.80	3.20	4.00	(Bertoldi and Atanasiu 2006)	Current 'A' level set at 3.2, but some products reported at 4 or 5. Assume that the EU program will aggressive, with the market average reaching the A level by 2010, and reaching 4 by 2020. Further Assume that market for this product in EEU and FSU is largely harmonized with WEU from 2010 on.
LAM	2.64	2.96	4.00	(McNeil and Letschert 2007)	Same as WEU, except baseline at 'E' level
CPA	2.60	3.20	4.00	(Lin J. 2006)	Baseline Corresponds to 2005 Standard (Split Systems). Reach Standard in 2009 is 3.2. Assume new standards at 4 by 2020
SAS-PAS	2.55	3.20	4.00	(Danish Energy Management 2004), (McNeil and Iyer 2007)	Weighted average based on Baseline efficiency in India, Malaysia and Thailand. Assumes Harmonization with Chinese standards by 2010
Other Regions	2.40	2.60	3.20		Estimate based on current lack of efficiency programs. Will reach China 2009 standard by 2020.

3.1.4 Washing Machine

Washing machine energy varies by product class, and by the number of loads used. The three types of washer can be characterized as: horizontal axis, vertical axis and impeller type. Washing machine energy consumption can be reduced both through the efficiency of the motor system, and the reduction of hot water use. Table 12 summarizes efficiency scenarios for washing machines.

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[19] Cooling only systems are rare in Japan. Our Japan scenario is slightly more conservative than the citation, since efficiencies in that report relate to stock, while our asssumed efficiencies refer to new products only. Updates to Top Runner standards which will come into effect in 2010 are somewhat difficult to interpret due to a change in the perfomance metric used by the program. Finally, comparison between Japanese COPs and those in other countries is difficult due to differences in test procedures.

Table 12 Baseline Energy Consumption and High Efficiency Scenario for Washing Machines

Region	kWh			Reference	Assumption
	Base Case	2010 Target	2020 Target		
PAO	60	14	14	(Murakami, Levine et al. 2006)	New High Efficiency washing machine (54Wh/cycle) becomes mandatory by 2010 (assumes 250 cycles per year)
NAM	194	194	194	US Standard (2007)	No further efficiency improvement after 2007 standard set at 775Wh/cycle
WEU	126	119	119	(GfK 2005), (Bertoldi and Atanasiu 2006)	The current labeling program pushes the whole market to the Level A by 2010 (80% is Level A or better in 2004), assumes 2.5kg/load and 250cycles/year
EER	128	119	119	(GfK 2005), (Bertoldi and Atanasiu 2006)	The current labeling program pushes the whole market Level A by 2010 (67% is Level A or better in 2004), assumes 2.5kg/load and 250cycles/year
FSU	169	119	119		Level C is reached by 2010, and level A becomes mandatory that year, assumes 2.5kg/load and 250cycles/year
LAM	191	149	108	(Lutz, McNeil et al. 2008), US Standard, European Label	For horizontal axis machines, European Level C in 2010, Level A in 2020 (same usage as baseline, and baseline is level E), 2004 US standard adopted in 2010, 2007 US standard in 2020 for vertical axis machines
SSA	181	97	68	(Pretoria 2003), US Standard, European Label	
MEA	183	141	99	(Davoudpoura and Ahadib 2006), US Standard, European Label	
CPA	12	6	6	(Lin and Iyer 2007)	Based on 32Wh/kg/cycle for the baseline and 17Wh/kg/cycle for the efficiency scenario (current endorsement label), assumes 2.5 kg/cycle and 250 cycles/year
SAS-PAS	190	102	102	(Letschert and McNeil 2007)	Based on India Market consideration (semi automatic machines versus horizontal axis)

3.1.5 Fans

Fan energy consumption is clearly a function of cooling degree days, which determine the length of the season in which fans are used, and the number of hours per day they are necessary. Data on fan energy is very sparse, however. Therefore, we estimated fan energy at the region level only, and extended some estimates to regions with similar climates.

Table 13 Baseline UEC per region for Fans

Region Number	UEC (kWh)	Reference/Assumption
PAO	21	IEA Energy Indicators
NAM	50	(USDOE 2001))
WEU	50	Same as NAM
EEU	50	Same as NAM
FSU	50	Same as NAM
LAM	88	Same as MEA
SSA	88	Same as MEA
MEA	88	(Davoudpoura H. and M.S. Ahadib 2006)
CPA	10	Statistical year book 2002
SAS-PAS	150	(Murthy K.V.N., Sumithra G.D. and Reddy 2001)

Potential fan efficiency improvement is based on studies in the U.S. targeting ceiling fans. U.S. ceiling fans often are fitted with lighting fixtures, and both the mechanical and lighting energy are considered for efficiency by the USEPA Energy Star program. For our study, we consider only mechanical efficiency. Energy Star is 18% more efficient than the baseline, and the best technology available is 39%. Those will be the targets for 2010 and 2020 (USDOE 2005).

Table 14 High Efficiency Scenario for Fans

Region	Fans			Source	Assumption
	Base Case	2010 Target	2020 Target		
PAO	21	17	13	(USDOE 2005)	Energy Star Level by 2010, best technology available by 2020
NAM+WEU+EER+FSU	50	41	31		
LAM+SSA+MEA	88	72	54		
CPA	10	8	6		
SAS-PAS	150	123	92		

3.1.6 Televisions

For televisions, we model only color televisions, since EES&L programs will only cover new products. This is a rapidly evolving product, but one which is relatively uniform across regions, as it is manufactured mostly by large multinational companies for global markets.

The consumption of a TV is mainly dependent on the size and the image technology. We will consider three types of TVs: CRT, LCD and Plasma TVs, with respectively an average power of 70, 180 and 300W. We do not consider any regional scenarios because of a lack of data, but we do look at the global market of TVs and the potential for energy efficiency improvement. Display Bank provides data and projections on market shift from CRTs to LCD and plasma TVs between 2003 and 2010 (Jones, Harrison and Fairhurst 2006). We assumed that CRTs decrease at a constant rate and that their lost market share splits between plasma and LCDs. The market research firm Gfk found that the daily viewing time was 232 minutes per person in Europe, 260 in the US, 240 in Japan and 150 in South Korea (Bertoldi and Atanasiu 2006). We therefore assumed an average of four hours per day per TV. The resulting market share and UEC for televisions are shown in Table 15

Table 15 Baseline UEC and Market Shares of CRT, LCD and Plasma TVs

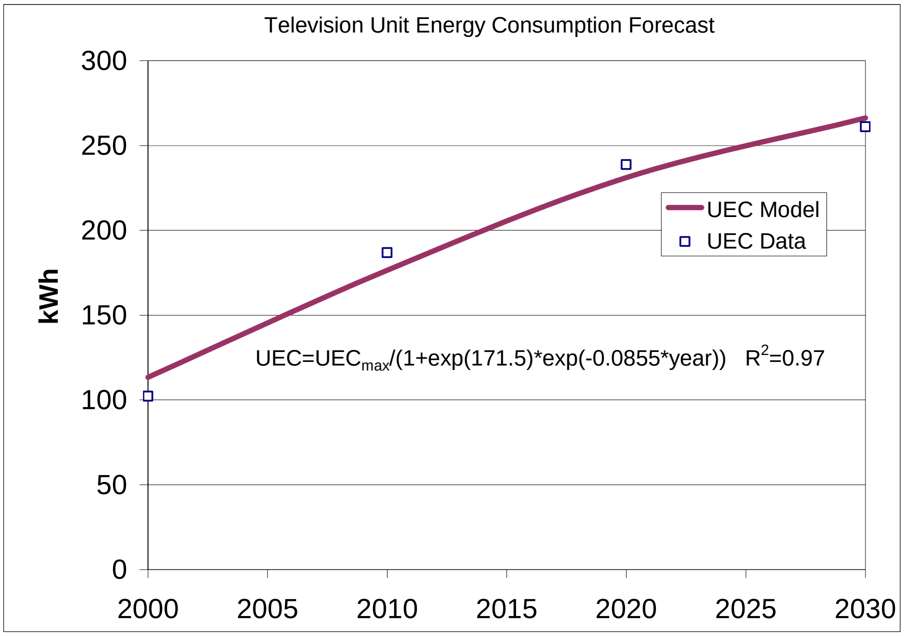
Technology:	Power rating W	UEC (4 hrs per day)	Market Share			
			2000	2010	2020	2030
CRT	70	102	100%	43%	18%	8%
LCD	130	190	0%	43%	55%	61%
Plasma	300	438	0%	14%	26%	32%
		Average UEC kWh	**102.2**	**186.9**	**238.8**	**261.1**

For the purpose of demand forecasting, the weighted average unit energy consumption (UEC) was modeled with a logistic function as a function of time. The results are a time dependency of UEC given by

$$UEC = UEC_{max} / (1+\exp(171.5) * \exp(-0.0855 * year))$$

Where UEC_{max} is taken to be 300 kWh / year

Figure 18 Television UEC Forecast



A recent study (Armishaw and Harrison 2006) considering the environmental impacts of TVs found that LCD consumption can be reduced by 34% by using "super bright LEDs" instead of CFL/discharge backlighting and that plasma TVs' consumption can be reduced by 36% by incorporating an energy recovery circuitry and additional effects from large-scale integrated circuits (LSI). Combining those technical improvements to market share projections provides two scenarios of UEC that are time dependent and reflect the evolution of the market towards more energy consuming TVs.

Table 16 Efficiency Scenario for Televisions

Region	TVs, Efficiency			Source	Assumption
	Base Case	2010 Target	2020 Target		
All regions	100%	137%	148%	(Armishaw and Harrison 2006)	34% improvement on LCD, 36% on Plasma TVs by 2010

3.1.7 Stand-by Power

The stand-by power diffusion model is described in section 2.1. Since this particular end-use is active 24h hours a day, the base case UEC is a straightforward calculation. We assume the average base case stand-by wattage to be 5W per product. For a maximum 60W stand-by power (which represents 12 devices consuming a stand by power of 5W), the annual consumption is 512 kWh, given by

$$UEC(kWh) = 60W \times 24h \times 365 \times 10^{-3} = 512kWh\,.$$

Efficiency scenarios are given simply as 3W and 1W stand-by, values that appear commonly as proposed standards or endorsement levels.

Table 17 Efficiency Scenario for Stand-By Products

Region	Stand By, kWh			Assumption
	Base Case	2010 Target	2020 Target	
All regions	44	26	9	3W in 2010, 1W in 2020

3.1.8 Ovens

In terms of final (site) energy, gas ovens are found to be slightly more consumptive than electric ones in the European Union and the United States. In terms of emissions, however, an electric oven generally produces much more greenhouse gases. Therefore we distinguish ovens by type of energy used. Estimates of market share of electric versus fuel for cooking are given in Table 18[20].

Table 18 Share of Commercial Cooking Fuels

Region	Fuel Share		Reference
	Elec	Fuel	
PAO	22%	78%	(EDMC)
NAM	61%	39%	(USDOE 2007)
WEU	59%	41%	IEA
EEU	59%	41%	Same as WEU
FSU	22%	78%	DHS Surveys

The most common ways to improve efficiency in an oven are: decreasing the thermal mass, optimizing the vent flow, and increasing the insulation. Those options combined with others have been studied in a report for the SAVE II program[21]. This report (Kasanen 2000) found that an economically acceptable package could provide a 48%-improvement and that the maximum potential for savings was 54% compared to the baseline for electric ovens. Results for gas ovens were almost identical, with a 47% improvement at the current economically acceptable level, and a maximum potential of 55%. Table 19 shows estimations of baseline energy consumption for each energy type, as well as our assumptions for efficiency targets in 2010 and 2020.

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[20] Cooking energy type is used as a proxy for oven energy type, as the latter is not widely available. Use of different energy types for oven and stoves is generally rare, however, so cooking fuel is a reasonable approximation.

[21] SAVE II is a program sponsored by the European Union, covering a variety of products and including several elements, including labeling and .

Table 19 Efficiency Scenarios for Ovens

Ovens. kWh	Baseline		2010 Target		2020 Target		Reference	Assumption
Region Number	Elec	Fuel	Elec	Fuel	Elec	Fuel		
PAO+WEU+EER+FSU	132	167	70	89	61	77	(Kasanen 2000)	Economically acceptable target in 2010, maximum technical potential in 2020
NAM	167	248	88	131	77	114	(U.S. Department of Energy 1993)	Same efficiency improvement as Europe, 110cycles/year

3.1.9 Water Heating

Water heating energy using electricity, natural gas or other fuels is largely driven by the technology used to heat water. In particular, ownership of instantaneous shower-type water heaters will contribute significantly to electricity use, an electric or gas-storage type water heater can contribute more to household energy consumption than any other end-use, except perhaps space heating and lighting. Therefore, the most important driver of water heater energy is ownership of these types of equipment, which is modeled in Section 2.1.1. The consumption of these devices is also not simply determined, as it depends on climate, the size of households, the capacity of the device (tank size), and on cultural practices and preferences. For this reason, rather than attempt to model these effects, we make an estimate of water heater unit energy consumption for each region, based on available data. Data sources for these estimates are provided in Appendix 3. The results are summarized in Table 20.

Table 20 Water Heating Consumption and fuel mix per region

	Useful Water Heater Energy	Fuel Share		
	kWh/Unit	Elec	Fuel	Other
PAO	2985	43%	57%	0%
NAM	3994	38%	62%	0%
WEU	2486	34%	58%	8%
EEU	458	34%	58%	8%
FSU	2075	13%	48%	38%
LAM	955	9%	54%	37%
SSA	414	1%	2%	97%
MEA	414	2%	73%	25%
CPA	1062	Time dependent - see Appendix 6		
SAS-PAS	225	0%	13%	87%

Finally, as the table indicates, we treat the Centrally-Planned Asia region, which includes China, as a special case. Coal is still the main source of residential space heating in large segments of Chinese society, but the country is experiencing a transition to other fuels and electricity, which are likely to be the subject of future efficiency programs.

Therefore, fuel shares for both space and water heating in China are modeled as dynamic over time. The details of our assumptions about fuel share transition in China are given in Appendix 6

The Efficiency of electric water heaters for most regions is based on a study for the European Commission (Sakulin and Hoelblinger 2000) which proposes a rating system for residential water heaters. For North America, baseline estimates and efficiency targets are based on (Rosenquist, McNeil et al. 2006). Finally, estimates for the CPA region are based on a recent study considering the potential for standards for instantaneous gas water heaters in China. Table 21 and

Table **22** show efficiency targets in the high efficiency scenario.

Table 21 - Unit Baseline and Target Efficiency Levels for Electric Storage Water Heaters

Region	Electric WH, Efficiency			Source	Assumption
	Base Case	2010 Target	2020 Target		
PAO	0.83	0.88	0.91	(Sakulin and Hoelblinger 2000)	Level E to Level C in 2010, and Level A in 2020
NAM	0.92	0.92	2.50		Heat Pump Water Heaters become Mandatory in 2020
WEU	0.83	0.88	0.91		Level E to Level C in 2010, and Level A in 2020
EER	0.79	0.83	0.88		Level E to Level C in 2010, and Level A in 2020
LAM	0.79	0.88	0.91		Level F to Level C in 2010, and Level A in 2020
FSU+SSA+MEA+CPA+SAS-PAS	0.76	0.83	0.88		Level G to Level E in 2010, and Level C in 2020

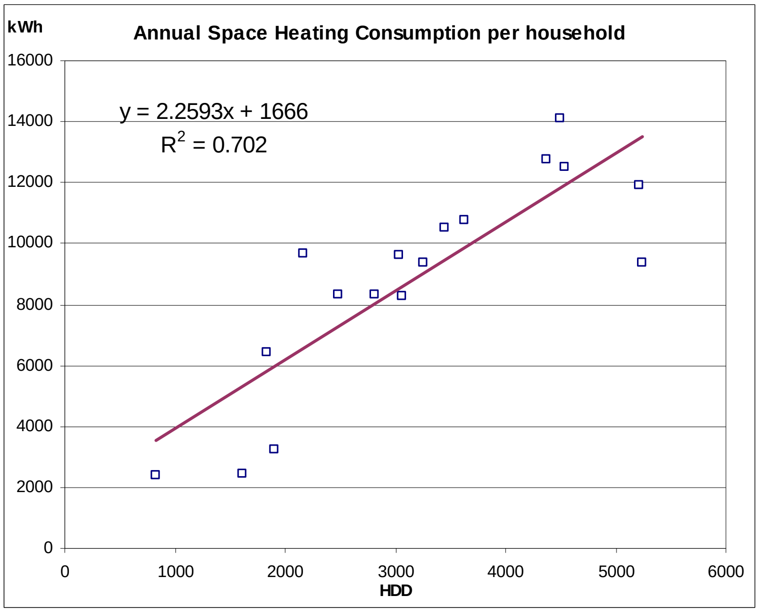
Table 22 Unit Baseline and Target Efficiency Levels for Gas Water Heaters

Region	Gas WH, Efficiency			Source	Assumption
	Base Case	2010 Target	2020 Target		
PAO	0.83	0.83	0.83	Top Runner Website - http://www.eccj.or.jp	Efficiency for both boiler and instantaneous alredy very high. No further improvement
NAM	0.59	0.62	0.62	(U.S. Department of Energy-Office of Energy Efficiency and Renewable Energy 2000)	No further improvement after 2010
WEU+EER +FSU+LAM +SSA+MEA+SAS-PAS	0.48	0.59	0.62		Base Case is the baseline from the last rulemaking (1998), current US standard adopted in 2010, and probable next US standard level by 2020
CPA	0.86	0.88	0.96	(Lin J. 2006)	All gas heaters are instantaneous

3.1.10 Space Heating

In temperate and cold countries, space heating can be the highest single consumer of energy within the home. Most (but not all) space heating using electricity, natural gas, LPG or oil happens in industrialized (OECD) countries or transition economies (roughly regions 1 through 5), and China. Although space heating intensity varies by household area, equipment efficiency and construction quality, the most important determinant of the heat content needed to provide comfort is climate. For this reason, we model *useful energy* (the output of heating devices, not the energy supplied to them) to heat the household in terms of *heating degree days*, which have been defined for a wide range of international locales by the World Resources Institute (Baumert and Selman 2003). Heating degree days are defined to be roughly proportional to heating load. Therefore, we fit actual loads from 17 countries to a line. The results of the fit are shown in Figure 19. The data show a good agreement with the assumption of a linear dependency.

Figure 19 Space Heating Consumption Model



Unlike useful energy, *final energy* is dependent on equipment efficiency and fuel used. In addition to electricity and the commercial household fuels, district heat is an important component of residential space heating in Western Europe, Eastern Europe, and the Former Soviet Union[22]. While there are ample opportunities for improving the efficiency of district heat, it is unlikely that these will be the subject of an EES&L program. Therefore, we subtract the district heat portion of space heating for these regions in estimates of covered end-use energy and savings. The fraction of electricity versus. fuels, excluding district heat are shown in Table 23.

Table 23 Space Heating fuel mix per region

Region	Electricity	Fuel	Reference/Assumption
PAO	46%	54%	IEA Energy Indicators
NAM	30%	70%	(DOE/EIA 2001)
WEU	8%	92%	(European Comission 2002)
EEU	0%	100%	(Novikova A.)
FSU	0%	100%	Assumed to be like region 4
CPA	Time Dependent- see Appendix 6		(Zhou, McNeil et al. 2007)

As in the case of water heating, Chinese space heating is treated as a special case. The details of our assumptions about fuel share transition in China are given in Appendix 6.

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[22] IEA indicates that Western Europe has 7%, Eastern Europe 41% and Former Soviet Union 64% of District Heating (IEA Indicators and International Energy Agency (2004). Coming in from the Cold - Improving District Heating Policies in Transition Economies. Paris.)

Fuel-based space heating systems, such as furnaces or boilers lose efficiency through heat that escapes with flue gases as part of the combustion exhaust. These can be substantially reduced with the addition of heat transfer components. Electric heat pump efficiency can also be increased, generally through the same technologies that improve air conditioner efficiency. Table 24 and Table 25 show our estimates of base case efficiency, and assumed efficiency targets.

Table 24 Electric Space Heating Efficiency

Heating System	Electric Space Heating, Efficiency		Assumption
	Base Case	2010 Target	
Room Heater	100%	100%	No Losses
Central Heating	78%	90%	Assumed to have same efficiency as Gas Boiler/Furnace

Table 25 Fuel Space Heating Efficiency

Heating System	Fuel Space Heating, Efficiency		Reference	Assumption
	Base Case	2010 Target		
Room Heater	64%	80%	(U.S. Department of Energy 1993)	Baseline at current U.S. Standard Target based on engineering estimates
Central Heating	78%	90%	(European Comission 2002)	Average Sales of boilers in 2005 in UK is our baseline, the sales of condensing boilers in the same year our efficiency target for 2010

3.1.11 Residential Sector Summary

To summarize, we present all of the parameters used to define baseline energy consumption and efficiency targets for 2010 and 2020. These parameters, which essentially define Module 2 for the residential sector, are provided in Table 26.

Table 26 Efficiency Scenario Parameters for Residential Sector

End Use	Region	Units	Base Case Average Efficiency	2010 Average Efficiency	2020 Average Efficiency
Electricity					
Incandescent Lamp	All	Watts	60	15	15
FluorescentLamp	PAO+NAM+WEU	Watts	40	36	36
	Other	Watts	46	40	36
Refrigeration	PAO	kWh/year	537	476	318
	NAM	kWh/year	562	506	391
	WEU	kWh/year	364	268	271

	EEU	kWh/year	483	268	271
	FSR	kWh/year	644	483	271
	LAM	kWh/year	440	261	216
	SSA	kWh/year	445	364	271
	MEA	kWh/year	445	364	271
	CPA	kWh/year	489	353	302
	SAS-PAS	kWh/year	548	301	223
Oven	PAO	kWh/year	167	89	75
	Other	kWh/year	132	69	61
Standby	All	Watts/Device	5	3	1
Washing Machine	PAO	kWh/year	60	14	14
	NAM	kWh/year	194	194	194
	WEU	kWh/year	126	119	119
	EEU	kWh/year	128	119	119
	FSR	kWh/year	169	119	119
	LAM	kWh/year	191	149	108
	SSA	kWh/year	181	97	68
	MEA	kWh/year	183	141	99
	CPA	kWh/year	12	6	6
	SAS-PAS	kWh/year	190	102	102
Television	All	Efficiency Rating	100%	135%	135%
Space Cooling	PAO	EER	3.9	4.8	5.8
	NAM	EER	3.4	3.4	3.4
	WEU+EEU+FSU	EER	2.8	3.2	4.0
	LAM	EER	2.6	3.0	4.0
	MEA+SSA+SAS-PAS	EER	2.4	2.6	3.2
	CPA	EER	2.6	3.2	4.0
Water Heating	PAO	Efficiency Factor	0.83	0.88	0.91
	NAM	Efficiency Factor	0.92	0.92	2.50
	WEU	Efficiency Factor	0.83	0.88	0.91
	EEU+FSU	Efficiency Factor	0.79	0.83	0.88
	LAM	Efficiency Factor	0.79	0.88	0.91
	MEA	Efficiency Factor	0.76	0.83	0.88
	SSA+SAS-PAS	Efficiency Factor	0.76	0.83	0.88
	CPA	Efficiency Factor	0.76	0.83	0.88
Fans	CPA	kWh/year	10	8	6
	WEU+EEU+FSU	kWh/year	50	41	31
	LAM+MEA+SSA	kWh/year	88	72	54
	Other	kWh/year	88	72	54
Space Heating	PAO	Efficiency Rating	1.5	2.0	2.0
	NAM	Efficiency Rating	1.5	2.0	2.0
	Other	Efficiency Rating	1.0	1.0	1.0
Natural Gas, LPG + Oil					
Water Heating	PAO	Efficiency Rating	0.83	0.83	0.83
	NAM	Efficiency Rating	0.59	0.62	0.62
	CPA	Efficiency Rating	0.86	0.88	0.96
	Other	Efficiency Rating	0.48	0.59	0.62
Space Heating	PAO	Efficiency Rating	0.71	0.77	0.77

	NAM	Efficiency Rating	0.77	0.88	0.88
	WEU	Efficiency Rating	0.77	0.88	0.88
	EEU	Efficiency Rating	0.71	0.77	0.77
	CPA	Efficiency Rating	0.70	0.78	0.83

3.2 Commercial End-Use Intensities and High Efficiency Scenarios

In contrast to the residential sector, commercial sector end-use demand is difficult to assess at the equipment level. In general, sufficient data is not available to determine the total number of light bulbs, air conditioner units or boilers used in all businesses and government offices. Instead, as discussed in 2.4.2, we forecast the demand in terms of intensity per unit floor space (kWh/m^2). Therefore, for the commercial sector, the assessment of efficiency potential is calculated from direct end-use demand estimates.

The main energy consuming products in the commercial sector, while generally delivering the same services as the residential products, are distinct from them in terms of capacity and technology type, and are not as well covered in the energy efficiency literature. In addition, the commercial sector is less often targeted for EES&L programs from which equipment type, efficiency and use pattern data could be obtained. In spite of these limitations, we believe that the generalized estimates we make for these end-uses are reasonable, and provide a useful picture of the magnitude and distribution of potential savings in the sector.

3.2.1 Lighting

Many factors determine lighting energy intensity such as the number and type of lamps, the efficiency of the ballast and the fixture, the hours of usage, and the type of controls. A wealth of information concerning lamp technology advancement as well as penetration of lighting equipment in OECD countries and some non OECD countries is available from “Light’s Labor’s Lost” publication from the International Energy Agency (IEA 2006) . Information for China was available from previous work done at LBNL on China (Zhou, McNeil et al. 2007). For Latin America, studies for the largest countries (such as Brazil, Mexico, Argentina, Chile and Uruguay) were available. Appendix 5 describes lighting intensity per region as well the source of data. We compiled information on the types of technology used for lighting equipment, such as the share of the penetration of linear fluorescent lamps such as T12, T8 and T5 as well as incandescents, CFLs and Halogens.

As described in section 2.2.1, lighting energy consumption is a function of lighting equipment penetration, fixture efficiency, and hours of usage. Assumptions of hours of use per day for each fixture are given in Appendix 5. Annual lighting intensity is then given by:

$$\text{Intensity} = 29.9 \div \text{eff coeff} \times \text{Hours of use} \times \text{Penetration}$$

Where 29.9 kWh/m^2 is the reference intensity. As mentioned in Section 2.2, we assign the Japanese value of lighting intensity to be the reference.

Fluorescent tubes, also called linear fluorescent lamps (LFL) are the most widely used type of lamp in the commercial sector for two reasons: they typically long operating lives compared to incandescent lamps and produce much light per watt. Different types of LFLs exist, named according to tube diameters. For example, the oldest type is T12 and has a diameter of 12/8 of an inch. T8 is a more recent, slimmer version (8/8 of an inch, or one inch) that consumes less energy for the same lighting output. More recently, an even slimmer fluorescent tube was introduced, T5 (5/8 of an inch). However, the switch from one LFL type to another is not straightforward as it usually requires a new fixture which optimizes performance. Moreover, ballasts needed to operate LFL reduce the overall fixture efficacy due to loss of energy occurring in its operation. Electronic ballasts reduce system energy consumption by 10% over conventional line-frequency magnetic ballasts. Other types of lamps include incandescent lamps, which are the least efficient type, halogen, high pressure mercury vapor, and the more efficient CFLs. Recently, advances in lighting control and censor technology, architectural daylight, and task lighting are offering powerful tools that can help significantly reduce lighting energy use, even more so in countries where average hours of usage is high.

In order to account for the efficiency level of each region, penetration of each lamp type and respective efficiency were estimated for each region. As an example, Table 27 shows the assumption for the OECD Pacific region (PAO). The table gives the prevalence (share) of each type of lighting, along with its efficiency relative to T12 lamps, and the light output per watt, from which the efficiencies were derived.

Table 27. Lighting Equipment Efficiency - PAO Region

	Equipment Share	Equipment Efficiency	Lumens/W
T12	28%	100%	65
T8	38%	115%	75
T5	8%	138%	90
Incandescent	3%	25%	16
CFL	20%	92%	60
Halogen	0%	28%	18
Other	5%	69%	45
Total	**100%**	**105%**	**68.7**

Regional assumptions for the base year and for the 2010 and 2020 targets are represented in Table 28. In the base year, differences between regions are due to differences in lamp types in use and also due to lamp efficacy differences. Difference in lamp efficacy between regions are related mostly to T12 and T8 lamp types and represents the various penetration levels of magnetic and electronic ballasts. The energy efficiency target in 2010 includes the implementation of stringent lamp type efficacy for T12 and T8 of 3% for Pacific OECD and North American countries and 5% for Non OECD countries and OECD Europe. It also includes the replacement of half the stock of T12 with T8 for 80%

of lamps, and T5 for 5%, in OECD countries and with T8 for 100% of lamps in non OECD countries as well as the replacement of 50% of incandescent lamps by CFL. The 2020 target includes the complete phase out of T12 replaced with T5 and the replacement of half the stock of T8 with T5 in OECD countries. In non OECD countries, the replacement with T5 target is less aggressive, T12 are replaced with T5 for 50% of lamps, the rest are replaced with T8. The resulting efficiency factors by region are shown in Table 28.

Table 28. Lighting Equipment Efficacy Assumptions

Region	Base	2010 Target	2020 Target
PAO	1.05	1.09	1.24
NAM	0.97	1.08	1.27
WEU	0.94	1.00	1.18
EEU	0.81	0.97	1.13
FSU	0.77	0.95	1.07
LAM	0.84	1.00	1.12
MEA	0.88	1.01	1.11
SSA	0.70	0.93	1.09
CPA	0.84	0.99	1.09
SAS-PAS	0.84	1.00	1.11

3.2.2 Space Cooling

Space cooling (air conditioning) is achieved using several distinct technologies: Chillers, central air conditioners and heat pumps are all common, especially in OECD countries. In developing countries it is also common to cool commercial floor space, such as office buildings, with residential-style single unit air conditioners. Finally, a hybrid of central and individual systems, a ‘multi-split’, is composed of a single outdoor compressor unit operating multiple compressor units in a ductless system. Multi-split systems are particularly popular in Japan.

In order to estimate current baselines and likely efficiency targets, we relied on ratings systems and standards currently in place in the United States, Europe and Japan. For the U.S., we relied heavily on detailed assessments of cost-effective (minimum Life-Cycle Cost) efficiency levels, weighting them by the market share held by each. For Japan, we assumed the base efficiency to be at the current level specified by the Top Runner program for multi-splits, but to reach three EER (W/W) by 2010 and four EER (W/W) by 2020[23].

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[23] New targets for 2010 for air conditioning systems have already been announced by Top Runner. In this case, the analysis includes as ‘potential savings’ S&L regulations that have been formulated, but which have not yet taken effect.

Table 29 - Unit Baseline and Target Efficiency Levels for Commercial Space Cooling

Region	EER			Source	Assumption
	Base Case	2010 Target	2020 Target		
PAO	2.47	3.00	4.00	Top Runner Website - http://www.eccj.or.jp/top_runner/chapter7_3_02.html	Multisplits dominate. Top Runner Target for multisplits raised to 3 by 2010 and 4 by 2020.
NAM	8.49	9.01	9.01	(Rosenquist, McNeil et al. 2006)	Minimum LCC for Commercial AC+HP weighted by floor space share. No improvement for chillers
WEU	3.27	3.75	4.07	((SAHEB, Becirspahic and Simon) quoted in (Bertoldi and Atanasiu 2006)), (Adnot and Waide 2003)	Market average rating for chillers and package terminal units reaches 'B' level by 2010, 'A' level by 2020. RAC improvement same as residential.
EER+FSU	3.14	3.75	4.07	((SAHEB, Becirspahic et al.) quoted in (Bertoldi and Atanasiu 2006)), (Adnot and Waide 2003)	Same as WEU, except baseline at 'E' level
Other Regions	3.14	3.75	4.07	((SAHEB, Becirspahic et al.) quoted in (Bertoldi and Atanasiu 2006)), (Adnot and Waide 2003)	Same as WEU, except baseline at 'E' level

3.2.3 Ventilation

Data that portray energy use for ventilation (fans) in the service sector is very limited. Table 30 shows data gathered. These data were then used to estimate ventilation intensity in NAM, EU and LAM. Ventilation intensity in the other regions was estimated based on the cooling penetration function described in Section 2.2.2.

Table 30. Ventilation Energy Intensity

	kWh/m2/year	Source
USA	14.5	(EERE 2007)
Canada	45.3	(OEE 2007)
EU	15.5	(Bertoldi and Atanasiu 2006)
Uruguay*	10.3	(UTE 1999)
Chile*	11.3	(Deirdre 1999)

*For these countries, only the share of electricity use for cooling was available. Hence, we used our estimate of floor space to calculate electricity used per m2

We found little international data relating specifically to the cost-effective efficiency potential of commercial ventilation systems. In general, however, the improvement of ventilation efficiency through motor efficiency and blade design is well-understood. We rely on a single source (Fraunhofer ISI 2001), which estimated that commercial ventilation systems in Western Europe could be improved, on average, between ten and

20%. We not that this range agrees well with a source focusing on the United States (Rosenquist, McNeil et al. 2006), which found a minimum life-cycle cost improvement, weighted over equipment types, of 16%.

Table 31 - Target Efficiency Improvement Levels for Commercial Ventilation

Region	2010	2020	Source	Assumption
All Regions	10%	20%	(Fraunhofer ISI 2001)	10% represents an easily achievable target, and 20% is the maximum cost-effective efficiency level

3.2.4 Refrigeration

Another important share of electricity is consumed for refrigeration. Only a few national data are available (Table 31). Estimates for the total European consumption range from 70 to 100 TWh per year (Bertoldi and Atanasiu 2006), representing about 8.5 % of the total non-domestic electricity consumption.

Table 32. Refrigeration Energy Intensity

	kWh/m2/year	Source
USA	9.94	(EERE 2007)
Brazil*	13.00	(COPPE 2005)
Uruguay*	7.75	(UTE 1999)
Chile*	11.26	(Deirdre 1999)
South Africa	13.36	(Haw and Hugues 2007)

*For these countries, only the share of electricity use for cooling was available. Hence, we used our estimate of floor space to calculate electricity used per m2

Commercial refrigeration covers a wide-range of products, including supermarket refrigerators, reach-in freezers, reach-in refrigerators, ice machines, vending machines, walk-in coolers and walk-in freezers (Rosenquist, McNeil et al. 2006). All of these are likely present in industrialized countries, where supermarkets are common, but most of them exist in developing countries as well, especially in urban areas. Therefore, we use data from the United States as a model. We recognize that much of the refrigeration in small grocery stores and restaurants in the developing world is likely to be provided by the same type of equipment used in residences. This should not present an unduly large error, however, since the general level of efficiency improvement for refrigeration in the sectors is similar.

Table 33 - Target Efficiency Improvement Levels for Commercial Refrigeration

Region	2010	2020	Source	Assumption
All Regions	34%	34%	(Rosenquist, McNeil et al. 2006)	U.S. cost-effective efficiency improvement levels, weighted by market share (percent of electricity consumption) for each equipment type.

3.2.5 Office Equipment

The authors of (Kawamoto, Koomey et al. 2000) estimated that 8.6% of the electricity consumed by office equipment is used in ‘Low-Power’ mode. We interpret this consumption as standby power losses. Accordingly, we construct an efficiency scenario based on the following assumptions:

- The average standby power of each piece of office equipment in 2010 is 5 W.
- A standby requirement of 3W is implemented internationally in 2010 (40% reduction in low-power consumption)
- A 1W standby requirement is in place in all countries by 2020 (80% reduction in low-power consumption).

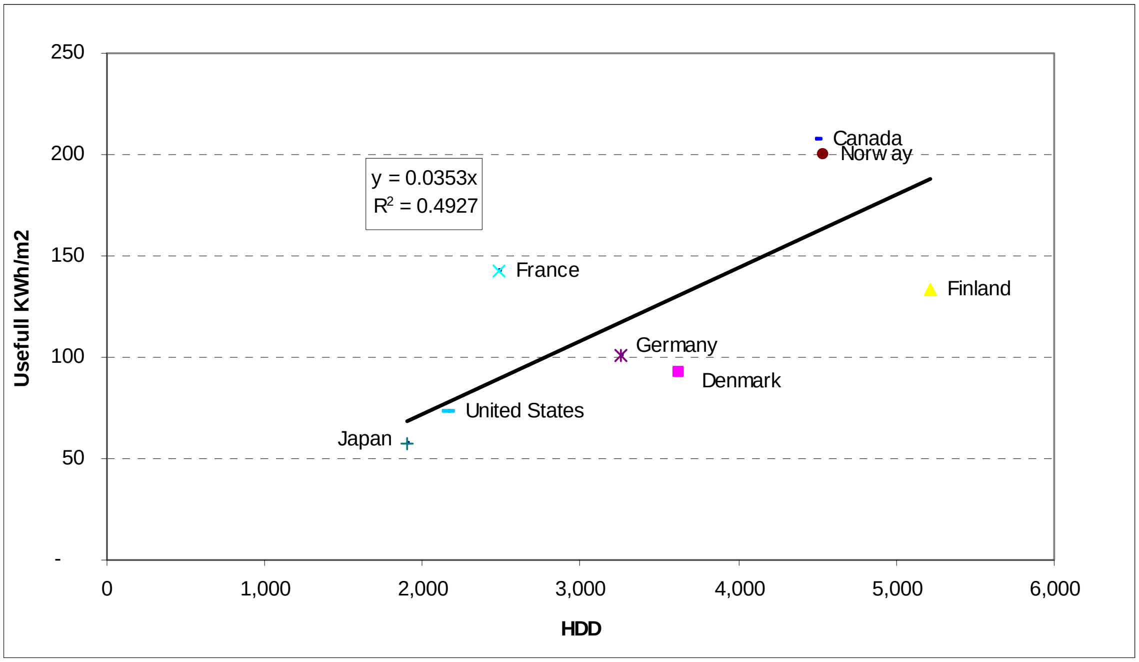
3.2.6 Space Heating

Space heating, like cooling, is climate dependent. Only a few data points were found and are described in Appendix 5. As in the case of the residential sector, the approach was to model space heating consumption according to useful energy, as a function of heating degree days (*HDD*). Like the residential case, the data show that useful energy is approximately proportional to HDD. Figure 20 shows the data compiled, and the resulting model of space heating useful energy, given simply by the following equation:

$$\textit{Useful Energy } (kWh/m^2) = .0353 \times HDD$$

Once established, this relationship is combined with estimates of fuel share based on IEA (2007) data to calculate intensity per fuel types.

Figure 20. Space Heating Useful Energy Demand Model



In the commercial sector, the vast majority of space heating energy is provided by commercial fuels like natural gas and heating oil. If electric space heating is used, heat pumps predominate, but we expect these to be utilized in large measure only in the United States and Japan. Commercial space heating has not been the target of efficiency standards, despite being the largest single end-use in non-tropical regions. For this reason, there is not a great wealth of international data with descriptive ratings systems and baseline estimates of equipment efficiency. We model space heating efficiency generally according to efficiencies prevailing in the United States, and estimates of cost effective improvement potential found in (Rosenquist, McNeil et al. 2006) with the important difference being that we assume that condensing (90% efficiency) furnaces will become cost effective in North America by 2020, and will therefore be the target of a standard.

Table 34 - Target Efficiency Improvement Levels for Commercial Space Heating

Electricity					
PAO	247%	300%	400%	Top Runner Website - http://www.eccj.or.jp/top_runner/chapter7_3_02.html	Heat pumps assumed to have roughly the same heating as cooling efficiency
NAM	313%	358%	368%	(Rosenquist, McNeil et al. 2006)	Cost Effective Efficiency Improvement for commercial Heat Pumps
Other Regions	100%	100%	100%		Electric Space Heating small, or dominated by resistance Heating, with no significant efficiency improvement possible
Fuel					
NAM	0.76	0.79	0.85	(Rosenquist, McNeil et al. 2006)	Cost Effective Efficiency Improvement for commercial gas and oil fired furnaces and boilers, weighted by shares of floor space
Other Regions	0.74	0.78	0.81	(Rosenquist, McNeil et al. 2006)	Same efficiency levels as U.S. but assumes Boilers only

3.2.7 Water Heating

Water heating energy intensity was available for only a handful of countries. For regions where too few data points by country were available, we based the water heating energy consumption on IEA data. The IEA (IEA 2007) collects data for 140 countries. We assumed that the fuel consumed in the category called “commercial sector” is primarily used for space and water heating. We therefore calculated fuel intensity by region based on the IEA data and subtracted the space heating energy intensity described in the previous section, to arrive at water heating intensity. Table 35 shows the resulting estimates.

Table 35 - Commercial Water Heating Demand Assumptions

	Useful Energy (kWh/m^2)
NAM	57.5
FSU	55.7
MEA	46.3
PAO	38.4
EEU	28.9
WEU	22.5
LAM	14.4
SAS-PAS	11.5
CPA	10.4
SSA	4.1

For most of these regions, water heater use is already pervasive, so useful water heater energy intensity is not expected to grow further. For the four regions where commercial water heating is the least intensive (LAM, SAS-PAS, CPA and SSA), we expect that intensity will increase over time with economic development. The model determining the evolution in time of water heating intensity for these regions is discussed in Appendix 5.

As in the case of space heating, commercial water heating efficiency is modeled largely from estimates from the U.S. Estimates provided in (Rosenquist, McNeil et al. 2006), which cover storage tank water heaters, as well as instantaneous water heater systems. The latter are considered to be significant only in North America and Japan, where the U.S. market share is used for both. For the percentage of the market heated by boilers, the space heating efficiency is taken to be representative of water heating efficiency as well. For other regions, the U.S. efficiency levels are used, along with the assumption that boilers dominate commercial water heating equipment.

Table 36 - Target Efficiency Improvement Levels for Commercial Water Heating

Fuel					
PAO+NAM	0.78	0.81	0.82	(Rosenquist, McNeil et al. 2006)	Cost Effective Efficiency Improvement for commercial gas and oil fired water heaters and boilers, including instantaneous water heaters
Other Regions	0.74	0.78	0.81	(Rosenquist, McNeil et al. 2006)	Same efficiency levels as U.S. but assumes boilers only

Finally, we do not consider efficiency improvement for electric water heating as this is a relatively small commercial end-use, which is already relatively efficient. In the case of the United States, (Rosenquist, McNeil et al. 2006) we did not find significant cost-effective improvement potential for this end-use.

3.2.8 Commercial Sector Summary

To summarize, we present all of the parameters used to define baseline energy consumption and efficiency targets for 2010 and 2020. These parameters, which essentially define Module 2 for the residential sector, are provided in Table 37.

Table 37 Efficiency Scenario Parameters for Commercial Sector End-uses

End-use	Region	Units	Base Case Average Efficiency	2010 Average Efficiency	2020 Average Efficiency
			Electricity		
Lighting	PAO	%	1.05	1.09	1.24
	NAM	%	0.97	1.08	1.27
	WEU	%	0.94	1.00	1.18
	EEU	%	0.81	0.97	1.13
	FSR	%	0.77	0.95	1.07
	LAM	%	0.84	1.00	1.12
	SSA	%	0.88	1.01	1.11
	MEA	%	0.70	0.93	1.09
	CPA	%	0.84	0.99	1.09
	SAS-PAS	%	0.84	1.00	1.11
Space Cooling	NAM	EER	2.47	3.00	4.00
	WEU	EER	8.53	9.05	9.05
	EEU	EER	3.27	3.75	4.07
	FSR	EER	3.14	3.75	4.07
	CPA	EER	3.14	3.75	4.07
	EEU	EER	2.52	2.98	3.60
	FSR	EER	2.40	2.80	3.20
	LAM	EER	2.40	2.80	3.20
	MEA	EER	2.50	3.10	3.60
	NAM	EER	2.48	3.10	3.60
Refrigeration	All	% improvement	0%	34%	34%
Ventilation	All	% improvement	0%	10%	20%
Office Equipment	All	Standby Watts/Device	5	3	1
Space Heating	PAO	% Efficiency	323%	394%	394%
	SAS-PAS	% Efficiency	313%	358%	368%
	SSA	% Efficiency	100%	100%	100%
	WEU	% Efficiency	100%	100%	100%
	CPA	% Efficiency	100%	100%	100%
	EEU	% Efficiency	100%	100%	100%
	FSR	% Efficiency	100%	100%	100%
	LAM	% Efficiency	100%	100%	100%
	MEA	% Efficiency	100%	100%	100%
	NAM	% Efficiency	100%	100%	100%
			Natural Gas, LPG + Oil		
Space Heating	PAO	% Efficiency	74%	78%	81%
	NAM	% Efficiency	76%	79%	85%
	WEU	% Efficiency	74%	78%	81%
	EEU	% Efficiency	74%	78%	81%
	FSU	% Efficiency	74%	78%	81%
	LAM	% Efficiency	74%	78%	81%
	MEA	% Efficiency	74%	78%	81%
	SSA	% Efficiency	74%	78%	81%
	CPA	% Efficiency	74%	78%	81%

	SAS-PAS	% Efficiency	74%	78%	81%
Water Heating	PAO	Efficiency Factor	0.78	0.81	0.82
	SAS-PAS	Efficiency Factor	0.78	0.81	0.82
	SSA	Efficiency Factor	0.74	0.78	0.81
	WEU	Efficiency Factor	0.74	0.78	0.81
	CPA	Efficiency Factor	0.74	0.78	0.81
	EEU	Efficiency Factor	0.74	0.78	0.81
	FSR	Efficiency Factor	0.74	0.78	0.81
	LAM	Efficiency Factor	0.74	0.78	0.81
	MEA	Efficiency Factor	0.74	0.78	0.81
	NAM	Efficiency Factor	0.74	0.78	0.81

4 Module 3 - Stock Accounting

The third Module of the analysis uses an accounting model that brings together the forecasts of energy demand with unit savings potential in order to forecast savings potential in terms of Mt of carbon by country and at the global level. In order to achieve this, the impacts analysis considers a temporal dimension to program impacts. Like any market transformation program, the total transformation of the market does not happen instantaneously. In particular, standards and labeling programs generally only have an effect on *new* equipment, not on retrofits. For example, homeowners and businesses with refrigerators and air conditioners already installed at the time the government makes a new minimum efficiency requirement will not be required to purchase high efficiency equipment to substitute their old equipment[24]. Instead, the equipment owner will continue to operate their old equipment until it wears out, and will replace it with equipment affected by the policy. In addition, purchases of equipment for new homes, or by first-time buyers entering the market, will be affected by the program[25].

In past studies (M.A.McNeil, V.E.Letschert et al. 2006) and (McNeil and Letschert 2007) the penetration rate of each equipment type was modeled by making an estimate of the market entry rate, that is, sales, of new equipment. Sales, in turn were decomposed into new purchases (from either increases in diffusion, or increase in households), and replacements.

The calculation of stock turnover from sales is difficult when scaled to all end-uses in all regions for two reasons. First, little actual sales data are available for calibration. Second, the assessment of replacements of previously installed equipment requires modeling the uptake of equipment several decades back in time in an iterative calculation which is cumbersome and speculative. For these reasons, we employed a highly simplified method of stock calculation.

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[24] This is not necessarily the case for some programs, which can target retrofits through a buy-back program, for example.

[25] The model does not consider the case in which an equipment owner replaces still-operating equipment specifically in order to improve efficiency. This effect is called *early replacement* and, although it is observable, it is relatively uncommon.

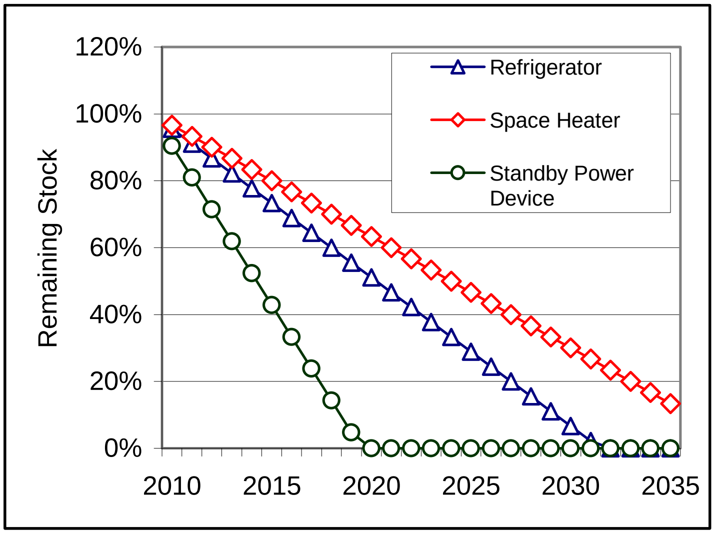
In this method, we consider the stock of each end-use in each year, and make an estimate of the portion of each that are impacted by programs in place starting in 2010 and 2020. For example, obviously none of the stock of refrigerators in 2009 could be affected by a MEPS or labeling program implemented in 2010; therefore all of this stock is operating at the base line, and none of it under the high efficiency regime. In 2010, the incremental stock (due to new households and increased diffusion) will be regulated by the program, and therefore will operate at the 2010 efficiency level. In addition, some of the previously existing stock will have been retired, and replaced by more efficient equipment than would have been the case in the absence of the program.

In the residential sector, the total stock of equipment in a given year for each country is given by

$$S_i(y) = Diffusion_i(y) \times HH(y) ,$$

In this equation, $Diffusion_i(y)$ is the modeled diffusion rate of equipment type i (e.g., televisions) in year y. $HH(y)$ is the number of households in that year. In each year after 2009, the pre-2010 stock decreases due to retirements. The time it takes to retire all of the pre-program stock depends on the average life of the product. We assume that the stock decreases linearly and reaches zero after 1.5 times the average lifetime. Figure 21 shows the percentage of 2009 stock remaining for three end-uses with significantly different lifetimes. We assume an average lifetime of only 7 years for stand-by (mostly consumer electronics) making these products, owned by households in 2009, nearly fully retired by 2020. On the other hand, a space heating system, such as a boiler or room heater, tends to be very durable and lasts about 20 years. Therefore, even by 2035, we expect that some small percentage of the 2009 stock will still be operating. This means that, for this product, the impacts of the 2010 EES&L program will not yet be fully realized by 2030 (much less those of the 2020 scenario).

Figure 21 - Percentage of 2009 Remaining 2010-2025



Assumptions of average equipment lifetime for all end-uses are presented in Table 38.

Table 38 Average Equipment Lifetimes

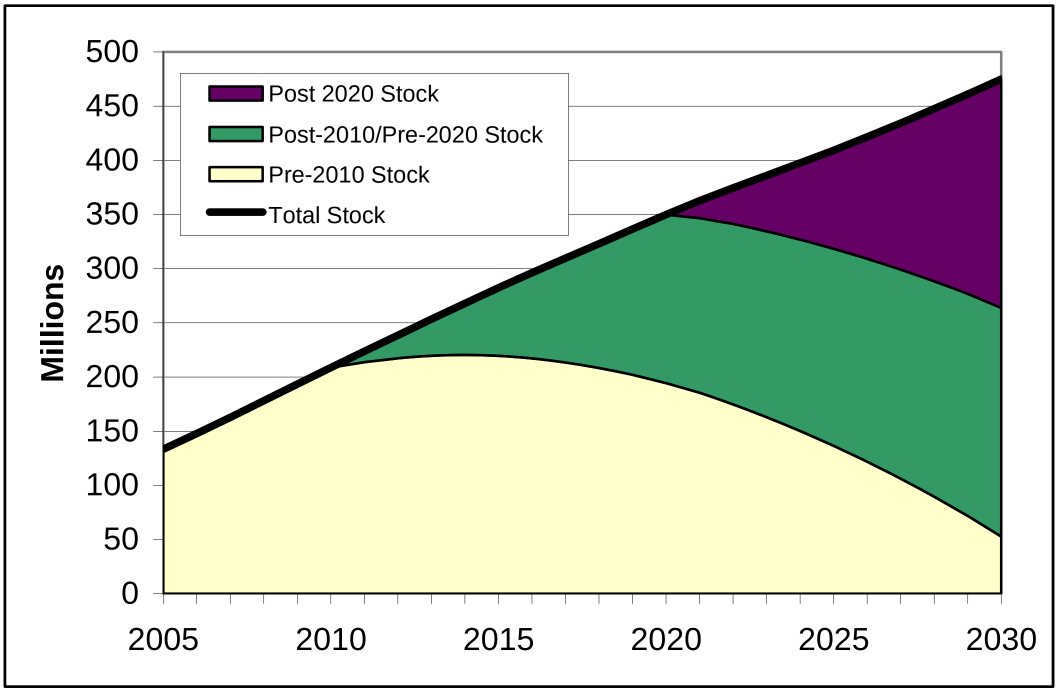
End-use	Lifetime (years)	Reference
Residential Equipment		
Fluorescent Lamp Ballast	14	(Rosenquist, McNeil et al. 2006)
Refrigeration	15	(European Comission 2000)
Air Conditioning	12	(Rosenquist, McNeil et al. 2006)
Washing Machine	15	(Novem and Ademe 2001)
Fan	10	LBNL Estimate
Television	10	LBNL Estimate
Stand-by Power Devices	7	LBNL Estimate
Oven	15	(Kasanen 2000)
Water Heating	15	(Novem 2001)
Space Heating	15	(European Comission 2002)
Commercial Equipment		
Lighting Equipment	14	(Rosenquist, McNeil et al. 2006)
Space Cooling	15	(Rosenquist, McNeil et al. 2006)
Space Heating	19	(Rosenquist, McNeil et al. 2006)
Ventilation	16	(Rosenquist, McNeil et al. 2006)
Refrigeration	10	(Rosenquist, McNeil et al. 2006)
Water Heating	8	(Rosenquist, McNeil et al. 2006)
Office Equipment	5	LBNL Estimate

An equivalent calculation of remaining stock can be made for 2020, when a new set of generally more stringent EES&L programs comes on line. With this, the stock in each year can be divided into three categories:

- *Pre 2010 Stock* – Products in use before implementation of 2010 programs – operating at baseline efficiency.
- *Post 2020 / Pre 2020 Stock* – Products purchased between 2010 and 2020 – operating at first tier high efficiency level.
- *Post 2020 Stock* – Products purchased in 2020 or later – operating at second tier high efficiency level.

The composition of the stock into these three categories over time is shown graphically in Figure 22, for the particular case of refrigerators in the SAS-PAS region.

Figure 22 – Stock of refrigerators in SAS-PAS region by category.



Stock turnover calculations in the commercial and industrial sectors proceed in a similar way to those of the residential sector, but with an important distinction. In the residential sector, we track the total number of individual units of equipment. This is not possible in the commercial sector, where instead, we track the consumption of end-uses as a share of total sector energy. Nevertheless, we can track the stock turnover of these end-uses by knowing something about the real equipment they represent. For example, if the mean lifetime of commercial ventilation equipment is 15 years, we can estimate the portion of the stock in each category, in percentage terms.

Once the amount of stock in each category is estimated, calculation of delivered (site) energy and savings is straightforward. Energy (either electric or fuel) demand for each end-use and region is given by:

$$E_{i,j}(y) = S_{\Pr e-2020}(y) \times UEC_{i,j}^{Base}(y) + S_{2010-2020}(y) \times UEC_{i,j}^{Eff\,1}(y) + S_{Psst-2020}(y) \times UEC_{i,j}^{Eff\,2}(y)$$

In this equation,

S = the stock of products in each category in year *y*
UEC(y) = annual unit energy consumption (kWh) of product type *i* in region *j* in year *y*.

The superscript on the variable UEC determines the overall energy demand, and savings. UEC values in the *Base*, *Eff1* (2010) and *Eff2* (2020) case are the principle parameters of Module 2, shown in Table 26 and Table 29.

In the Base Case, all products operate at the base case efficiency:

$$E_{i,j}^{BaseCase}(y) = S_{Total}(y) \times UEC_{i,j}^{Base}(y)$$

Savings is given by the difference of the two

$$E_{i,j}^{BaseCase}(y) - E_{i,j}(y)$$

5 Savings Potential Results and Conclusions

Once the activity forecast has been created in Module 1, the base case and high efficiency scenarios have been determined in Module 2, and these elements are brought together through the stock accounting Module 3, we can evaluate: (1) energy demand; (2) energy savings; and (3) emissions reduction potential at the end use, national, regional and global level. This corresponds to the final step shown in Figure 1.

We report two main metrics for evaluating the potential of EES&L programs. These are (1) delivered (site) energy savings and (2) emissions reductions. Delivered energy is an important metric because it is the energy which is actually reduced by equipment efficiency, and therefore what is usually targeted in metrics for EES&L programs. On the other hand, in global environmental terms, the emissions created when we generate and deliver this energy is what is important. For this reason electricity is tracked separately from commercial fuels (natural gas, LPG and fuel oil) in our results. We do not report the often quoted metric of primary energy, choosing carbon dioxide emissions as the main environmental indicator instead. We also do not evaluate financial savings, as this is a highly complex analysis in itself, requires large amounts of data we do not have access to, and changes continuously from fluctuations in energy prices and currency exchange rates.

5.1 Demand Forecast

A forecast of delivered energy demand is an important result in itself. We believe the forecast provided for this study to be among the most detailed bottom-up demand forecasts performed at a global level to date. The demand forecast is shown below in Figure 23 through Figure 30. Results are divided into two regional categories: OECD and Non-OECD[26], into the two building sectors (residential and commercial) and into electricity and fuels.

As mentioned in Section 1, the consumption of each end-use can be compared to the U.S. Department of Energy's International Energy Outlook (USEIA 2007), an independent top-down forecast of energy demand. The economic growth scenario represented in the figures closely matches the IEO macroeconomic projection.

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[26] These categories are not exact, since Mexico, which is an OECD member, is included under Non-OECD as part of the Latin America (LAM) region.

Figure 23 - Projection of Residential Electricity Demand in OECD regions 2005-2030

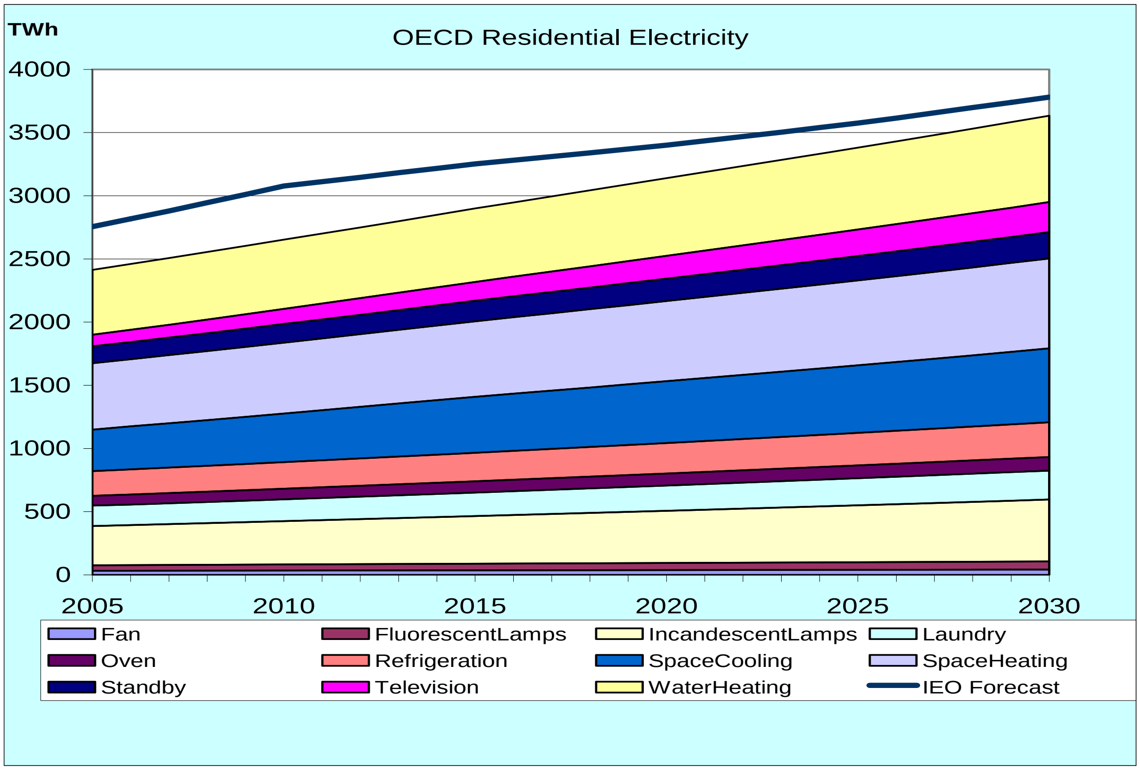


Figure 24 - Projection of Residential Electricity Demand in Non-OECD regions 2005-2030

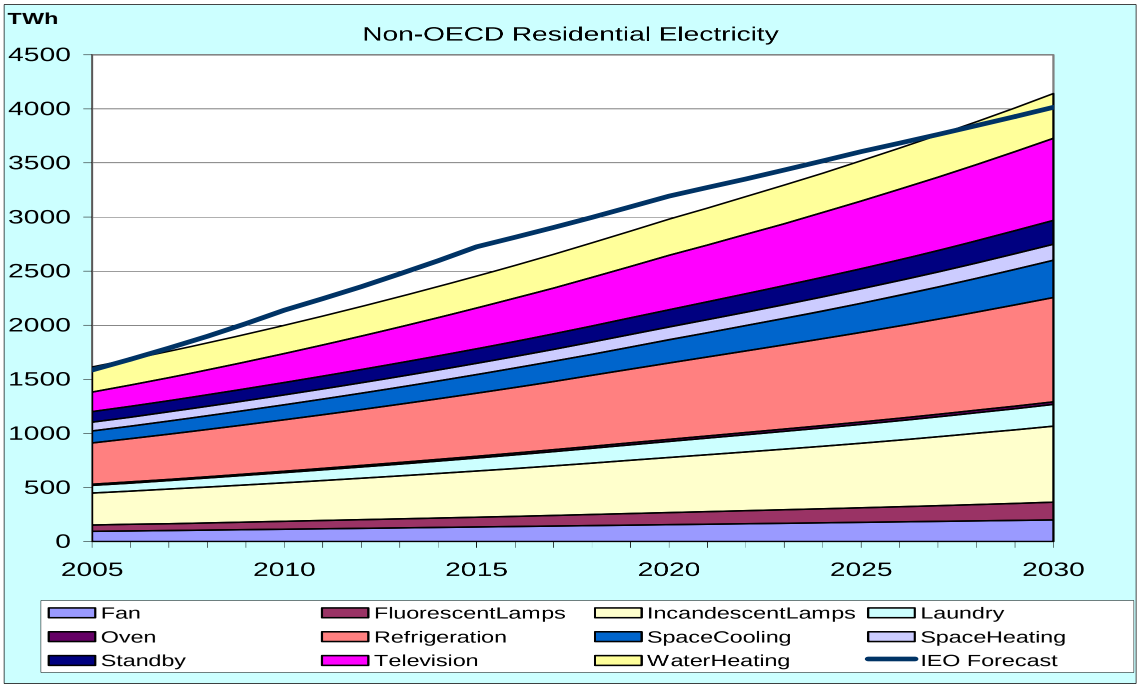


Figure 25 - Projection of Residential Fuel Demand in OECD regions 2005-2030

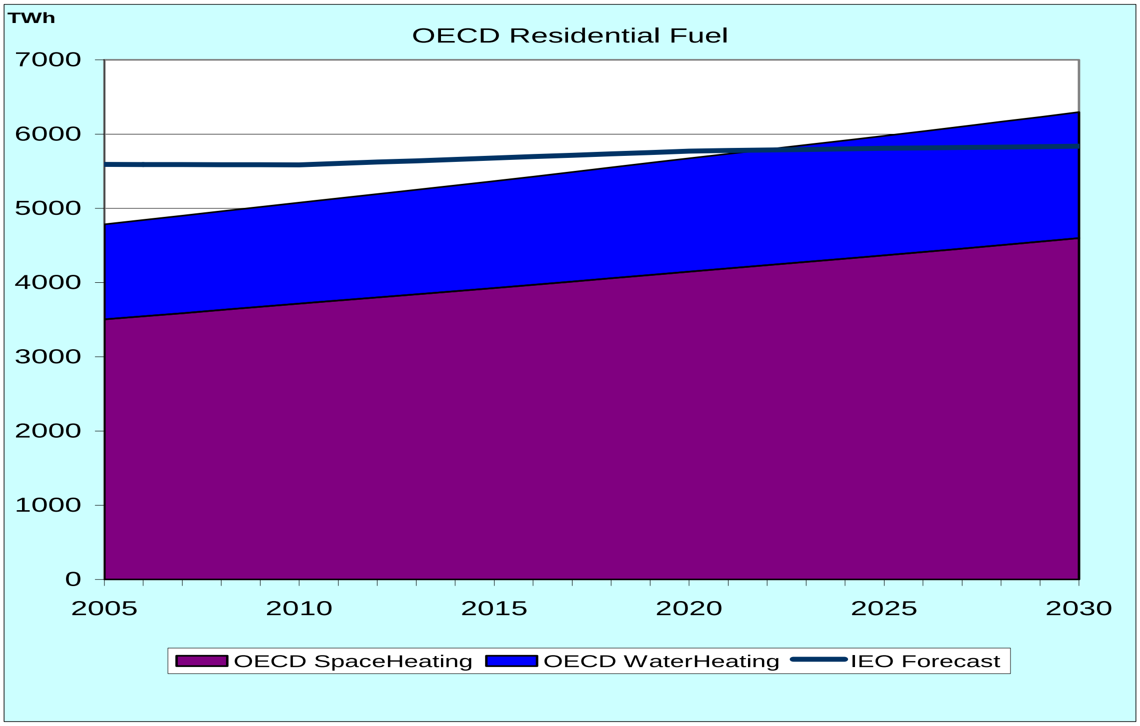


Figure 26 - Projection of Residential Fuel Demand in Non-OECD regions 2005-2030

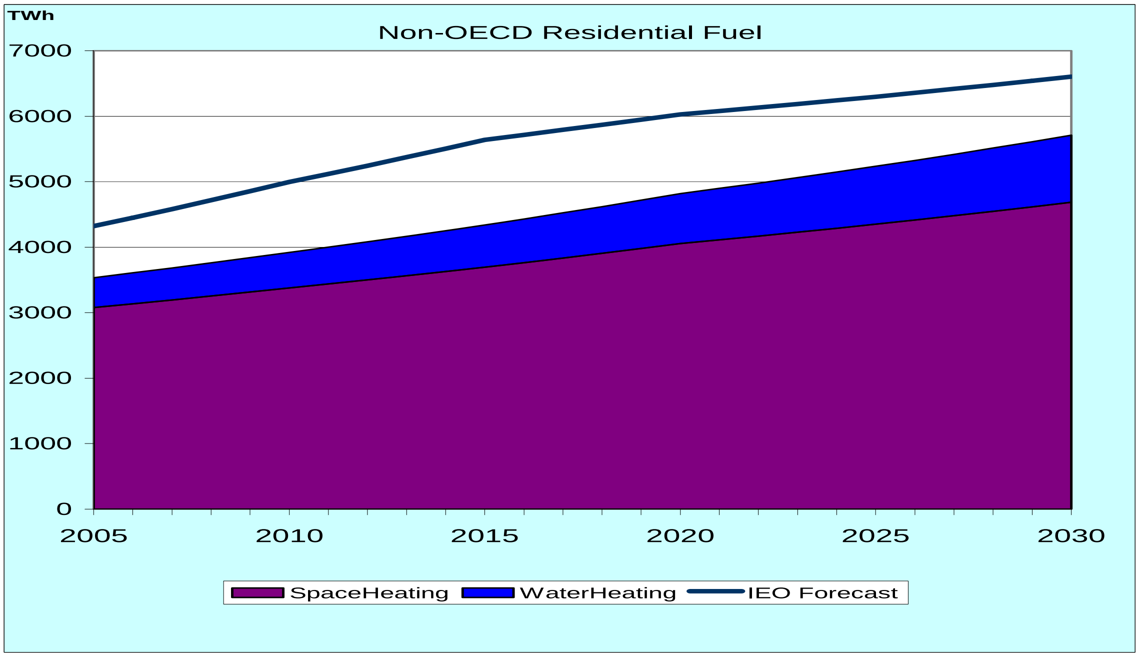


Figure 27 - Projection of Commercial Electricity Demand in OECD regions 2005-2030

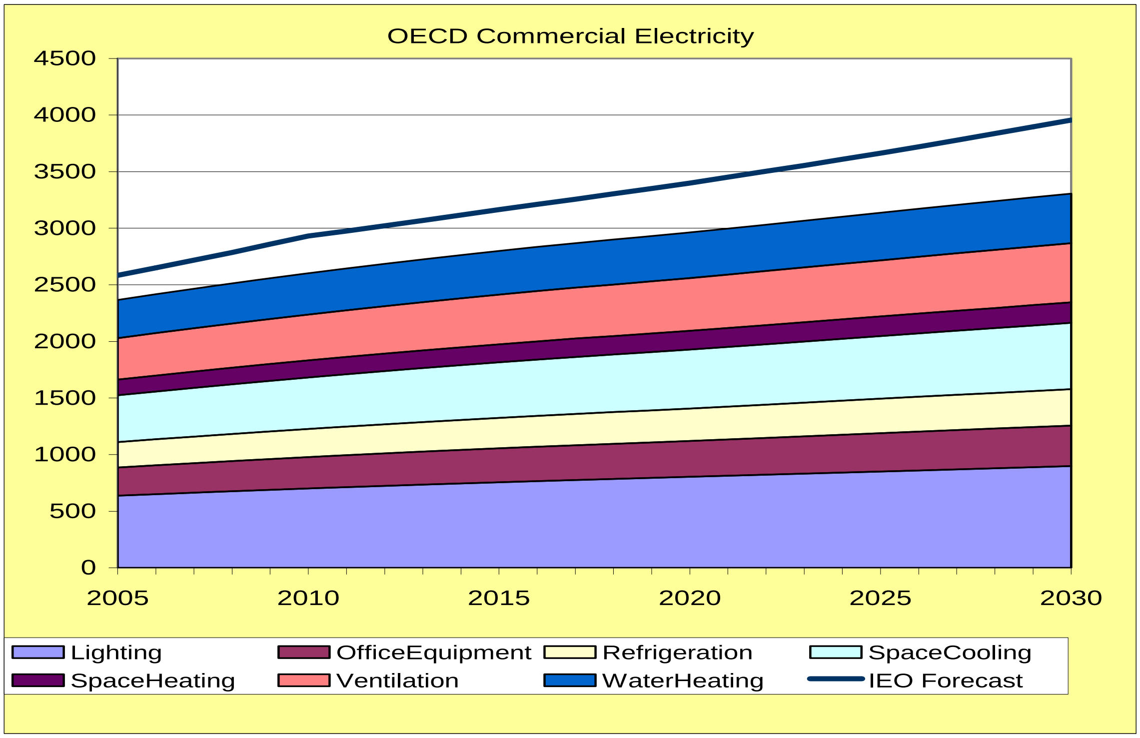


Figure 28 - Projection of Commercial Electricity Demand in Non-OECD regions 2005-2030

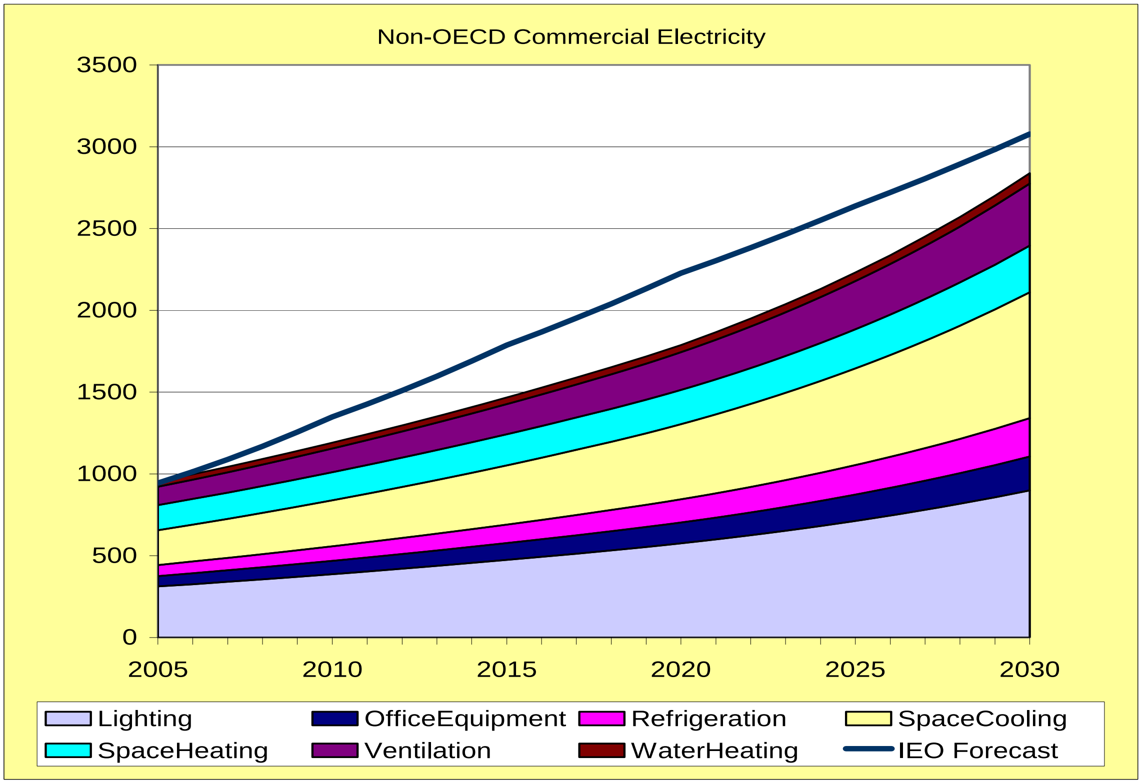


Figure 29 - Projection of Commercial Fuel Demand in OECD regions 2005-2030

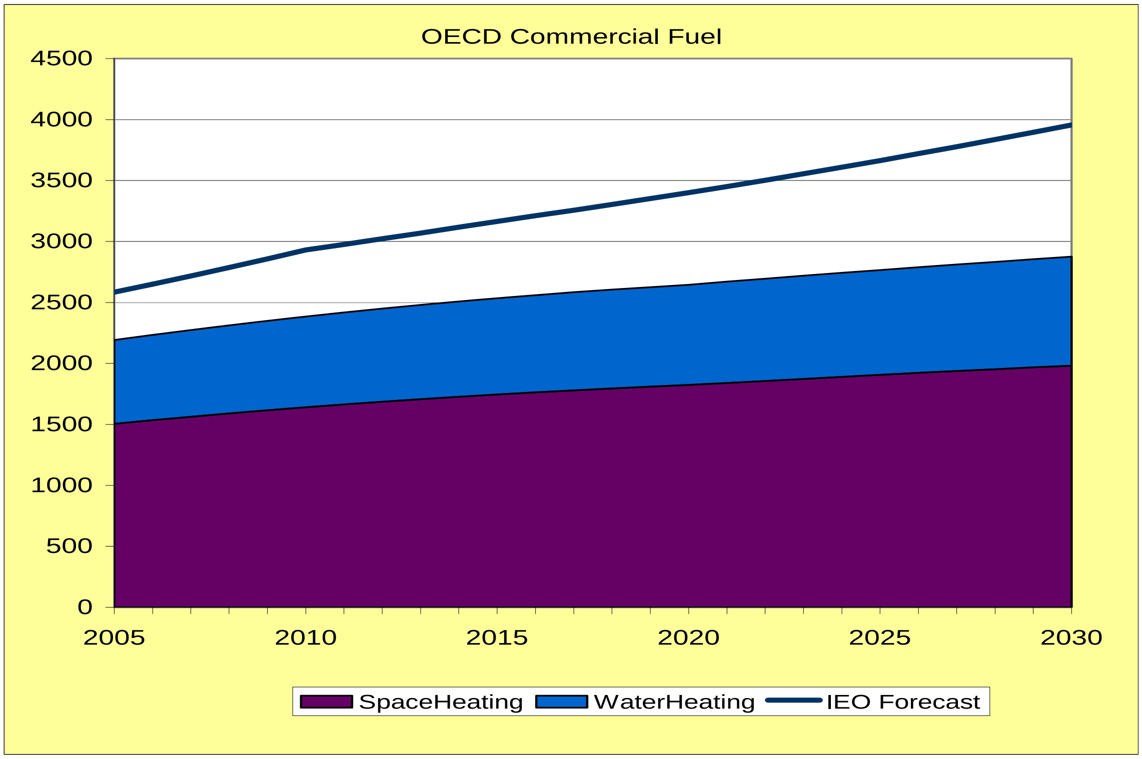
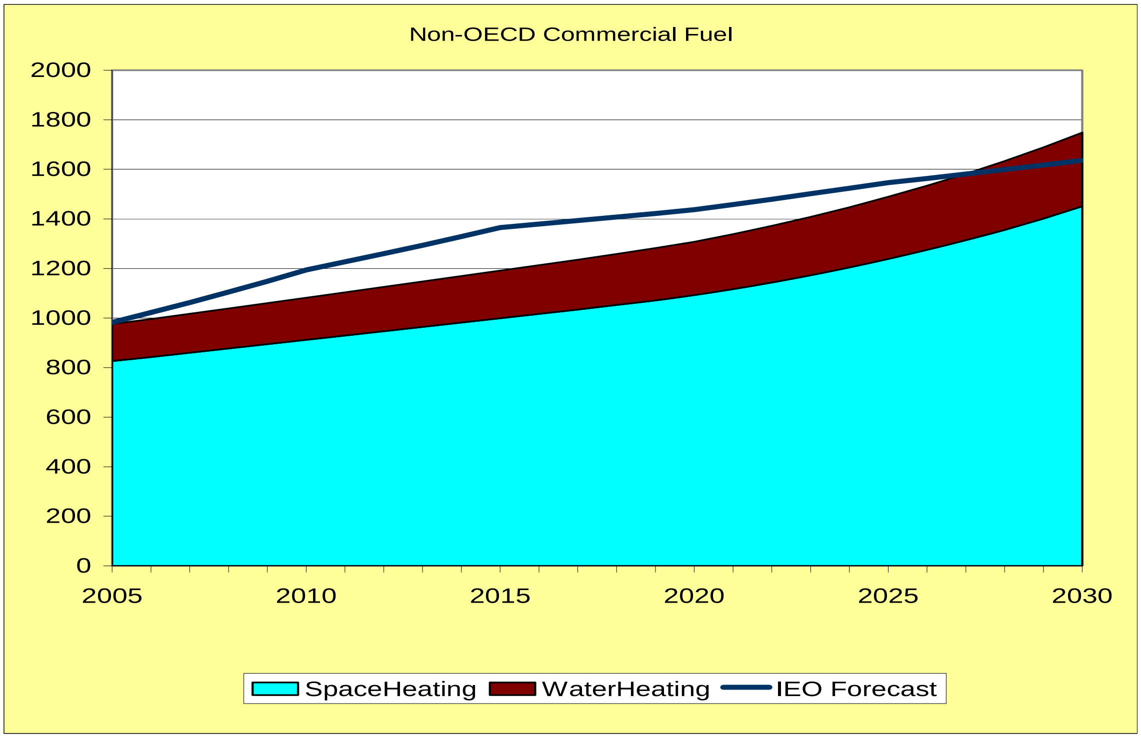


Figure 30 - Projection of Commercial Fuel Demand in non-OECD regions 2005-2030



Several important characteristics can be gleaned from the results.

- In total, the OECD countries still use more energy in their buildings than the non-OECD countries. This is true in both sectors, and for both electricity and fuels.
- The energy use in both sectors for both fuels is growing in both regions, although the growth is slower in the OECD countries.
- The differential between OECD and non-OECD countries is smallest in the residential sector, where electricity in non-OECD countries has nearly caught up to the OECD. Residential electricity in the two regions will cross-over sometime between 2010 and 2020.
- In terms of fuels, consumption between non-OECD and OECD countries is already quite close. Fuel consumption in non-OECD countries is dominated by space heating in the Former Soviet Union region (FSU). Fuel consumption is not predicted to grow dramatically in either region.
- Energy consumption in the commercial sector is still much lower in non-OECD countries. However this is the more rapidly growing sector in the region. While residential electricity in the developing and transitioning countries is expected to increase threefold between 2005 and 2030, commercial energy will increase by a factor of four.
- Finally, we note that the agreement between our demand forecast and the International Energy Outlook is quite good. In general, our projections cover a large percentage of the energy demand in IEO, but are slightly lower. This is expected, because we exclude some small miscellaneous end-uses in our bottom-up forecast. Only in two cases – residential non-OECD electricity and OECD commercial electricity does our estimate exceed that of the *IEO* in the base year. In these cases, it is likely that our demand assessment is an overestimate, but one of only a few percent.

Figure 31 and Figure 32 show the results for the residential sector from a new angle. These charts show energy demand divided into end-use components for each of our ten regions, in 2005 and in 2030. This presentation reveals some interesting details. First, North America (NAM) currently has the world's most consumptive residential sector. In 2030, we predict that it still will, although China will be second, and will have come a long way towards catching up[27]. The rest of Asia (SAS-PAS) will be the third most consuming region, with electricity consumption almost as high as China's. Electricity demand will quadruple in this region over the next 25 years or so. Space cooling will become very important in tropical and sub-tropical Asia by 2030. Much of the electricity in Asia, however, will still be consumed by the basic appliances – refrigerators and televisions. All together Asian refrigerators and televisions will consume more energy in 2030 than all of Latin American households.

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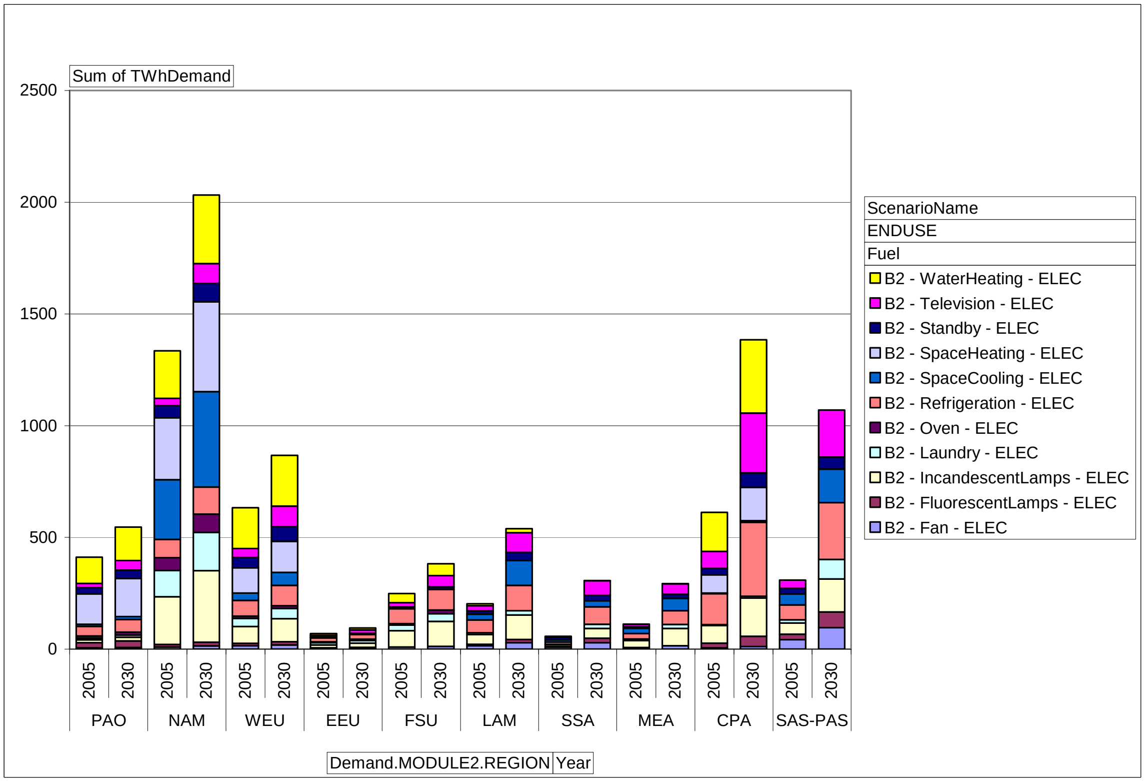
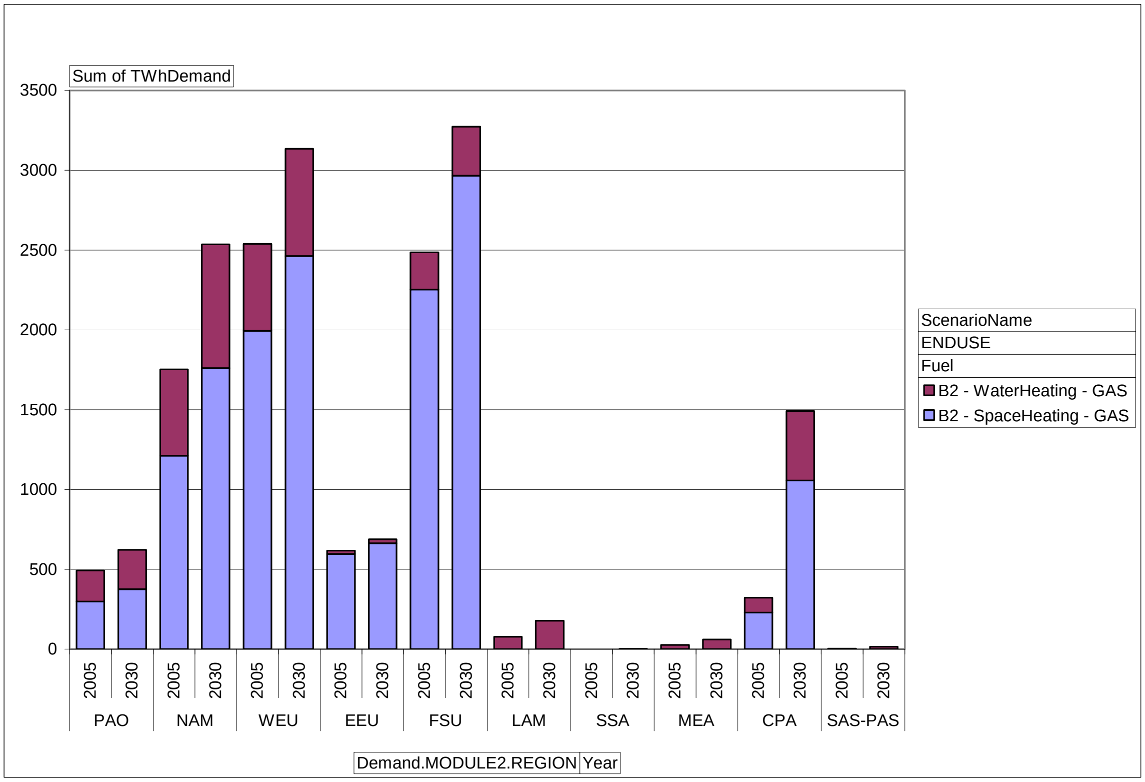
[27] Much has been made about China overtaking the United States as the world's largest energy consumer. The majority of this energy (about 70%) is used in industry, however.

Figure 31– Residential Sector Delivered Electricity Demand 2005 and 2030



The situation for fuel consumption is much different, as shown in Figure 32. Fuel consumption is predominately used for space heating in temperate or cold climates, although use for water heating is not insignificant. Space heating demand is basically saturated on a per household basis in the OECD regions, so the growth is driven purely by an increase in number of households, which is small in PAO and WEU. Likewise, space heating consumption in the FSU region is very large, but not expected to grow much in the next 25 years.

Figure 32– Residential Sector Delivered Fuel Energy Demand 2005 and 2030



5.2 Potential Energy Savings

Energy savings (for both electricity and fuels) that would result from the broad adoption of EES&L are shown for the Residential sector in Figure 33 and for the Commercial sector in Figure 34. These results derive from a combination of all of the individual features modeled by the analysis – economic growth, end-use demand share, and availability of cost-effective technologies for energy improvement. In the residential sector, space heating is expected to provide the largest opportunity for energy savings in the home, due to the dominance of this end-use in terms of energy consumption in the industrialized countries, transition economies, and China. It is important to keep in mind, however, that this savings will translate into much fewer emissions reductions than most other end-uses per unit energy savings, since it is mostly fuel energy[28]. Perhaps not surprisingly, the second highest opportunity for savings is from CFL replacement of incandescent lamps throughout the world. The next three end-uses in terms of potential energy savings are televisions, refrigerators and stand-by power.

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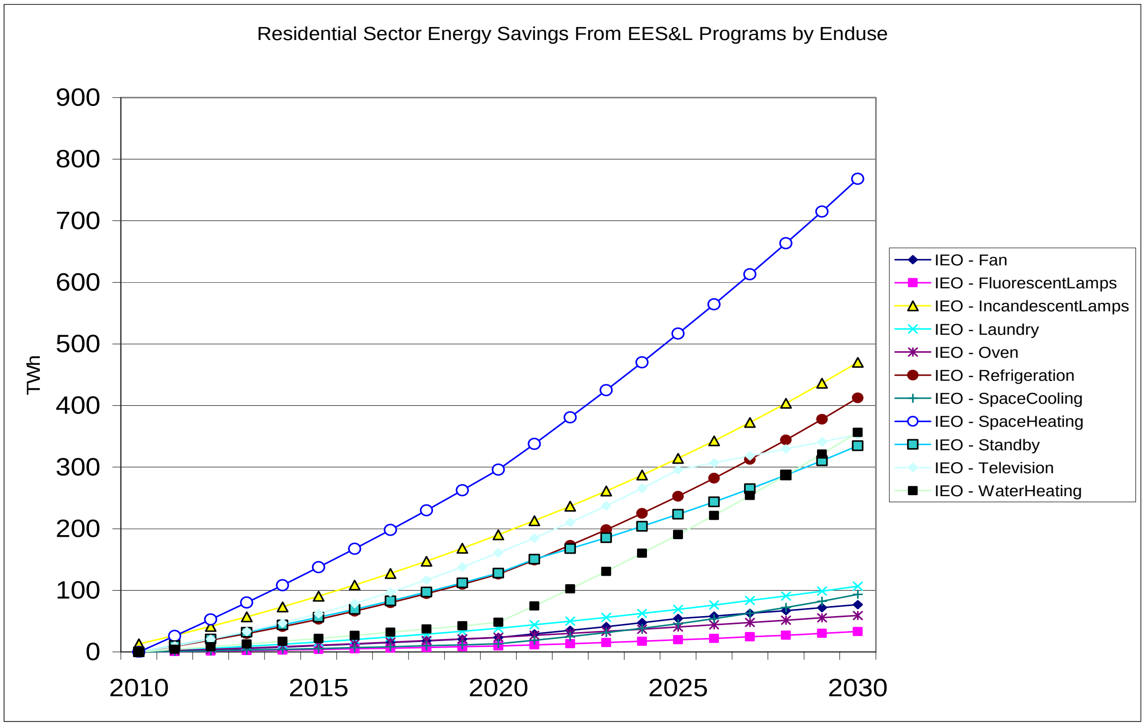
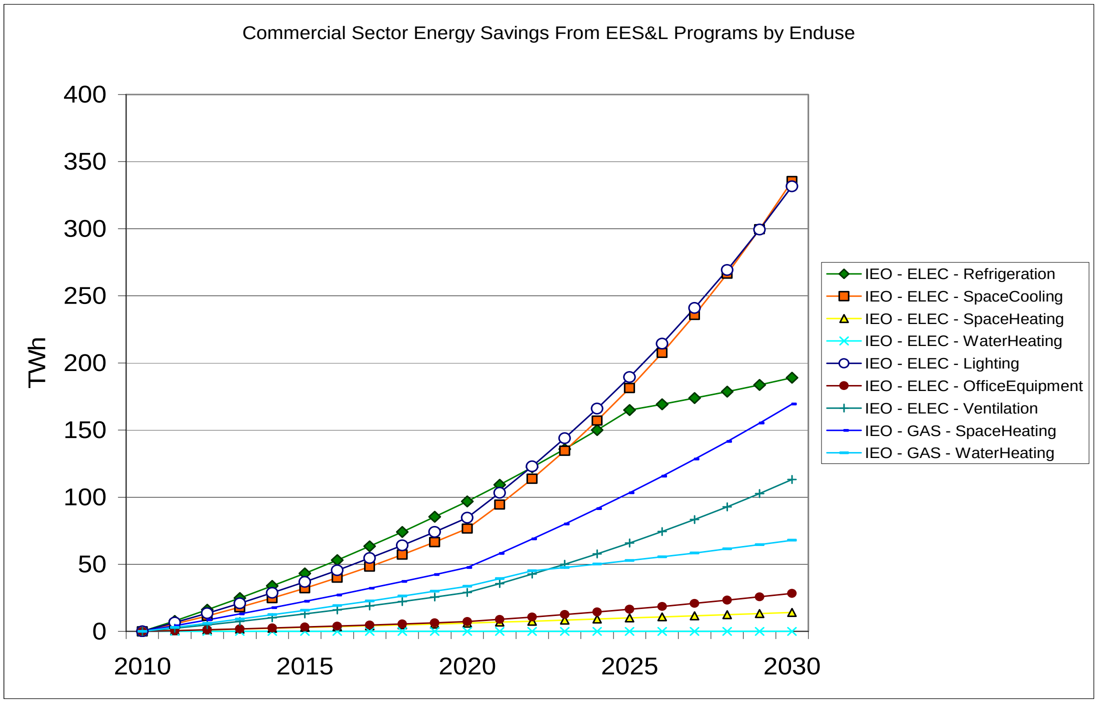
[28] Also, much of the space heating in the EEU and FSU regions are provided with district heat, which we do not consider as a likely candidate for EES&L programs.

Figure 33 Residential Delivered Energy Savings (TWh) by End-use 2010-2030



In the commercial sector, space cooling and lighting are expected to provide the largest potential for energy savings, followed closely by refrigeration.

Figure 34 Commercial Delivered Energy Savings (TWh) by End-use 2010-2020



5.3 Potential Emissions Reductions

Finally, energy demand savings is converted to carbon dioxide mitigation through the use of electricity generation carbon factors. We used the estimates of current carbon factors used in the SRES scenarios (from IEA data). Instead of relying on a particular external scenario built on unknown assumptions, we made the simplifying assumption that carbon factors, which take into account both the electricity generation mix, and transmission and distribution losses, would decrease by 1% per year in all regions. The carbon factors derived in this way are shown in Table 39.

Table 39 - Electricity carbon factors 2000-2030

	Electricity Carbon Factor (kg per kWh of CO_2)						
Region	**2000**	**2005**	**2010**	**2015**	**2020**	**2025**	**2030**
PAO	672.8	614.6	572.0	503.1	447.5	373.2	315.7
NAM	619.6	553.7	503.2	423.3	355.9	287.4	231.4
WEU	400.3	358.3	328.1	277.6	236.8	197.9	166.1
EEU	575.5	535.5	509.0	457.6	416.0	365.4	322.6
FSU	575.5	535.6	509.0	457.7	416.0	365.6	322.6
LAM	1060.9	964.9	922.7	808.6	743.7	594.0	503.5
SSA	1101.1	935.8	862.8	721.9	643.1	514.8	433.5
MEA	412.6	457.6	480.7	434.4	405.0	346.9	304.4
CPA	1181.4	1019.6	969.5	856.4	791.5	654.9	574.0
SAS-PAS	955.9	836.7	787.3	687.1	627.5	531.3	466.0
World	653.1	621.1	590.7	561.7	534.2	508.0	483.1

Emissions savings potentials are shown in Figure 35 for the residential sector and in Figure 36 for the commercial sector. The results follow those for energy savings, with some important distinctions. First, space heating is not the most important end-use in terms of emissions mitigation, because it is primarily supplied by less carbon-intensive fuels. Standby power and televisions are both very important end-uses in terms of carbon mitigation. This is due to the relative availability of these devices in the developing world. In general, the savings potential in the non-OECD region is *much higher* than in the OECD countries. Even though, industrialized country households currently use many more times the energy as developing country ones, the growth of energy demand is largely in the latter. Further, there is a greater potential for efficiency, since equipment in these countries is starting from a lower baseline. This finding would seem to recommend an acceleration of the shifting focus of EES&L programs towards developing countries.

Overall, commercial sector emissions reduction potential is about a third of that from the residential sector. Also, although opportunities are larger in the non-OECD countries, the gap with the OECD is not as great. A remarkable feature is the dominance of space cooling energy as a key area for the potential of policy intervention in developing countries, which of course include tropical regions. Also, the lighting savings potential is expected to be very high in these countries due to the relatively low penetration of high-efficiency equipment.

Figure 35- Residential Building Sector Annual Emissions Mitigation Potential by End-Use

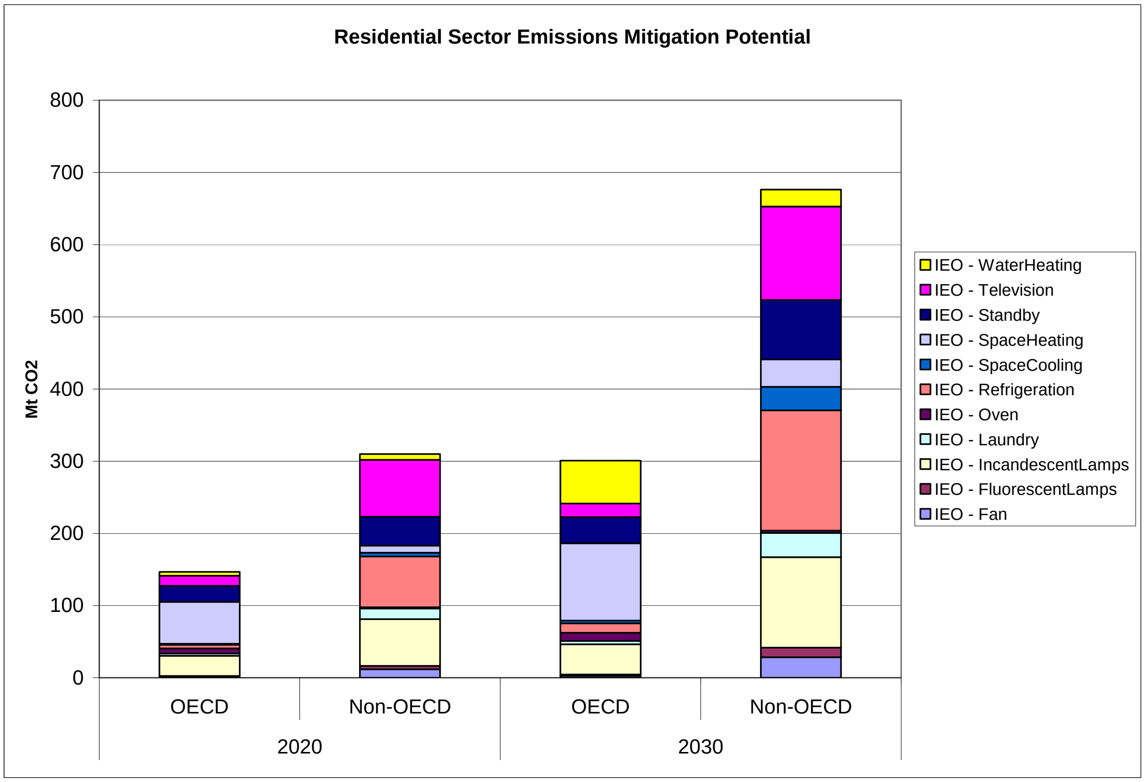
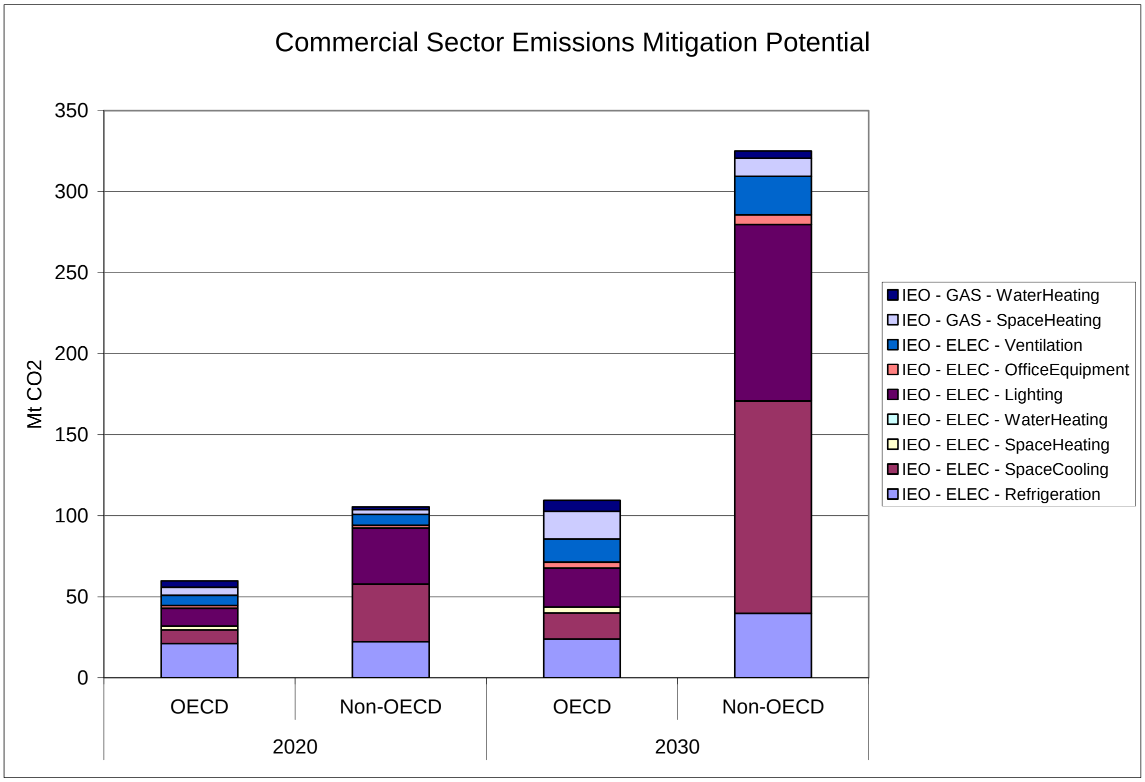


Figure 36- Commercial Building Sector Annual Emissions Mitigation Potential by End-Use



Emissions mitigation potentials by end-use are summarized in

Table 40. Annual Emission Reduction Potential by End-Use (Mt CO_2)

Residential				Commercial			
Type	End Use	2020	2030	Type	End Use	2020	2030
Electricity	Fan	13.2	31.4	Electricity	Lighting	45.7	132.7
	FluorescentLamps	5.8	14.9		OfficeEquipment	3.3	9.6
	IncandescentLamps	92.8	167.4		Refrigeration	43.3	63.7
	Laundry	17.7	37.9		SpaceCooling	44.1	147.2
	Oven	8.7	14.8		SpaceHeating	2.4	3.6
	Refrigeration	75.5	179.5		Ventilation	13.0	38.2
	SpaceCooling	6.9	36.5				
	SpaceHeating	32.4	48.9				
	Standby	62.2	118.4				
	Television	92.6	148.2				
	WaterHeating	7.8	64.1				
Fuel	SpaceHeating	32.4	48.9	Fuel	SpaceHeating	7.9	28.3
	WaterHeating	7.8	64.1		WaterHeating	5.6	11.3
Total		**455.8**	**975.0**	**Total**		**165.2**	**434.7**

In addition to the end-use breakdown, it is of great interest to know where geographically, emissions reduction potentials are largest, because it indicates which governments should be most encouraged and aided in developing effective EES&L programs. Mitigation potential by region are shown in **Table 41**.

Table 41 Annual Emission Reduction Potential by Region

Region	Residential		Commercial		Total	
	2020	2030	2020	2030	2020	2030
PAO	30	49	12	20	41	69
NAM	78	178	31	54	109	232
WEU	39	74	17	35	56	110
EEU	9	17	2	5	10	23
FSU	28	68	2	5	30	73
LAM	48	96	18	49	67	145
SSA	20	51	4	15	24	65
MEA	16	35	5	15	20	50
CPA	107	224	53	161	161	385
SAS-PAS	82	186	21	75	103	261
Total	**457**	**977**	**165**	**435**	**622**	**1412**

The table shows two important results.

- The region which contains China (Centrally Planned Asia[29]) has the greatest potential for mitigation in absolute terms, with 224 Mt CO_2 of avoided emissions in 2030 in the residential sector, and 161 Mt CO_2, in the commercial sector.

- Aside from China, the rest of Asia (SAS-PAS) will also see great opportunities for emissions reduction. This region will be have the second highest potential by 2030, almost equaling that of CPA in the residential. Savings potentials in the commercial sector will continue to lag significantly however. Finally, other regions show a large potential for savings, especially North America and Latin America.

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[29] China composes most of the region defined in the IPCC Special Report on Emissions Scenarios as Centrally-Planned Asia, which also includes Cambodia, Laos, North Korea, Mongolia and Viet Nam.

Table 42– Gt CO_2 Emissions Mitigation Potential from EES&L Programs 2120-2030

Year	Residential			Commercial			Total		
	ELEC	FUEL	TOTAL	ELEC	FUEL	TOTAL	ELEC	FUEL	TOTAL
Annual Emissions Avoided									
2020	0.42	0.04	0.46	0.15	0.01	0.17	0.57	0.05	0.62
2030	0.86	0.12	0.98	0.40	0.04	0.43	1.26	0.15	1.41
Percentage of Sector Fuel Emissions Avoided									
2020	11.8%	2.1%	8.3%	5.0%	1.8%	4.4%	8.6%	2.0%	5%
2030	22.9%	5.6%	16.7%	11.5%	4.9%	10.2%	17.5%	5.4%	11%
Cumulative Emissions Avoided									
2020	2.2	0.2	2.5	0.8	0.1	0.9	3.1	0.3	3.3
2030	9.0	1.0	10.0	3.6	0.3	4.0	12.6	1.4	14.0

The "bottom line" result is the potential impact of EES&L in actually slowing the growth or even reducing emissions on a global scale. In order to make a comparison, we simply subtracted emissions reductions from the IEO baseline. The results are shown in Figure 37 and **Figure 38**. The results show that, in the residential building sector, potential emissions reductions are large enough to level sector emissions by 2015, and reduce them after about 2020, bringing the emissions of the world's homes almost back to 2005 levels by 2030. In the commercial building sector, EES&L programs are likely to level growth, but not reverse it.

Figure 37 Carbon Dioxide Emissions 2005-2030 with and without EES&L programs.

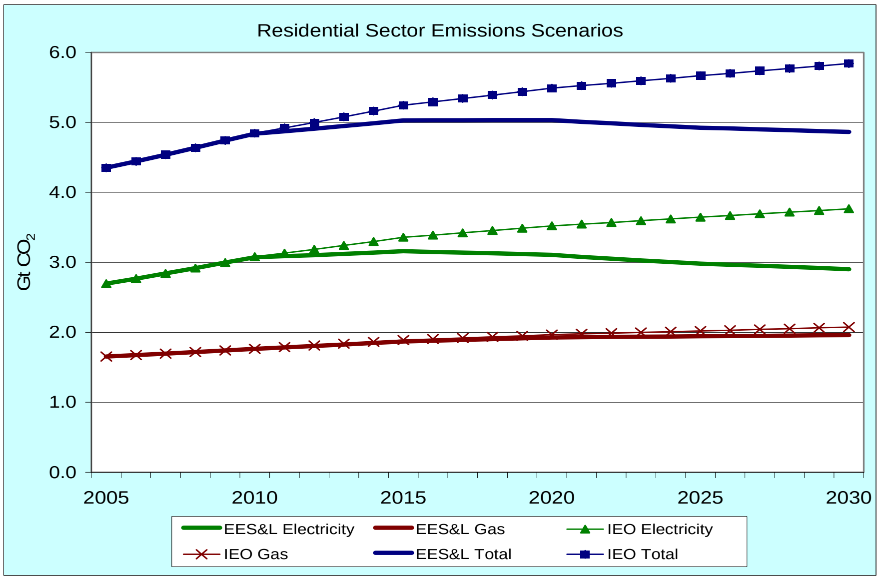
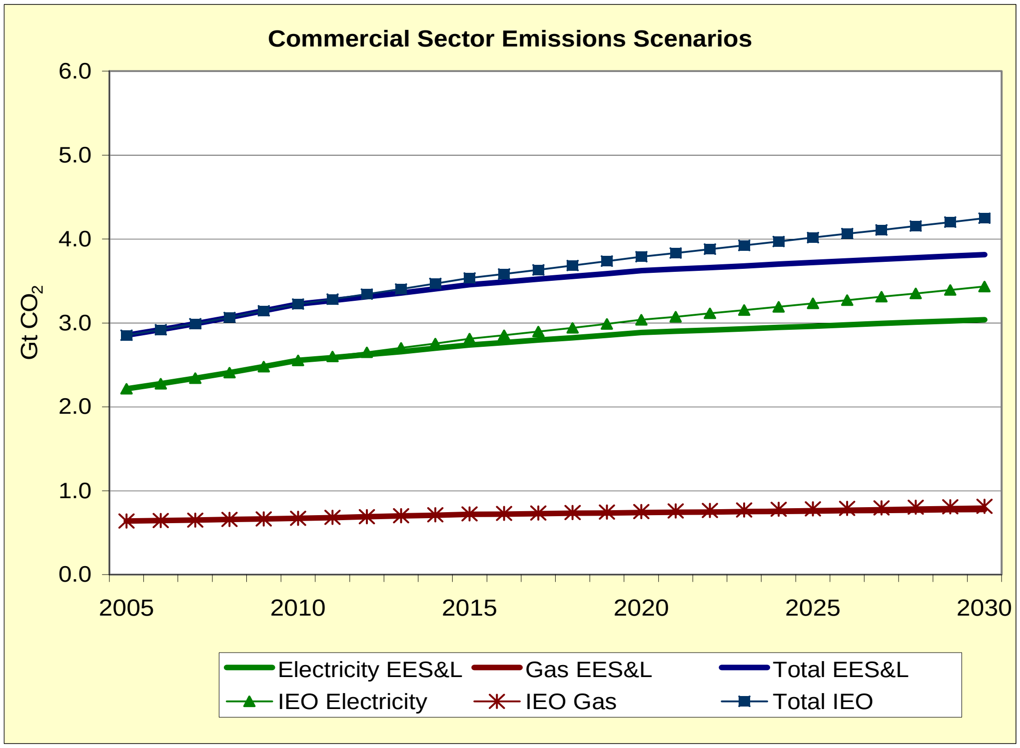


Figure 38 Carbon Dioxide Emissions 2005-2030 with and without EES&L programs.



Finally, we compare our results to the assessment of the potential for CO_2 emissions mitigation in buildings recently published by the IPCC (Levine, Urge-Vorsatz et al. 2007) That study was not limited to EES&L programs, rather, it considered market transformation mechanisms in terms of a supply-curve analysis, considering variable scenarios in terms of cost per unit of carbon dioxide (US\$/tCO_2). It concluded that a reduction of approximately 3.2, 3.6 and 4.0 billion tons of CO_2/yr are possible in 2020, at zero US\$/tCO_2, 20 US\$/tCO_2 and100 US\$/tCO_2 respectively, and that "..extrapolation of these potentials to the year 2030 suggests that, globally, about 4.5, 5.0 and 5.6 $GtCO_2$ at negative cost, <20 US\$/tCO_2 and <100 US\$/tCO_2 respectively, can be reduced (approximately 30, 35 and 40% of the projected baseline emissions)". Our analysis would indicate, therefore, that EES&L programs could account for about 20% of total "zero cost" potential in 2020, and about 33% of the potential in 2030.

This result can be interpreted as being consistent with the IPCC findings for the following reasons:

- The EES&L programs we have considered cover only the efficiency of the equipment installed in buildings. Building codes that consider the thermal insulation of the building, the type and capacity of the equipment and the density of lighting can have as much of an effect as equipment efficiency. This is especially true of space heating equipment, which is by far the largest end-use in terms of delivered energy, already has a relatively high efficiency, has low turnover rates, but whose energy intensity is dramatically impacted by thermal insulation of the building shell. For these reasons, it is reasonable that equipment efficiency only accounts for a fraction of the total potential.

- The implied fraction of the IPCC estimates met by EES&L increases over time, from 20% in 2020 to 33% in 2030. This is expected since EES&L programs target only *new* equipment, and there is therefore a steep increase in savings potential in the years after program implementation due to the gradual turnover of the stock. By 2030, the highest efficiency equipment determined by the 2020 program levels will have largely (but not totally) saturated the stock, and annual savings will start to level.

5.4 Sensitivities and Uncertainties

In an analysis such as this, some discussion of uncertainties is appropriate. There are many elements, not totally under analytical control, that generally fall into categories of inaccuracy, imprecision, and unpredictability.

First of all, the analysis relies on dozens of separate technical parameters, for which we used our own judgment rooted in experience and best practice. There will certainly be many inaccuracies in these parameters. Indeed, it is our hope that the publication of this report to the international energy analysis community may help stimulate discussion, data sharing and increased focus on use patterns, equipment types and efficiency baselines around the world. It is extremely difficult to quantitatively assess such errors, but they are likely no less than 10-20% for each individual parameter. On average, errors may be similar or less due to canceling effects, since we are likely to overestimate as often as underestimate. It must be said however, that a larger overall error may occur due to an omission or false assumption about energy patterns in a particular region or end-use.

Second, due to the scope of the project, some details were necessarily disregarded. These include economic and social differences between countries within a region, cultural practices, and consumer preferences. Again, we hope to have provided a framework where many of these considerations can be taken into account in considering the global crisis of energy-related emissions.

Another error may present itself in the development of global models for equipment saturation as a function of income. While we are confident in the general patterns modeled and observe statistical variability generally on the order of just a few percent, we recognize that many of the characteristics of the current world imbedded in the analysis may not hold over several decades.

In terms of whether the emissions reductions we identify would actually occur, however, all of the previous errors are probably small in comparison with our inability to predict two things:

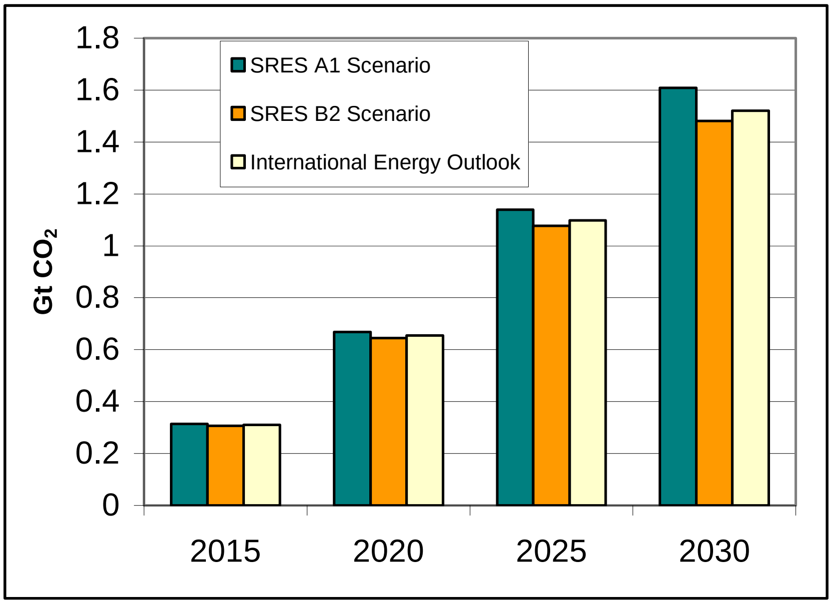
- The macroeconomic reality of the world and each individual region over the next 22 years.

- The targets that governments will choose in their EES&L programs, and their aggressiveness and capability in implementing them.

The second of these, of course, cannot ever be known, but we believe that our scenarios are transparent enough to be scrutinized for feasibility.

The dependency of our results on macroeconomic realities can in some measure be evaluated, since we have more than one forecast of macroeconomic growth (in terms of GDP per capita). Figure 39 shows the dependence of carbon mitigations on economic scenarios, using GDP growth scenarios defined by the IPCC's *Special Report on Emissions Scenarios (SRES)* together with the U.S. DOE's International Energy Outlook. The difference in total emissions in these scenarios grows over time, reaching a maximum in 2030 as would be expected since the scenarios are characterized by a constant growth rate, by which incomes diverge over time. The largest difference occurs between the SRES B2 "moderate growth" scenario and the A1 "high growth" scenarios, with the IEO scenario falling somewhere in between the two. The difference in emissions mitigation is a few percent between the B2 and A1 scenarios. This can be explained, in large part, by saturation effects. In the OECD regions where consumption is highest, building energy demand is driven less by economic growth since residences already have all major appliances and adequate heating and cooling. Furthermore, commercial energy demand grows less rapidly per unit GDP in these countries. In regions in transition, such as Asia, there is a significant transformation of energy demand but by 2020, most houses will have most equipment types and additional growth will likely not increase ownership of a product such as refrigerators. Where we do see a significant influence is in the extremely poor countries of Sub-Saharan Africa and Asia. The more detailed understanding of the impact of different economic growth scenarios in these countries and others in the developing world could be an interesting area of future research utilizing the BUENAS model.

Figure 39 Dependence of Carbon Dioxide Mitigation on Economic Scenario



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Appendices

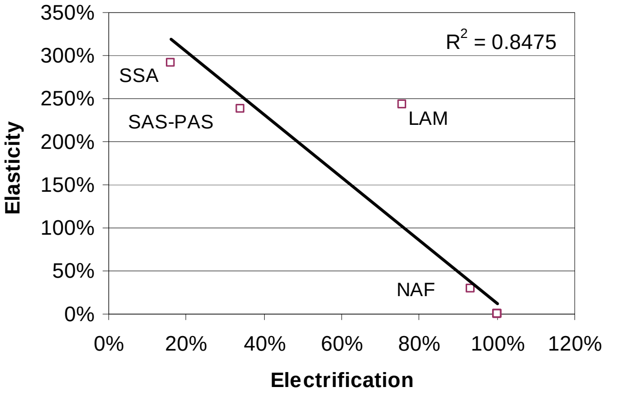
Appendix 1 - Saturation Model

A.1.1 Electrification

The electrification rate for each country is calculated by assuming an electrification growth rate related to economic growth and to the current electrification rate. In order to determine the relationship between electrification growth and economic growth, we compared historical rates for different years compiled by DHS (Demographic and Health Survey, http://www.measuredhs.com/) with the economic growth (GDP per capita) for a sample of developing countries.

The relationship between the rate of electrification and economic growth is itself a function of the level of economic development. Poor countries with low electrification rates will prioritize electrification as a basic standard of living indicator, and will tend to exhibit high electrification-economic growth elasticity (proportionality). Once access to electricity is widespread, the rate of connections slows until access is nearly universal and therefore does not increase further as the economy grows. Accordingly, we force the elasticity to be equal to 0 for an electrification of 100%. The relation between economic growth and growth in electrification is shown in Figure A.1.1.

Figure A.1.1. Relationship between electrification-economic growth elasticity and current level of electrification



$$\frac{\Delta Electrification}{Electrification} = (-3.73 \times Electrification + 3.85) \times \frac{\Delta GDP}{GDP}$$

A.1.2 Refrigeration

A close look at the results of the modeling effort for one end use is useful to understand the method. Refrigerators were the first appliance studied using econometric diffusion modeling, because they are both highly desirable, but relatively expensive for low-income households in developing countries. In addition, they account for a significant amount of residential electricity consumption.

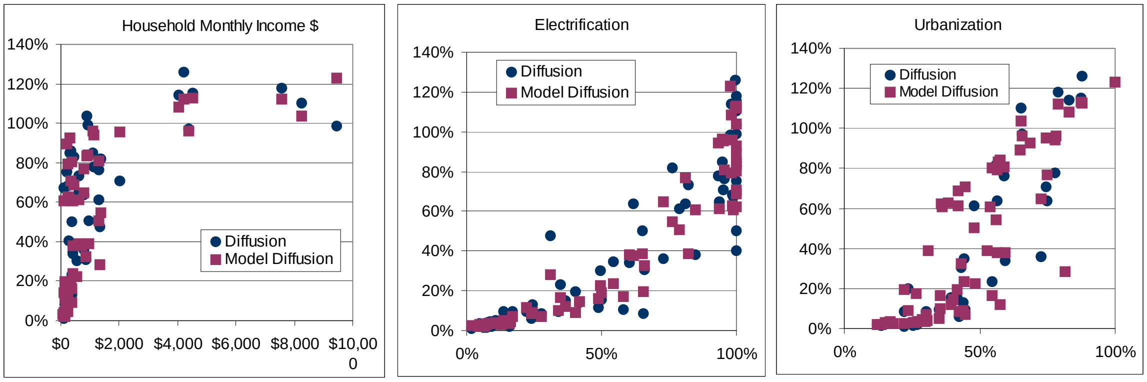
Table A.1.2 Linear Regression Results for Refrigerators Diffusion

Observations	64
R^2	0.92

	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	4.75	0.19	25.53	6.4E-34
βinc	-6.0E-05	4.5E-05	-1.34	1.9E-01
βelec	-3.55	0.25	-14.12	1.0E-20
βurb	-2.69	0.51	-5.28	1.9E-06

With an R^2 of 0.92, refrigerator ownership is very well described by a logistic functional form with income, electrification rate and urbanization as independent variables. Each of these variables is statistically significant. Each parameter also has the expected sign that ownership increases with increasing household income, electrification, or urbanization. Electrification has by far the lowest p-value which means it's the most determining variable in the decision of buying a refrigerator.

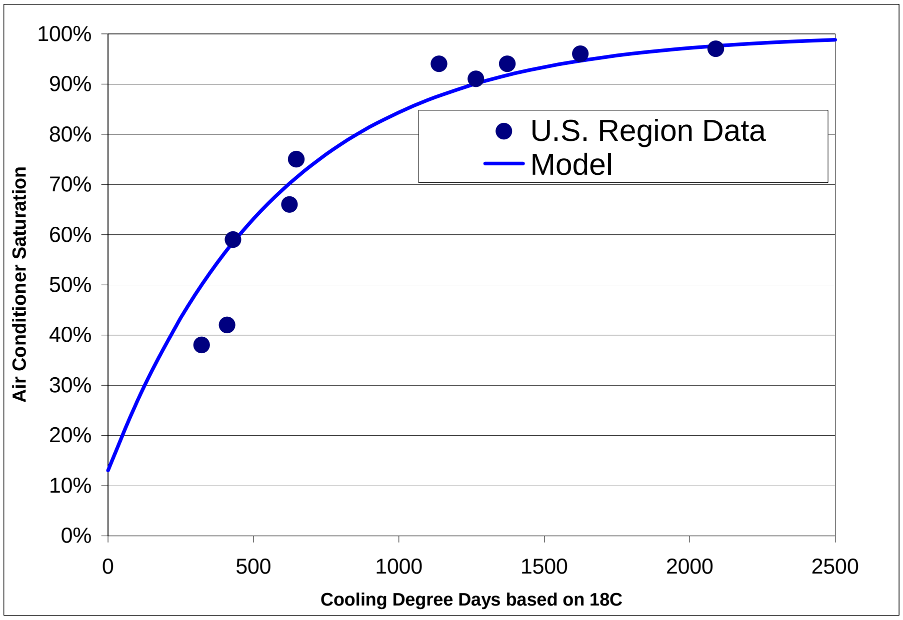
Figure A.1.2 Saturation Model and Data for Refrigerators



A.1.3 Air Conditioners

Figure A.1.3 shows the relationship between Cooling Degree Day and the maximum air conditioner saturation level, as determined by U.S. Data.

Figure A.1.3. Maximum Air Conditioner Saturation vs. CDD



As described in Section 2.1.2, the income dependency of air conditioner ownership is determined by dividing actual saturation by the theoretical maximum, in order to yield an estimate of *availability*. The availability variable is shown in Figure A.1.4, along with the fit to a logistical function.

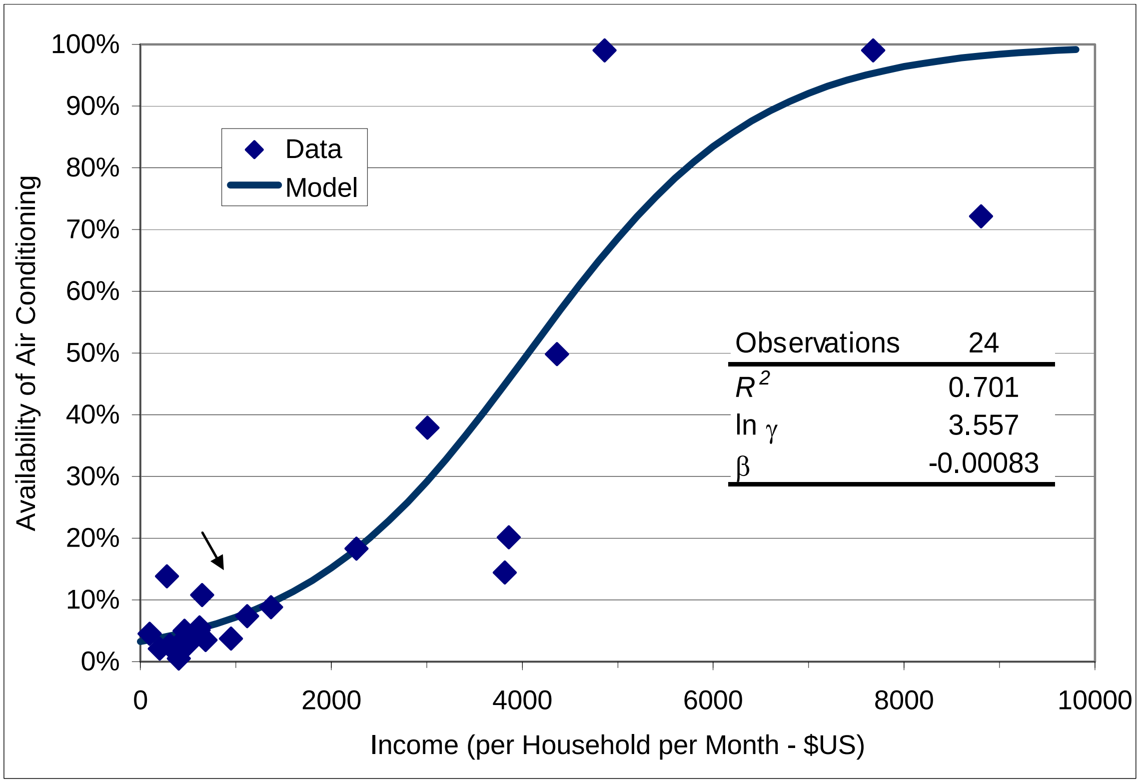


Figure A.1.4

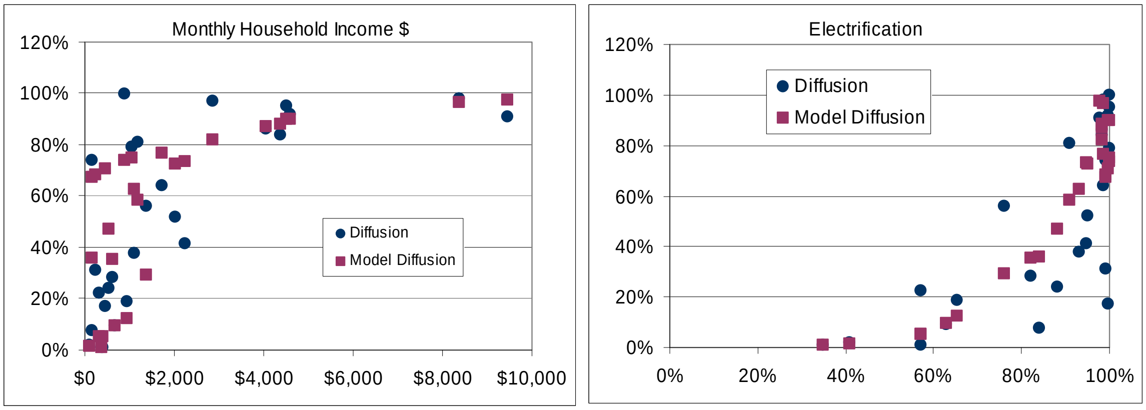
A.1.4 Washing Machines

Like refrigerators, washing machines are also a highly desirable product, and one of the first appliances purchased by low-income households. Washing machines are generally less expensive than refrigerators, allowing for more rapid uptake as incomes rise. For these reasons, the relationship between income and diffusion for washing machines is similar to that of refrigerators. Electrification is also a statistically significant determinant of washing machine ownership. Urbanization, however, was not found to be a significant variable for this appliance; therefore, we eliminated this variable in the linear regression. The resulting fit has an R^2 of 0.64.

Table A.1.3 Linear Regression Parameters for Washing Machines Diffusion

Observations	27			
R2	0.64			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	7.98	1.525	5.23	2.3E-05
βinc	-3.2E-04	1.5E-04	-2.16	4.12E-02
βelec	-8.74	1.863	-4.69	9.11E-05

Figure A.1.5 Data and Modeled Diffusion for Washing Machines



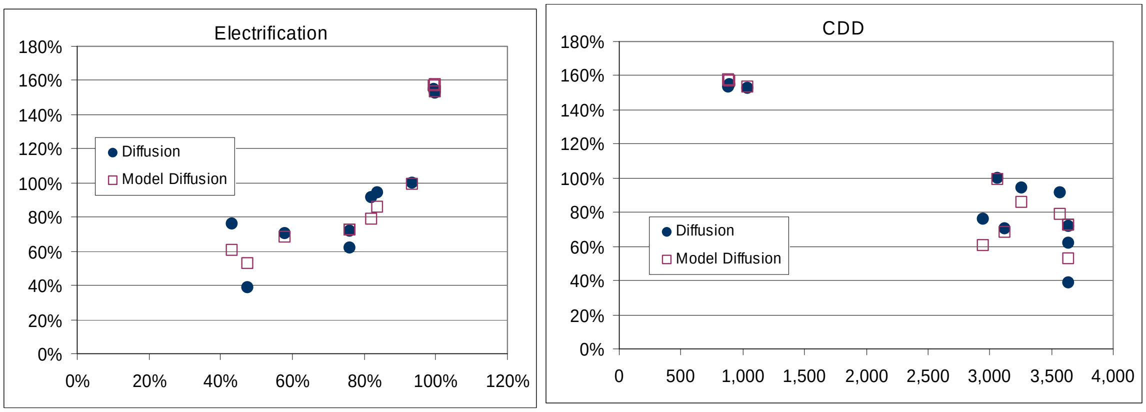
A.1.4 Fans

The ownership of fans is found to be a function of electrification rate and climate only. Income doesn't seem to play an important role which is probably due to the low investment that a fan represents for a household.

Table A.1.4 Linear Regression Parameters for Fans Diffusion

Observations	11			
R^2	0.92			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	1.02	0.466	2.19	0.060211
βElec	-1.4E+00	4.0E-01	-3.51	7.91E-03
βCDD	3.3E-04	7.2E-05	4.60	0.001762

Figure A.1.4 Data and Modeled Diffusion for Fans



A.1.5 Televisions

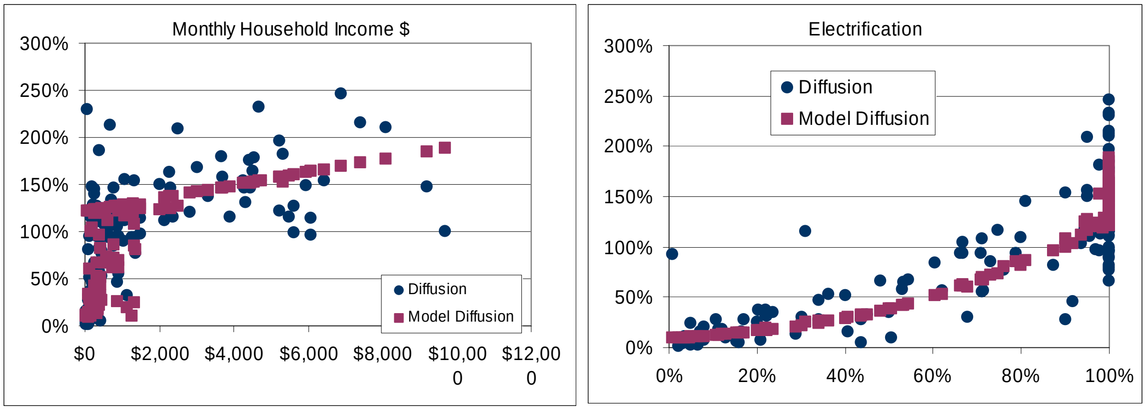
Of the appliances studied, televisions are by far the least expensive, and among the most desirable. Also, it is common for even developing country households to own more than one television. Television ownership closely follows lighting as the second use of electricity in the household. We collected 139 data points for television diffusion for countries with a wide range of incomes. The data is well described by linear regression of the logistic function, which shows an R^2 of 0.75.

Table A.1.5 Linear Regression Parameters for Televisions Diffusion

Observations	139			
R^2	0.75			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	3.50	0.136	25.75	3.88E-54
βinc	-9.5E-05	3.3E-05	-2.90	4.33E-03
βelec	-3.11	0.196	-15.81	1.32E-32

As Table A.1.5 shows, the parameters describing income and electrification are highly statistically significant. As in the case of washing machines, urbanization was not a statistically significant parameter for televisions, and it was therefore not included in the regression.

Figure A.1.6 Data and Modeled Diffusion for Televisions



A.1.6 Stand-By Power

Stand-by power is perhaps the most diverse end use category in the residential sector. There are literally dozens of home electronics products and small appliances which consume power continually while not in active mode. Clearly it is impossible to model each of these product classes individually. Therefore, we adopt a generic approach which simply enumerates the number of devices using standby power. The relationship derived from the countries for which data were available is shown in Figure A.1.7. The relationship is given by

$$DeviceNb = \frac{\mathrm{SB}_{\mathrm{Max}}}{SB_{Ave} \times (1 + \gamma \times \exp(\beta \times Inc))}$$

Where *DeviceNb* is the number of device consuming standby power

SB_{Max} is the average maximum power of stand by (60W)

SB_{Ave} is the average power of a stand by appliance (5W)

Inc is the average household income

The regression for Stand By appliances differs a little from other appliances because few surveys were available for developing countries. To improve our balance between regions, we weighted our data by population in the regression. The regression calculation was performed in *Statistica*.

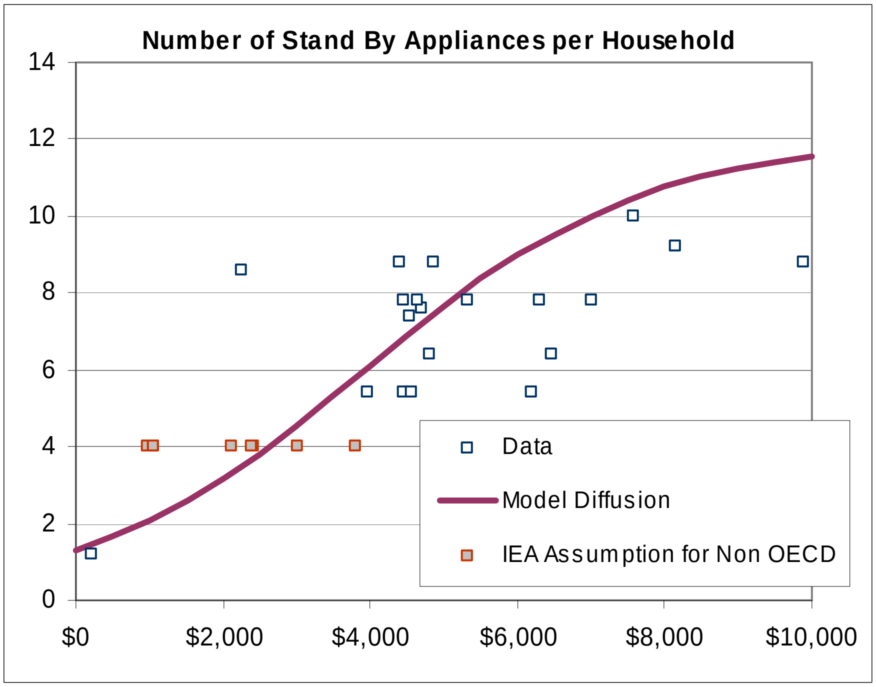
Table A.1.6 Linear Regression Parameters for Stand By Power

Observations	21
Correlation r	0.95

	Coefficients
lnγ	2.10
βinc	-4.81E-04

Our resulting regression was compared to IEA assumptions for some non-OECD countries in figure A.1.7.

Figure A.1.7 Data and Modeled Diffusion for Stand By Products



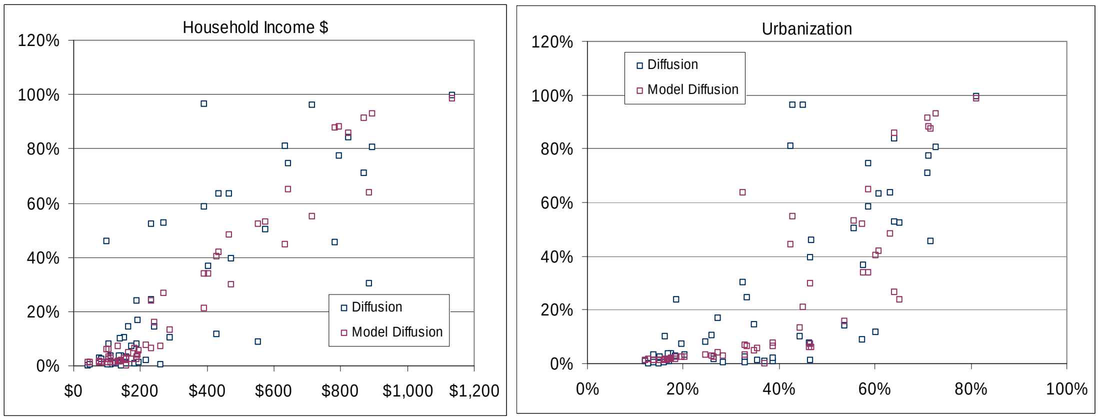
A.1.7 Cooking

Table A.1.7 Linear Regression Parameters for Commercial Fuel Share

Observations	55
R Square	0.66

	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	5.53	0.498	11.11	2.45E-15
βinc	-5.1E-03	1.2E-03	-4.13	1.34E-04
βurb	-4.89	1.698	-2.88	5.76E-03

Figure A.1.8 Data and Modeled Share of commercial Fuel



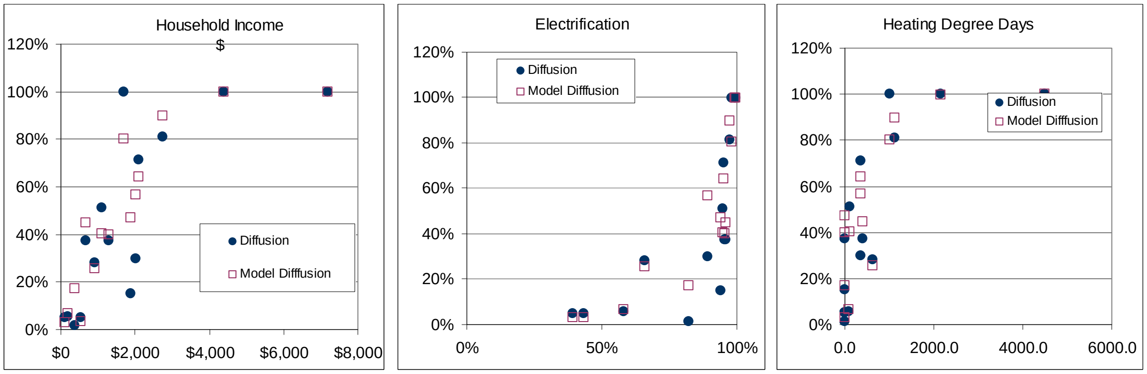
A.1.8 Water Heating

Table A.1.8 Linear Regression Parameters for Water Heaters Diffusion

Observations	15
R^2	0.77

	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	5.53	2.314	2.39	3.59E-02
βinc	-6.1E-04	4.6E-04	-1.32	2.15E-01
βelec	-4.53	3.047	-1.49	1.66E-01
βHDD	-1.45E-03	0.001	-2.22	4.87E-02

Figure A.1.9 Data and Modeled Diffusion for Water Heaters



Appendix 2 - Saturation Data Tables

A.2.1 Electrification Rates

Table A.2.1. Electrification rate and Monthly Household Income from selected developing countries:

Country	Year	Electrification	Household Income
Benin	1996	15%	$ 159
	2001	22%	$ 185
Burkina Faso	1993	6%	$ 113
	1999	7%	$ 133
Cote d'Ivoire	1994	37%	$ 293
	1999	48%	$ 324
Ghana	1993	31%	$ 93
	1998	43%	$ 97
Malawi	1992	3%	$ 59
	2000	5%	$ 83
Mali	1996	6%	$ 96
	2001	11%	$ 115
Senegal	1993	26%	$ 350
	1997	32%	$ 371
Uganda	1995	7%	$ 98
	2001	9%	$ 129
Egypt	1992	93%	$ 518
	1995	96%	$ 539
Bolivia	1994	64%	$ 393
	1998	71%	$ 437
Brazil	1991	71%	$ 1,078
	1996	94%	$ 1,119
Colombia	1990	90%	$ 829
	1995	92%	$ 869
Dominican Republic	1991	78%	$ 575
	1999	91%	$ 747
Guatemala	1995	61%	$ 816
	1999	71%	$ 883
Bangladesh	1994	18%	$ 133
	2000	32%	$ 157
India	1993	51%	$ 155
	1999	60%	$ 201
Indonesia	1991	49%	$ 237
	1997	80%	$ 308
Nepal	1996	18%	$ 98
	2000	25%	$ 107
Philippines	1993	65%	$ 367
	1998	71%	$ 387

A.2.2 Lighting

Table A.2.2. Number of Lights per Household

Country	Year	No. of Points	Reference
Pune			(Kulkarni and Sant 1994)
Low Income	1989	2.0	
Middle Income	1989	5.7	
Ahmednagar			
Low Income	1989	2.9	
Middle Income	1989	5.7	
Talegaon			
Low Income	1989	2.6	
Middle Income	1989	5.3	
Brazil	1991	10.0	(Gadgil and Jannuzzi 1991)
Guadalajara	1993	8.7	(Friedmann, DeBuen, Sathaye J. et al. 1995)
Monterrey	1993	11.1	
Caracas	1993	10.6	(Figueroa and Sathaye 1993)
Morocco	1997	7.6	(IEA/OECD 2001)
Uruguay	1997	8.1	(McNeil 2003)
Ghana	1997	10.0	(Constantine and Denver 1999)
Sri Lanka	1997	14.2	(CLASP 1997)
Argentina	2000	13.7	(Lutz, McNeil, Tanides et al. 2008)
Australia	1999	15.0	(IEA 2006)
Austria	2006	26.0	
Canada	1999	27.0	
China	2003	6.7	
Croatia	2006	14.0	
Czech Republic	2006	10.0	
Denmark	2006	25.4	
Finland	2006	23.5	
France	2006	18.9	
Germany	2006	32.0	
Greece	2006	7.0	
Iceland	1999	20.0	
Ireland	1999	20.0	
Italy	2006	18.0	
Lithuania	2006	6.0	
Netherlands	2006	40.0	
New Zealand	1999	23.0	
Norway	1999	35.0	
Portugal	2006	11.4	
Russian Federation	2000	3.8	
Slovenia	2006	19.0	
Spain	2006	25.0	
Sweden	2006	22.0	
United Kingdom	2006	20.0	
United States	1999	30.0	

A.2.3 Refrigeration

Table A.2.3. Diffusion Data for Refrigerators

Country	Year	Income	Electrification	Urbanization	Diffusion	Reference
		$/HH	%	%	%	
Albania	2000	$446	44.6	100.0	83	1
Armenia	2000	$221	22.1	100.0	75	2
Australia	1998	$4,229	422.9	99.6	126	3
Austria	1995	$4,373	437.3	98.4	97	3
Belize	2000	$1,318	131.8	79.0	61	4
Benin	2001	$178	17.8	24.0	6	2
Bolivia	1998	$424	42.4	60.2	34	2
Brazil	1996	$1,117	111.7	93.2	78	2
Bulgaria	2000	$305	30.5	100.0	85	5
Burkina Faso	1999	$126	12.6	13.0	3	2
Cambodia	2000	$130	13.0	15.8	2	2
Cameroon	1998	$211	21.1	16.9	10	2
Chad	1997	$101	10.1	1.8	1	2
China	2002	$290	29.0	100.0	40	6
Colombia	2000	$793	79.3	81.0	64	2
Comoros	1996	$184	18.4	27.6	9	2
Costa Rica	2000	$1,312	131.2	95.7	76	7
Côte d'Ivoire	1999	$329	32.9	50.0	16	2
Croatia	2000	$925	92.5	100.0	99	5
Dominican Republic	1999	$710	71.0	61.7	64	2
Egypt	2000	$616	61.6	93.8	65	2
Gabon	2000	$1,333	133.3	31.0	48	2
Germany	2003	$4,519	451.9	100.0	115	8
Ghana	1998	$96	9.6	42.0	14	2
Guatemala	1999	$867	86.7	66.0	31	2
Guinea	1999	$230	23.0	16.4	7	2
Haiti	2000	$197	19.7	34.0	10	2
Honduras	2000	$407	40.7	54.5	35	9
India	1999	$191	19.1	58.0	11	2
Indonesia	1997	$301	30.1	49.0	11	2
Japan	2002	$8,249	824.9	100.0	110	10
Jordan	1997	$1,087	108.7	94.7	85	2
Kazakhstan	1999	$245	24.5	98.1	79	2
Kenya	1998	$153	15.3	7.9	4	2
Kyrgyzstan	1997	$103	10.3	98.8	67	2
Madagascar	1997	$92	9.2	7.3	1	2
Mali	2001	$110	11.0	10.8	5	2
Mauritania	2001	$242	24.2	22.2	10	2

Mexico	2000	$2,030	203.0	95.0	71	11
Morocco	1992	$545	54.5	49.5	30	2
Mozambique	1997	$73	7.3	4.7	4	2
Nicaragua	1998	$370	37.0	34.8	23	1
Niger	1998	$112	11.2	6.7	3	2
Nigeria	1999	$128	12.8	36.6	15	2
Panama	2001	$1,370	137.0	76.2	82	12
Peru	2000	$778	77.8	73.0	36	2
Philippines	1998	$400	40.0	84.7	38	2
Romania	2000	$383	38.3	100.0	50	5
Rwanda	2000	$98	9.8	6.2	1	2
Senegal	1997	$368	36.8	24.4	13	2
Singapore	1998	$9,461	946.1	97.7	99	14
Slovakia	2003	$880	88.0	100.0	104	15
South Africa	1998	$957	95.7	65.3	50	1
Sweden	1995	$4,050	405.0	98.2	114	3
Tanzania	1999	$122	12.2	9.2	2	2
Thailand	2000	$631	63.1	82.1	74	16
Togo	1998	$126	12.6	9.0	4	2
Turkmenistan	2000	$335	33.5	100.0	86	2
Uganda	2001	$124	12.4	4.4	2	2
United States	2001	$7,584	758.4	100.0	118	17
Uzbekistan	1996	$244	24.4	98.4	68	2
VietNam	1997	$126	12.6	65.6	8	2
Yemen	1997	$240	24.0	40.3	20	2
Zambia	2002	$166	16.6	13.7	10	2

A.2.4 Air Conditioners

Table A.2.4. Saturation Data for Air Conditioners

Country	Year	GDP/HH/Mo.	CDD	Diffusion	Climate Max	Availability	Reference
India	1999	$201	3120	2%	100%	2%	21
Australia	1998	$4,364	839	40%	80%	50%	3
Thailand	2000	$646	3567	11%	100%	11%	16
Albania	2002	$501	683	2%	74%	3%	1
Egypt	2003	$682	1836	3%	97%	4%	2
Brazil	1996	$1,119	2015	7%	98%	7%	1
Ghana	1997	$96	2949	5%	100%	5%	20
Nicaragua	2001	$403	3250	1%	100%	1%	1
Panama	2000	$1,370	3638	9%	100%	9%	12
Honduras	2001	$429	2289	3%	99%	3%	9
China	2000	$277	1046	12%	87%	14%	6
Paraguay	1992	$610	2197	5%	98%	5%	23
Sri Lanka	1999	$337	2943	2%	100%	2%	25
Mexico	2003	$2,265	1560	17%	95%	18%	22

Country	Year	GDP/HH/Mo.	CDD	Diffusion	Climate Max	Availability	Reference
Indonesia	1997	$308	3545	3%	100%	3%	2
Philippines	2003	$464	3508	5%	100%	5%	2
Singapore	2003	$8,805	3261	72%	100%	72%	14
South Africa	2002	$950	824	3%	80%	4%	24
Spain	2001	$3,858	702	15%	75%	20%	18
Italy	1996	$3,816	600	10%	69%	14%	18
Canada	2003	$4,863	171	42%	31%	134%	19

A.2.5 Washing Machines

Table A.2.5 Diffusion Data for Washing Machines

Country	Year	Income	Electrification	Urbanization	Diffusion	Reference
		$/HH	%	%	%	
Argentina	2001	$2,243	224340.9	94.7	41.3	26
Austria	1995	$4,373	437263.5	98.4	84.0	3
Brazil	1996	$1,117	111706.2	93.2	37.6	1
Costa Rica	1998	$1,192	119240.2	90.8	81.0	7
Egypt	1995	$528	52754.5	88.1	24.0	2
Germany	2003	$4,519	451892.0	100.0	95.2	8
Ghana	1997	$95	9499.0	40.9	1.7	17
Japan	1991	$8,379	837887.1	98.5	98.0	10
Mexico	2000	$2,030	202956.8	95.0	52.0	11
Nicaragua	1998	$370	37015.3	34.8	0.8	1
Panama	2001	$1,370	136975.5	76.2	56.0	12
Peru	1994	$668	66769.3	63.0	9.3	1
Romania	1997	$446	44601.3	99.7	17.0	5
Singapore	1998	$9,461	946107.9	97.7	90.8	12
Slovakia	2003	$880	87964.6	100.0	99.9	15
South Africa	1998	$957	95665.5	65.3	18.7	1
Sri Lanka	1999	$328	32787.6	57.1	22.3	25
Thailand	2000	$631	63107.3	82.1	28.3	13
Turkey	2002	$1,065	106501.4	100.0	79.0	27
Ukraine	1999	$158	15779.9	99.1	74.0	28
Uruguay	2002	$1,724	172426.7	98.6	64.0	29
Uzbekistan	1998	$252	25249.9	99.2	31.0	2
Vietnam	2002	$154	15385.5	84.2	7.5	2

A.2.6 Reference Key for Refrigerators, Air Conditioners and Washing Machines

Key	Reference
1-	Living Standards Measurement Survey, World Bank Surveys clearing House, http://www.worldbank.org/LSMS/guide/select.html
2-	DHS, Demographic Health Surveys, StatCompiler, Survey Indicators, 2006 http://www.statcompiler.com/statcompiler/start.cfm?
3-	IEA Indicators
4-	Population and Housing Census 2000, Belize Central Statistical Office, 2000, http://censos.ccp.ucr.ac.cr/cgi-bin/login.pl
5-	Status of Electricity End-Use Efficiency in Buildings and Energy Services, Brussels, Belgium, 9-10 December 2004
6-	China Statistical Yearbook, National Bureau of Statistics of China, 2003
7-	Censos de Población y Vivienda 2000, Instituto Nacional de Estadística y Censos, http://censos.ccp.ucr.ac.cr/cgi-bin/login.pl
8-	Federal Statistical Office Germany 2004, http://www.destatis.de/basis/e/evs/budtab63.htm
9-	Household Survey, Instituto National de estadistica - INE, 2001 http://200.30.134.19/ine/censo%202001/Presentacion/Viviendas.pdf
10-	H. Nakagami, Lifestyle Change and Energy Use in Japan: Household Equipment and Energy Consumption, Energy Vol. 21, No. 12, pp. 1157-1167, 1996
11-	Censo de Vivienda y Población, Instituto Nacional de Estadística, Geografía e Informática, 2000 http://censos.ccp.ucr.ac.cr/cgi-bin/login.pl
12-	Population and Housing Census 1990, 2000, Dirección de Estadística y Censos de Panamá, http://censos.ccp.ucr.ac.cr/cgi-bin/login.pl
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14-	Singapore department of statistic, household expenditure survey, 1992, 1998 and 2002
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16-	National Statistical Office Thailand, Population and Housing Census 2000, http://web.nso.go.th/pop2000/table/eadv_tab15.pdf
17-	Energy Information Administration, Residential Energy Consumption Survey: Housing Characteristics Tables, 1993, 1997, 2001
18-	G. Henderson, , Home air conditioning in Europe – how much energy would we use if we became more like American households?, eceee 2005 summer proceedings
19-	Statistics Canada, Income Statistics Division, Cansim, Catalogue no. 62F0026MIE. http://www40.statcan.ca/l01/cst01/famil09b.htm
20-	Ghana Living Standards Survey, LBNL Survey, 1997
21-	NSSO (National Sample Survey Organization) March 2001. Consumption of some important commodities in India. New Delhi: NSSO, Department of Statistics, Government of India. [Report No. 461. NSSO 55th Round 1999/2000.]
22-	Report on air conditioning and refrigeration equipment in Mexico, STAT-USA, 2003 http://strategis.ic.gc.ca/epic/internet/inimr-ri.nsf/en/gr-92379e.html
23-	Censo, Dirección General de Estadísticas, Encuestas y Censos, 1992
24-	Appliance Labelling Study , Department of Minerals and Energy Pretoria, Capacity Building in Energy Efficiency and Renewable Energy, Report No. 2.3.4-05, 2003
25-	Sri Lanka, LBNL Survey, 1999
26-	Censo Nacional de Población, Hogares y Viviendas, Instituto Nacional de Estadística y Censos (INDEC), 2001.
27-	SIS, State Institute of Statistics. Building census 2000. Ankara: Prime Ministry of Turkey, 2002.
29-	UTE Household Energy Consumption Survey, 2002-2003

A.2.7 Fans

Table A.2.7 Diffusion Data for Fans

Country	Year	Electrification	Cooling Degree Days	Diffusion	source
China	2002	100.0%	1046	152.4%	statistical year book 2002
Ghana	1999	43.2%	2949	75.8%	LBNL
Hong Kong, China (SAR)	1989	93.4%	3065	100.0%	
India	1999	58.0%	3120	70.0%	NSSO
Japan	1998	99.6%	896	154.4%	IEA
Panama	2001	76.2%	3638	72.0%	world bank
Panama	1990	47.5%	3638	38.6%	Centro centroamericano de poblacion
Panama	2000	76.1%	3638	62.1%	Centro centroamericano de poblacion
Singapore	*1989*	83.8%	3261	94.0%	energy policy
Thailand	2000	82.1%	3567	91.2%	2000 Census, National Statistic Office
United States	2001	100.0%	882	153%	RECS

A.2.8 Televisions

Source: International Telecommunication Union (ITU). 2007. World Telecommunication Indicators 2006, accessed through Earthtrends (http://earthtrends.org/searchable_db/index.php?theme=4).

Table A.2.6 Diffusion Data for Televisions

ISO	income in $	electrification	diffusion
AGO	315.5003	12%	17%
ALB	445.5228	100%	77%
ARG	2299.837	95%	118%
ARM	221.151	100%	128%
AUS	4438.896	100%	175%
AUT	4753.63	100%	154%
AZE	255.8656	100%	145%
BDI	38.24764	7%	16%
BEL	4334.931	100%	131%
BEN	172.3469	22%	37%
BFA	132.5765	13%	9%
BGD	151.5397	20%	37%

ISO	income in $	electrification	diffusion
BGR	304.7482	100%	117%
BHR	6445.845	99%	369%
BHS	5613.527	100%	127%
BIH	267.4374	100%	66%
BLR	322.5331	100%	95%
BLZ	1317.568	79%	93%
BOL	430.3425	60%	85%
BRA	1086.616	95%	111%
BRB	5613.527	100%	98%
BTN	104.664	11%	18%
BWA	1139.994	22%	32%
CAF	105.709	3%	3%
CAN	4542.108	100%	178%

ISO	income in $	electrification	diffusion
CHE	6077.359	100%	115%
CHL	1496.368	99%	114%
CHN	261.2494	99%	114%
CIV	323.974	50%	35%
CMR	217.7413	20%	26%
COD	36.84643	7%	2%
COG	364.0634	21%	7%
COL	792.8027	81%	146%
COM	173.8295	29%	13%
CPV	465.9431	36%	52%
CRI	1311.805	96%	110%
CYP	3659.274	100%	179%
CZE	1027.821	100%	119%
DEU	4303.357	100%	147%
DJI	355.0181	24%	35%
DNK	5233.89	100%	197%
DOM	746.7687	67%	93%
DZA	898.9434	98%	113%
ECU	427.9162	80%	110%
EGY	615.5771	94%	103%
ERI	85.44304	17%	27%
ESP	3695.221	100%	158%
EST	735.1918	100%	117%
ETH	42.82112	5%	4%
FIN	4271.367	100%	154%
FJI	920.7106	71%	55%
FRA	4444.946	100%	149%
GAB	1332.984	31%	115%
GBR	4685.341	100%	233%
GEO	186.9147	100%	147%
GHA	98.85167	45%	32%
GIN	234.375	16%	15%
GMB	209.295	41%	16%
GNB	121.8324	44%	28%
GRC	2324.092	100%	146%
GTM	882.8857	67%	105%
GUY	333.5181	72%	57%
HKG	6434.342	100%	154%
HND	406.9885	55%	68%
HRV	924.5593	100%	95%
HTI	196.6117	34%	27%
HUN	925.1937	100%	119%
IDN	257.5273	53%	65%
IND	201.1062	92%	46%
IRL	5964.444	100%	148%

ISO	income in $	electrification	diffusion
IRN	544.0789	98%	97%
ISL	6078.851	100%	96%
ISR	5498.657	100%	116%
ITA	3898.257	100%	116%
JAM	1322.68	90%	154%
JOR	1072.977	95%	155%
JPN	8085.483	100%	210%
KAZ	247.1046	100%	140%
KEN	150.3414	8%	21%
KGZ	116.6655	100%	95%
KHM	130.1649	16%	4%
KOR	2832.466	100%	120%
KWT	11673.98	100%	377%
LAO	142.075	68%	30%
LBN	2515.616	95%	209%
LSO	175.2356	5%	24%
LTU	708.5555	100%	133%
LUX	9193.252	100%	148%
LVA	695.9636	100%	212%
MAC	3319.139	100%	137%
MAR	521.4664	71%	108%
MDA	84.67071	100%	81%
MDG	96.22585	8%	7%
MDV	1273.424	1%	93%
MEX	2029.568	95%	150%
MKD	444.2287	100%	80%
MLI	109.2807	11%	28%
MLT	2291.987	100%	163%
MNG	150.0064	90%	28%
MOZ	96.33781	7%	7%
MRT	230.2273	22%	31%
MUS	1288.778	100%	129%
MWI	81.88273	5%	3%
MYS	1492.696	97%	97%
NAM	874.7083	34%	46%
NER	118.3801	7%	8%
NGA	124.8087	40%	52%
NIC	388.5441	48%	66%
NLD	4439.538	100%	146%
NOR	6887.242	100%	247%
NPL	103.4392	15%	5%
NZL	3025.375	100%	168%
OMN	4488.95	94%	450%
PAK	380.8433	53%	57%
POL	1029.356	100%	90%
PRT	2378.002	100%	115%

ISO	income in $	electrification	diffusion
PYF	5238.622	100%	121%
ROU	383.4896	100%	185%
RUS	303.9696	100%	110%
SLV	654.2603	71%	93%
SVK	820.3746	100%	89%
SVN	2139.044	100%	112%
SWE	4509.166	100%	164%
TCD	106.1972	2%	1%
TJK	69.4274	100%	230%

ISO	income in $	electrification	diffusion
TKM	334.8463	100%	127%
UKR	156.3116	100%	115%
USA	7412.905	100%	215%
UZB	265.7821	100%	119%
ZAF	904.615	66%	93%

A.2.9 Stand-By Power

Table A.2.7 Standby Power per Household (Electrified), 1999-2000

	Average standby power (W/home)	Income $	Reference
Austria	44	4868	(IEA 2001)
Belgium	27	4469	
Canada	38	4692	
Denmark	39	5338	
Finland	39	4447	
France	27	4577	
Germany	44	4412	
Iceland	39	6312	
Ireland	32	6460	
Italy	27	3973	
Japan	46	8151	
Luxembourg	44	9901	
Netherlands	37	4533	
Norway	39	7000	
Spain	20	3812	
Sweden	39	4659	
Switzerland	27	6208	
United Kingdom	32	4817	
United States	50	7584	
India	6	205	NSSO 1999
Argentina	43	2243	(Lutz, McNeil et al. 2008)

A.2.10 Cooking

Source: DHS Surveys

Table A.2.8 Use of Commercial Fuel in Non-OECD countries

Country	Year	Income $ per Month	urbanization	Commercial Fuel Share
Armenia	2000	234	65%	52%
Armenia	2005	272	64%	53%
Bangladesh	2004	189	25%	8%
Benin	1996	159	37%	1%
Benin	2001	183	39%	1%
Bolivia	1994	393	59%	58%
Bolivia	1998	437	61%	63%
Bolivia	2003	465	63%	63%
Burkina Faso	2003	143	18%	3%
Cambodia	2000	138	17%	4%
Cambodia	2005	173	20%	7%
Cameroon	2004	242	54%	14%
Colombia	1995	869	71%	71%
Colombia	2000	796	71%	77%
Colombia	2005	896	73%	81%
Congo	2005	430	60%	12%
Dominican Rep	1991	575	56%	50%
Dominican Rep	1996	645	59%	74%
Dominican Rep	2002	824	64%	84%
Egypt	2000	635	43%	81%
Egypt	2005	715	43%	96%
Eritrea	1995	78	17%	1%
Eritrea	2002	76	18%	3%
Ethiopia	2000	44	15%	0%
Ethiopia	2005	50	16%	0%
Ghana	2003	107	46%	8%
Guinea	2005	262	33%	0%
Haiti	2000	195	36%	1%
Haiti	2005	219	39%	2%
Honduras	2005	471	47%	39%
India	1992	151	26%	10%
India	1998	191	27%	17%
Indonesia	2002	290	44%	10%
Jordan	2002	1134	81%	100%
Kenya	2003	157	20%	3%
Lesotho	2004	191	19%	24%
Madagascar	2003	106	26%	1%
Malawi	2000	83	15%	2%
Mali	2001	113	28%	0%
Moldova, Rep.	2005	100	47%	46%

Country	Year	Income $ per Month	urbanization	Commercial Fuel Share
of				
Morocco	2003	553	57%	9%
Mozambique	2003	105	33%	2%
Namibia	2000	886	32%	30%
Nepal	2001	112	14%	3%
Nepal	2006	141	16%	10%
Nicaragua	2001	403	58%	37%
Niger	2006	132	17%	1%
Nigeria	2003	134	46%	1%
Peru	2000	783	72%	45%
Rwanda	2000	103	14%	0%
Turkmenistan	2000	393	45%	96%
Uganda	2000	124	12%	1%
Uganda	2006	143	13%	0%
Zambia	2001	166	35%	14%
Zimbabwe	1999	235	33%	24%

A.2.11 Water Heating

Table A.2.9-1 Diffusion Data for Water Heaters

	Year	Income $	Electrification	HDD	Diffusion	Reference
Brazil	2000	1109	95%	118	51%	(Jannuzzi G. 2005)
Canada	1998	4384	99%	4493	100%	IEA Indicators
Costa rica	2000	1295	96%	1	37%	censo 2000, ducha caliente
Egypt	2002	666	96%	400	37%	World Bank
Ghana	1999	99	43%	0	5%	(Constantine and Denver 1999)
India	1999	201	58%	80	6%	Based on (Letschert and McNeil 2007)
Lebanon	2004	2747	97%	1117	81%	(Anwar 2005)
Mexico	2000	2109	95%	364	71%	Censo
Mexico	1994	2030	89%	364	30%	
Philippines	1995	379	82%	2	2%	(Garcia 1994)
South Africa	2000	906	66%	630	28%	(Pretoria 2003)
Thailand	1990	544	39%	1	5%	
United States	1998	7192	100%	2159	100%	IEA Indicators
Uruguay	2000	1684	98%	1019	100%	(McNeil 2003)
Venezuela	2001	1890	94%	1	15%	INE Venezuela

Appendix 3 – Unit Energy Consumption Modeling

A.3.1 Lighting

Table A.3.1 Hours of Usage per Region

Region number	Hrs per day	Source/ Assumption
PAO	1.0	Calibrated on IEA data (IEA 2006)
NAM	2.5	Calibrated on IEA data (IEA 2006)
WEU	1.0	Calibrated on IEA data (IEA 2006)
EEU	2.5	(Bertoldi and Atanasiu 2006)
FSU	4.7	Calculated from (IEA 2006)assumes all incandescent (60W)
LAM	2.6	(Figueroa and Sathaye 1993), (Friedmann, DeBuen et al. 1995)
SSA	4.4	(Constantine and Denver 1999)
MEA	4.4	(IEA/OECD 2001)
CPA	1.4	Calculated from (IEA 2006)assumes IL are 60W and FL 40W, and 15W CFL use is 4hrs
SAS-PAS	3.3	Calculated from (CLASP 1997), assumes 15W CFL use is 4hrs

A.3.2 Air Conditioning

Table A.3.2.1 Linear Regression Parameters for AC Energy Consumption

Observations	35			
R^2	0.75			
	Coefficients	*Standard Error*	*t Stat*	*P-value*
lnγ	-969.50	380.124	-2.55	0.015744
βInc	3.5E-01	5.1E-02	6.72	1.36E-07
βCDD	1.4E+00	1.6E-01	8.94	3.28E-10

Figure A.3.1 Data and modeled AC Energy Consumption

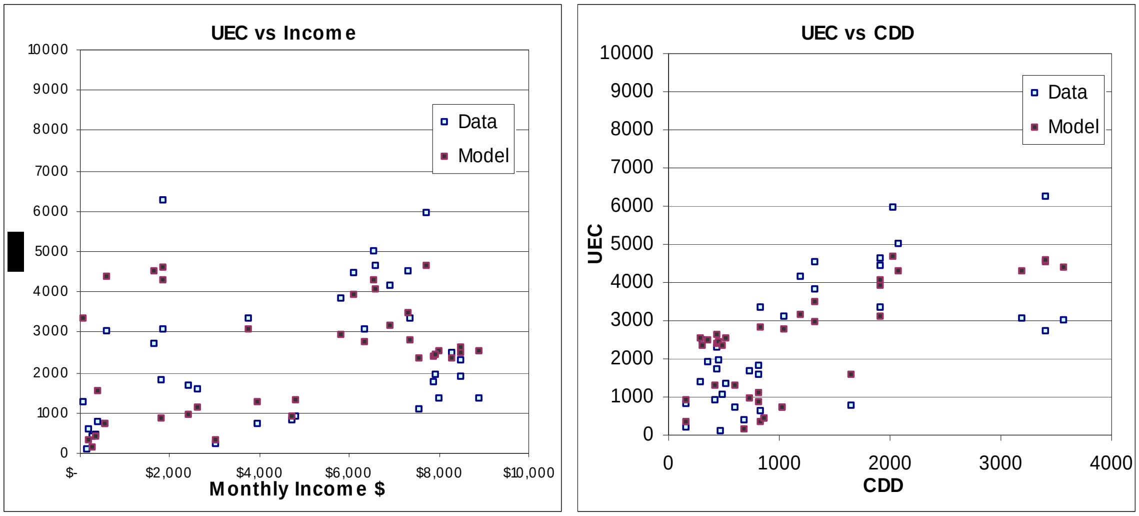


Table A.3.2.2 AC Energy Consumption Data

City/Region	Year	CDD	Income	Data UEC	Reference
Beijing	1999	693	$2,700	396	(Brockett 2002)
Brazil, Sao Paulo	1987	740	$2,535	1680	(Jannuzzi and Schipper 1991)
California	2001	420	$8,154	967	(Henderson 2005)
Canada	2001	171	$6,023	832	(Aydinalp 2002)
EN Central	2001	435	$7,576	1355	(Henderson 2005)
ES Central	2001	1057	$6,100	2888	(Henderson 2005)
Florida	2001	2079	$6,284	4855	(Henderson 2005)
Ghana	1997	2949	$950	1276	(Constantine and Denver 1999)
Guangzhou	1999	1649	$1,845	757	(Brockett 2002)
Hong Kong, China (SAR)	1980	1911	$4,591	3333	(Lam 2000)
Hong Kong, China (SAR)	1993	1911	$6,618	4444	(Lam 2000)
Hong Kong, China (SAR)	1996	1911	$6,583	4620	(Lam 2000)
Iran, Islamic Rep. of	2001	1037	$2,788	731	(Davoudpoura and Ahadib

					2006)
Italy	2000	600	$4,925	727	IEA Energy Indicators
Kagoshima	1992	974	$6,049	811	(Matsukawa 1998)
Korea, Rep. of	2004	744	$3,629	4804	(Choi 2006)
Lebanon	2002	812	$2,131	1574	(Anwar 2005)
Los Angeles	2001	357	$8,154	1885	(Sailor and Pavlova 2003)
Malaysia	2001	3411	$3,646	2700	(Mahlia 2002)
Mid Atlantic	2001	519	$7,684	995	(Henderson 2005)
Mountain	2001	814	$7,444	2850	(Henderson 2005)
New England	2001	293	$8,566	805	(Henderson 2005)
New Zealand	2000	165	$4,969	212	IEA Energy Indicators
NY	2001	488	$7,266	703	(Henderson 2005)
Pacific	2001	309	$7,972	938	(Henderson 2005)
Philippines -Cebu	1989	3409	$1,902	6240	(Garcia 1994)
Philippines -Manilla	1989	3191	$1,902	3067	(Garcia 1994)
S Atlantic	2001	838	$7,096	3137	(Henderson 2005)
Saudi Arabia -Dammam	1990	2933	$7,244	9700	(Al-Sulaiman and Zubair 1996)
Saudi Arabia- North Area	1990	1320	$7,244	3825	(Al-Sulaiman and Zubair 1996)
Shanghai	1999	875	$1,727	433	(Brockett 2002)
Shenyang	1999	469	$1,424	98	(Brockett 2002)
South Africa	1998	824	$4,332	1800	(Pretoria 2003)
Texas	2001	1327	$7,050	4327	(Henderson 2005)
Thailand	1992	3567	$2,134	3000	(Schipper, Meier, Meyers et al. 1992)
WN Central	2001	459	$7,609	1768	(Henderson 2005)
WS Central	2001	1203	$6,635	4012	(Henderson 2005)
Yixing	1999	841	$1,162	595	(Brockett 2002)

A.3.3 Water Heating

Water Heating useful energy was not modeled but averaged by region, weighted by GDP.

Table A.3.3-1 Water Heating Energy Consumption

Country	**Year**	**useful Hot water/hh, kWh**	**Reference**
Australia	1998	2979.94	IEA
Austria	1995	2315.37	IEA
Brazil	2005	450.65	(Jannuzzi G. 2005)
Canada	1998	5031.39	IEA
china	2000	1062.03	(Zhou, McNeil, Fridley et al. 2007)
Denmark	1997	3848.73	IEA
Finland	1994	4292.57	IEA
France	1998	2219.64	IEA
Germany	1997	1901.42	IEA
Greece	2004	361.91	Enerdata
India	2000	224.77	(Letschert and McNeil 2007)
Iran, Islamic Rep.	*2001*	266.73	(Davoudpoura and Ahadib 2006)

of			
Italy	1998	1592.34	IEA
Japan	2002	2971.36	JRI, 2002
Lebanon	2002	889.94	(Anwar 2005)
Mexico	1999	1504.26	Claudia Sheinbaum, Personal Communication.
Morocco	2005	657.10	(Guemra 23-25 Novembre 2005)
Netherlands	1995	2469.03	IEA
New Zealand	1995	4135.33	IEA
Norway	1998	4359.76	IEA
Russia	1985	2075.27	(Nekrasova O.A. 1991)
Slovenia	2003	457.72	(Urbancic 2006)
Spain	2003	1727.66	Enerdata
Sweden	1995	4822.96	IEA
United Kingdom	1998	3690.82	IEA
United States	1998	3917.58	IEA
Uruguay	1995	443.61	(McNeil 2003)

Table A.3.3-2 Fuel Shares for Water Heaters

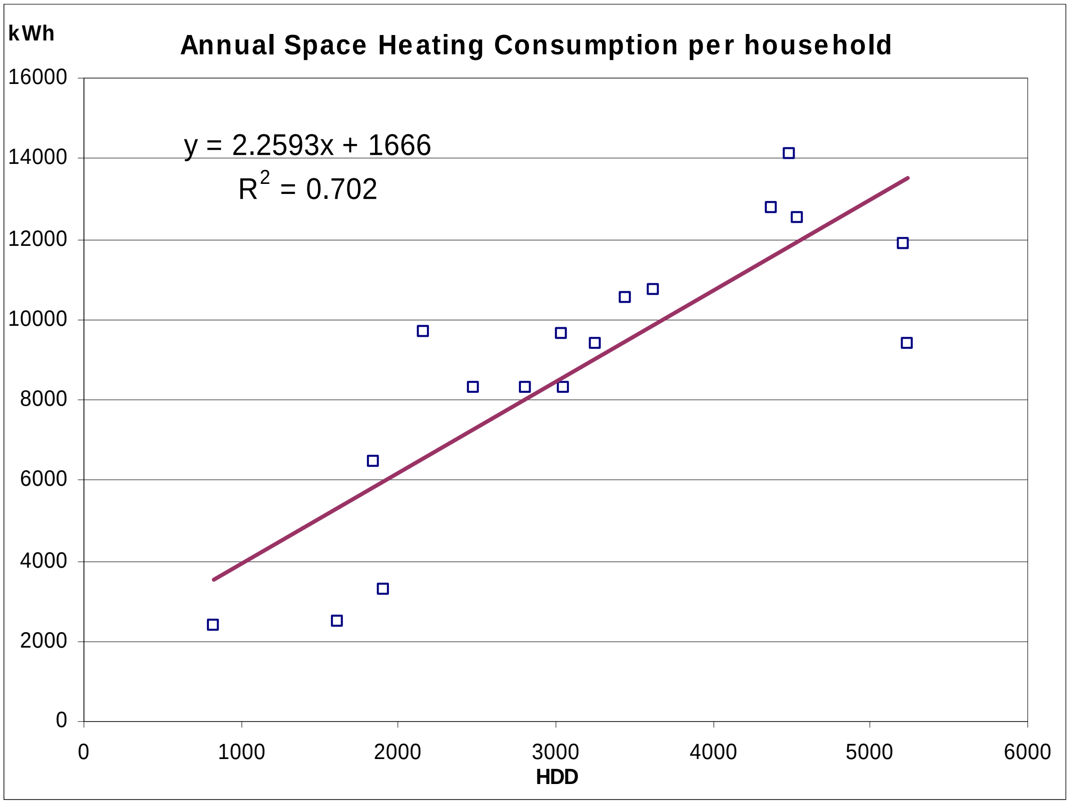
	Fuel Share			**Reference**
	Elec	Fuel	Other	
PAO	43%	57%	0%	(EDMC 2007), assumes that final energy shares are the same as shares of users
NAM	38%	62%	0%	(USDOE 2007)
WEU	34%	58%	8%	IEA Indicators
EEU	34%	58%	8%	Assumes the same as WEU
FSU	13%	48%	38%	Assumed to be equal to primary cooking fuel share from DHS
LAM	9%	54%	37%	
SSA	1%	2%	97%	
MEA	2%	73%	25%	
SAS-PAS	0%	13%	87%	
CPA	Time dependent - see Annex 6			

A.3.4 Space Heating

Table A.3.4 Space Heating Energy Consumption

Country	year	HDD	useful energy kWh/hh	%Elec	%Fuel	%DH	Reference
United States	1998	2159	9692	30%	53%	0%	IEA Energy Indicators
Canada	1998	4493	14099	32%	47%	0%	IEA Energy Indicators
France	1999	2478	8313	30%	31%	4%	IEA Energy Indicators
Denmark	1997	3621	10750	6%	13%	57%	IEA Energy Indicators
Austria	1995	3446	10510	10%	25%	11%	IEA Energy Indicators
Australia	1998	828	2377	33%	39%	0%	IEA Energy Indicators
Finland	1994	5212	11894	20%	0%	44%	IEA Energy Indicators
Sweden	1995	4375	12770	27%	1%	43%	IEA Energy Indicators
Netherlands	1995	3035	9620	0%	96%	3%	IEA Energy Indicators
Japan	1998	1901	3260	46%	0%	0%	IEA Energy Indicators
Italy	1998	1838	6444	24%	47%	0%	IEA Energy Indicators
Germany	1997	3252	9389	7%	37%	10%	IEA Energy Indicators
Norway	1998	4535	12518	65%	0%	1%	IEA Energy Indicators
New Zealand	1995	1609	2461	40%	20%	0%	IEA Energy Indicators
United Kingdom	1998	2810	8303	13%	78%	1%	IEA Energy Indicators
Russia	1985	5235	9376	0%	100%		(Nekrasova O.A. 1991)
Hungary	1998	3057	8288	0%	100%		(Novikova A. working paper)

Figure A.3.4 Data and Modeled Space Heating Consumption



Appendix 4 - Commercial Activity Modeling

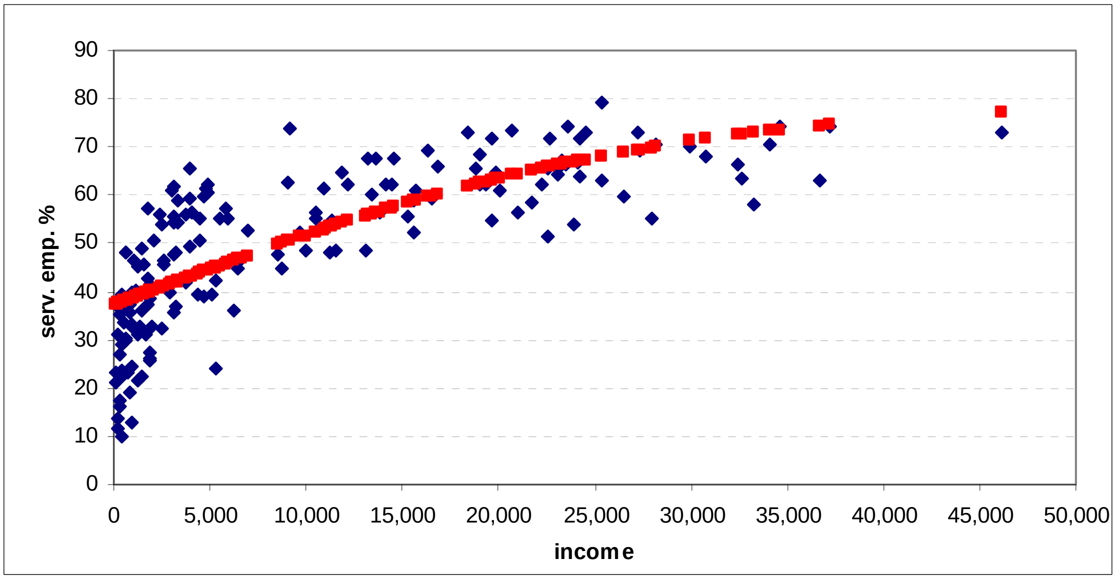
Table A.4.1 ISIC subsector 50 to 99

-	50 – 52 G:	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods;
-	55 H:	Hotels and restaurants;
-	60 – 64 I:	Transport, storage and communications;
-	65 – 67 J:	Financial intermediation;
-	70 – 74 K:	Real estate, renting and business activities;
-	75 L:	Public administration and defense; compulsory social security;
-	80 M:	Education;
-	85 N:	Health and social work;
-	90 – 93 O:	Other community, social and personal service activities;
-	95 P:	Private households with employed persons;
-	99 Q:	Extra-territorial organizations and bodies

Table A.4.2 Average Unemployment rate – 1980-2005

Region	Unemployment Rate (%)
PAO	3.7
NAM	6.0
WEU	9.0
EEU	11.8
FSU	9.6
LAM	6.5
SSA	8.0
MEA	10.7
CPA	3.2
SAS-PAS	4.5

Figure A.4.1 Service Employment Share versus Income

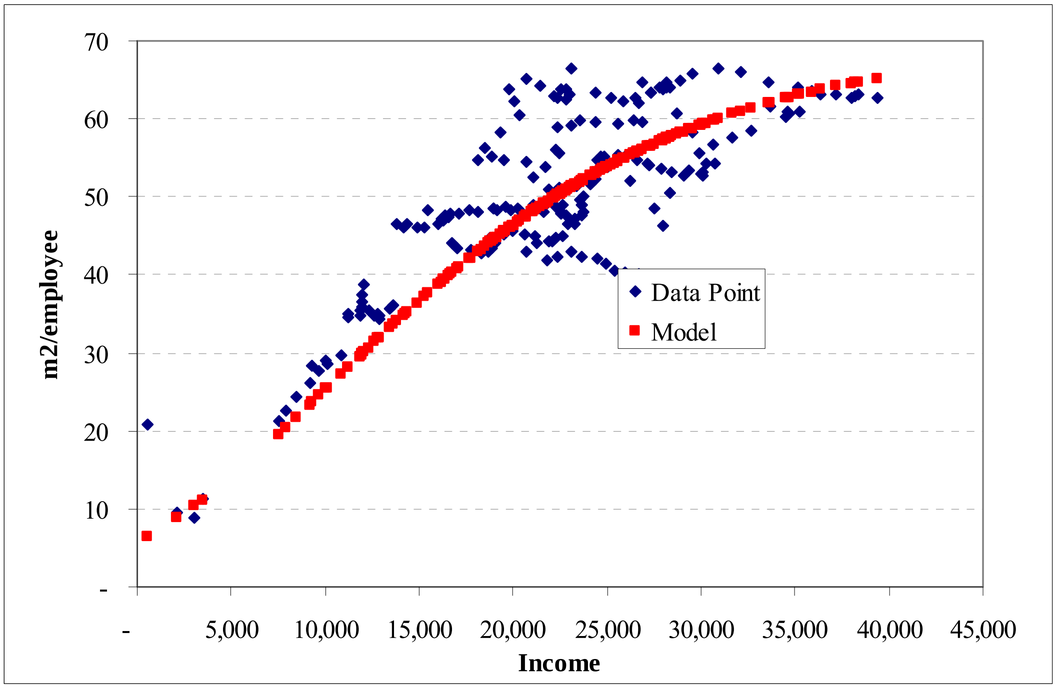


Equation: $$SES = \frac{Max}{1 + \alpha e^{\beta Income}}$$

Where:

Max = 80
β = -7.40238E-05
α = 1.148114156
R2 = 74.86%

Figure A.4.2 Floor Space per Employee Model



Equation: $$FE = \frac{Max}{1 + \alpha e^{\beta Income}}$$

Where:

Max	=	70
β	=	-0.00011285
α	=	5.238321269
R^2	=	70.5%

Appendix 5 - Commercial Enduse Intensities

Table A5.1. Lighting Intensity

h/day	Country	kWh/m2	Source	Income	Efficiency Factor Assumption	Hours of Use Factor Assumption	Penetration
7	Japan	29.9	(IEA 2007)	39,550	1.05	1.00	105%
11	United States	61.4	(EERE 2007)	38,748	0.97	1.52	131%
	Hong Kong*	23.1	(EMSD 2007)	32,365	1.05	0.69	118%
	Canada	52.1	(OEE 2007)	26,074	0.97	1.10	153%
	Israel	72.6*	(Mills 2002)	25,716	0.83	1.52	132%
	Australia	30.5	(AGO 1999)	23,118	1.05	1.00	107%
5	EU	27.8	(IEA 2007)	20,252	0.94	0.69	126%
	New Zealand	20.2	(EECA 2004)	15,659	1.05	1.00	71%
	Argentina	28.9	(Lutz, McNeil et al. 2008)	9,132	0.81	1.00	78%
	Uruguay	37.0	(UTE 1999)	7,048	0.81	1.52	66%
	Chile*	46.9	(Deirdre 1999)	6,006	0.81	1.52	83%
	Brazil*	53.5	(COPPE 2005)	4,206	0.81	1.52	95%
	China	9.9	(Zhou, McNeil et al. 2007)	1,162	0.81	1.00	27%
	Pakistan*	23.3	(Mills 2002)	722	0.81	1.52	42%
	India*	18.4	(Singh and Michaelowa 2004)	596	0.81	1.00	50%

*: For these countries, only the share of electricity use for cooling was available. Hence, we used our estimate of floor space to calculate electricity used per m2

Table A.5.2 Energy Intensity for Cooling

	Fuel	kWh/m2/year	Source
Japan	electricity	15.82	(EDMC 2007)
	natural Gas	16.17	(EDMC 2007)
US	electricity	31.14	(EERE 2007)
	natural Gas	0.27	(EERE 2007)
Canada	electricity	16.09	(OEE 2007)
EU	electricity	13.16	(Bertoldi and Atanasiu 2006)
Brazil*	electricity	26.00	(COPPE 2005)
Chile*	electricity	12.20	(Deirdre 1999)
China	electricity	8.00	(Zhou, McNeil et al. 2007)
Hong Kong*	electricity	56.66	(EMSD 2007)
India*	electricity	9.81	(Singh and Michaelowa 2004)

*: For these countries, only the share of electricity use for cooling was available. Hence, we used our estimate of floor space to calculate electricity used per m2

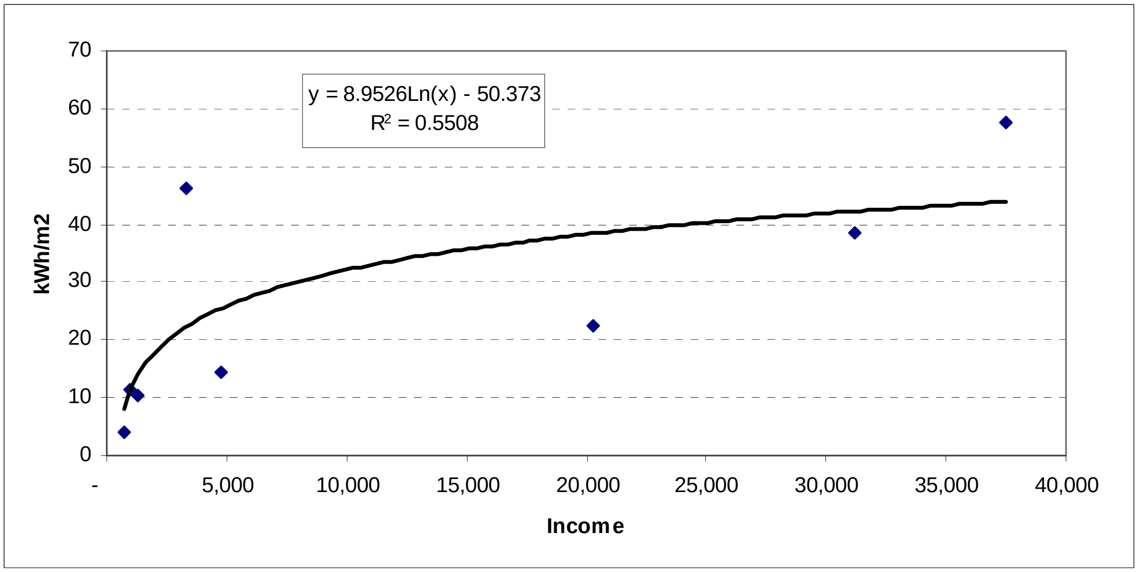
Table A.5.3. Energy Intensity for Space Heating

	average 2000-02-04	Source
Denmark	120 kWh/m2	(Odysee 2007)
Finland	162 kWh/m2	(Odysee 2007)
France	164 kWh/m2	(Odysee 2007)
Germany	126 kWh/m2	(Odysee 2007)
Norway	160 kWh/m2	(Odysee 2007)
Japan	71 kWh/m2	(EDMC 2007)
Canada	266 kWh/m2	(OEE 2007)
United States	87 kWh/m2	(EERE 2007)

Table A.5.4. Energy Intensity for Water Heating

	Fuel	kWh/m^2	Source
Japan	Electricity	1.6	(EDMC 2007)
	Natural Gas	19.1	(EDMC 2007)
	Fuel Oil	32.3	(EDMC 2007)
USA	electricity	7.5	(EDMC 2007)
	Natural Gas	24.3	(EDMC 2007)
	Fuel Oil	2.9	(EDMC 2007)
Canada	electricity	3.5	(OEE 2007)
	Natural Gas	28.7	(OEE 2007)
	Fuel Oil	1.3	(OEE 2007)
China	electricity	0.1	(Zhou, McNeil et al. 2007)
	Natural Gas	0.6	(Zhou, McNeil et al. 2007)
	Fuel Oil	10.8	(Zhou, McNeil et al. 2007)
	Coal	3.2	(Zhou, McNeil et al. 2007)
	Heat	0.4	(Zhou, McNeil et al. 2007)

Figure A5.1 Water Heating Intensity Model for developing countries



Appendix 6 - China Enduse Model

Because of the importance of China to global energy demand, and because of the rapid evolution of that country's economy, we model the evolution of fuel choices for space heating in Chinese households with a time dependent model. This model relies heavily on a recent study performed at LBNL forecasting energy demand parameters in China (Zhou, McNeil et al. 2007). Table A.6.1. shows the fuel market shares in 2005 and 2030 from that study.

A.6.1. Evolution of Space Heating Fuel in China 2005-2030

		% Penetration 2005				% Penetration 2030			
Area	Region	Elec	HP	Gas	Coal or Biomass	Elec	HP	Gas	Coal or Biomass
Rural	North	1.0	1.7	4.2	93.1	4.0	6.7	16.7	72.6
	Transition	70.0	0.0	4.2	25.8	70.0	0.0	14.2	15.8
Urban	North	1.6	3.3	35.9	59.2	4.0	8.0	38.0	50
	Transition	56.8	12.5	30.8	-	55.4	20.0	30.0	-

By using the floor space shares from each climate zone for both rural and urban areas , we estimate that the use of natural gas and oil for space heating to be about 14% in 2005 nationwide. This fraction is expected to rise to 34% by 2030. Overal, electric space heating is not expected to change from its level of about 32%, but the contribution from heat pumps will increase from 1% to about 9%, with electric resistance heat decreasing by the same amount. Water heating fuel shares are expected to follow those of space heating, with the assumption that those using natural gas or oil boilers for space heating will also utilize them for hot water.

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