GEA Chapter 10 - Online appendix

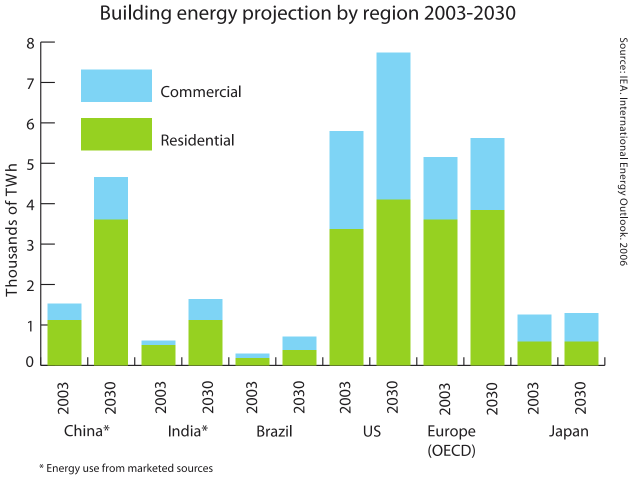

Figure 10.A.1. Building primary energy consumption in selected countries in 2003 and WBCSD projections under business-as-usual for 2030
Source: WBCSD (2008)

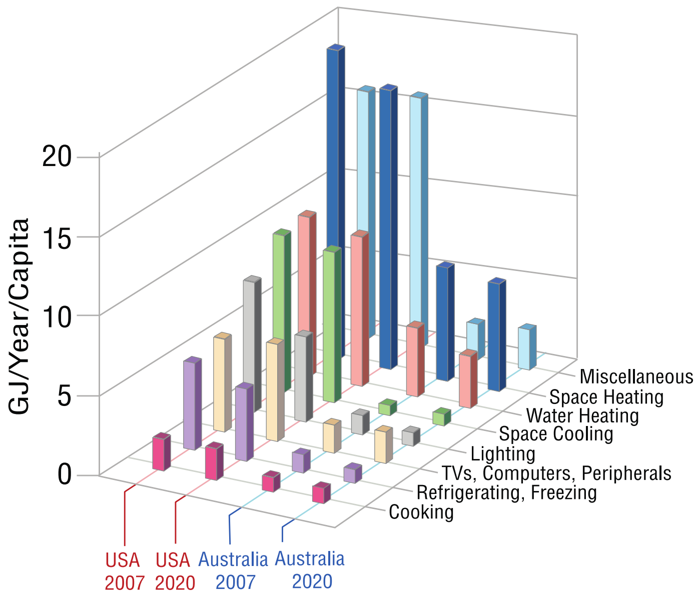

Figure 10.A.2. Residential annual primary energy use per capita by end use for USA and Australia in 2007 and 2020 (GJ/year/capita)
Source: US EIA (2008) and DEWHA (2008)

Figure 10.11 shows the trends in per capita primary energy consumption by end-use in residential buildings of the United States and Australia. Despite differences in current patterns of energy use, there are common features: energy for traditional use – space and water heating, lighting, and refrigerating is declining, whereas energy for new uses - such as entertainment, ICT services, including personal computers (PC), and space cooling is growing. ‘Miscellaneous’ includes all end-uses not otherwise listed (e.g., clothes washing, clothes drying, dishwashing, and other electricity uses including small appliances and electronics other than PCs).

Box 10.A.1. Energy poverty and local renewable energyin the developing world: case study of India

Renewable energy and distributed generation are crucial for energy security and energy independence. Building- or community-level solar, wind or other renewable technology options could play a major role in attaining energy independence in developing countries such as India. To deliver a sustained economic growth through 2032 and to meet the lifeline energy needs of all citizens, India needs, at the very least, to increase its primary energy supply by 3 to 4 times and its electricity generation capacity/supply by 5 to 6 times of their 2004 levels (Government of India,2006).

Efficiency enhancements and distributed generation is very important for meeting basic energy requirements for the millions of people without access to electricity. Roughly 25% of the app. 1.6 billion without such access are in India (Planning Commission, 2006). For them, life comes to a standstill after dusk. Inadequate lighting is not only an impediment to progress and development opportunities, but also has a direct impact on the health, environment, and safety of millions of people, as they are forced to light their homes with kerosene lamps, dung cakes, firewood, and crop residue after sunset. The initiative of “Lighting a Billion Lives (LaBL)”(TERI, 2008) aims to bring light into the lives of one billion rural people by replacing the kerosene and paraffin lanterns with solar lighting devices. This will facilitate education of children; provide better illumination and kerosene-smoke-free indoor environment for women to do household chores; and provide opportunities for livelihoods both at the individual level and at village level.

Figure 10.A.3. Solar chimneys in the Environmental Building, Building Research Establishment, Garston (UK).
Note: Sunlight shining on the translucent towers induces raising air motion, with the bouyancy forces enhanced by the cylindrical towers at the top. Adjustable external shading devices can be seen between and on either side of the solar chimneys
Source: Dennis Gilbert, London.

Further details on the Modeling Logic, Structure, and Main Assumptions of the GEA Building thermal energy scenarios

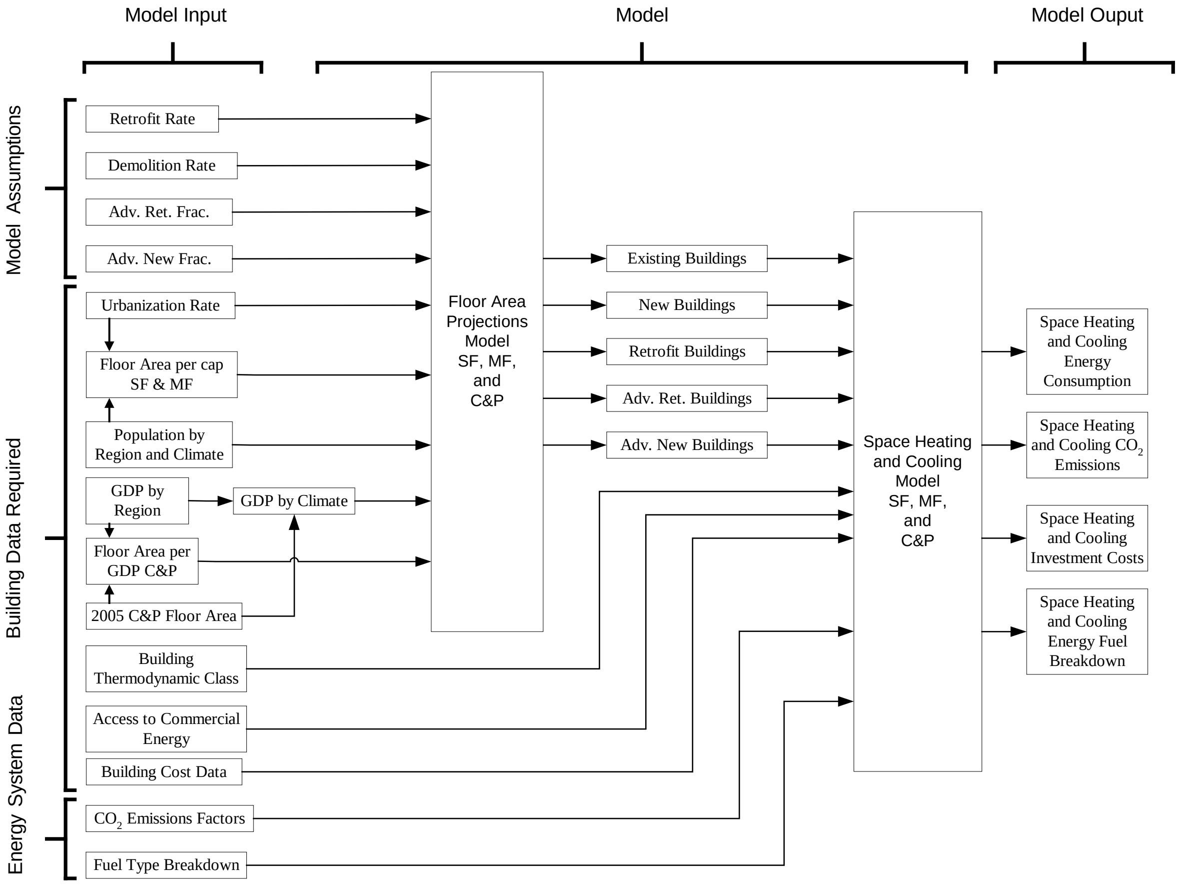

Figure 10.A.4. Model Logic Diagram

Notes: SF – single family; MF – multi family; C&P – commercial and public; Adv. Ret. Frac. – the fraction of advanced retrofit buildings in the retrofit building stock; Adv. New Frac. - the fraction of advanced new buildings in the new building stock; GDP – gross domestic product

A broad range of data sources are used in the model. The most useful data for existing buildings come from government statistical agencies, available in most OECD countries. Such data from developing countries are either not accessible in English or can be controversial. Advanced retrofit and advanced new building information comes from the best practices documented by the widest range of sources, including email search queries, case studies from insulation manufacturers, personal communications, and some government databases of best practice information.

Unfortunately, this wide range of data was still often not sufficient, as much of the required information has never been collected or reported. To fill in this gap, very extensive, several-year expert consultations have been performed and missing data filled in on this basis, with substantial input from the authors of this chapter.

Description of Climates

Within each of the 11 GEA regions there are up to four different climate zones: Warm Moderate, Cold Moderate, Arid, and Tropical. These definitions follow loosely from the Köppen Climate zones, excluding the polar climates where there is an insignificant amount of buildings. Figure 10.26 presents the Köppen-Geiger world map of Climate Zones, while Table 10.13 shows the aggregation of the Köppen-Geiger climate zones into GEA climate types.

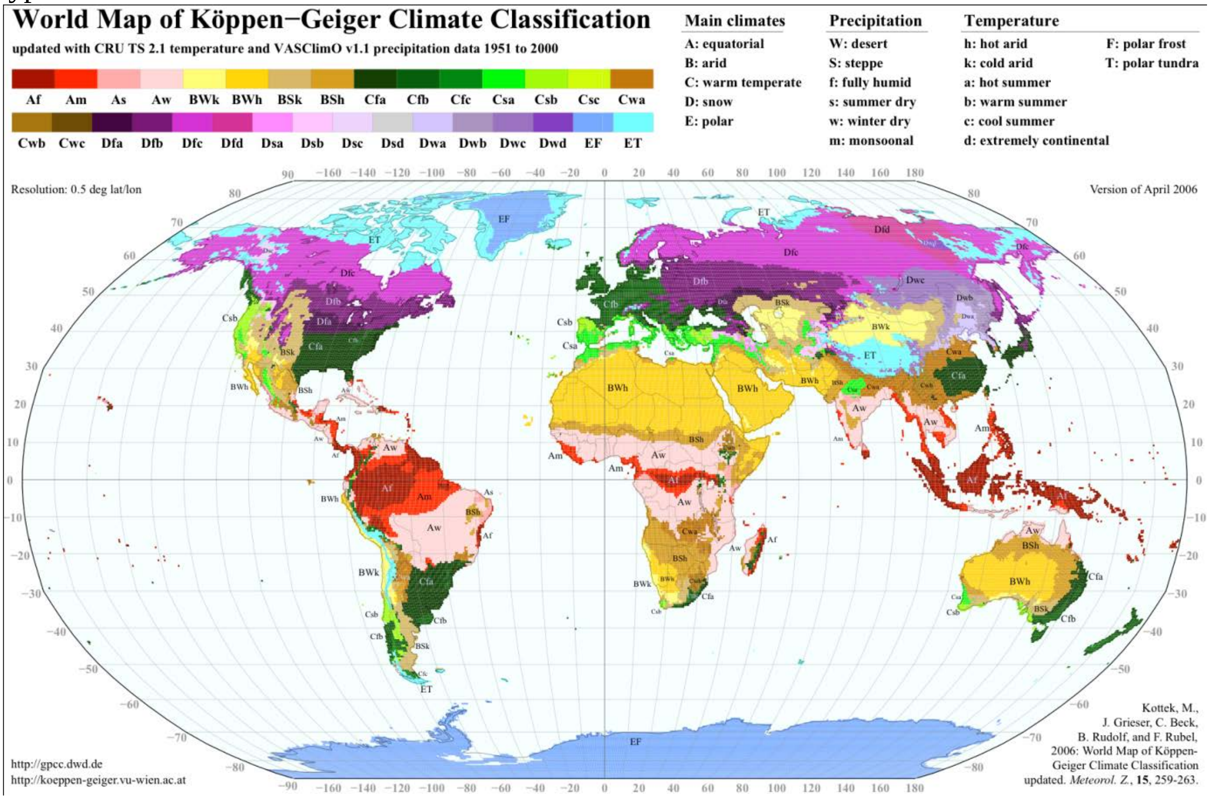

Figure 10.A.5. Climate zone classification of the world.
Source: Rubel and Kottek, 2010.

Table 10.A.1. Aggregation of Köppen-Geiger climate zones into GEA climate types

GEA climate type	Main climates	Precipitation	Temperature	Climate zones abbreviation
Warm moderate	warm temperate	fully humid	hot summer	Cfa
	warm temperate	fully humid	warm summer	Cfb
	warm temperate	fully humid	cool summer	Cfc
	warm temperate	summer dry	hot summer	Csa
	warm temperate	summer dry	warm summer	Csb
	warm temperate	summer dry	cool summer	Csc
	warm temperate	desert	hot summer	Cwa
	warm temperate	desert	warm summer	Cwb
	warm temperate	desert	cool summer	Cwc
Cold moderate	snow	fully humid	hot summer	Dfa
	snow	fully humid	warm summer	Dfb
	snow	fully humid	cool summer	Dfc
	snow	summer dry	hot summer	Dsa
	snow	summer dry	warm summer	Dsb
	snow	summer dry	cool summer	Dsc
	snow	desert	hot summer	Dwa
	snow	desert	warm summer	Dwb
	snow	desert	cool summer	Dwc
Tropical	equatorial	fully humid	-	Af
	equatorial	monsoonal	-	Am
	equatorial	summer dry	-	As
	equatorial	winter dry	-	Aw
Arid	arid	desert	cold arid	BWk
	arid	desert	hot arid	BWh
	arid	steppe	cold arid	BSk
	arid	steppe	hot arid	BSh
×	polar	-	polar tundra	ET
	polar	-	polar frost	EF

Data from Existing Models

Population data for each region supplied by the GEA model is broken into respective climate zones based on data supplied from the BUENAS model (McNeil and Letschert, 2008). Data from BUENAS are also used to project commercial and public building stock, but only base year data on floor area are used. Data regarding rates of urbanization, population, and regional GDP for the world, complete with projections through to 2100, are taken from the GEA database (IIASA, 2007). To determine the split of buildings for each region and climate zone within each region, BUENAS data are used to determine the relative fractions of population living in certain climates for the base year, and then these are held fixed to the end of the simulation period.

Building Stock Assumptions

To reflect the energy transformation path philosophy, building energy retrofits accelerate to levels considered easily tolerable and feasibly maximum: 3% of the stock/yr after 2020, until when it is assumed to be 1.4%. Demolition rates are obtained using the Odyssey Database, statistical agencies, and personal communications with experts. For most regions, 0.5% is used as the demolition rate. For SAS, PAS, and LAC, it is 1%, for MEA and CPA, it is 1.5%, and for AFR, it is 0.03%. Buildings are retrofitted and demolished until less than 10% of the original 2005 levels of building stock remains. This 10% or less, depending on the region, signifies building stock that cannot be extensively retrofitted and is considered "Heritage" building stock. New buildings are the difference between total floor area requirements and the available building stock (existing building stock less demolition) for each year. The commercial floor area in the first year is determined based on BUENAS data, except for regions where BUENAS commercial floor area estimates differed greatly from other sources. For example, for CPA, specific commercial and public floor area were updated based on recent floor area growth predictions for the region (Yanbing and Qingpeng, 2005). Commercial floor area is divided by GDP in 2005, resulting in a commercial floor area elasticity (Bressand et al., 2007). This ratio is then multiplied by changing GDP. Since the developing world has a higher ratio of commercial floor area to GDP than the developed OECD countries, the ratio is assumed to increase over time and eventually achieve OECD levels of floor area elasticity, representing a shift to higher GDP output per unit floor area. For OECD countries, this ratio is assumed to be constant over the whole period of analysis. Residential floor area growth is based on floor area per building type per capita for the various regions, with data collected from the Odyssey Database for the European Union, Chinese energy demand models (Yanbing and Qingpeng, 2005), and assumptions that the developing world will have the same standard of living, or strive to achieve similar standards, as OECD countries by 2050. Per capita living space in developed countries is less easy to project as many trends compete (including declining household size, urbanization, declining population, lifestyle changes, etc.). These are then combined with the urbanization rate and population growth time series to produce the total floor area for both single-family and multifamily buildings.

Table 10.14 shows the model results for floor area in absolute values and the percentage of its change by 2050 in relation to 2005 for each of the 11 regions.

Table 10.A.2. Building Floor Area projections for different GEA regions for 2005 and 2050 (bln.m^2)

Region	Residential			Commercial		
	2005	2050	Change	2005	2050	Change
NAM	11.0	14.0	28%	7.7	11.7	51%
WEU	14.7	14.3	-3%	5.9	13.0	119%
PAO	5.2	4.4	-16%	2.1	3.5	70%
EEU	2.8	3.4	18%	0.3	1.9	483%
FSU	6.7	9.0	33%	0.7	3.6	442%
CPA	43.1	53.7	25%	12.8	29.4	130%
SAS	11.2	67.9	508%	2.5	14.1	471%
PAS	3.5	18.1	415%	1.4	6.1	329%
MEA	3.1	18.2	481%	0.7	4.3	549%
LAC	5.6	23.1	315%	1.6	6.8	323%
AFR	9.0	27.1	201%	1.2	4.7	307%
World	**115.9**	**253.2**	**118%**	**36.8**	**99.1**	**169%**

How the Chapter 10 Building Scenarios Relate to the Main GEA Scenarios (Chapter 17)
As mentioned earlier, the building energy scenarios presented in this chapter have been developed in close cooperation with the main GEA scenarios presented in Chapter 17 (referred to here as IIASA, 2007), and harmonized to their buildings components. They are not identical, as the applied method, modeling logic, and some of the input data are different, but during the harmonization process the largest possible consistency was insured. This section compares the two pathway analyses for the building sector, and explains differences when they occur. The main assumptions and results for these two scenario sets are presented in Table 10.17, and the development of energy demand in the two scenario sets as indexed to 2005 is compared in Figure 10.36.

Table 10.A.3. Comparison of GEA main pathways (KM17) and the corresponding scenarios for final thermal energy use in the building sector (KM10)

Scenario category	**Scenario name**	**Main scenario description and assumptions**	**Results for 2050 (final energy)**	**Intensity reduction 2005 - 2050**
GEA main scenario (KM17)	GEA supply	High energy demand The lower bound of potential energy efficiency improvements giving rise to an upper bound of energy demand across the GEA pathways. Focus on supply-side transformations	25 Pwh	+43.8%
Corresponding Building scenario (KM10):	Sub-optimal	Accelerated introduction of building codes and renovation dynamic (app. 3% of floor area/year) Suboptimal energy performance target levels in codes and renovation	21 Pwh	+32.5%
Differences between GEA main and building scenario		GEA supply includes in addition to heating also: 1) energy for cooking from direct use of fossil fuels (eg, natural gas); 2) energy for hot water, if not electric (eg from direct solar or boilers); but does not include electricity use for cooling unlike CEU model	4 Pwh	11.3%
GEA main scenario (KM17):	GEA efficiency	Rapid introduction of stringent efficiency regulations, technology standards, and environmental externality pricing Efficiency improvements in the use of energy for heating and cooling, which also enable to net zero energy use, incl.renewables Policies to improve thermal insulation and renovation Almost the complete global building stock over the period to 2050. The rate of retrofit increases to about 3% annually	12 Pwh	-33.0%
Corresponding Building scenario (KM10):	State-of-the-art	Accelerated introduction of building codes and renovation dynamic (app. 3% of floor area/year) State-of-the-art energy performance target levels in codes and retrofits, after a decade of “learning” period No lifestyle changes or additional building-integrated renewable	9 Pwh	-46.4 %

Scenario category	Scenario name	Main scenario description and assumptions	Results for 2050 (final energy)	Intensity reduction 2005 - 2050
		Energy service levels same or improved No fuel poverty by 2050		
Differences between GEA main and building scenario		GEA mix includes in addition to heating also: 1) energy for cooking from direct use of fossil fuels (eg, natural gas); 2) energy for hot water, if not electric (eg from direct solar or boilers) But GEA does not include electricity use for cooling unlike CEU model	3 Pwh	13.4%

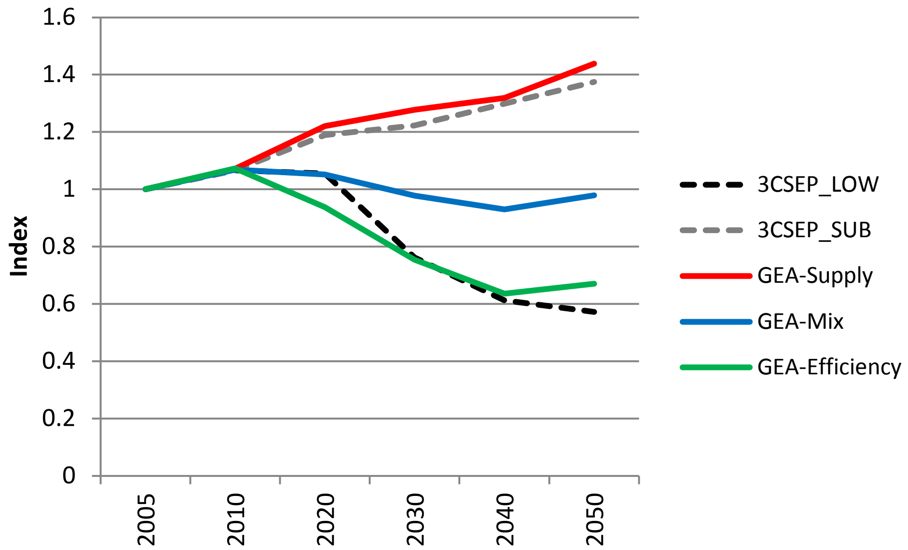

Figure 10.A.6. Annual dynamics of energy use indices in relation to 2005 for the building component of the main GEA pathways and the Chapter 10 building scenarios for heating and cooling. Source: Model results and IIASA, 2007.

Limitations of the GEA Building Thermal Energy Scenarios

By far the most important limitation of the work is the lack of availability of building stock and energy use data worldwide. For some regions, such as certain parts of OECD, the situation is somewhat better, although for there, also, the data are not provided to the level of detail the GEA building model requires, such as breakdown by building type. The model is rather accurate for OECD countries and has been calibrated from many angles, including comparisons to output from IEA models and the BUENAS model mentioned earlier. However, for regions with little floor space and specific energy demand information, or very contradictory data, expert judgment was applied to provide middle-ground, realistic assumptions. For some of these parameters – such as specific energy demand of Asian multifamily dwellings – even slight changes can affect the final output significantly. As a result, these findings need to be considered only as indicators, but not as absolute final values, since as more accurate data become available on the various inputs, the results change. However, the trends of the findings – such as showing that large reductions are possible as compared to 2005 even while increasing amenity and service levels significantly, and that the lock-in risk is considerable – are robust.

Description of the BUENAS Model

In order to evaluate the potential for appliance efficiency programs to mitigate future carbon emissions, LBNL developed the BUENAS model. BUENAS models energy demand for residential end-uses.[1] The model is a driver-based, global, and modular tool that forecasts energy demand of each end-use at the country or regional level, according to population forecasts and projections of economic growth. Figure 10.37 illustrates the modules of BUENAS. The first module forecasts household appliance ownership rates according to forecasts of GDP per capita, household size, urbanization, and electrification. The relationship between these variables and appliance diffusion is established through regression analysis applied to a dataset taken from standard of living surveys, census databases, and literature (McNeil and Letschert, 2010).

A second module keeps track of baseline efficiency for existing and new appliances, and sets targets for the efficiency of new equipment by a specified year. This module determines the aggressiveness of efficiency scenarios, and assumes that all new equipment meets the target, but existing equipment is not retrofit. In this way, the scenarios include minimum efficiency performance standards (MEPS) for new equipment.

Finally, a third module tracks market penetration and stock turnover for efficient products according to estimates of product lifetime. In this module, the first two components are brought together and savings are calculated as the difference in energy use in the efficiency scenario versus the base case.

A schematic diagram of the BUENAS model is shown in Figure 10.37.

[1]BUENAS also includes commercial building end-uses and industrial motors. Only residential electricity uses were included for the GEA study.

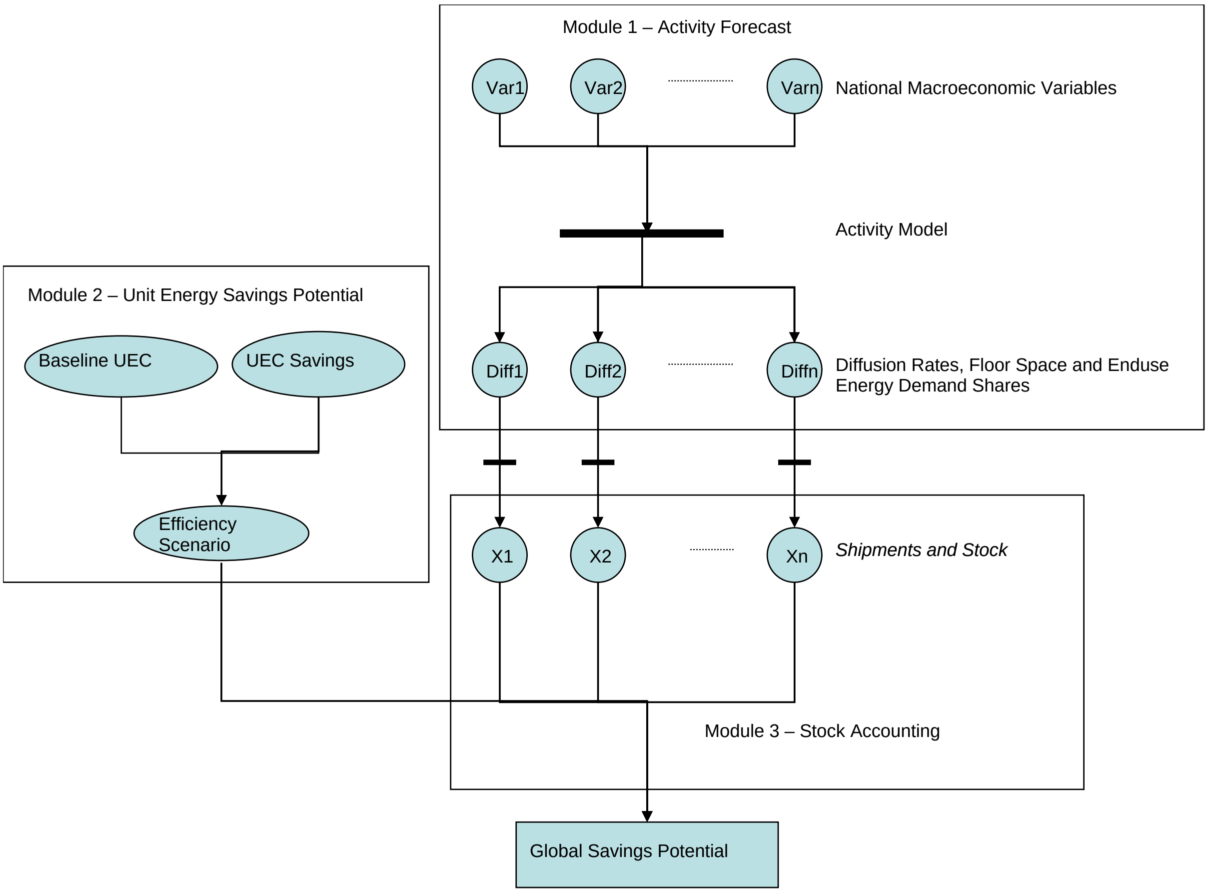

Figure 10.A.7. Bottom-up energy analysis system (BUENAS) flowchart.

Modification of BUENAS for GEA Appliance Energy Scenarios

Several important modifications made to BUENAS for the current study are:

- electricity demand and savings projections were extended to 2050;
- population and GDP forecasts were adopted from the International Institute for Applied Systems Analysis (IIASA) in order to agree with the other analysis modules presented; and
- efficiency levels implementation dates were made more aggressive, with the 2020 targets representing a very high efficiency, or visionary, scenario.

In the original definition of BUENAS, the two-tier standards scheme anticipated a move to best practice in 2020. This definition included levels that were implemented as MEPS in some countries. An exception was made for products not yet regulated in major economies, such as televisions. In this case, achievable efficiency improvements were taken from the literature. In addition, targets were scaled back to more moderate levels in regions where standards have yet to take hold in a significant way. The 2010 tier was defined as a much more moderate target, which would either establish standards or make an incremental increase in stringency, and which could likely be ratcheted to the 2020 target.

For the current study, the 2010 target was kept as is, but the 2020 target was made much more aggressive, in order to model truly aggressive or visionary actions and to better represent what is technically possible if the world's governments were to take appliance efficiency improvement much more seriously than they do today (Table 10.18).

Table 10.A.4. Appliance final unit energy demand assumptions for efficiency scenario

Appliance	Region	kWh / year Base	2010[2]	2020	2020 Assumption
Refrigerators	PAO	537	476	238	Consumption reduced by half between 2010 and 2020 including downsizing.
	NAM	562	506	253	
	WEU	364	268	134	
	EEU	483	268	134	
	FSU	644	483	242	
	LAM	440	261	131	
	MEA+SSA	445	364	182	
	CPA	489	353	177	Consumption reduced by half between 2010 and 2020.
	SAS-PAS	548	301	151	
Fans	NAM+WEU+EER+ FSU+PAO	50	41	25	
	LAM+SSA+MEA	88	72	44	
	CPA	10	8	5	
	SAS-PAS	150	123	75	Consumption in 2020 is 50% of Base Year
Washing Machines	PAO	96	96	96	No Improvement after 2010
	NAM	995	775	239	Reduction vs. base year of 75% by 2020, including switch to cold cycles.
	WEU	221	71	55	
	EEU	320	211	80	
	FSU	320	211	80	
	LAM	96	70	80	Horizontal axis - EU Level A in 2020 . Reduction vs. base year of 75% by 2020, including switch to cold cycles horizontal axis fully-automatic wash.
	SSA	190	119	84	
	MEA	183	121	80	
	CPA	12	6	6	Cold wash impeller wash. Endorsement label level by 2020.
	SAS-PAS	190	102	55	Reduction vs. base year of 75% by 2020, including switch to cold cycles horizontal axis fully-automatic wash.
TV (Eff.)[3]	All regions	100%	137%	150%	34% improvement on LCD, 36% on Plasma TVs by 2010. 50% improvement in 2020 relative to base year.
Standby	All regions	44	26	0.9	3W in 2010, 1W in 2020. Very small (0.1W) by 2020
Ovens	PAO+WEU+EER+FSU	132	70	61	Maximum technical potential in 2020
	NAM	167	88	77	Same efficiency improvement as Europe, 110cycles/year

Source: McNeil et al., 2008.

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[2] UEC assumptions for 2010 taken from unmodified BUENAS model (McNeil et al., 2008)
[3] Performance for televisions is measured in terms of efficiency relative to the base case. All other appliances are modeled in terms of annual energy consumption (kWh).

Box.10.A.2. Case study: selected policy and compliance tools to reduce energy use in Japanese buildings (policies, incentives, and best practices).

In this section, we highlight a few existing Japanese administration tools for reducing energy use in buildings and mitigation of urban heat islands. High level of energy conservation has been achieved by the combination of regulations, incentives and visualizations.

The policy regarding energy conservation in buildings is The Law concerning the Rational Use of Energy. This law requires residential multi-family building owners to report energy conservation measures when they build and renovate residential buildings with a floor area of over 300 m^2 and report to regulatory authority regarding energy consumption every three years. Reports are not requested for buildings under 300m^2. The law also requires companies which consume a certain amount of energy to report to regulatory authority about energy consumption every year. Top runner standard was set for home appliances such as air conditioners, water heaters, cooking stoves, as well as boilers and lighting equipment. Visualization of energy performance is very important to improve energy efficiency of newly built residential buildings and to promote circulation of energy efficient used residential buildings. The building performance labeling system and CASBEE for detached residential buildings and new commercial construction, existing building and renovation were developed to visualize energy performance of buildings in Japan.

The Japanese government has set heat island action outlines and building guidelines to mitigate the effect of heat islands. The subsidy program for local governments, which reduces environmental loads through urban development, was set by MLIT, Japan. CASBEE for heat island and CASBEE for urban development were developed to visualize energy performance of urban area. Cabinet Office, Japanese government selected 6 environmental model cities in 2008. These cities pursue substantial CO_2 reduction through various measures and the Japanese government backs these actions.

Box.10.A.3. Case Study: Indian rating program for commercial buildings

It is projected that the commercial building sector will grow at 7% annually in India. Currently, India has only 200 million m² of built area, and by 2030, it is expected that 869 million m² of additional space will be constructed. In other words, 70% of the construction of commercial buildings of 2030 is yet to take place (Architectural Curriculum in India, 2008). In an effort to establish energy use patterns in these buildings, the Bureau of Energy Efficiency, Government of India is undertaking a few benchmarking studies. In a recently concluded study (Bureau of Energy Efficiency, 2008), energy consumption of 711 government buildings was collected and analysed across five climate zones of India. An assessed range based on the database for government buildings across different climatic zones ranged between 54 to 753 kWh/m² per annum in the warm-humid (150 buildings surveyed), composite (435 buildings surveyed), and temperate (87 buildings surveyed) climatic zones. The estimated range lies between 54 to 624 kWh/m² (21 buildings surveyed) in the hot-dry climatic zone and between 54 to 97 kWh/m² (18 buildings surveyed) in the cold climatic zone. The opportunity for energy saving in government buildings is evidenced from this range in their annual energy consumption.

In another study currently underway under USAID/BEE ECO III program, a total of 91 office buildings, 30 hotels, and 20 hospital buildings were studied and average energy consumption in offices ranged between 142–285 kwh/m²/yr in hot climates. Average energy consumption in hotels varied between 211–264 kwh/m²/yr in hot climates and consumption in hospitals ranged between 157–255 kwh/m²/yr.

Based on the above study and estimation of potential to bring down the energy consumption levels, in commercial buildings, the Bureau of Energy Efficiency has launched an energy rating program for commercial office buildings.

An Energy Performance Index (EPI) in kWh/m²/yr will be considered for rating the building. Bandwidths for EPI for different climatic zones have been developed based on percentage of air conditioned space. For example, a building in a composite climatic zone like New Delhi, and having air conditioned area greater than 50% of their built up area, the bandwidths of EPI can range between 190–90 kWh/m²/yr. Therefore a building would receive a 5 Star rating if its EPI fell below 90kWh/m²/yr, and 1 Star if it is between 165–190 kWh/m²/yr.

Similarly, the same building in a warm and humid climatic zone like Chennai, where the bandwidths of EPI range between 200–100 kWh/m²/yr, would receive a 5 Star rating if its EPI fell below 100 kWh/m²/yr and 1 Star if it is between 200–175 kWh/m²/yr.

In a composite climatic zone, buildings which have air conditioned area that is less than 50% of their built up area have bandwidths of EPI that can range between 80–40 kWh/m²/yr. For the same building in a warm and humid climatic zone like Chennai, the bandwidths of EPI vary between 85–45 kWh/m²/yr (Bureau of Energy Efficiency, 2009).

Figure 10.39 in the GEA Chapter 10 Online Appendix shows diagrammatically the combined effect of three policy instruments, namely appliance standards, labeling, and financial incentives. Minimum performance standards are needed to eliminate inefficient products from the market and labeling beyond the minimum standard level stimulates technological innovation, as energy efficiency then becomes a competitive issue between manufacturers. In addition, rebates for the most energy-efficient products encourage market penetration, thus reinforcing and sustaining market transformation. Unfortunately, quantitative evaluations of policy packages are difficult and rare. For this reason, only a qualitative assessment is possible for policy packages in this report.

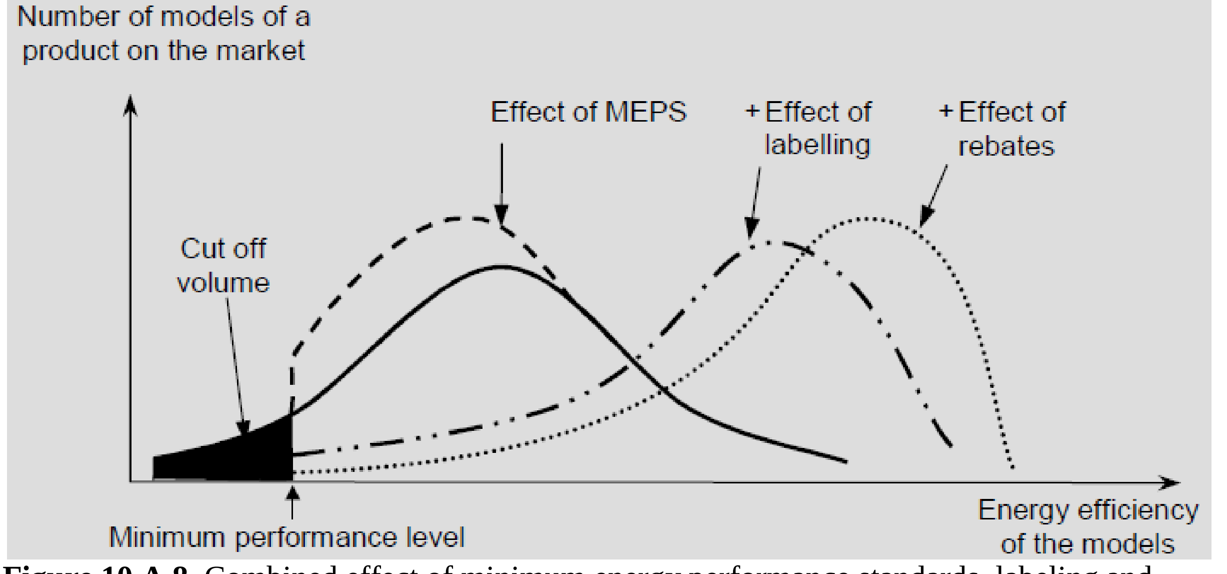

Figure 10.A.8. Combined effect of minimum energy performance standards, labeling and rebates. Source: IEA, 2005a.