

BEST PRACTICE POLICIES FOR LOW CARBON & ENERGY BUILDINGS

BASED ON SCENARIO ANALYSIS

May 2012



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Foreword

What is the global potential for building energy-related GHG emission mitigation that best-practice policies can deliver by 2020, 2030 and 2050?

GBPN commissioned this study to answer this question. The results presented in this report, drawn from an analysis of building energy use in eleven regions worldwide, provide insight into the best possible scenario for low building energy consumption in our four focus regions of China, EU, India and the USA. More strategically, the scenarios produced provide an illustration of the pathways to deep cuts in building energy use and related emission.

The process of conducting the study also brought together a number of key organizations that are working to inform better building energy policy. I'd like to thank the International Energy Agency, World Business Council for Sustainable Development, the United Nations Environment Program, the Wuppertal Institute and our GBPN regional hubs and partners – The Building Performance Institute Europe, the Institute for Market Transformation U.S.A, the China Sustainable Energy Program and the Shakti Sustainable Energy Foundation India for their role in providing data and reviewing results. Thanks to these organizations, the scenarios presented in this report are based on the best available data possible and thus represent as accurately as the data allows, the energy and GHG abatement potentials of the building sector.

A challenging result of this study is that of the 'moderate' scenario that shows we risk significant lock-in of the impacts of inefficient buildings if we maintain our current rate of policy development and reform. In simple terms, our current best efforts are not good enough to achieve the best possible reduction in building energy use.

The results challenge us to aim to make our current state-of-the-art policies and technologies mainstream as quickly as possible. We should therefore strive for nothing less than a world in which building codes require the best possible performance level for their climate-zone, new buildings are at least near zero energy, deep retrofitting of existing buildings is common and where buildings are integrated with renewables. To achieve this requires a move to policy packages that effectively integrate regulatory, incentive and voluntary policy strategies to achieve clear measurable, reportable and verifiable goals for reducing absolute energy demand in the building sector.

In commending this report I encourage all organizations working in this field to analyze the results of this work, and join with the GBPN and its partners to work together to achieve the mitigation potentials described by the 'deep' scenario presented in this report. This is not only the best possible scenario for our building sector; it is also the best scenario for our climate and our prosperity. So, we must aim for nothing less than the best.

Peter Graham, PhD

Executive Director

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CONTENTS

Executive Summary	12
Chapter 1 - Introduction	12
1.1 The Significance of Buildings in Fighting Climate Change.....	12
1.2 Scope and Purpose.....	13
1.3 Structure of the report.....	14
Chapter 2 - Modelling Energy Use and GHG Emissions in Buildings	16
2.1 Top-down, bottom-up, and hybrid methods.....	16
2.1.1 <i>Top-down methods</i>	17
2.1.2 <i>Bottom-up methods</i>	17
2.1.3 <i>Hybrid methods</i>	19
2.2 Component-based and performance-based methods	19
2.3 The Lock-in Effect.....	20
Chapter 3 - Methodology Used in the Study and Assumptions .	23
3.1 Overview of the Modelling Logic.....	23
3.2 Scenarios considered.....	25
3.2.1 <i>Deep Efficiency Scenario</i>	25
3.2.2 <i>Moderate Efficiency Scenario</i>	25
3.2.3 <i>Frozen Efficiency Scenario</i>	27
3.3 Regions and Focus Geographic Areas.....	28
3.4 Climate Classification.....	28
3.5 Building Types Classification	33
3.5.1 <i>Location</i>	33
3.5.2 <i>Building type</i>	33
3.5.3 <i>Building vintage</i>	34
3.6 Scenario methodologies	35
3.6.1 <i>Building stock</i>	35
3.6.2 <i>Thermal comfort</i>	38
3.6.3 <i>Water heating</i>	40
3.6.4 <i>Energy-Related CO₂ Emissions</i>	43
3.7 Modelling Platform.....	44
3.7.1 <i>Modelling tool</i>	44

3.7.2	<i>Developing and management of the dynamic database solution</i>	44
3.7.3	<i>Front-end and back-end of the model</i>	44
Chapter 4	- Model Results	48
4.1	Floor Area	48
4.2	Final Energy Use	50
4.2.1	<i>Final Energy Use for Space Heating & Cooling</i>	50
4.2.2	<i>Final Energy Use for Water Heating</i>	59
4.2.3	<i>Final Energy Use for Space Heating & Cooling and Water Heating</i>	62
4.3	Lock-in Effect	66
4.4	Energy-Related CO ₂ Emissions	69
4.4.1	<i>Energy-related CO₂ Emissions from Space Heating & Cooling</i>	69
4.4.2	<i>Energy-related CO₂ Emissions from Water Heating</i>	70
4.4.3	<i>Energy-related CO₂ Emissions from Space heating & Cooling and Water Heating</i>	73
Chapter 5	- Sensitivity analysis	76
5.1	Specific energy consumption	76
5.2	Retrofit rates – Deep Efficiency Scenario	78
5.3	Retrofit rates – Moderate Efficiency Scenario	86
5.4	Adjustment factor	92
5.5	Summary	97
Chapter 6	- Review of Existing Studies on Modelling Energy Use and GHG Emissions in Buildings	101
6.1	Scenarios, Assumptions and Methodologies	106
6.2	Results Comparison	116
6.2.1	<i>Final Energy: World</i>	119
6.2.2	<i>CO₂ emissions: World</i>	126
6.2.3	<i>Comparison by regions</i>	135
6.3	Results Comparison	145
Chapter 7	- Policy relevant messages	152
Chapter 8	- Conclusions	155
8.2	Gaps in knowledge	155
8.3	Directions for further research	159
Chapter 9	- References	161

Please, see the Annex of the Report in a separate document

EXECUTIVE SUMMARY

Background, Aims and Scope

Buildings are both a key contributor to climate change, and hold the largest and most cost-effective mitigation potential. They account for about a third total global final energy demand and about 30% of global energy-related CO₂ emissions. It is often suggested that buildings have the largest low-cost climate change mitigation potential. Despite this tremendous hypothesized opportunity to significantly decrease the consumption of energy and emissions in buildings, there are few studies that rigorously quantify this potential.

This report presents a unique attempt to assess the importance of the buildings sector in mitigating climate change using scenario analysis, and to offer policy insights on how the savings potentials can be best captured based on the scenario analysis. Over half of the global building final energy use is for space heating and cooling; water heating adds another 10-20%. Therefore, the focus of this particular report is on thermal energy uses, which account for approximately two thirds of the total final energy use. The report focuses on four regions: USA, EU-27, China and India. Together, these regions were responsible for more than 60% of the 2005 final building energy use (see Figure 1).

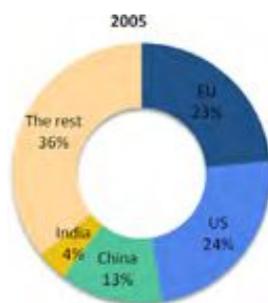


Figure 1. Share of building final thermal energy use by key world region in 2005.

The scenarios developed in this study are policy-relevant techno-economic scenarios, which do not aim at forecasting the future. Rather, the scenarios present the potential trends of building energy use under different decision regimes.

The purpose of the scenario assessments is to highlight the consequences of certain policy directions/decisions in order to inform policy-making. The primary aim of this particular scenario analysis is to illustrate how far the building sector can contribute to ambitious climate change mitigation goals (“deep” scenario); how these might be different from a hypothetical reference scenario (“frozen

efficiency” scenario), and to show an intermediate scenario (“moderate efficiency” scenario). Since the ambitious scenario offers the main insights, we often focus on findings from this “deep” scenario.

This report focuses on the efficiency “lever” of building sector mitigation, and few interventions from the other two key levers (behavioural change and decarbonisation through renewable energy) have been covered: only where they were essential to be considered for the efficiency lever, too. Therefore, the three scenarios depict three worlds in which buildings have very different energy efficiency levels – reached through different dynamics.

The Executive Summary mainly focuses on final energy use. The reason for this is due to CO₂ projections being a composite of demand-side developments and supply-side decarbonisation trends, and such figures may distort building-sector achievements. Concretely, major improvements in CO₂ emissions may not mean good results in the building sector but rather successful fuel switches to low-carbon fuels; and vice versa.

Key global findings: potentials for climate change mitigation

The research has reaffirmed the hypothesis: buildings are a key lever in mitigating climate change.

The scenario assessment has shown that by 2050, global world building final energy use can be reduced by about one-third, (- 29% with water heating; -34% for space heating and cooling only) as compared to 2005 values (Figure 2) despite an approximate 127% simultaneous increase in floor area as well as a significant increase in thermal comfort levels – assuming full thermal comfort in all the buildings of the world.

This is in stark contrast with a hypothetical no-action scenario in which energy use increases by 111% (frozen efficiency scenario). However, even if today’s policy trends and ambitions are implemented, global building energy use will still increase by about a half of 2005 levels (+48%, moderate scenario, Figure 2), pointing out the significant gap between what is possible and where even today’s ambitious policy trends are taking us.

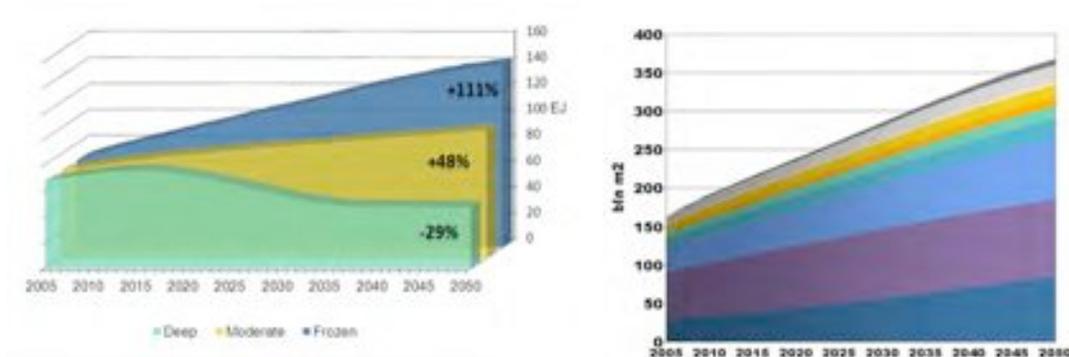


Figure 2. World total final building thermal energy for three scenarios, contrasted by floor area development during the same period. For the final energy, percentage figures show the change of the scenario in 2050 as compared to 2005. Floor area is by main building type.

We have reviewed eighteen global and selected regional¹ studies that assess energy saving or CO₂ reduction potential in the building sector, including those from the IEA, WBCSD, Greenpeace, and McKinsey². Although most studies have different projection periods, assumptions, methods and thus their results should be compared with caution, a few trends are clear:

- Building energy use is projected to grow significantly in the next few decades. Without action, total building final energy use, and thus corresponding emissions, is expected to grow by 60 – 90% of the 2005 value by 2050, as demonstrated by different reference scenarios), from about 110 EJ to approximately 165 – 200 EJ
- Improved efficiency alone will not bring the sector’s emissions anywhere near what is needed for reaching ambitious climate targets. Total final energy use at best stays constant until 2050 for the entire sector. This means that in order to reach stringent climate goals, policies pushing for energy-efficiency need to go hand-in-hand with the other levers such as switching to low-carbon fuels (renewables) and encouraging behavioural and lifestyle change.
- There are significantly larger opportunities for bringing heating/cooling energy use down compared to other building end-uses; up to a 60% reduction can be achieved by 2050, as compared to 2005 (Laustsen model).
- Policies focusing on holistic/systemic opportunities in buildings are likely to achieve much more significant reductions than those focusing on individual building components. Performance-based building policies are

¹ Regional studies were reviewed if they covered the same focus regions as in this study. For a full list and references to the studies please see the main report.

² Section 6.2 in the full report provides details on the studies.

- able to unlock substantially larger heating/cooling energy efficiency potentials than policies focusing on individual technologies/components.
- Another interesting finding from comparing the 18 models was that studies optimizing mitigation over a longer period achieved higher and more dynamic reductions as opposed to studies focusing on the shorter-term. This points to the crucial importance of strategic, long-term policy-making and the stability of policy structures.

Key global findings: insights from the scenario analysis

1. How a low-energy future is possible for buildings – and how it can go very wrong

The message from the scenario analysis is clear: a low energy pathway is feasible for thermal building energy uses.

Globally, today's final building thermal energy use can be reduced one-third by 2050, despite the major (111%) growth in floor area and service levels during the period. The worldwide roll-out of already proven and cost-effective best-practices and technologies for the building envelope, including space heating, cooling and water heating requires strong policy support, but there are no insurmountable technological barriers.

On the other hand, if policy efforts are not ambitious enough, like in the Moderate Efficiency scenario, global thermal energy use will increase 46% by 2050, instead of declining (see Figure 3). This means that 80% of the 2005 thermal final energy use will be locked-in by 2050 due to the long-term presence and relatively slow major retrofit cycle of the built infrastructure. The size of the lock-in effect is considerable in all regions. Therefore if ambitious climate mitigation targets become the policy targets later, it will not be possible to utilize much of this unlocked potential, unless only at prohibitive costs.

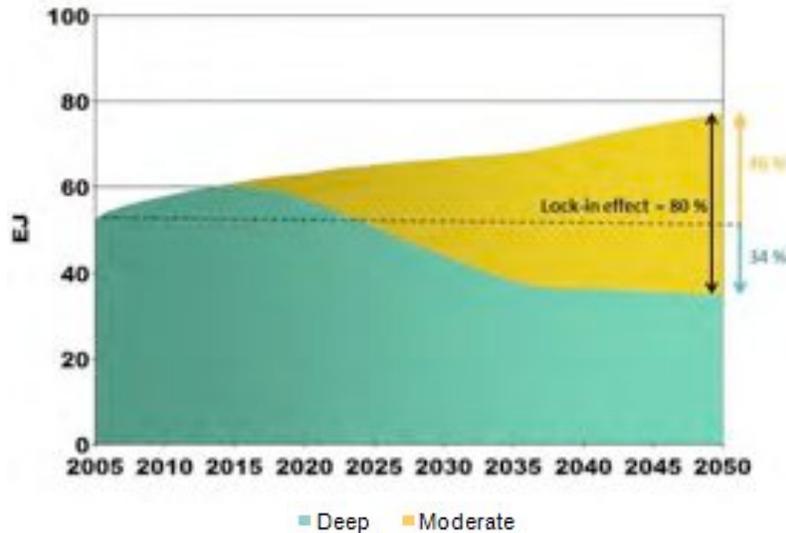


Figure 3. The lock-in effect: World final energy use for space heating and cooling for Moderate Efficiency and Deep Efficiency scenarios.

2. Why fast policy action is crucial

The research demonstrates the crucial importance of immediate action and the high cost of delay. The high lock-in risk points to the crucial importance of early action, strategic policy planning, as well as the primary importance of ambitious energy performance levels in building codes for new construction and retrofits. Reducing building energy use by the mid-century in a meaningful way requires worldwide building codes to adopt performance levels demonstrated by the state-of-the-art technology in a particular climate zone, even if it is not yet common practice. An accelerated transformation of the construction industry and markets is of paramount importance for determining 2050 emissions.

3. Why action in the developing world is crucial

The major increase in energy use and related CO₂ emissions will come from the developing world due to rapid economic development, expanded access to energy services and population growth. Global building floor area is projected to increase by almost 127% by 2050 with most of this growth coming from developing countries. How such an expansion will affect building energy use and GHG emissions greatly depends on the energy performance of the buildings constructed in the next 40 years, the energy used in these buildings, including how energy will be utilized in these buildings. In developed countries the depth of building renovation is most crucial, as the buildings that determine emissions levels on a mass scale in 2050 already mostly exist.

4. Why action in urban areas is crucial

The report for the first time quantified the role of cities in building energy use: buildings in urban areas account for 70% of the total, despite the fact that the rural population is still larger with as high values as 82% for the US (see Figure 4).

With increasing urbanization this trend continues: 85% of growth in building energy use during the projection period comes from urban areas, 70% of it from developing country cities. Urban policies in developing countries, partially at limiting floor space growth, sprawl and energy performance levels are especially crucial for a low-carbon building world.

A key policy implication is that policies and programs that are defined and implemented by cities can play an equally important or even larger role in curbing building thermal energy use as those by national governments. Urban policies that affect building energy use (beyond building codes – if in their authority - and support programs), can include: optimized urban planning and (de)zoning (these all affect building energy use), building permission conditions, mitigating heat islands, promotion of energy cascading opportunities, preferential property tax regimes, etc. Urban policies in developing countries, partially at limiting floor space growth, sprawl and energy performance levels are especially crucial for a low-carbon building world.

5. Why action on specific building type is crucial

The importance of building type is extremely variable by region.

Final energy use as well as reduction opportunities from residential buildings dominate in most regions and scenarios, with 75% of 2005 thermal energy use in this subsector, declining to 70% by 2050 in the deep scenario. Worldwide, a large proportion of final thermal energy use, and thus emission reduction opportunities, comes from single-family (SF) houses, using 54% of all world thermal energy demand, with multifamily buildings adding another 21%.

In the US, urban single-family buildings are responsible for approximately half of final thermal building energy use, commercial for approximately 27%, with MF and rural SF buildings both having an approximately equally small role. In contrast, in the China, commercial buildings dominate (especially towards the end of the period), followed by urban multifamily buildings, urban SF almost playing no role, and rural buildings declining in their importance. In India, energy use from SF rural buildings dominate throughout the period despite urbanization, with MF buildings growing from 9% to 25% of all thermal building energy use by

2050. In the EU, there is more balance among these four building types, although their importance changes slightly with a steadily declining role of rural SF building energy use and growing commercial sector. The growing importance of commercial buildings, particularly in India and China must be highlighted and be treated as a crucial factor in reducing GHG emissions globally.

Key findings: further major regional messages

While the feasibility message is universal, there are very large regional differences (see, for instance,

Figure 4). Increased energy efficiency offers large opportunities to reduce absolute thermal energy use in the EU and the USA; after an initial period of growth it can also be feasible to slightly reduce Chinese energy use; but in India, keeping building thermal energy use growth under 200% of 2005 levels by 2050 will already be a significant achievement. Reduction potentials in the EU and the US are above 60%; CO₂ savings can be measured in gigatons (1.8 and 1.3Gt, respectively). In China, the growth of floor space can be offset by energy efficiency improvements. Similarly, most developing countries will increase their thermal energy use in all scenarios due to the rapid growth in population and affluence, while most developed countries can achieve considerable reductions in energy use.

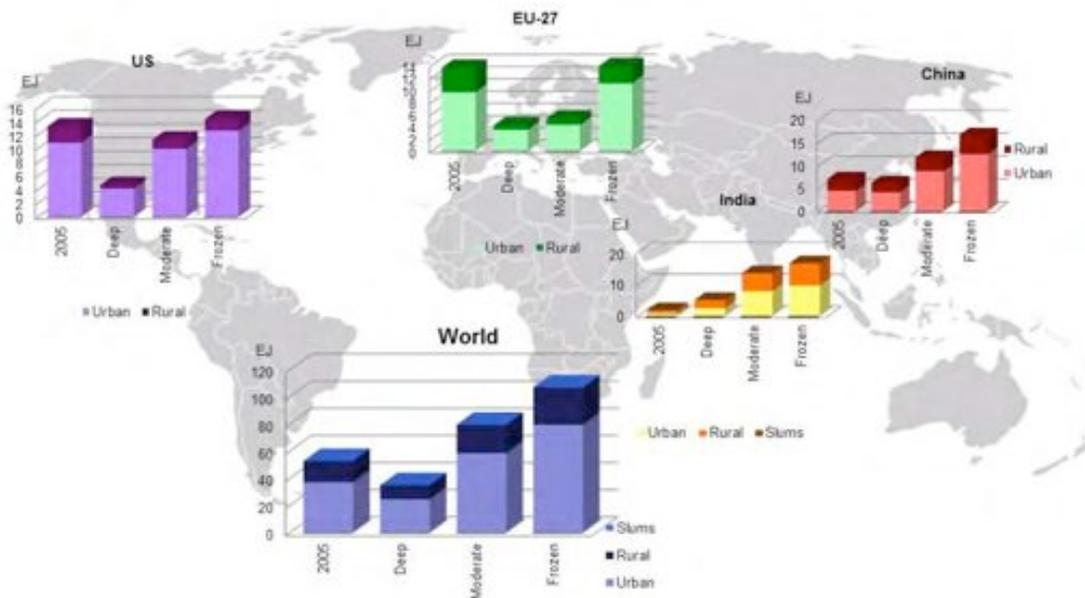


Figure 4. Final Thermal Comfort Energy in Rural and Urban buildings for the world and four key regions under the three scenarios

Compared to thermal, hot water represents a smaller contribution of building energy use as well as CO₂ emissions universally with a range of 15-25% of thermal final energy use in the different regions, the world average being 20%.

The research in the report highlighted that in 2050 building thermal energy use in the USA and Europe will mainly be determined by the retrofitted building stock, whereas in China and India (especially the latter) the key driver is new construction, thus new construction; requiring the main policy attention. While policies in Europe are already strong in terms of new construction, the major impact is offered by very low energy retrofits with an accelerated retrofit dynamic. In the EU-27 policies and policy directions in place have the potential of capturing a large fraction of the cost-effective potentials, however, all other regions are still heading towards a significant lock-in. In the US, this is approximately half of 2005 final energy use that is to be locked in by 2050; in China, approximately two-thirds; and in India over 400%. In India this points to the crucial importance of the ambition of building codes in terms of energy performance.

Key messages from the sensitivity analysis

The sensitivity analysis demonstrated that even large changes in the achievable specific energy consumption figures for advanced new and retrofit buildings do not alter the main message of the scenarios: the finding that a low-energy pathway is possible is robust even against relatively large changes in assumed specific energy consumption values.

The sensitivity analysis to retrofit rates demonstrated that a too fast acceleration in retrofit rates is not desirable. An increased retrofit rate also has a slightly higher lock-in effect. As a policy implication, in an ideal case, the retrofit dynamic is accelerated only when the market is ready for advanced retrofits. In fact, the research warned that if performance levels in building codes and retrofits remain far from state-of-the-art levels, accelerating building retrofits will not bring climate benefits or may even increase the lock-in risk.

Sensitivity to adjustment factors underscored that, especially in India, but also in China, policies to encourage limitations in residential floor space per capita are a crucial lever influencing building energy use and emissions. Therefore, policies such as progressive property taxes, zoning and building size restrictions, etc., are all crucial policies affecting future building energy use in these countries.

Model description and key assumptions

Figure 5 illustrates the modelling logic. To produce practical results globally, seventeen climate zones are differentiated; the most important building types in both rural and urban areas are handled separately; five building vintages are distinguished (existing, new, retrofitted, advanced new, advanced retrofitted), and a number of demographic and macroeconomic factors are applied (including population predictions, urbanization rates and GDP values).

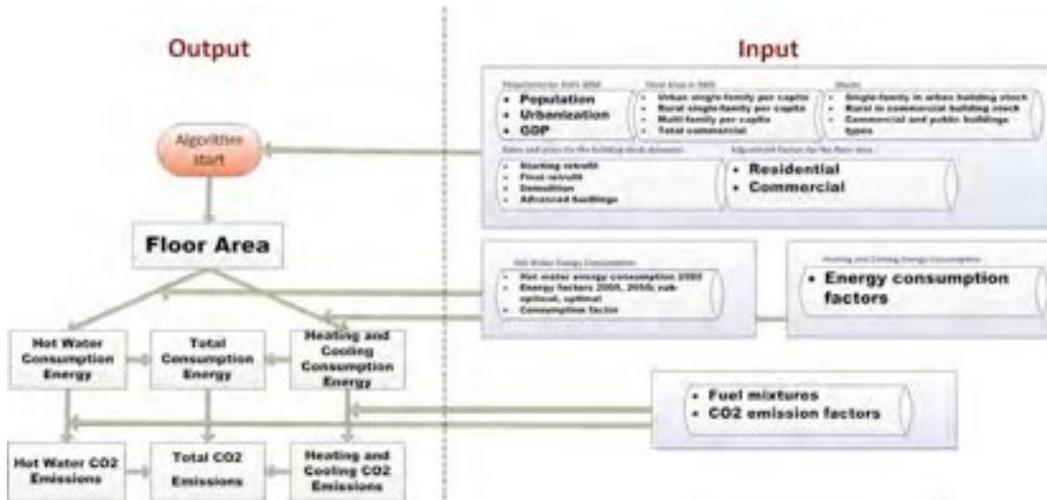


Figure 5. Flowchart representing the modelling logic for 3CSEP-HEB.

CHAPTER 1 - INTRODUCTION

1.1 The Significance of Buildings in Fighting Climate Change

“Warming of the climate is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level”(Metz et al. 2007)

Global GHG emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Metz et al. 2007) and are projected to grow faster with current policies and technologies. Emissions from buildings are also growing rapidly as the expansion of building areas and energy-consuming equipment are rapid (IEA 2008).

The building sector is responsible for over 30% of global energy-related carbon dioxide emissions (Metz et al. 2007; Zhengen et al. 2011). A significant share of these emissions can be avoided through methods that are cost and energy efficient, these provide the same or higher level of energy services and can be done by improving the efficiency of:

- Building envelopes,
- Heating and cooling systems,
- Hot water heating,
- Lighting,
- Appliances.

Switching from fossil fuels to renewable energy sources and energy carriers with lower a CO₂ emission factor (including low carbon electricity generation) can make an impact, along with behavioural changes and strong policy support. These are all low cost CO₂ measures/strategies, which make the building sector the highest in terms of mitigation potential for worldwide CO₂.

According to the literature the building sector (residential, commercial and services) accounts for about 25-40% of total global energy demand (IEA 2009; IEA 2010b; Greenpeace International 2010) and about 30% of global energy-related CO₂ emissions (Metz et al. 2007; IEA 2009; IEA 2010a; IEA 2010b). The reason is that buildings produce GHG emissions during all stages of their life cycle including construction, operation, maintenance and demolition (ECOFYS GmbH 2004). In residential buildings the operation stage itself accounts for nearly 80% of the total CO₂ emissions, mainly from space heating and cooling, hot water, lighting and household appliances (WBCSD 2009). Therefore, GHG emissions from building operations considerably contribute to global warming.

Within this, thermal uses, i.e. heating, cooling and hot water, together represent the single largest energy use in buildings, i.e. the largest source of emissions.

1.2 Scope and Purpose

The purpose of the present study is to assess energy and CO₂ emission scenarios that estimate the contribution the building sector can make in order to achieve ambitious climate change mitigation goals on global and regional scales between now and 2050. The focus of this report is on space heating and cooling as well as hot water. Since over half of global final energy use in buildings is for space heating and cooling and water heating is also responsible for 10-20% (IEA 2006a), approximately two thirds of the total final energy use is covered through the analysis of thermal energy performance. The scenarios developed in this study are policy-relevant techno-economic scenarios, which do not aim at forecasting the future, but rather at presenting potential trends of building energy use under different conditions. The purpose of such scenario assessment is to highlight the consequences of certain policy directions/decisions in order to inform policy-makers. Therefore, by nature, such scenario analyses tend to depict "extreme" hypothetical future pathways, since making any input parameter or assumptions less stringent can show the intermediate lines within the ranges of what is possible. Instead, policy-making is informed primarily by showing the extremities of possibilities within the solution space.

The primary purpose of this particular scenario analysis is to illustrate how much the building sector can contribute to climate change mitigation; and to show an intermediate scenario. Accordingly, certain scenario assumptions may look too negative or too ambitious for certain regions as compared to actual expectations. However, these scenarios still draw the attention to the role of key strategic decisions in shaping energy futures and should be used for informing building-related energy policy-makers about the consequences of certain potential decisions, rather than as predictions of the future. This particular reports focuses on analysing the state-of-the-art of the building sector's role in reaching ambitious climate stabilisation goals.

There are some very important factors that could not be addressed in this technical document. The energy consumption of buildings is largely influenced by the lifestyle of inhabitants, yet this is only considered in some exceptional cases (e.g. in China, where lifestyle can be one of the most important parameters affecting energy use). Even in these cases, substantial simplification was necessary. Moreover, implementation issues, e.g. the availability of skilled workforce and financing questions are not in the scope of this research.

This modelling work is grounded on a novel performance-based approach to analysing building energy use. This approach considers a building as an entire

complex system and not as a sum of individual components³. Therefore, national and regional building energy consumption dynamics are not modelled based on individual energy-efficiency measures, but based on marker exemplary buildings with measured, documented energy performance.

The present work is focused mainly on building energy demand and the pathways for its reduction, mainly through energy efficiency measures. The analysis does not consider the decarbonisation of energy supply or the utilization of renewable energy in buildings (except for water heating, where solar solutions are integral elements of efficiency-related improvements). Throughout the study, final energy is modelled. Furthermore, the minimization of final energy use, primary energy use, or CO₂ emissions may require different technological solutions. Therefore, technology-specific conclusions can also change depending on the parameter to be minimized. However, the largest share of thermal energy is used for heating, and the conversion between final and primary energy is more or less similar for the most popular heating technologies. In the case of cooling and water heating where electricity use is very important, differences between final and primary energy consumption can be large, but these differences are not reflected in the CO₂ emission values because of the different emission factors used for different forms of energy. In addition, the main advantage of using final energy is that the supply side of the energy sector (especially electricity production) does not have to be modelled. In this way, the effects of changes in energy supply and energy use are not mixed. For the same reason, the fuel mix is kept constant in the calculation of CO₂ emissions.

This study aims at providing a robust and reliable ground for further policy recommendations to realize the potentials presented and to seize the opportunities outlined.

1.3 Structure of the Report

The report is organized in the following way: it starts with the Executive Summary of the study organized around four key regions, describing the main trends and results for final thermal energy use and related CO₂ emissions. Chapter 1 provides a general introduction to the problem analysed and presents the purpose and scope of the study. Chapter 2 discusses the main theoretical aspects of the study, including methodological approaches in energy modelling and the concept of the lock-in effect. This information is crucial for understanding the angle from which the whole subsequent analysis will be made. Chapter 3 thoroughly describes the methodology of the elaborated model, including modelling logic, scenarios elaborated, geographical and climatic classification considered, main assumptions and data sources. Chapter 4 shows the scenario

³ The performance-based approach does not mean looking only at the overall energy performance of the whole building, but it also considers the energy performance of each end-use, for example building energy performance for space heating.

results for the world and four key regions with the focus on energy use for space heating and cooling, water heating, and the related CO₂ emissions. Chapter 5 focuses on sensitivity analysis of several important input parameters. Chapter 6 is devoted to the comparative analysis of existing energy models for the building sector in terms of their mitigation strategies, methodologies, assumptions, input data and results. Chapter 7 provides the main policy relevant messages of this research, while Chapter 8 gives conclusion of the study including the gaps in knowledge revealed in the field and the directions for further research.

CHAPTER 2 – MODELLING ENERGY USE AND GHG EMISSIONS IN BUILDINGS

Methodological choices have a crucial role in energy modelling, since all existing methods have their own advantages and disadvantages. Finding the optimal trade-off between the benefits and limitations of different approaches is an inevitable step in energy modelling studies. The objectives of the research already largely determine the suitability of different methods for given purposes.

In the current analysis, the important goals were directly related to the methodology. First, a major objective was to use all available information about trends and opportunities in the building sector. Reflecting this effort, to identify the potentials of different approaches from this perspective, top-down, bottom-up, and hybrid methods are briefly reviewed in Section 2.1. A second aim was to arrive at regional and global conclusions on which recommendations for flexible but strong policies can be based. Characteristics of policy recommendations from the study are partly rooted in the engineering approach of the investigation, so the component-based and performance-based methods of building energy use modelling are compared in Section 2.2. The third goal was to find an approach, which is suitable to illustrate the risks of the lock-in effect, i.e. the potential delay of energy performance improvement due to insufficiently ambitious policies. The concept of the lock-in effect and the methods that are able to give account of it are explained in Section 2.3.

As a result, this section frames the analysis and lays the theoretical ground for the chosen methodological approach.

2.1 Top-down, bottom-up, and hybrid methods

According to the literature there are two main approaches to energy modelling: top-down (decomposition) and bottom-up (synthesis) (IPCC 1996; Novikova 2010; Novikova 2008; Böhringer & Rutherford 2007; Repetto & Austin 1997; Richards 2011; Wing 2006; Cunha da Costa & Fallot 2002; Rivers & Jaccard 2005; Böhringer & Rutherford 2006)(Isaac & Van Vuuren 2009; Kavgić et al. 2010; Swan & Ugursal 2009). Generally, in energy analysis top-down models study the relations between energy and macro-economic variables, while bottom-up modelling analyses individual technologies, incorporating them into a larger energy system (Novikova 2008; Novikova 2010).

2.1.1 Top-down methods

“Top-down studies assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks. [...] Top-down studies are useful for assessing cross-sectoral and economy-wide climate change policies, such as carbon taxes and stabilization policies” (Levine et al. 2007).

Novikova (2008) proposes the following typology of top-down models:

Input-output models “describe the complex interrelationships among economic sectors using sets of simultaneous linear equations with fixed coefficients”. The models of this type consider aggregated demand exogenously and provide the details for each sector on how it can be met.

Keynesian or effective demand macroeconomic models describe investment and consumption patterns in different sectors of the economy. They often include forecasts built with macroeconomic and econometric techniques on the basis of data series. Such models allow for measuring the influence of policies’ introduction on macroeconomic indicators (economic growth, employment, etc.)

Computable general equilibrium models (CGE) evaluate the behaviour of economic actors on the basis of microeconomic principles. The main aim of such models is to simulate the behaviour of key market parameters, e.g. production or exchange rate, by using the equations of economic actors’ behaviour and analysing them in different states of equilibrium.

The obvious drawback of top-down modelling is that dealing with highly aggregated data on macro level, they are unable to consider the processes on the lower levels of analysis (e.g. adoption of a discrete technology) (Böhringer & Rutherford 2006). A top-down model usually does not capture the whole process of the technological change and has the tendency to overestimate the costs of energy or mitigation policy implementation (Wing 2006).

2.1.2 Bottom-up methods

Bottom-up models are more appropriate for technological assessment (Novikova 2010), as they include thorough data on technologies and costs, which allow for describing energy consumption in great detail (IPCC 1996). The technologies’ data among others typically include engineering information on life-cycle costs and thermodynamic efficiencies (McFarland, Reilly & Herzog 2004).

According to Worrell, Ramesohl & Boyd (2004), bottom-up models differ on the basis of content and scope (“the degree of activity representation, technology representation, and technology choice”), the aim and degree of macroeconomic data integration.

Novikova (2008) and Worrell et al. (2004) outline the following types of bottom-up models:

Scenario models which construct a storyline with the implementation of certain technological changes (usually improvement), and a reference baseline without significant changes; the potential is calculated as a difference between the reference baseline and the scenario with technological changes.

Potential estimates that often take a form of energy efficiency *supply curves* characterizing the potential as a step-wise function of marginal costs per unit of energy saved, with each step representing a certain energy efficiency measure.

Simulation models provide a quantitative illustration of exogenously defined scenario strategies.

Optimization models that aim to find the optimal allocation of resources and other factors, for instance, investments required or the technology penetration rate needed to allow sectoral energy consumption for meeting a target at minimal costs.

Integrated models include the interaction between changes in energy use and the economy instead of using a present economic development scenario (Worrell et al. 2004)

Besides technological analysis bottom-up models often include economic estimates, such as energy expenses and investment costs. The detailed information on available technologies and their efficiencies gives the opportunity to model the direct cost and benefits of incremental investments in energy efficiency and switching to “cleaner” fuels (Jaccard & Bailie 1996). The results from individual sectors may be then aggregated in order to estimate the overall technological and/or economic potential for energy and/or emissions reduction (Repetto & Austin 1997).

In the climate change mitigation literature, the same advantages are highlighted. “Bottom-up studies are based on assessment of mitigation options, emphasizing specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. [...] Bottom-up studies are useful for the assessment of specific policy options at sectoral level, e.g. options for improving energy efficiency” (Levine et al. 2007)

However, compared to top-down models, bottom-up ones are typically unable to track the interactions between the energy sector and other sectors of the economy (IPCC 1996). Bottom-up models also have a weakness in measuring the effects of the changes occurring at the microeconomic level on the situation at the macroeconomic level (Cunha da Costa & Fallot 2002). Another drawback of these models is that they may overestimate the potential penetration of a technology as they take energy prices and some other variables exogenously

(McFarland et al. 2004). A high number of exogenous variables might cause significant deviations from reality (Cunha da Costa & Fallot 2002). Bottom-up models are often characterized by “technological optimism”, which means lower than in reality costs of, for example, mitigation or technology’s adoption (Wing 2006).

2.1.3 Hybrid methods

Hybrid models combine certain features of both bottom-up and top-down approaches and, ideally, aim at overcoming weaknesses of the traditional approaches and integrating their strengths. Such a model would include detailed information on specific technologies (as the bottom-up approach) together with real market data in order to explain the behaviour of economic actors and interactions between economic sectors (as the top-down approach). However, it should be noted that in reality it is rather difficult to realistically present economic actors’ behaviour at the technology-specific level (Wing 2006).

One possible classification differentiates two types of hybrid models: one moving from top-down approach to bottom-up and the other one moving in the opposite direction (Novikova 2008).

Böhringer & Rutherford (2006) use a different approach to classify hybrid models. The first group includes the models resulted from coupling existing top-down and bottom-up models (e.g. Hudson & Jorgenson 1974). Böhringer and Rutherford state that such models may face the problems with consistency of the results due to their complexity. The second group of the hybrid models presumes constructing an integrated modelling framework, which combines top-down and bottom-up features.

2.2 Component-based and performance-based methods

Buildings’ energy simulation can be broadly categorized on the basis of overall structure as either performance-based (also named: system-based, holistic) or component-based. As stated:

*“The **component-based** approach is a piecemeal approach, which recognizes buildings as a sum of individual components. While **performance-based** (system-based) recognizes that buildings are more complex systems than just the sum of their components. It also recognizes that the same levels of energy performance can be obtained through different pathways – i.e. different packages of energy-efficiency measures, which gives optimal freedom for the constructors and designer to reduce energy consumption in a particular set of circumstances. [...] This new thinking is reflected in performance-based building energy regulations – i.e. that specify building codes based on energy use per square meter useful space, or other similar complex systemic performance indicators,*

rather than those regulating individual building components. The performance-based regulations specify building codes based on energy use per square meter useful space, or other similar complex systemic performance indicators rather than those regulating individual building components”(Ürge-Vorsatz et al. 2012).

2.3 The Lock-in Effect

This section discusses a very important concept for analysing different pathways of energy demand. It is devoted to illustrate the amount of potential energy savings, which will be lost in case the efforts for its realization are not ambitious enough. This concept is relatively new in the field of energy modelling and the available literature is very limited. Therefore, the meaning of this concept needs to be discussed in more details.

The utilization of the lock-in concept in the literature is rather limited. For example, it is stated in Groot et al. (2001) that increasing investment subsidies for energy-saving technologies can lock energy saving potential in relatively inferior technologies. Once a new technology is adopted the knowledge and awareness of how to use the technology spreads, which results in a learning effect for the institutions that have not yet adopted the technology. Consequently, the technology evolves over time and ultimately matures. The risks to adopt a mature technology are much lower than those of an absolutely new one, which create the incentives for institutions to wait with adoption. This delay causes the lock-in effect of energy savings, which could have been achieved in the situation when the majority of institutions adopt the technology at an early stage of its introduction. Thus, the lock-in of energy savings always goes hand in hand with the delay in the adoption of energy efficient technologies.

Norberg-Bohm (1990) and Mulder (2005) show that the widespread adoption of existing energy-saving technologies could significantly reduce energy use, especially in the short and medium term. Mulder uses the term “energy efficiency paradox” to describe the lock-in effect. Mulder defines it as “a considerable gap between the most energy efficient and cost-effective technologies available at some point in time and those that are actually in use” (Mulder 2005). Thus, the main reason for the lock-in effect is the delay in adoption and slow diffusion of new and more efficient technologies.

Jaffe and Stavins (1994) provide certain explanations for a gradual diffusion of energy efficient technologies and the subsequent lock-in effect: market failures, information problems, principal/agent slippage, unobserved costs, private information costs, high discount rates, and heterogeneity among potential adopters. They demonstrate how the proliferation of energy efficiency technologies can be directly hindered by principal/agent problems in new residential buildings. Jaffe and Stavins also have revealed that “artificially low” energy prices and high discount rates can provide another explanation for the

lock-in effect. Among the factors that may accelerate the diffusion of energy efficient technologies, they noted lower adoption costs, government programs in the form of subsidies or tax credits, departures from temperate climatic conditions, increases in income and education level.

The phenomenon of the lock-in effect in the building sector is not surprising, according to Rohracher (2001) it can be caused by low levels of innovation, mass production from large suppliers, and separation of design from construction. Dewick and Miozzo (2004) in their study of the Scottish building sector point out that “the different aims of the parties involved in the construction chain may not be easily reconciled and traditional approaches to construction may reinforce these differences, hindering efforts to introduce innovation.”

While there has not been an extensive discussion in the literature of the lock-in risk in the building sector, this concept clearly illustrates the significance of strong policies that are insufficiently ambitious in efficiency targets – ones that prevail today in many developed countries. While from an energy savings perspective the lock-in effect is less problematic since energy saving targets may be reached at a later stage, i.e., in the next renovation or construction cycles, from a climate change perspective, it is essential that buildings deliver greater energy savings in the midterm, such as 2050, although some potentials will never be possible to unlock, which is more due to building structures related to urban design, plot sizing, and orientation, etc.

In the current study concept of the lock-in effect is used to illustrate the energy savings, which are not going to be realized due to moderate technological improvements and policy efforts instead of ambitious ones. Lock-in effect is calculated as the difference in the thermal energy use levels achieved under two CEU scenarios: Moderate Efficiency and Deep Efficiency – in relation to the base year (2005).

The architecture of the Moderate Efficiency scenario is based on present efforts taking place in countries, jurisdictions, and institutions strongly committed to solving the climate change problem. Many countries, foundations and institutions recognize the importance of the building sector for climate change mitigation, and have passed improved building codes or encouraged high-efficiency or even nearly zero-energy buildings and facilitated an acceleration of energy efficiency retrofit activities. However, in few of these cases level of building energy performance can be considered as low, especially in case of building renovation. Therefore, the Moderate Efficiency scenario already depicts a world in which strong efforts are devoted to solving the building energy problem, and, thus, shows the danger with which even a well-intended path might be associated.

The lock-in problem originates from the fact that if moderate (i.e. not low enough) performance levels become the standard in new and/or retrofit buildings, it can either be impossible or extremely uneconomic to further reduce energy

consumption in such buildings for many decades to come and in some cases, for the entire remaining lifetime of the building. In other words, if during a refurbishment or new construction, a holistic optimization of building envelope and technologies is not followed, later installation of even the highest efficiency equipment or building materials will not be able to capture all the savings, otherwise attainable in a comprehensive refurbishment. For instance, heat losses and gains will still occur through other, non-optimized building parts. Finally, each retrofit is associated with significant transaction costs and inconveniences, including finding contractors, planning, preparing contracts, perhaps obtaining the financing, putting up scaffolding or other construction support structures, painting and finishing surfaces after it is done, etc. Thus in subsequent “top-up” retrofits, energy savings are smaller and costs higher, with fixed costs comparable to those for a comprehensive, deep retrofit. As a result, going back for non-captured savings after moderate retrofits or new construction is typically so expensive on a specific cost, such as cost/t CO₂ saved, basis that other mitigation or sustainability measures will likely become much more attractive, whereas this is not the case if they are originally part of an integrated, deep design retrofit or construction.

CHAPTER 3 – METHODOLOGY USED IN THE STUDY AND ASSUMPTIONS

3.1 Overview of the Modelling Logic

During this study a model – 3CSEP HEB (Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings) for analysing building energy use and CO₂ emissions has been elaborated. This model is novel in its methodology as compared to earlier global energy analyses and reflects the emerging new paradigm – the performance-oriented approach to buildings energy analysis. As opposed to component-oriented methods, a systemic perspective is taken: the performance of whole systems (e.g. whole buildings) is studied and these performance values are used as inputs in the scenarios. Apart from capturing the interplay of components, this approach allows for the continuous improvement of the analysis if new empirical data from various parts of the world become available. Accordingly, we calculate with the overall energy performance levels of buildings regardless of the measures applied to achieve it. Once a concrete building has reportedly achieved a certain ambitious level of energy performance either through new construction or renovation (which typically means a 70-90% reduction in space heating and cooling energy needs) this level is considered to be a best practice. We assume that the same energy performance level can be achieved in other buildings in the same region and climate zone. Buildings in the best-practice performance category are called ‘advanced’ buildings. In contrast, energy consumption in sub-optimal new constructions or sub-optimally retrofitted existing buildings is just 30-40% below current levels. In different scenarios, the shares of standard, sub-optimal, and advanced buildings are different, as it is explained in Section 3.2. When, on the basis of empirical evidence or data transfer, energy intensity values (kWh/m²/year) are obtained for a given region and climate zone for each building type, total final energy consumption for space heating and cooling can be calculated from these energy intensities and floor area predictions for each building category. Therefore, building stock scenarios and achieved energy performance levels together determine scenario results for space heating and cooling.

At the same time, the energy performance of exemplary water heating systems may not be indicative of the average energy performance that can be achieved in a given region and climate zone. If, for example, a solar system in a particular building in a particular country performs very well, it may be impossible to reach the same performance level in other buildings in the same country and climate zone due to the lack of adequate non-shaded roof area, different building structure, or different consumption volumes or patterns. Thus, different buildings

require different solutions – much more than in the case of space heating and cooling. (One reason for this difference is that water heaters concentrate energy, so the minimization of losses is not enough for energy efficiency.) In accordance with the diversity of solutions required in each region, we made regional assumptions about advanced and sub-optimal technology mixes. For each individual technology in each region, an average achievable efficiency was assumed. The technology mix and the individual efficiencies together determine the efficiency of water heating in all regions. The concrete technological scenarios (technology mixes and efficiencies) are only specific realizations of achievable region-level energy performance levels: other technology mixes or individual technological efficiencies can reach the same regional efficiencies. Nevertheless, the given concrete technological scenarios serve as a justification for the applied regional energy performance levels.

The elaborated model is in the framework of the bottom-up approach, as it includes rather detailed technological information for one sector of economy, however, it also benefits from certain macroeconomic (GDP) and socio-demographic data (population, urbanization rate, floor area per capita, etc.).

The scenarios developed in the study analyse pathways in which energy efficiency in the building sector changes to given – ambitious or less ambitious – levels (a detailed description of the scenarios is given in Section 3.2.). The output parameters of the scenarios are final energy consumption and the associated CO₂ emissions. The time frame for the analysis is from 2005 to 2050, since statistical data after 2005 were not available for several regions, and predictions after 2050 are extremely speculative. Results are analysed at the global (whole world) and regional (four key regions) levels. A detailed description of the geographical classification is given in Section 3.3. The climate classification (which is based on the number of heating degree days, cooling degree days, and the average relative humidity) is explained in Section 3.4. The categorization of building types (single-family, multi-family, commercial and public, plus commercial and public subcategories) and building vintages (existing, new, retrofit, advanced new, advanced retrofit) is given in Section 3.5. After the general part of the methodological description, the approach to building stock, space heating & cooling energy, water heating energy, and CO₂ calculations is explained in Section 3.6.1, 3.6.2, 3.6.3, and 3.6.4, respectively. Due to the large volume of country-specific information and assumptions, some details are given in a methodological annex (Annex 5 and Annex 6).

As it will become even more evident from the detailed methodological description, the approach of the study is predominantly bottom-up: we start from individual buildings or systems and make predictions about the whole building sector. At the same time, we also use certain elements of top-down methodologies, e.g. population and urbanization data for the residential floor area calculation or GDP as a driver of commercial and public floor area dynamics.

This hybrid approach is designed to make maximum use of all currently available relevant information.

3.2 Scenarios considered

We consider different scenarios for energy use dynamics. These scenarios –a very ambitious, a moderately ambitious, and a “business as usual”– are briefly described below. The main aim of this project is to investigate what buildings can achieve to mitigate climate change through the various opportunities.

3.2.1 *Deep Efficiency Scenario*

This scenario demonstrates how far today’s state-of-the-art construction and retrofit know-how and technologies can take the building sector in reducing energy use and CO₂ emissions, while also providing full thermal comfort in buildings. In essence, we determine the techno-economic energy efficiency potentials in the building sector.

In this scenario, exemplary building practices are implemented worldwide for both new and renovated buildings. Over the 10-year period from 2012 to 2022 advanced buildings are widely proliferating in all regions, replacing conventional new and retrofit buildings on the market. . The transition period allows markets and industries to prepare for the large-scale deployment of the high efficient building construction technologies, materials and know-how. Necessary ambitious enabling policies can also be implemented and the vital supporting institutional framework introduced. After 2022, most renovations and newly built structures will be of a very high-energy efficient design as exemplary buildings in the same (or a similar) climate zone. For regions where the best building design practices have not yet been proven, e.g. in most of the developing world, the energy consumption figures for each building category are transferred from the same climate zones of other regions.

In the Deep Efficiency scenario, the energy efficiency of water heating also increases much more rapidly than before the modelled period. Besides the important roles of improved stoves in developing countries and condensing gas heaters in other countries, the share of solar water heaters climbs fast and becomes very significant in most regions (for a detailed regional description, see Annex 5). Similarly efficient heat pump systems can also provide hot water in many of the regions. Waste heat recovery in multifamily and commercial and public buildings gains momentum, water saving technologies become common.

3.2.2 *Moderate Efficiency Scenario*

The rationale for this scenario is to illustrate the development of the building energy use tacking into account current policy initiatives, particularly

implementation of Energy Building Performance Directive (EPBD) in the EU and building codes for new buildings in other regions.

The scenario assumes an accelerated renovation rate (i.e. annually reconstructed buildings) to reflect that many countries recognized the importance of the quick implementation of energy-efficient retrofits and energy-efficient building codes. In all regions retrofit rates start to increase from the level of 1.4% in 2005 and reaches “accelerated” levels by 2020, and stay unchanged afterwards. These “accelerated” rates are different in different regions. For the key regions the following values are used: US and EU-27 – 2.1%, China – 1.6% and India – 1.5%. However, these accelerated retrofit buildings and new constructions still result in far lower efficiency levels than what is achievable with state-of-the-art solutions (hence, the name is Moderate Efficiency scenario).

New buildings are built to approximately regional code standards in existence at the time of this study; renovations are carried out to achieve approximately 30% energy savings from the existing stock average, as opposed to the state-of-the-art that reach 90% of savings in some climate and building types, as demonstrated by best-practices.

The ambitious European Energy Performance of Buildings Directive is taken into in this scenario. It is assumed that in the EU-27 all new buildings will achieve high level of energy performance for space heating and cooling (25 kwh/m² year) by 2020. By that time only half of retrofit buildings in Europe will comply with such a performance level and by 2030 in all retrofit buildings (except for cultural and historical ones) energy use can be significantly reduced.

EPBD (2002/91/EC)

The European Parliament and Council adopted the Energy Performance in Buildings Directive in 2003 in order to introduce energy performance in buildings in all EU Member States. The MS have to:

- Develop a framework to calculate energy performance in buildings,
- Set minimum energy performance requirements in new buildings and by larger renovations of existing buildings,
- Demand for energy certification of buildings by construction, sale and rental,
- Inspect boilers and air condition systems.

The Directive was recast in 2010 adding further requirements for:

- Nearly Zero Energy Buildings by 2020 for all new builds and by 2018 for all new public
- Renovation of existing buildings

currently existing programs like the boiler scrappage scheme in the UK (Energy Saving Trust 2011) or the efficient stove initiative in India (Block 2011). Average

efficiency values show what is achievable with condensing tankless gas water heaters in regions where gas is available, improved electric systems equipped with add-on heat pumps, good stoves in India, and a slightly increased share of solar water heaters in China (for details, see Annex 5). As stated before, the same efficiency levels can be achieved with a different technology mix, so the only purpose of referring to this particular technology mix is to justify the applied efficiency values.

On the basis of the Moderate scenario the Lock-in set-up is constructed particularly for the purpose of calculating the lock-in effect. This “sub-scenario” is utilized only to illustrate the potential lock-in effect in building infrastructure that can be caused by accelerated and major policy efforts that compromise in performance levels, i.e. do not mandate the state-of-the-art that is also economically feasible, both in new construction and retrofit.

Technically, the Lock-in set-up is the Moderate scenario with the retrofit rate accelerated to 3% after 2020 in all the regions (as for the purpose of comparison it has to have the same retrofit rate as Deep Efficiency scenario to illustrate only the effect of the proliferation of advanced buildings), and, therefore, its results are not presented in other parts of the report.

3.2.3 Frozen Efficiency Scenario

It is important to emphasize that because of recent advances in scenario science, baselines are constructed only for exceptional use when it is unavoidable that one must have a baseline. Therefore, this scenario, will not receive the level of effort and rigor that the mitigation scenarios do.

Frozen Efficiency scenario assumes that the energy performance of new and retrofit buildings do not improve as compared to their 2005 levels and retrofit buildings consume around 10% less than standard existing buildings for space heating and cooling, while most of new buildings have higher level of energy performance than in Moderate scenario due to lower compliance with Building Codes. Retrofit rates are assumed to be constant throughout the analysed period at the level of 1.4%. Advanced new buildings are assumed only in Western Europe (namely Germany as 5% and Austria as 10% of the new building stock) and their share in the new building stock does not change over the time. Advanced retrofit buildings are not considered for all regions.

For water heating it is assumed that the fuel mix and efficiency of water heaters do not change during the analysed period.

3.3 Regions and Focus Geographic Areas

The main regional focus of the study is three big countries: USA, China, India as well as members of the EU-27. As can be seen from Figure 2. US, China, India are parts of bigger regions: NAM, CPA and SAS, correspondingly. Therefore, the model allows for presenting the results separately for these countries, for the rest of these regions excluding these countries and totals for the whole region (e.g. US, NAM excluding US, total NAM). As for EU-27, it is presented separately in the model, as it is not a part of any bigger regions: its countries-members belong to three different regions: WEU, EEU and FSU. Model allows for obtaining results for this region both for individual countries and for the whole EU-27.

There are eleven regions considered in the model (see Figure 2). North America (NAM), Western Europe (WEU), Eastern Europe (EEU), Former Soviet Union (FSU), Latin America (LAC), Pacific OECD (PAO), Centrally Planned Asia (CPA), Pacific Asia (PAS), South Asia (SAS), Middle East and Africa (MEA), and Africa (AFR). These regions together cover the globe.

Figure 2. Regions analysed in the model with the focus on four key regions

3.4 Climate Classification

Within each region different climate zones are considered in order to capture the difference in building energy use and renewable energy generation caused by climate variations. The differentiation among different climate zones is based on several climatic factors in terms their influence on building energy demand for space heating, cooling and dehumidification, namely:

- Heating Degree Days (HDD)
- Cooling Degree Days (CDD)

- Relative Humidity of the warmest month⁴(RH)
- Average Temperature of the warmest month (T)

These parameters are processed by means of GIS⁵ tool - spatial analysis - and performed with ArcGIS 9.3 software. Spatial analysis is one of the techniques used in GIS, which may be defined as “a general ability to manipulate spatial data into different forms and extract additional meaning as a result” (Fortheringham & Rogerson 1994). The main aim of spatial analysis is “to measure properties and relationships, taking into account the spatial localization of the phenomenon under study in a direct way” (Câmara et.al 2008).

According to Câmara et.al (2008), the greatest benefit of spatial analysis is the ability to visualize spatial patterns of various phenomena (e.g. population, weather, climate characteristics, economic indicators and many others) in the form of colourful maps. Moreover, spatial analysis is able to transfer the presented patterns into “objective and measurable considerations” (meaning numerical data in the form of tables and/or charts) (Câmara et al. 2008).

GIS analysis allowed for combining the parameters outlined above and selecting geographical areas, which correspond to specified criteria of such a combination. These criteria are presented in Câmara et al. 2008. Each selected geographical area corresponds to a certain climate zone categorized by energy needs for space heating, cooling and dehumidification. All climate zones produced in the result of GIS analysis are presented in Figure 3.

The main data source for GIS analysis was from NASA publicly available datasets (Atmospheric Science Data Center 2005). Input data for each parameter were obtained separately and can be presented in the form of maps (Figure 2). Figure 3 shows that there are 17 climate zones considered in the current study. Each of them is characterized in terms of heating and/or cooling demand, which varies from “low” to “very high” depending on the amount of average HDD and CDD in each area. The need for dehumidification is determined on the basis of combination of values for relative humidity and average temperature of the warmest month. It is assumed that if relative humidity of the warmest month is higher than 50% and average temperature of the warmest month is higher or equals 23°C, than dehumidification in buildings is needed (Table 1).

⁴July is assumed to be the warmest month for the Northern Hemisphere and January – for the Southern Hemisphere

⁵ Geographic information systems (GIS) are the “tools for the storage, retrieval and display of geographic information”

Table 1. Input Parameters for Climate Zones

Climate Zone	CDD10	HDD18	RH	Ave. T	Colour Code
1 Only Heating (Very high heating demand)	<1000	>=5000	<50	Or =<23	
2 Only heating (High heating demand)	<1000	>=3000 and <5000	<50	Or =<23	
3 Only Heating (Low and moderate heating demand)	<1000	>= 1000and <3000	<50	Or =<23	
4 Heating and Cooling (Very high heating demand and mostly Low cooling demand)	>=1000 and <2000 ⁶	>=5000	<50	Or =<23	
5 Heating and Cooling (High heating demand and mostly Moderate cooling demand)	>=2000 and <3000 ⁷	>=3000 and <5000	<50	Or =<23	
6 Heating and Cooling (High heating demand and Low cooling demand)	>=1000 and <2000	>=3000 and <5000	<50	Or =<23	
7 Heating and Cooling (Moderate heating demand and Moderate cooling demand)	>=2000 and <3000 ²	>=2000 and <3000	<50	Or =<23	
8 Heating and Cooling (Moderate heating demand and Low cooling demand)	>=1000 and <2000	>=2000 and <3000	<50	Or =<23	
9 Heating and Cooling (Low heating demand and Moderate cooling demand)	>=2000 and <3000 ²	>=1000 and <2000	<50	Or =<23	
10 Heating and Cooling (Low heating demand and Low cooling demand)	>=1000 and <2000	>=1000 and <2000	<50	Or =<23	
11 Only Cooling (Very high cooling demand)	>=5000	<1000	<50	Or =<23	
12 Only Cooling (High cooling demand)	>=3000 and <5000	<1000	<50	Or =<23	
13 Only Cooling (Low and moderate cooling demand)	>=1000 and <3000	<1000	<50	Or =<23	
14 Cooling and Dehumidification (Very high cooling demand)	>=5000	<1000	>=50	And >23	
15 Cooling and Dehumidification (High cooling demand)	>=3000 and <5000	<1000	>=50	And >23	
16 Cooling and Dehumidification (Low and moderate cooling demand)	>=1000 and <3000	<1000	>=50	And >23	
17 Heating and Cooling and Dehumidification	>=1000	>=1000	>=50	And >23	

Such a climate split gives the opportunity to capture variation in energy needs for heating, cooling and dehumidification in different geographical locations.

a)

b)

⁶ There might be some areas in this subcategory, where value of CDD is higher than 2000, but their number is insignificant

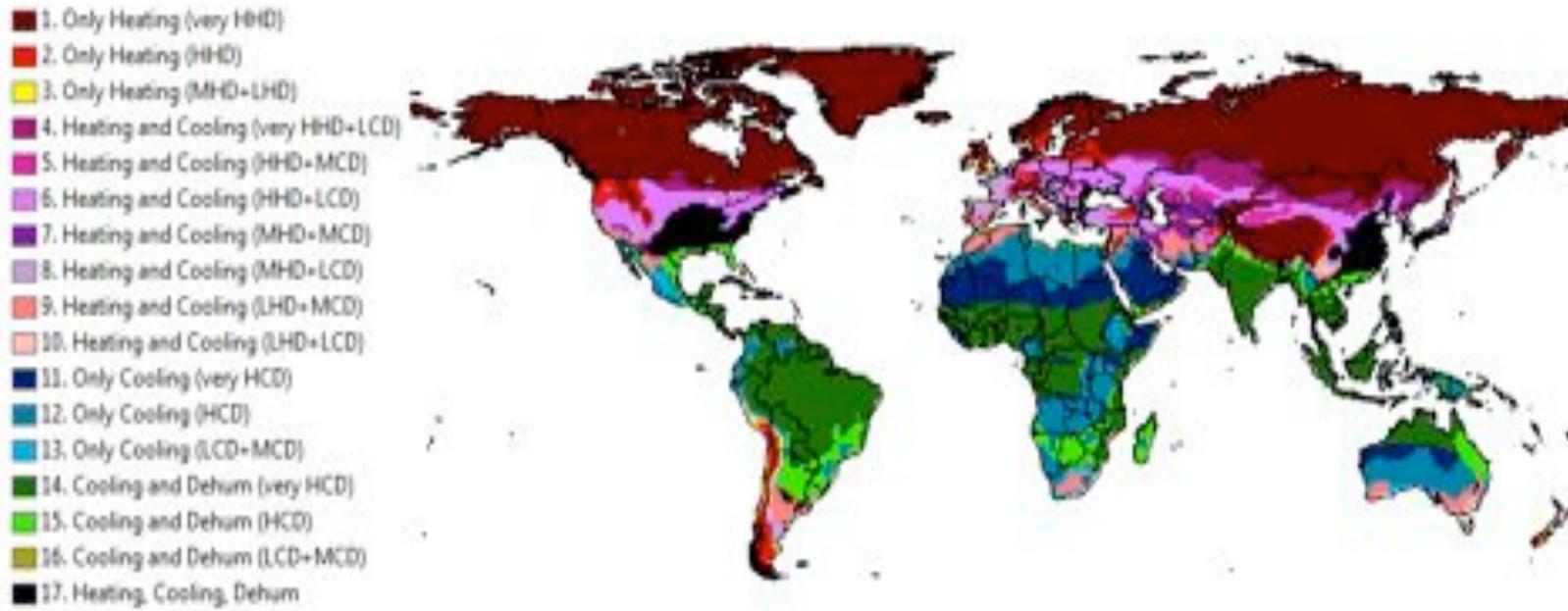
⁷ There are some areas in this subcategory, where value of CDD is higher than 3000, but their number is insignificant

Figure 3. Input Parameters for Climate Split: a) Heating Degree Days, b) Cooling Degree Days; c) Relative Humidity (%); d) Average Air Temperature (°C)

c)

d)

Figure 4. Composite Climate Split Used in the Model



3.5 Building Types Classification

The model has a comprehensive multi-level building type classification. Building categories are distinguished by their location (urban, rural, slum), building type (single-family, multifamily, commercial and public buildings with subcategories), and building vintage (existing, new, advanced new, retrofit, advanced retrofit).

3.5.1 Location

First, the split between urban and rural building areas is introduced. For residential buildings the split is made on the basis of urbanization rates projections for each region and country. For commercial and public buildings a certain small share (5-10%) of floor area is assumed to be rural. Due to the lack of such data in open sources, these assumptions are based on expert judgments.

The model takes into account existence of slums in India. The term 'slum' is used in this report in a general context to describe a wide range of low-income settlements and/or poor human living conditions. According to the literature slums are usually defined as *“a contiguous settlement where the inhabitants are characterized as having inadequate housing and basic services”* (UN-HABITAT 2003). What is also important to be noticed is that such non-regulated residential areas are often not recognized as legal and integral part of the city. The enumeration of slums has not yet been incorporated within mainstream monitoring instruments, as there is lack of agreed definition. According to UN-HABITAT (UN-HABITAT 2008) slums household is defined as *“a group of individuals living under the same roof lacking one or more of the following conditions: access to improved water, [...] sanitation facilities, sufficient living area, [...] quality of dwellings and security of tenure”*.

3.5.2 Building type

After the share of slums is subtracted from urban population, residential urban buildings are split into single-family (SF; detached or attached) and multifamily (MF; 4 or more levels, terraced, etc.), according to the population living in each building type. The split between urban SF and urban MF is done on the basis of region-specific data and assumptions. For Europe, BPIE provided country level SF-MF shares in urban areas (BPIE 2011b). For India, China, and the US, regional experts' assumptions were used. Shares of population living in SF and MF buildings are presented in Table 2, rural residential buildings are assumed to be only single-family ones. Commercial and public buildings both in urban and rural areas are divided into six sub-categories: hotels & restaurants, educational, hospitals, offices, retail buildings, and others, according to the share of the floor area for each commercial and public building type in the total commercial and public floor area (Table 2). Such data have been found only for a limited number

of regions and for other regions assumptions were made, proportionally to the collected data.

Table 2. Share of urban population living in single-family (SF) and multi family (MF) buildings

Regional Acronym	Single Family	Multi Family
US	72%	28%
EU-27	41%	59%
China	3%	97%
India	25%	75%

Table 2. Share of different commercial and public building types in total commercial and public floor area by region

Region	Education	Hotels & restaurants	Hospitals	Retail	Offices	Other	References
US	14%	9%	3%	16%	17%	41%	EIA 2008
EU-27	17%	11%	7%	15%	23%	27%	BPIE 2011
China	19%	14%	5%	14%	33%	15%	Zhou et.al 2011
India	15%	10%	4%	36%	11%	24%	Kumar et.al 2010
Other regions	16%	11%	5%	20%	21%	27%	Assumptions

3.5.3 Building vintage

In the energy scenarios, we take into account five building vintages with different levels of energy performance: standard, new, retrofit advanced new and advanced retrofit buildings. Standard buildings are those buildings, which had been built in the country or region prior to the analysed period. Hence, among others this vintage includes old buildings (typically representing buildings up to 1960), which are usually the least efficient ones. New buildings are the ones constructed in the country or region during a particular year within the analysed period. Correspondingly, retrofit buildings are those renovated during a particular year within analysed period. The same is applied to advanced new and advanced retrofit buildings with the only difference in specific energy use for space heating and cooling, as they consume much less.

3.6 Scenario methodologies

3.6.1 Building stock

A crucial step in producing scenarios is building floor area calculation. The building stock model is based on annual dynamics, including the following process in the existing building stock: demolition (a certain share of the building is demolished due to the end of the lifecycle or other reasons), renovation (a certain share of the building is renovated) and new construction (a certain number of new buildings is added every year).

Demolition rates vary from one region to another in the range of 0.3 – 1%. Demolition rates are obtained using the Odyssee Database (Odyssee 2009), statistical agencies, and personal communications with experts. For most regions 0.5% is used as the demolition rate.

Unfortunately, the literature is rather sparse on retrofit rates and most of the sources relate to EU region - e.g. Petersdorf et al. (2004) assume natural retrofit rate of 1.8% for the EU-15 (the member countries in the European Union before 2004) and Lechtenböhmer et al. (2009)- 1% autonomous refurbishment rate and 2.5% accelerated rate of retrofit in their mitigation scenario for EU-27. Others assume 25-30 years retrofit cycles (Lechtenböhmer et al. 2005; McKinsey 2009). Thirty years of a building's life cycle corresponds to 3.3% retrofit rate per year. In this model it is assumed that natural retrofit rates are between 0.7% - 2%, and the 1.4% value (corresponding to approximately 70-year building stock turnover rate) is considered as a normal retrofit rate in developed countries, which is increasing to 2020 in case of the Moderate Efficiency scenario to 2.1% in EU-27 and US, to 1.6% in China, 1.5% in India; in case of the Deep Efficiency scenario to 3% in all regions for quicker mitigation; in case of the Frozen Efficiency scenario the retrofit rate remains fixed (at 1.4% level) for the whole analysed period (Zhai et al. 2011; Zhai et al. 2011; Neuhoff et al. 2011; Jennings et al. 2011; ECEEE 2011; BPIE 2011a; Boermans 2011; UNDESA 2010; Rogner 2010; Olgay&Seruto 2010; Nock & Wheelock 2010; Barbier 2010; UNEP – Sustainable Buildings & Climate Initiative 2009; Coffey et al. 2008; Xavier et al. 2007; Wang & Zhang 1986; The Ecotope Group 1977).

Buildings are retrofitted and demolished until less than 5-8% of the original 2005 levels of building stock remains. This percentage - depending on the region - signifies building stock that cannot be extensively retrofitted and is considered 'Heritage' building stock. New buildings present the difference between total floor area requirements and the available building stock (existing building stock less demolition) for each year.

At the next step energy use for different end-uses is calculated using floor area estimations for each year and specific energy consumption values and other

necessary data (in case of energy use for water heating). The procedure for calculating floor area differs for residential and commercial and public buildings.

Residential Buildings

Residential floor area growth is based on floor area per capita estimates and population projections for each region or country with the assumptions that the developing world will have approximately the same standard of living in terms of living space per capita as OECD countries by 2050. This is then coupled with the urbanization rate to produce a total floor area for rural and urban buildings. The former are assumed to be single-family and the latter are split between single-family and multifamily (see Section 4.5). In case of declining population the immediate removal of building stock is assumed to be not realistic since capital stock typically retains value even with no occupancy and demolition can be more costly than leaving buildings unoccupied. However, in terms of energy consumption this building stock does not exist since energy consumption in unoccupied buildings is negligible and is therefore removed from the model.

Building floor area is also calculated for each climate zone by applying share of population for each climate zone within each region/country. Share of population for each climate zone was calculated by means of GIS analysis through overlaying created climate split with population grid.

Commercial and Public Buildings

This group of buildings includes all non-residential buildings, except for industrial ones.

The main driver for commercial floor area calculation is GDP per capita projections for each region or country commercial and public floor area in 2005 is divided by GDP in 2005 which yields “commercial and public floor area elasticity” (Bressand et al. 2007). This proportionality constant, when multiplied by GDP for a given year gives the commercial and public floor area demanded by the economy. Since the developing world has a higher ratio of commercial and public floor area to GDP than the developed OECD countries, the ratio is assumed to decrease over time and eventually achieve an average OECD level of floor area elasticity, representing a shift to higher GDP output per unit floor area synonymous with completed economic development.

The main drivers for residential and commercial floor area dynamics are population and GDP, respectively.

The Global Energy Assessment (GEA) model, constructed by International Institute for Applied Systems Analysis, supplies population, urbanization rate and GDP data and projections for each region and country (IIASA 2012). Population and GDP data used in the model for the 4 key regions are presented in the charts below.

As can be seen in Figure 5, US and EU-27 population levels remain relatively constant when considered relative to the developing world. In India increasing trend continues for the whole modelling period, while in China it reaches the peak around 2030 and then starts to decline. In addition GDP increases for all key regions with the highest projected increase in India and China (see Figure 6).

Figure 5. Population in USA, China, India and EU-27

Figure 6. GDP in USA, China, India and EU-27

Bottom-Up Energy Analysis System (BUENAS) projects the energy use of building equipment and project appliance. Data from the BUENAS model is also used to project the commercial and public building stock in 11 regions and EU-27 countries, but only the base year data on commercial and public floor area is used. As it was noted above, floor area per capita is one of the main input parameters for calculating residential floor area. Table 4 contains values for floor area per capita and commercial and public area numbers, borrowed in largely from the BUENAS model for four key regions.

Table 4. Input parameters for calculating floor area in key regions

Region	SF rural m ² /cap	SF urban m ² /cap	MF urban m ² /cap	Slums m ² /cap	Total commercial and public mln m ²
US	66	66	35	0	7093
EU-27	35.8	40	24.7	0	5889
China	27	29.1	24	0	9478
India	6.6	8.3	3.4	2	1856

Sources: (Ministry of the Interior and Kingdom Relations 2010), BUENAS, Odyssee (2009), etc

3.6.2 Thermal comfort

Thermal comfort combines space heating and cooling needs to maintain an acceptable indoor air temperature.

Space cooling energy demand is not as readily available as space heating in the open sources, since cooling is typically an electrical load that cannot be easily disaggregated from total electricity use. In addition, different regions have different demand for cooling and heating energy. As the model uses a performance-based approach combined energy consumption for space heating and cooling is taken as the main input data for the analysis.

Advanced buildings, according to the model's logic, have a state-of-the-art design, which allows for a significant reduction of thermal energy demand in most climate zones (up to 90%). This assumption is also in line with the concept of a passive house, which often does not include any "active" heating or cooling systems, with the usual energy performance for space heating and cooling presented at the level of 15 kWh/m² year in final energy.

However, advanced buildings considered in this study are incorporated in a broader concept, as they include any high efficient buildings, regardless energy efficiency measures (e.g. "passive" or "active" heating system), but with very low level of thermal energy use.

Experience shows that the high efficiency buildings are possible in areas as diverse as the German and Swiss Alps, China, India, Japan, Korea, Sweden, Norway, USA, Canada, Australia, Hungary, Poland), with heating and cooling degree-days rather variable among these locations (Feist et al. 2001; Firlag 2009; Schuetze & Zhou 2009; Concordia Language Villages 2009). Although it is not always feasible to achieve such an ambitious level of energy performance in very cold climates, according to Feist 2009, it is still possible to achieve low energy consumption for space heating (around 25 kWh/m² year) for new houses without increase in construction costs. Therefore, for cold climate zones of some regions slightly higher level of energy consumption up to 30 kWh/m²year is more feasible. Energy consumption lower than 15 kWh/m²year has been proven in Western Europe, but also increasingly in North America and Eastern Europe. While these buildings have impressive energy consumption, the technology or solutions used are not necessarily economically viable or possible for most buildings, especially regarding renovated structures.

Space cooling energy demand estimates are not as readily available as space heating, since cooling is typically an electrical load that cannot be easily disaggregated from total electricity use. In addition, not every region utilizes space cooling, just as not every region requires space heating.

Energy use for space heating and cooling is calculated by multiplying the estimated floor area values for each region, climate zone, building type (urban single-family, urban multi-family, urban commercial and public, rural single-family, rural commercial and public), building vintages (standard, new, retrofit, advanced new, advanced retrofit) and each year by specific energy consumption figures of exemplary buildings (in kWh/m² year) for the same categories. These results can be summed up in order to get the results for each region and then for the whole world.

One of the most important input parameters for thermal energy use calculation is specific energy consumption for space heating and cooling. Table 1 in Annex 1 shows the data points that are used as an input to the model for final thermal energy use calculation for Moderate Efficiency and Deep Efficiency scenarios. These data are coming from different sources (national building codes, publications, expert judgments, etc.). Unfortunately, the data on specific energy consumption for space heating and cooling is rather scarce, therefore, in some cases certain assumptions were made and transfer from one region to another was applied.

Key assumptions for input data on specific energy consumption for space heating and cooling

1) Energy consumption for space heating and cooling of residential buildings in rural areas is assumed to be 30% lower than in urban ones in developing regions and at the same level in developed ones.

2) Retrofit buildings consume 30% less than standard buildings in Moderate & Deep Efficiency Scenarios and 10% less in Frozen Efficiency Scenario for the regions in general.

3) Energy performance of advanced buildings is determined by best practices, which can be achieved in a particular climate zone, according to a number of case studies. Most of data are approximately at the level of 15-30 kWh/m², depending on the region.

4) Slums consume 70% less than single-family buildings for the region of India, in the climate zones, which require heating (as people in such areas usually use very inefficient fuel solution for heating), and only 95% for the climate zones where only cooling is needed.

5) Space heating & cooling in commercial and public buildings are determined by real case data and design alteration between building types for the missing data points (Hotels & Restaurants: 1.0, Education: 0.9, Hospitals: 1.3, Offices: 0.7, Retail: 0.8, Others: 0.6)

6) Values for EU-27 are the averages for each climate zone among EU countries.

For a detailed description of the data sources and assumptions, see Annex 6.

3.6.3 Water heating

As it is explained in Section 4.1, the methodology to determine water heating energy savings potential is somewhat different from the approach used in the case of space heating and cooling. As the performance level of individual advanced water heating systems is not always indicative of the regionally achievable average performance, regional technology mix assumptions and the assumed efficiencies of the technologies in these mixes are used together to determine regional average efficiency levels. Therefore, to assess the energy savings potentials in the case of water heating, *2005 residential and commercial and public hot water energy use* values are needed, plus the improvement potentials of *regional average energy performance* values must be estimated. In addition, the volume of hot water consumption is also expected to change in some regions, so this is also considered in the scenarios. The main steps and data sources are described below (for a visual presentation, see Figure 7); details are given in Annex 5.

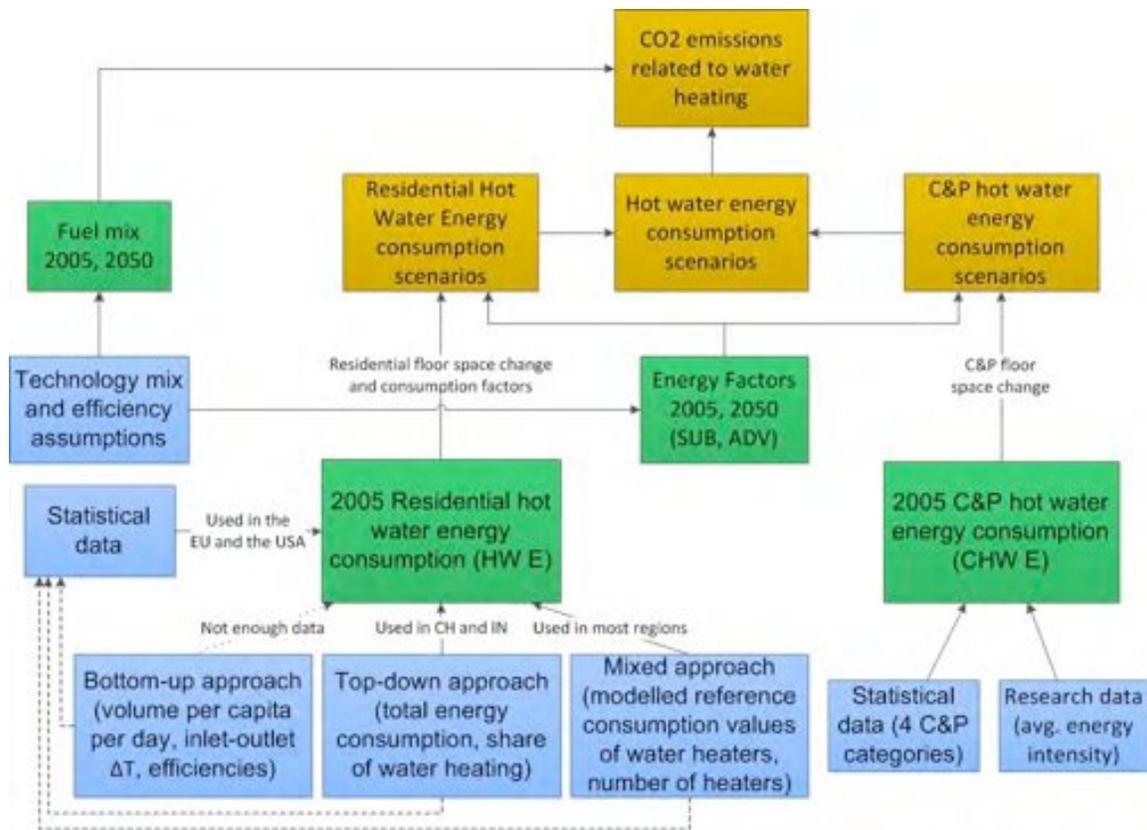


Figure 7. The main steps and data sources for water heating energy use model

2005 total hot water energy consumption values are obtained for residential and commercial & public buildings in different ways. For some regions, values are taken from statistical databases (e.g. US values from the US Energy Information Administration's database); for other regions research articles and reports were used (e.g. LBNL reports for China: e.g. Zhou et al. 2009; Fridley et al. 2008), and in some cases hot water energy use was calculated on the basis of existing information on sectoral energy use and our own assumptions on the share of water heating from total energy use (e.g. in the case of India).

Current average water heating efficiency is estimated on the basis of the technology mix and the efficiencies of current technologies in each region. Statistical databases and research articles/reports were the most important sources of information about the technology mix. Technological specifications, scientific reports, and measured values were used to estimate average efficiencies.

Future efficiencies are estimated on the basis of efficiencies of advanced water heating systems and potentials of different technologies. For each scenario, a potentially achievable technology mix was assumed and the efficiencies of technologies used in a given scenario were averaged to obtain advanced efficiency values.

In addition to technological change, consumption levels also affect final hot water energy demands. To give account of changes in consumption, floor area was used as a proxy. We used population predictions in the estimation of residential hot water consumption and assumed that per capita hot water consumption changes like per capita floor area. (There is very little available data on hot water consumption volumes, so trends are essentially unknown.) In most countries, this translates into increasing consumption (e.g. India, where both per capita floor area and hot water consumption are low and expected to grow quickly). In the case of China, we modified this assumption on the basis of expert opinions (Chinese per capita hot water consumption is expected to grow quicker than its per capita floor space, so we used an adjustment factor.) Water saving technologies with a potential to reduce consumption were considered when we determined future efficiencies.

To properly describe systems in which the useful energy of hot water can be larger than the final energy supplied by the fuel used for water heating (e.g. in solar systems, where fuels are only needed to provide backup), the Energy Factor (EF) was used as a measure of efficiency.

$$EF = \frac{\text{useful hot water energy}}{\text{final energy of the fuel used}}$$

In case of conventional systems using fossil fuels or biomass, EF is the same as efficiency. However, with the application of solar systems and heat pumps, we can easily obtain $EF > 1$ values for future average energy factors. (For an average solar system in a warmer moderate climate, $EF \approx 3$, for a basic air source heat pump in the same climate, EF is usually between 2 and 3.) Apart from calculating the average achievable EF on the basis of the assumed future technology mix, values were further increased to give account of water saving potentials and heat recovery (e.g. 20% consumption reduction was modelled by multiplying EF by 1.2; a 30% potential of heat recovery in 15% of the buildings was modelled by multiplying EF by $(0.85 + 0.15 \times 1.3)$).

Erreur ! Source du renvoi introuvable.. Detailed regional assumptions are given in Annex 5.

Region	Final Energy for Water Heating, PJ (PJ=10 ⁻³ EJ) (2005)		Energy Factor, 2050		
	Residential	Commercial and public	Frozen Efficiency*	Moderate Efficiency	Deep Efficiency
US	2237	493	0.66	1.00	1.94
EU-27	1867	564	0.83	1.18	2.32
China	1138	515	0.72	1.09	2.09
India	699	160	0.21	0.50	1.10

* In the Frozen Efficiency Scenario, 2005 Energy Factors are kept constant.

3.6.4 Energy-Related CO₂ Emissions

The final energy was first converted to the primary energy using primary energy factors (PEF) (Price et al. 2006; EPA 2011a; NHO 2009; Euroheat & Power 2006). Next, using the emission factors of primary fuels, CO₂ emissions were calculated for different types of fuels.

To obtain regional emission factors, country level emission factors were aggregated. For the country level emission factors various sources were used. The main sources were: (IEA; IEA 2007; IEA 2011; IPCC 2006) Other sources included (IEA 2007; IEA 2007; EPA 2011b; EC 2011; NIES 2010; DEFRA 2011; SEPA 2011). Table 3 provides emission factors for different regions. Table 3 presents the values of emission factors already multiplied by the primary energy factors.

Table 3. Emission Factors by Regions

Region	Emission factors, kgCO ₂ /kWh					
	Electricity	District heating	Coal	Gas	Oil	Bio liquid ⁸
US	1.676	0.138	0.354	0.222	0.312	0.002
EU-27	1.003	0.145	0.354	0.222	0.312	0.002
China	2.811	0.610	0.354	0.222	0.340	0.002
India	2.072	0.091	0.354	0.212	0.312	0.002

The emission factors are assumed to be constant for space heating and cooling from 2005 to 2050.

3.7 Modelling Platform

3.7.1 Modelling tool

The model is implemented in Microsoft Access 2010. MS Access is a database management system, which includes the database engine, Microsoft Jet, embedded means of data graphical representation, and the software developing VBA⁹ platform. It is perfect for small and middle-scale databases, providing a powerful and simple solution for both users and developers of the model.

⁸ Emissions factors for bio liquid do not include indirect emissions from biomass collection. Therefore, it does not take into account the unsustainability of traditional biomass and in reality it cannot be considered as a potential solution for decarbonisation of energy supply.

⁹ Visual Basic for Applications

3.7.2 Developing and management of the dynamic database solution

The final model software implementation provides a solution for the main challenge of the model: the dynamic objectives given a significant amount of the input. On one hand, the input and output compose a significant amount of interconnected data; certain output tables are inputs for the next stages of the algorithm. On the other, the employed data are not static, since one of the major aims is to be able to recalculate the output tables easily according to the original sophisticated algorithm. Furthermore, the data are highly disaggregated which provides a great flexibility but, meanwhile, requires an invention of easy ways for their custom various aggregations.

The software application of the model implementation is built upon the core software tool (MS Access 2010) that itself provides means:

- To store input and output tables in a clear and structured format
- To program a complex set of steps to calculate the output (the algorithm)
- To present data in tabular and graphical form
- To aggregate data easily
- To present the links between the tables in a graphical form
- To import data to and export from Excel

The final software implementation of the model gives possibilities for further modifications of the model. Also, it is compatible with MS Excel documents, which is crucial, since this is traditionally the main format used to store data.

3.7.3 Front-end and back-end of the model

The implementation of the model is a robust and reliable tool with a minimal probability of computational errors or software breakdowns. The tool represents a flexible and user-friendly solution providing various opportunities to work with large amounts of data create new scenarios and present data in a high visual quality.

For users, most of their interaction with the model can be limited with the use of the front-end of the application: user forms. Figure 8 is the screen shot of the form that enables to create floor area tables with custom setting. Figure 9 **Erreur ! Source du renvoi introuvable.** presents the form where the user can recalculate any output table. Given a chosen scenario, a relevant table with the standard name is automatically recalculated, once the user has pressed the relevant button. This might be needed if he or she enters new input data and wants to obtain the updated results

Floor Area Calculator

Retrofit:

Shift Year: Gradual change

Scenario:

Retrofit Rate:

Output table name:

Figure 8 Front-end: Floor Area Calculator

Scenario:

Figure 9. Front-end: Main Control Form

The heart of the back-end of the model implementation is the set of the linked input tables, the diagram of which is presented on Figure 10. Each rectangle represents a table with its field listed inside it. The lines between tables refer to the connections between two tables. Most of the lines have the figure of one on one end and the sign of infinity on other, which shows the relation between the tables “one-to-many”. This means that one record in the first table corresponds to many records in the other. The line with the figure of one at both ends represents a connection “one-to-one”, in which each record in one table is linked to a single record in the other. Lines without any marks at the ends refer to connection in many-to-many.

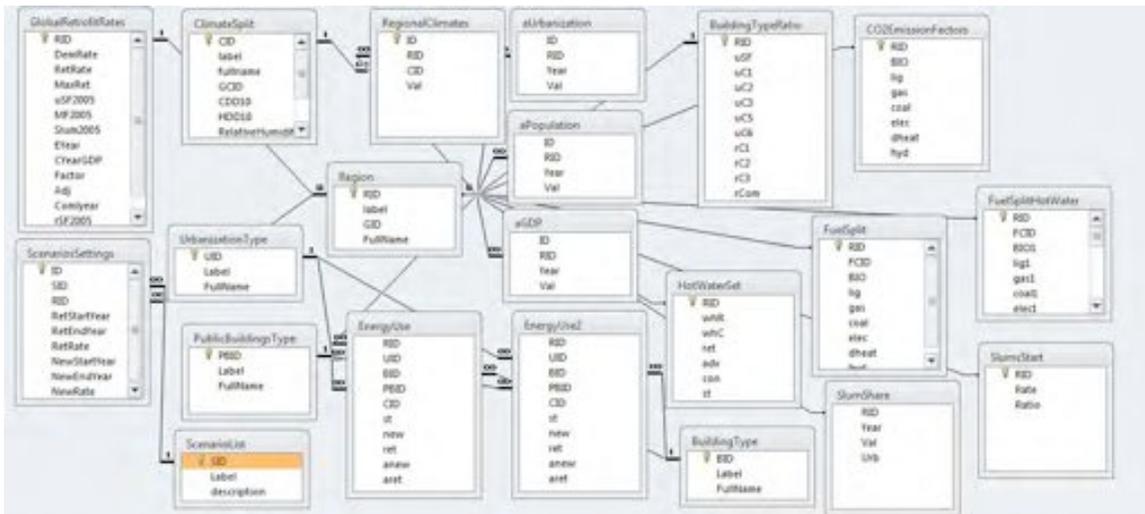


Figure 10. Back-end: Database diagram - all Input Tables

CHAPTER 4 – MODEL RESULTS

This section presents model results in this report for floor area, final energy use for space heating and cooling, water heating and CO₂ emissions for the world and four key regions, namely US, China, India and EU-27, for three scenarios: Frozen Efficiency, Moderate Efficiency and Deep Efficiency.

4.1 Floor Area

This section presents the results for floor area for the world and four key regions.

Global floor area grows by 127% from 2005 to 2050. In developed regions floor area increase is mostly driven by GDP while in developing regions the increase is due to a rise in population. GDP floor space per capita and commercial floor area grow elastically due to increased quality of life. In all regions - every year, a certain share of existing buildings is being demolished or renovated. Therefore, the amount of existing buildings is constantly decreasing in all regions. There is an assumed level of cultural and historical buildings (about 5-8%), which, can be renovated to a conventional (but not advanced) level. Therefore, part of the existing buildings becomes retrofitted or advanced retrofitted (in case of Deep Efficiency scenario) buildings every year. New buildings are added to the building stock every year, according to dynamics of population and commercial floor area elasticity. Frozen and Moderate scenarios do not assume proliferation of advanced buildings; however, they become a part of the building stock in the Deep scenario.

In developed regions floor area increase is more modest in comparison to developing regions. For examples, in US and EU-27 total floor area grows by 35% and 27% by 2050, while in India the floor area growth by 2050 is more considerable (386%). In China floor area growth is also significant but less rapid than in most developing regions (58%).

As can be seen from the figures (right column on Figure 11 - Figure 15) retrofit buildings play the most important role in developed regions as retrofit buildings have the largest share of the total building stock, in all scenarios. This presents both opportunity and risk. If the country follows the path of “deep” renovation, than it has a great potential to save energy through retrofitting existing buildings. However, if moderate level of renovation remains dominant, this opportunity will be lost and potential energy savings will be locked-in for several decades. Energy savings potential from these buildings can be realized through more

ambitious building codes and various incentives for constructing energy efficient building (e.g. grants, subsidies, tax deductions, etc.).

By 2050 developing regions (especially India) will have the greatest share of the building stock, belonging to new buildings and, therefore, most of potential energy savings can come through the construction of new energy efficient buildings. Therefore, ambitious building codes, requiring high levels of energy performance for new construction, might be one of the ways to stimulate realization of this potential. Interestingly, in China both retrofit and new buildings have significant shares in 2050 building stock, which means the necessity of combined political efforts targeting both of these categories.

Despite these differences a holistic approach is needed in all regions in order to stimulate the transformation of the building sector to a more advanced level of energy performance. This approach should cover both measures for new and existing buildings, including energy efficiency improvements, installation of renewable energy technologies and a change in the lifestyle (Table 4).

Table 4. Results for floor area in 2005 and 2050 for all regions

Region	2005	2050	
	bln.m2	bln.m2	Δ% to 2005
US	24.9	33.5	35%
EU-27	22.9	29.0	27%
China	44.4	70.0	58%
India	9.8	47.9	386%
Rest of the world	60.2	187.8	212%
World	162.2	368.3	127%

Figures on floor area by building vintages for the four key regions and the world are presented in the next section together with the results on space heating & cooling energy consumption.

4.2 Final Energy Use

4.2.1 Final Energy Use for Space Heating & Cooling

Table 5 demonstrates the results for final energy use for space heating and cooling for the world and key regions analysed in this study. The results for Deep Efficiency scenario clearly show a considerable potential to reduce energy use for these end-uses by 2050 in all regions.

At the global level if today's existing regional best practices in building construction and retrofit proliferate and become the standard, more than a third of global building heating and cooling final energy use can be saved by 2050 as compared to 2005 levels. This is in spite of a considerable growth in floor area during this period (see Section 4.1) and a significant increase in comfort and energy service levels arising from a general improvement in affluence. The potential savings correspond to a drop from 52.7 EJ in 2005 to 34.9 EJ in 2050 in final heating and cooling energy use.

At the same time, if only “moderate” performance levels of new and retrofit buildings are mandated or applied instead of the “deep” ones, global building heating and cooling final energy use will increase by 51% by 2050 as compared to 2005. This means that about 85% of potential global heating and cooling final energy savings in 2005 will be either lost or its realization will be postponed for an uncertain time, as it is not feasible or is extremely uneconomic to capture the remaining energy savings opportunities outside of renovation and construction cycles. The Frozen Efficiency Scenario demonstrates an even more considerable increase in final thermal comfort energy use – 103% by 2050 in relation to 2005.

In US energy saving potential from the proliferation of the state-of-the-art building solutions by 2050 is 65%. A bit higher level of energy savings (69%) can be achieved in the EU-27. In the Moderate Efficiency scenario the potentials for these regions are very different. While in the US most of these savings are lost, which results in a very modest energy saving potential by 2050, in the EU-27 a significant part of the energy savings can be realized through an effective implementation of EPBD. As Table 5 shows in Moderate scenario energy savings for space heating and cooling is only 15% in the US, while in the EU-27 is 61%.

In comparison to EU-27 and US, China has a much lower potential for thermal comfort energy use reduction in the Deep Efficiency scenario by 2050 – 12%. It can be explained by relatively low energy consumption for space heating and cooling in conventional Chinese buildings (Standard, New, Retrofit) in comparison to the ones in US and EU, zonal heating practices, different perception of the thermal comfort and higher floor area growth. In Moderate

Efficiency and Frozen Efficiency scenarios this energy saving potential is replaced by a significant thermal energy use growth: 68% and 138%, correspondingly.

In India, final energy use for space heating and cooling increases by 2050 even under Deep Efficiency scenario (188%), due to almost a fivefold increase in floor area by 2050 in relation to 2005 and higher living standards. However, in Moderate Efficiency and Frozen Efficiency scenarios the increase in energy use is much more considerable: 680% and 861%, respectively. India presents the highest increase in energy use among the four regions.

Table 5. Results for final energy use for space heating & cooling for the key regions

Region	Baseline	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
	EJ 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005
US	13.3	4.6	-65%	11.3	-15%	14.3	8%
EU-27	13.6	4.2	-69%	5.3	-61%	13.8	2%
China	7.0	6.1	-12%	11.7	68%	16.6	138%
India	1.7	4.9	188%	13.4	680%	16.5	861%
Rest of the world	17.2	15.0	-13%	37.9	120%	45.7	165%
World	52.7	34.9	-34%	79.5	51%	106.9	103%

Figure 11 - Figure 15 present results for final energy use by building vintages and floor area for the world, US, China, India and EU-27. These graphs demonstrate the size of the contribution of the new building stock to thermal comfort energy use in the developing countries and how vital energy efficiency requirements for these buildings are; and conversely, how important the existing building stock is in the developed regions. Since new buildings are cheaper to build to high-energy efficiency standards due to higher design flexibility, the developing world has a wider range of opportunities to realize this potential. Presented results show that even with the growth in floor area a significant amount of energy savings can be achieved through implementing already existing best practices and technological solutions in the building sector.

Figure 16 presents the results on space heating and cooling final energy use for three scenarios for each of the key regions and the world split by urban and rural areas. It can be clearly seen that urban areas are responsible for most of the energy use and in developing countries this contribution is growing together with the urbanization.

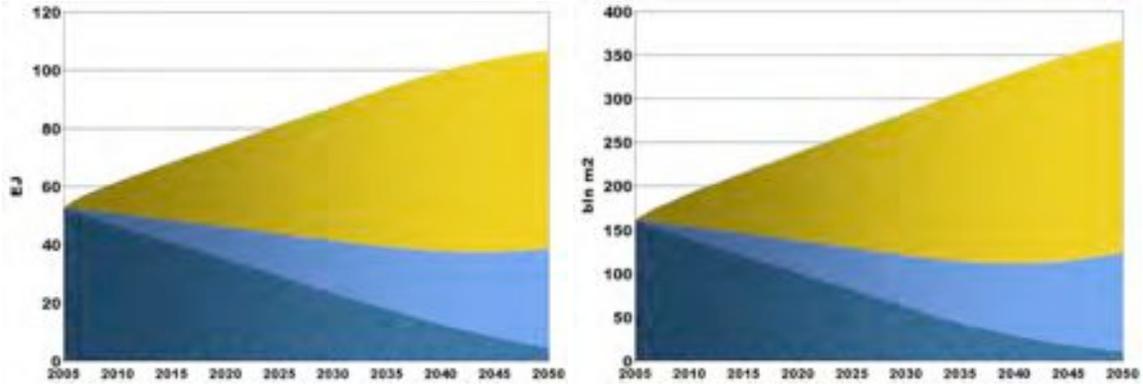
In the US and EU-27 final thermal energy use is projected to decrease by 2050 in rural areas in all scenarios, with the greatest potential in the Deep Efficiency scenario. It can be explained by overall decreasing tendencies in building energy consumption due to energy efficiency improvement and low population

growth rate. In China and India thermal comfort energy use increases by 2050 both in rural and urban areas in most of scenarios (except for the Deep scenario for China), however, this growth is lower for rural than for urban buildings, which can also be explained by the moving of the population to cities.

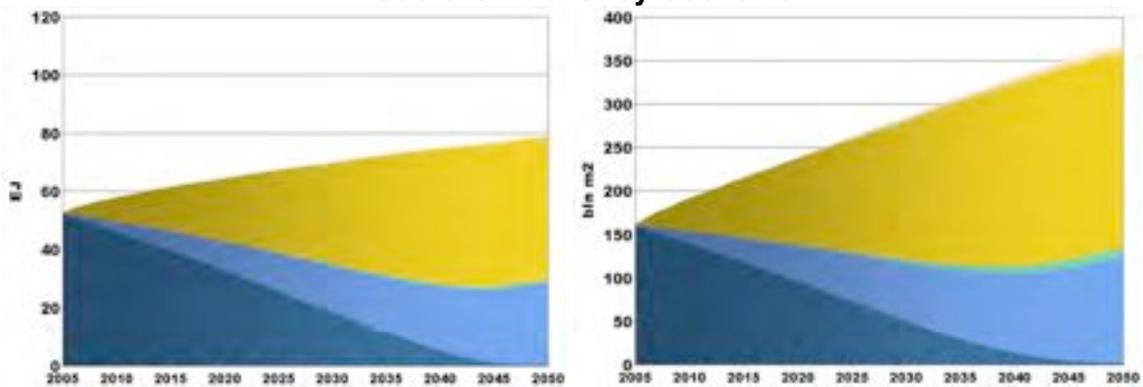
**World Final Energy
for Space Heating and Cooling**

**World Floor Area
bln m²**

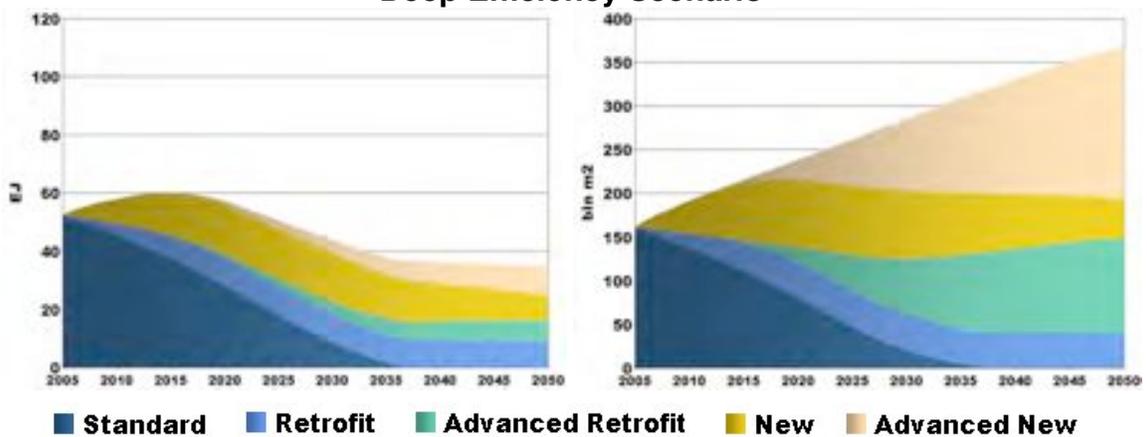
Frozen Efficiency Scenario



Moderate Efficiency Scenario



Deep Efficiency Scenario



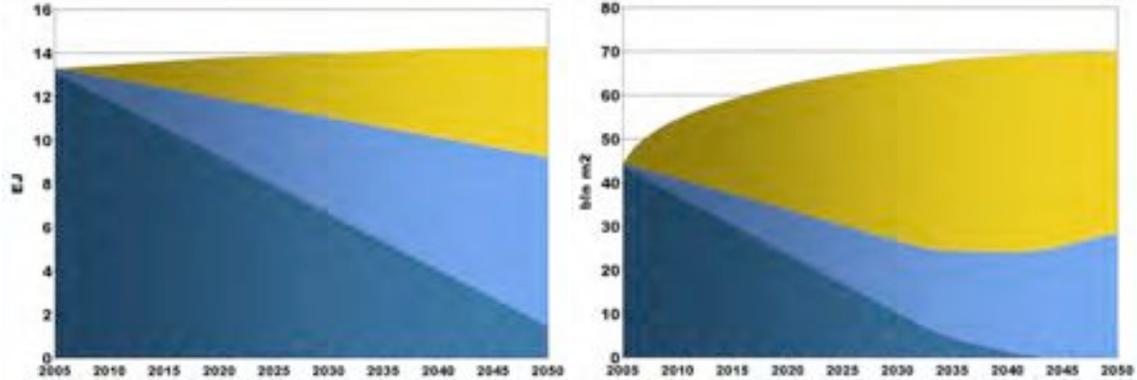
■ **Standard** ■ **Retrofit** ■ **Advanced Retrofit** ■ **New** ■ **Advanced New**

Figure 11. World final energy for space heating and cooling (left column) and floor area (right column) by vintage

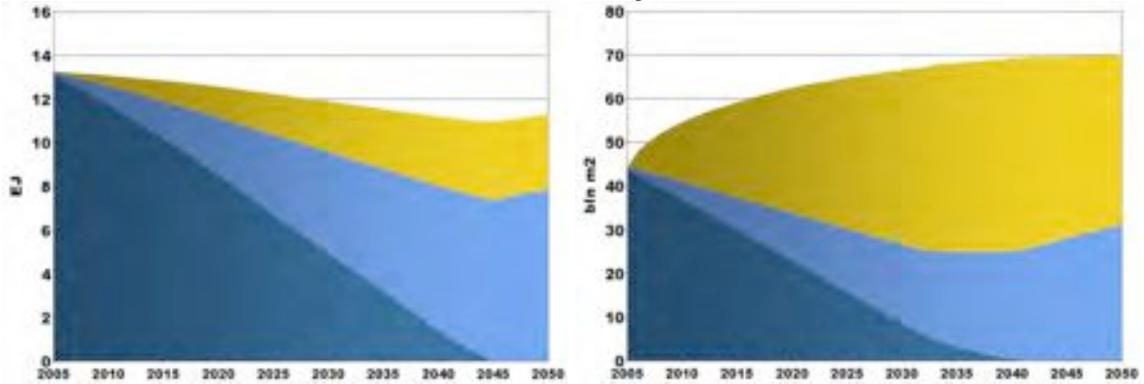
**US Final Energy
for Space Heating and Cooling**

**US Floor Area
bln m²**

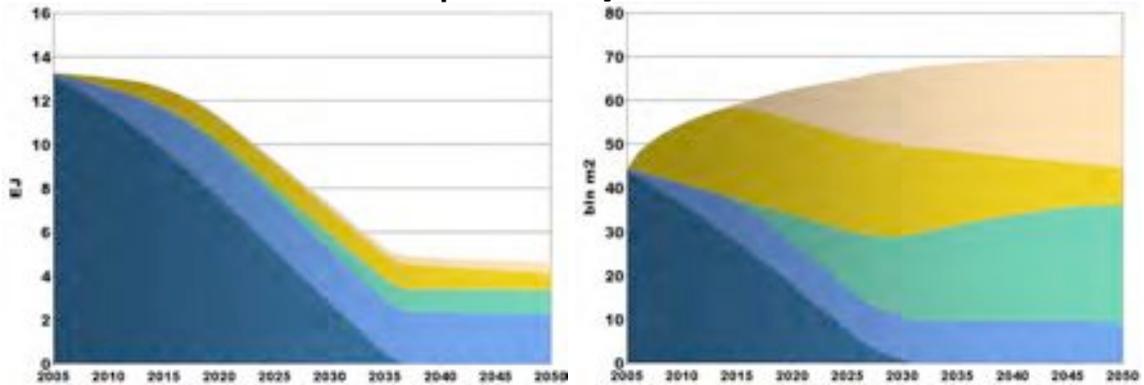
Frozen Efficiency Scenario



Moderate Efficiency Scenario



Deep Efficiency Scenario



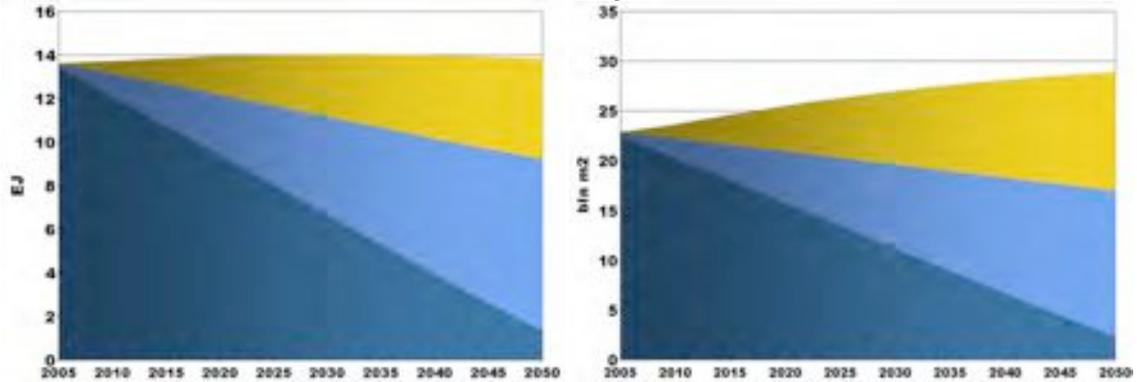
■ **Standard** ■ **Retrofit** ■ **Advanced Retrofit** ■ **New** ■ **Advanced New**

Figure 12. US final energy for space heating and cooling (left column) and floor area (right column) by vintage

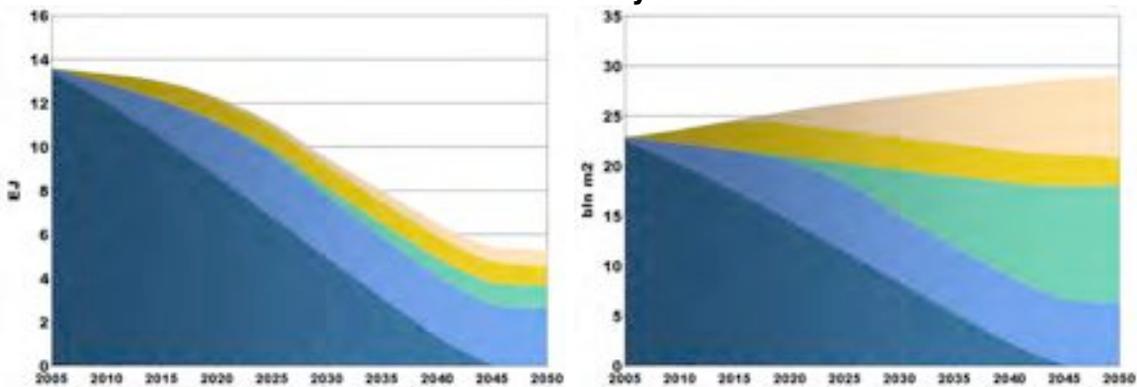
**EU-27 Final Energy EJ
for Space Heating and Cooling**

**EU-27 Floor Area
bln m²**

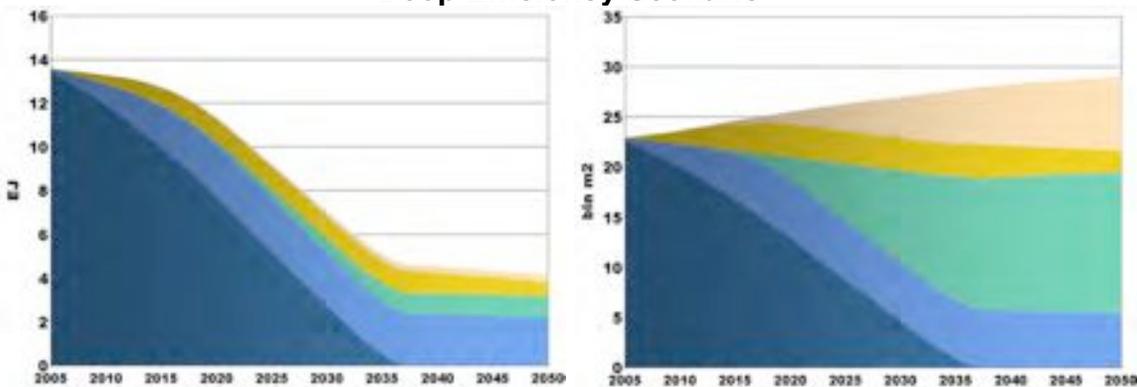
Frozen Efficiency Scenario



Moderate Efficiency Scenario



Deep Efficiency Scenario



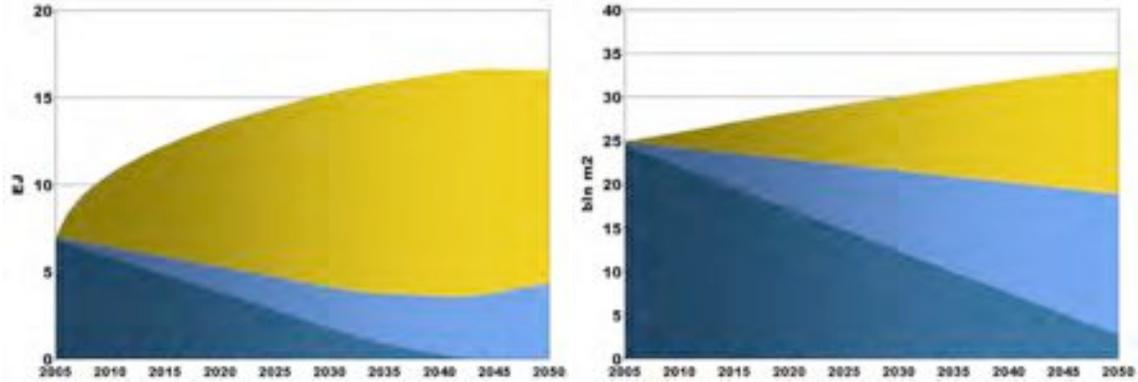
■ **Standard** ■ **Retrofit** ■ **Advanced Retrofit** ■ **New** ■ **Advanced New**

Figure 13. EU-27 final energy for space heating and cooling (left column) and floor area (right column) by vintage

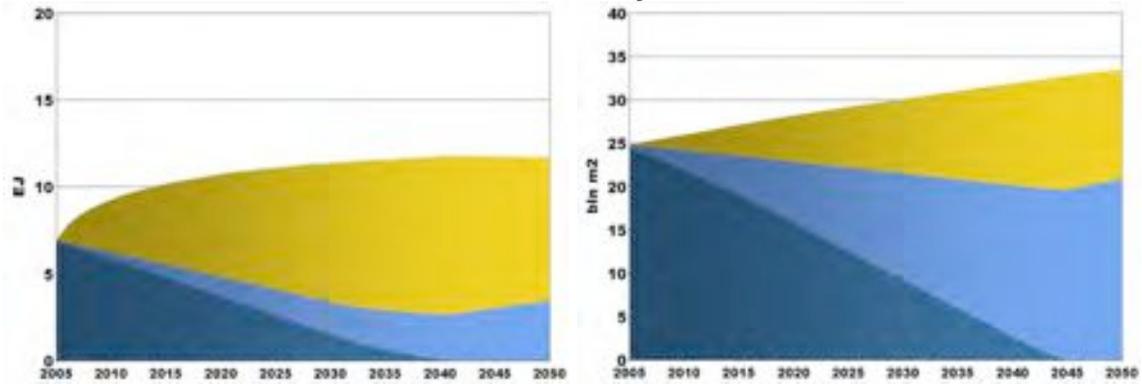
**China Final Energy
for Space Heating and Cooling**

**China Floor Area
bln m²**

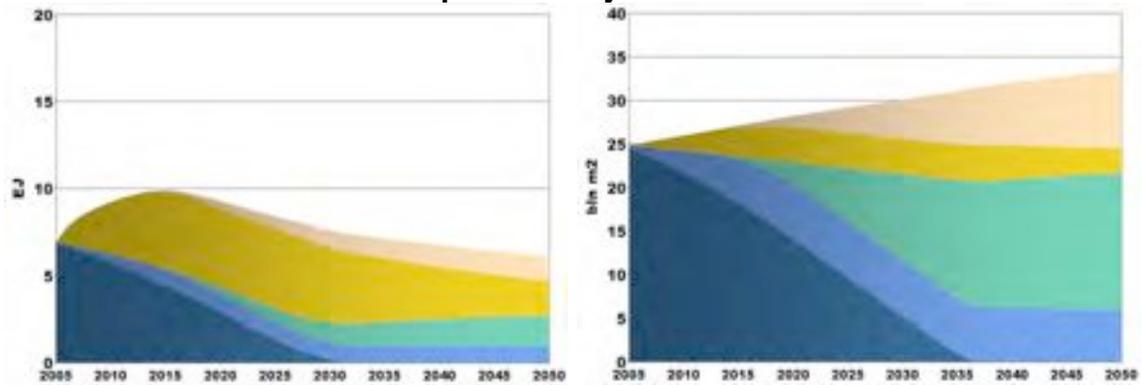
Frozen Efficiency Scenario



Moderate Efficiency Scenario



Deep Efficiency Scenario



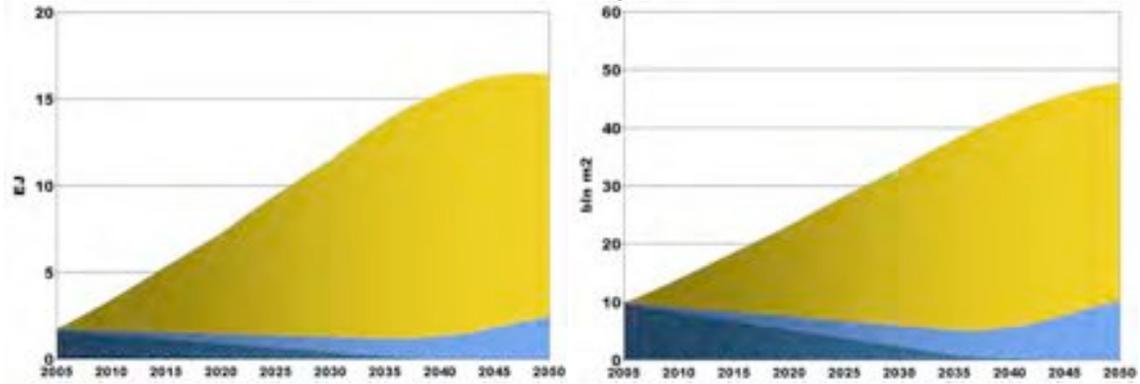
■ **Standard** ■ **Retrofit** ■ **Advanced Retrofit** ■ **New** ■ **Advanced New**

Figure 14. China final energy for space heating and cooling (left column) and floor area (right column) by vintage

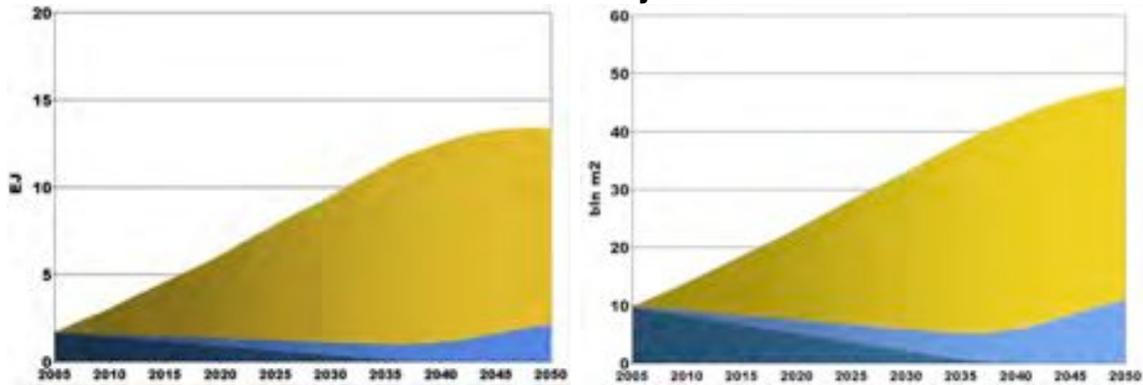
**India Final Energy
for Space Heating and Cooling**

**India Floor Area
bln m²**

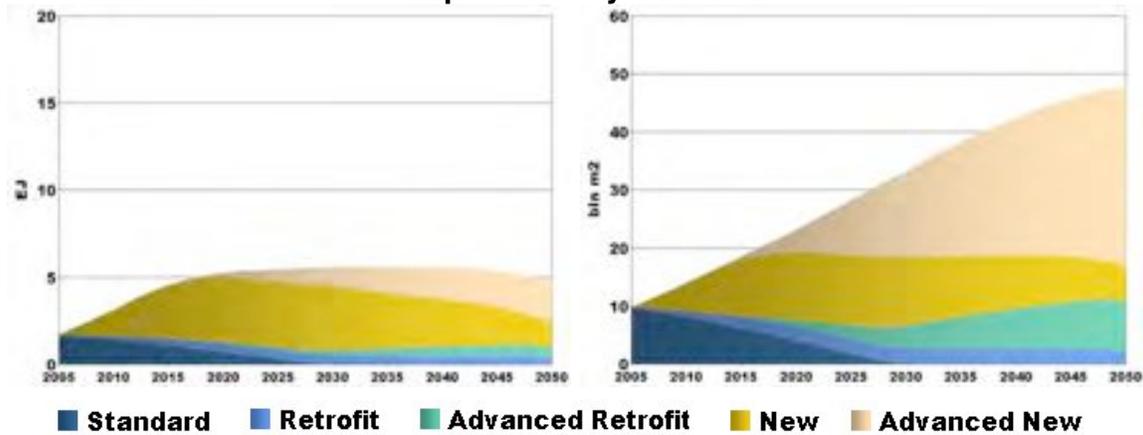
Frozen Efficiency Scenario



Moderate Efficiency Scenario



Deep Efficiency Scenario



■ Standard ■ Retrofit ■ Advanced Retrofit ■ New ■ Advanced New

Figure 15. India final energy for space heating and cooling (left column) and floor area (right column) by vintage

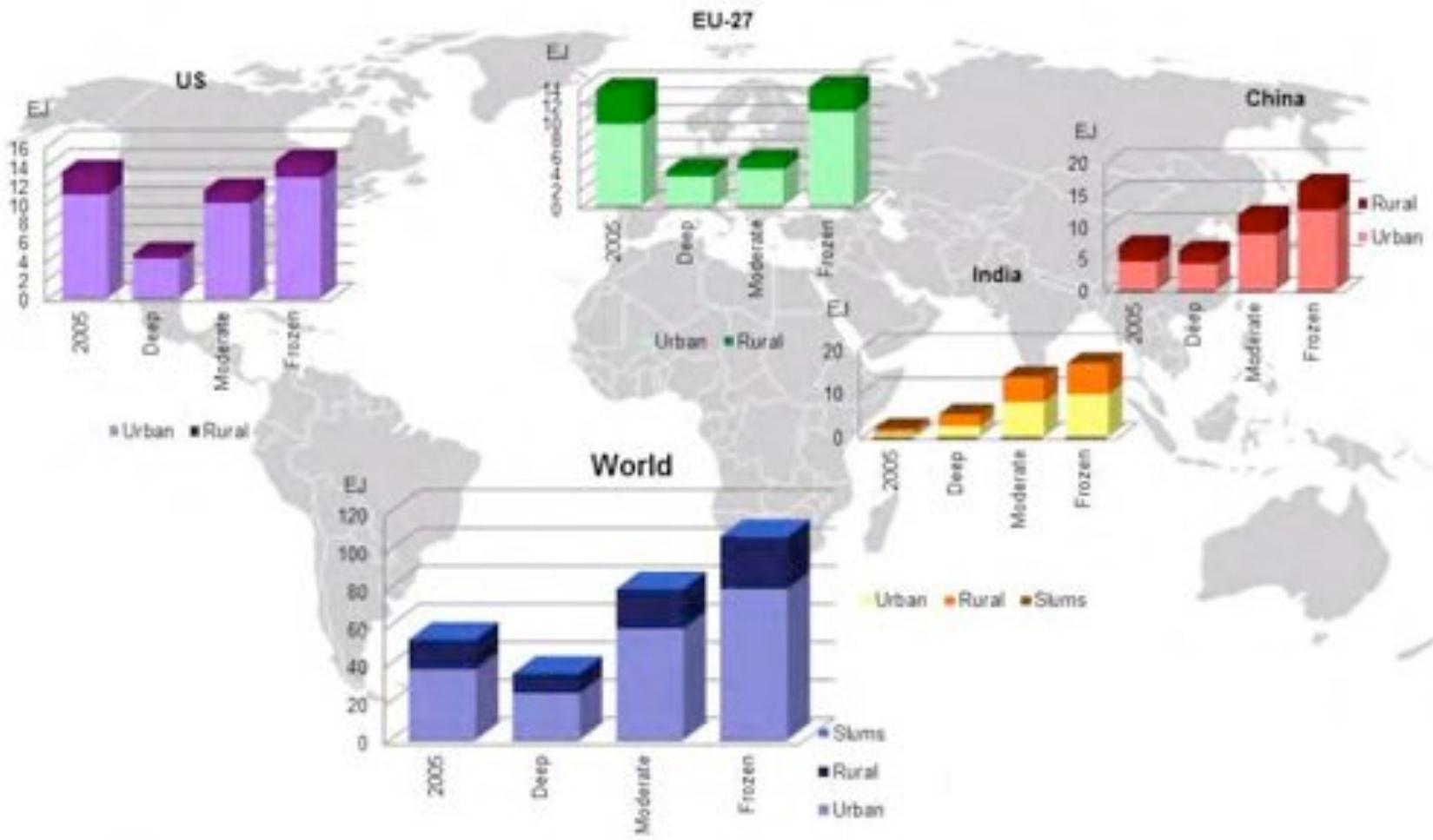


Figure 16. Final Thermal Comfort Energy in Rural and Urban Areas for world and four key regions

4.2.2 Final Energy Use for Water Heating

There are significant savings potentials for reduction of energy use for water heating in all studied countries and the world as a whole.

In the US region, there is a more than 40% difference between the 2050 values in the Frozen Efficiency scenario and the Moderate Efficiency scenario, which considers efficient gas heaters and add-on heat pumps. However, to achieve significant absolute reductions, heat pumps and solar systems must become common, and advanced heat recovery and water saving technologies are also necessary. The success of the ambitious implementation of renewable technologies will largely depend on the cost learning of solar systems: currently, there is an approximately twentyfold difference between prices in the US, where a solar system costs \$5000-7000, and China, where similarly efficient systems with somewhat shorter lifetimes (10-15 years as opposed to 20 years in the US) cost \$300-400.

In India advantageous climatic conditions and substantial economic obstacles are the most important factors. The first priority is to replace the very inefficient (10%) cook stoves. Due to the projected growth of both population and affluence, water-heating energy needs grow even in the ambitious Deep Efficiency scenario (by 16% by 2050). However, the difference between the different scenarios is very large; 110% in Moderate Efficiency scenario, and almost 400% in Frozen Efficiency scenario (Table 6).

China, as a world leader in solar water heating, has one of the biggest potentials to reduce water heating energy needs in the world. Although in the short term energy needs will most probably grow, the further spreading of solar systems, new heat pump solutions, efficient gas heaters as backup systems, heat recovery in the colder regions and improved rural water heating systems offer more than 35% absolute reduction.

The economic strength and the relatively advantageous policy-environment, plus the high current consumption values in the EU-27 make it relatively easy to avoid a surge in hot water related energy consumption. Values are slightly decreasing in the Moderate Efficiency scenario, and there is about 40% potential to decrease energy consumption with currently available technologies. The mix of measures is similar to those used in the US.

Table 6. Results for final energy use for water heating for all regions for three scenarios

Region	Baseline	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
	EJ 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005
US	2.7	1.6	-43%	2.4	-11%	3.6	34%
EU-27	2.1	1.2	-42%	1.3	-39%	2.7	26%
China	1.6	2.4	48%	3.8	131%	5.7	249%
India	0.9	1.0	16%	1.8	110%	4.2	391%
Rest of the world	6.7	6.3	-6%	10.0	50%	17.9	168%
World	14.0	12.5	-11%	19.3	38%	34.1	144%

WORLD

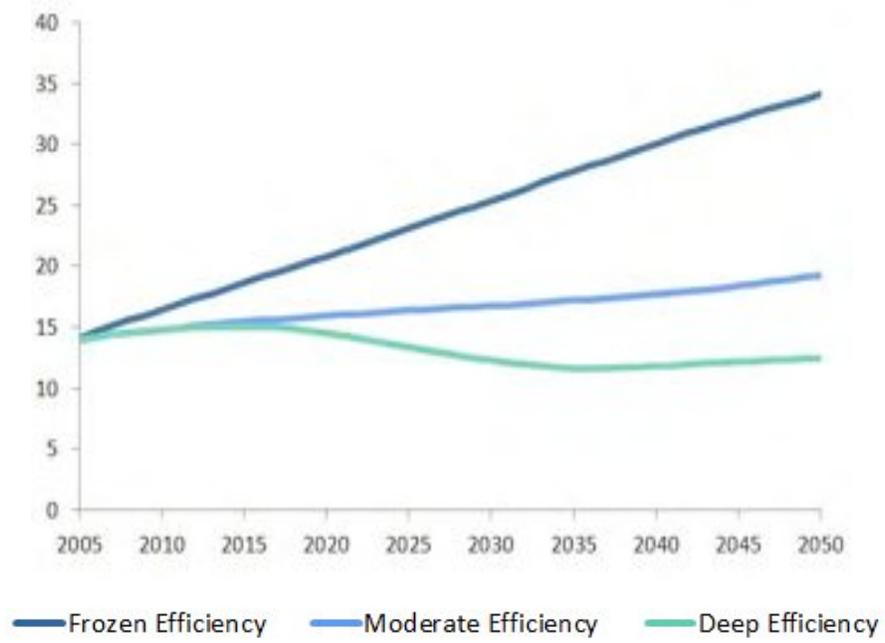


Figure 17. Final energy for water heating by scenarios for 4 key regions

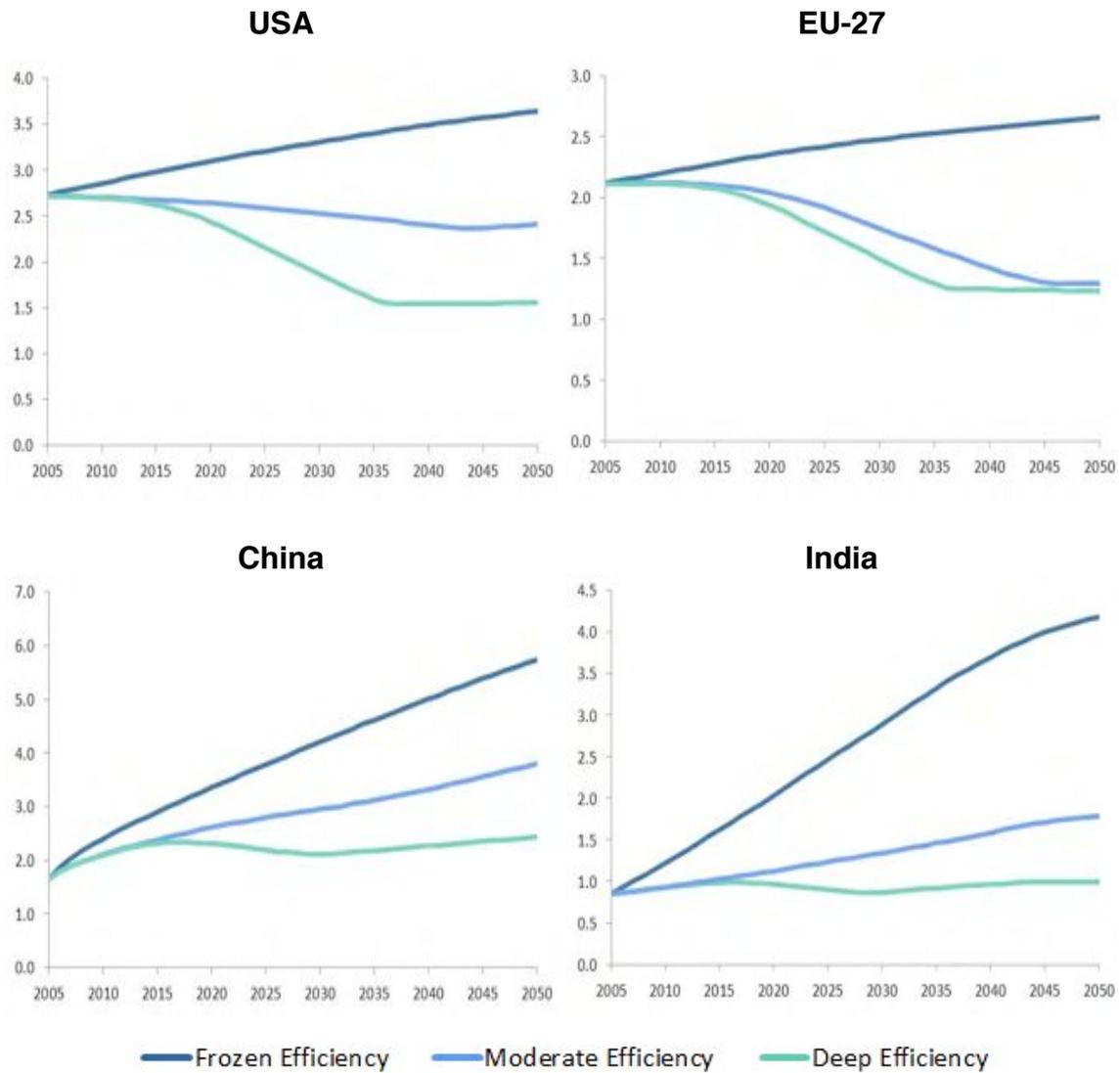


Figure 18. Final energy for water heating by scenarios for 4 key regions

4.2.3 Final Energy Use for Space Heating & Cooling and Water Heating

Table 7 presents the summary of the results for total final thermal energy use in all regions for three scenarios.

In all analysed regions and on the global scale, as it can be seen in Figure 19 and Figure 20, space heating and cooling is a more energy-consuming end-use than water heating, as it has a greater share in the total thermal energy use in the range of 65-87% for different regions and scenarios and about 80% for the world.

Figures show that the greatest energy saving potential for total final thermal energy use can be achieved in Deep scenario.

The global energy saving potential by 2050 for total final thermal energy use is 29%. In case best-practices for building space heating, cooling and water heating are not implemented in the coming 10 years Moderate Efficiency pathway will result in 48% increase in total thermal energy use, while in Frozen Efficiency scenario this growth is enormous and reaches 111% by 2050.

In the four key regions the situation is similar. If “moderate” efficiency measures are implemented in buildings instead of “deep” ones, then by 2050 China will increase its thermal energy consumption by 80% instead of reducing them in the Deep efficiency scenario; and without any energy efficiency improvements as in Frozen Efficiency case it will grow by up to 158%. The US and the EU-27 can reduce energy use in both Deep and Moderate scenarios, however, the potential in Moderate scenario is much lower in the US (14%), while in the EU-27 it is similar to the one in the Deep Efficiency scenario, mostly due to the implementation of EPBD (see Table 7). In the Frozen Efficiency scenario thermal energy use is projected to grow in these countries by 12% in US and by 5% in EU-27. India, as a fast growing economy, will increase its thermal energy consumption under all three scenarios. However, in Deep Efficiency scenario this growth is much lower than in Moderate and especially in Frozen scenarios: 131% vs. 491% vs. 701%, respectively.

Table 7. Results for final energy use for space heating & cooling and water heating for all regions for all scenarios

Region	Baseline	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
	EJ 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005	EJ 2050	Δ% to 2005
US	16.0	6.2	-61%	13.7	-14%	17.9	12%
EU-27	15.7	5.4	-65%	6.6	-58%	16.5	5%
China	8.6	8.6	-1%	15.5	80%	22.3	158%
India	2.6	5.9	131%	15.2	491%	20.6	701%
Rest of the world	23.9	21.3	-11%	47.8	100%	63.6	166%
World	66.7	47.3	-29%	98.7	48%	141.0	111%

WORLD

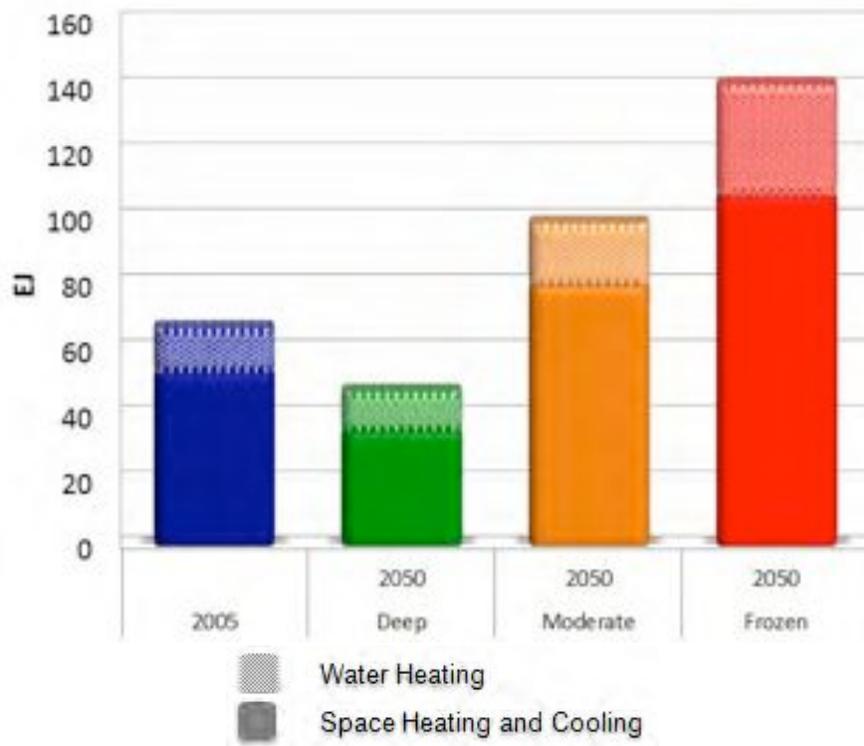


Figure 19. World total final thermal energy by end-use

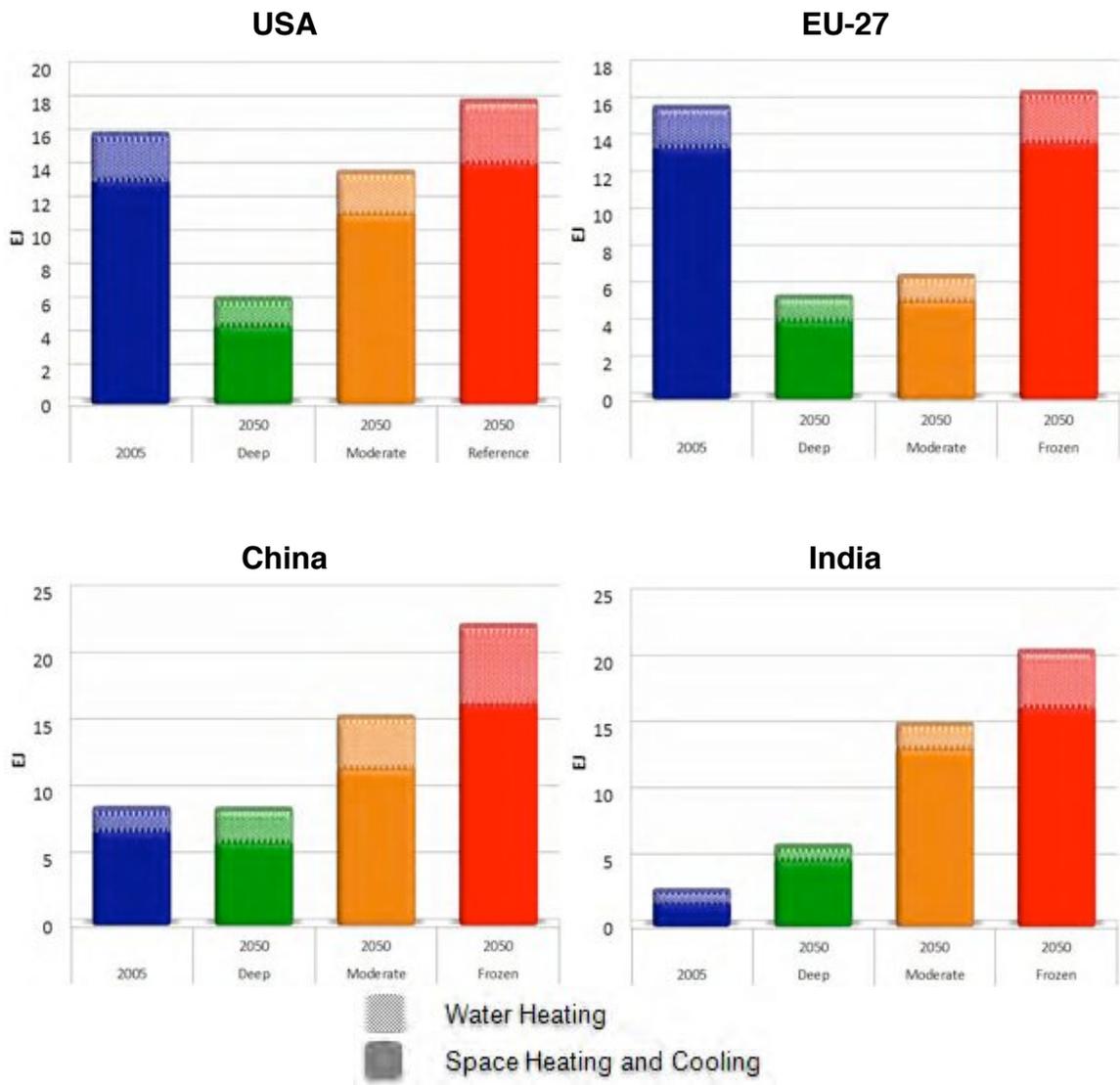


Figure 20. Final energy for space heating & cooling and water heating by end-uses for 4 key regions

4.3 Lock-in Effect

As it has been outlined earlier, the lock-in effect in this study means potential energy saving, which are not going to be achieved due to unambitious technological improvements and policy efforts in the building sector. In terms of modelling logic lock-in effect is calculated as the difference between thermal energy use levels in 2050 in two scenarios: Lock-in scenario and Deep Efficiency scenario – in relation to 2005.

The model demonstrates the major risk of the lock-in effect in the building infrastructure. If present standards prevail for new construction, combined with moderate efficiency levels for renovation, 80% of 2005 final heating and cooling energy and 48% of water heating use will be locked-in by 2050.

Table 8 shows lock-in effects for space heating and cooling, water heating and total thermal energy for the main analysed regions.

The lock-in risk is high in most of the key regions, in the range from 53% in the US to 414% in India for space heating and cooling energy use, clearly demonstrates urgency and necessity of effective policy development in the building sector for all the regions. In EU-27 a relatively small lock-in effect is the result of an effective implementation of EPBD, which presumes an improved energy performance of most new and retrofitted buildings in the 2020-2050 period even in the Lock-in scenario. Figure 21 and 22 show energy use dynamics and lock-in effect for space heating and cooling for the world, US, China, India and EU-27. Figures on the lock-in for water heating can be found in the Annex 3.

Table 8. Lock-in Effect in the main regions

Region	Space Heating and Cooling	Water Heating	Space Heating & Cooling and Water Heating
US	53%	32%	85%
EU-27	10%	4%	15%
China	63%	83%	146%
India	414%	94%	508%
Rest of the world	130%	55%	184%
World	80%	48%	74%

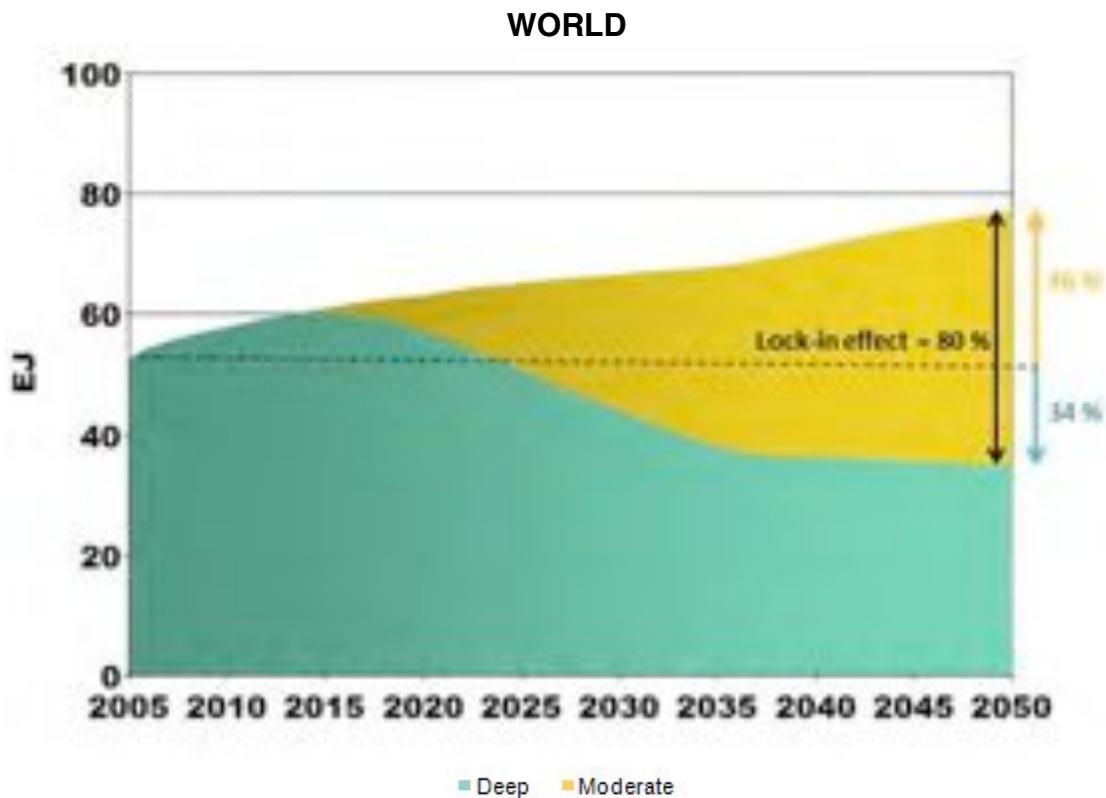
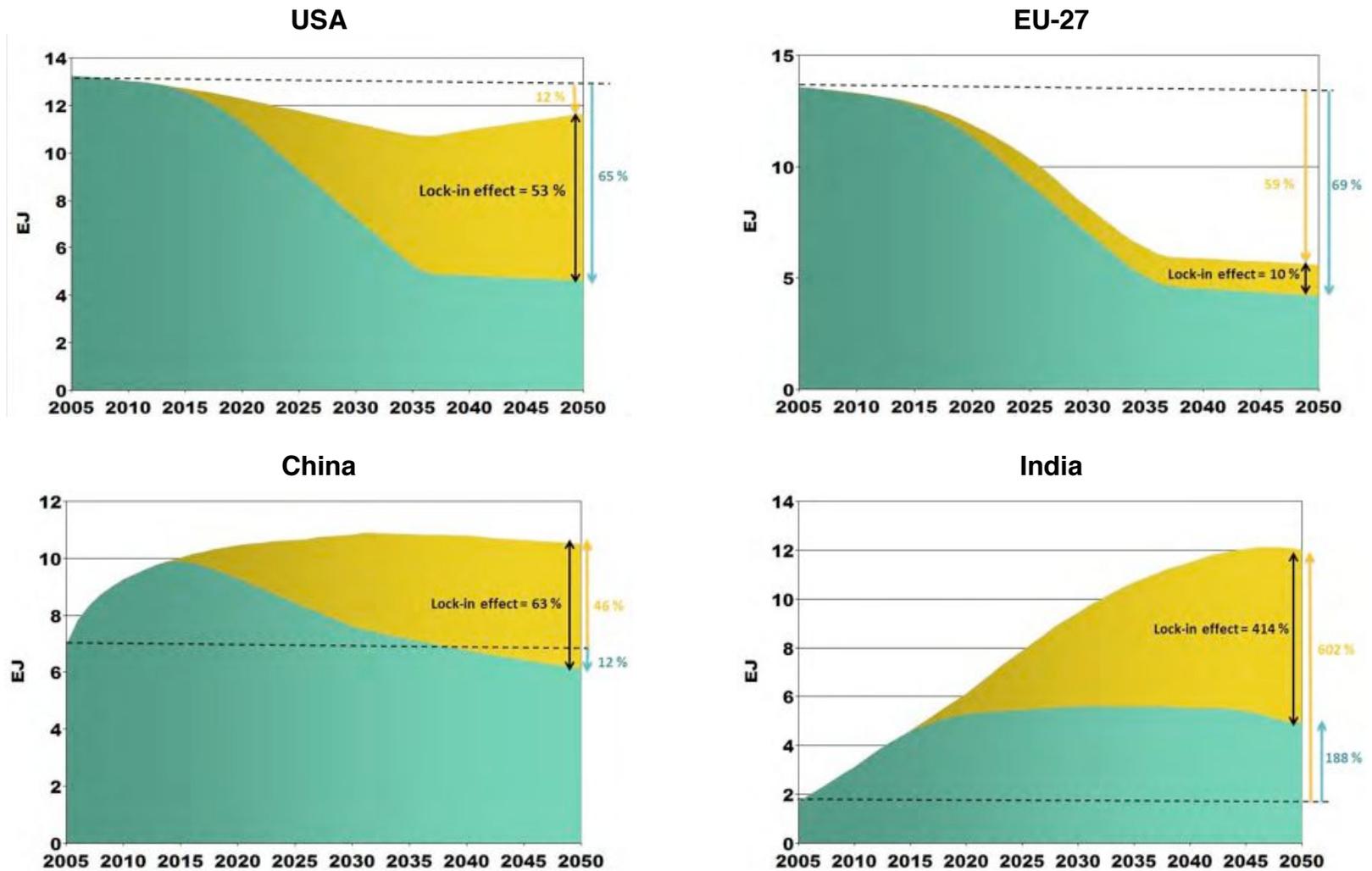


Figure 21. World lock-in effect for final energy use for space heating and cooling for Moderate Efficiency and Deep Efficiency scenarios

Figure 22. Lock-in effect for final energy use for space heating and cooling for Moderate Efficiency and Deep Efficiency scenarios for key regions



4.4 Energy-Related CO₂ Emissions

4.4.1 Energy-related CO₂ Emissions from Space Heating & Cooling

presents values of CO₂ emissions in 2005 and 2050 and percentage difference in three scenarios to 2005 for all key regions and the world.

US and EU-27 regions show reductions for two scenarios: the Moderate Efficiency (-15% and -61%) and Deep Efficiency (-65% and -69%). The reason for a significant mitigation potential in the EU-27, not only in the Deep but also in the Moderate scenarios, is an ambitious energy use reduction in new and retrofit buildings, as a result of EPBD implementation.

China presents a modest emissions reduction potential under the Deep scenario. This decrease is explained by 19% reduction of space heating and cooling energy use in this period and very low emission factors for biomass, as only direct CO₂ emissions are taken into account in this study. Under other two scenarios the country demonstrates a significant increase in CO₂ emissions related to energy use for space heating and cooling by 2050.

In most of the developing regions, like in India, CO₂ emissions will increase in all three scenarios, with the smallest increase under the Deep Efficiency one. Globally CO₂ emissions by 2050 to 2005 level will be reduced only for the Deep Efficiency scenario, this is by 47% (3.3Gt). In Frozen Efficiency and Moderate Efficiency scenarios global emissions will increase by 62% (4.3 Gt) and 19% (1.3Gt), respectively.

Table 9. Results for CO₂ emissions from space heating and cooling energy use for all regions for all scenarios

Region	Baseline	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
	Gt CO ₂ 2005	Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005
US	2.5	0.9	-65%	2.1	-15%	2.7	8%
EU-27	1.7	0.5	-69%	0.7	-61%	1.7	1%
China	0.5	0.4	-12%	0.8	68%	1.1	137%
India	0.1	0.3	188%	0.8	680%	0.9	858%
Rest of the world	2.2	1.6	-28%	3.9	81%	4.7	119%
World	6.9	3.6	-47%	8.2	19%	11.2	62%

4.4.2 Energy-related CO₂ Emissions from Water Heating

Figure 23 and Figure 24 present CO₂ emissions dynamics from water heating energy use for the world, US, China, India and the EU-27 regions. Table 10 presents values for CO₂ emissions in 2005 and 2050 and the percentage difference in three scenarios to 2005.

In the Frozen Efficiency scenario CO₂ emissions grow in all regions to different extents; growth in China and especially in India is, obviously, the highest. However, in the Moderate Efficiency scenario there is a CO₂ emission reduction by 2050 in developed regions: 32% in the US and 56% in the EU-27, while in China and in India under this scenario emissions are growing significantly.

In the Deep Efficiency scenario developed regions show a high potential for CO₂ emission reduction. The results for the US and the EU-27 demonstrate that almost half of CO₂ emissions in these regions can be avoided by 2050. In developing regions CO₂ emissions from water heating energy use are projected to grow in all scenarios.

Table 10. Results for CO₂ emissions from water heating for all regions for all scenarios

Region	Baseline Gt CO ₂ 2005	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
		Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005
US	0.3	0.2	-44%	0.2	-32%	0.4	34%
EU-27	0.3	0.1	-47%	0.1	-56%	0.3	24%
China	0.1	0.3	85%	0.4	160%	0.5	247%
India	0.1	0.2	223%	0.3	330%	0.3	387%
Rest of the world	0.6	0.7	15%	0.9	40%	1.3	111%
World	1.4	1.5	4%	1.7	21%	2.8	97%

WORLD

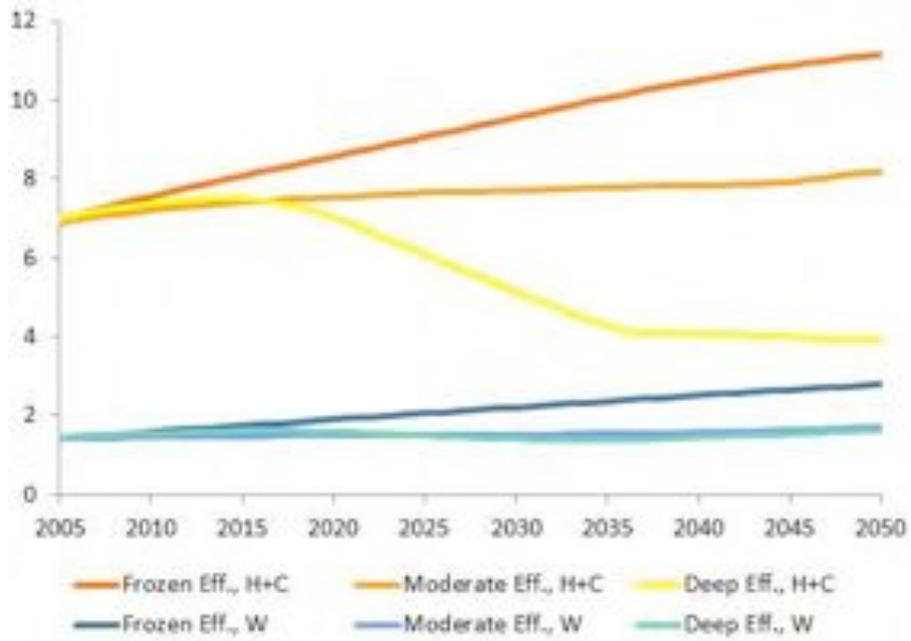
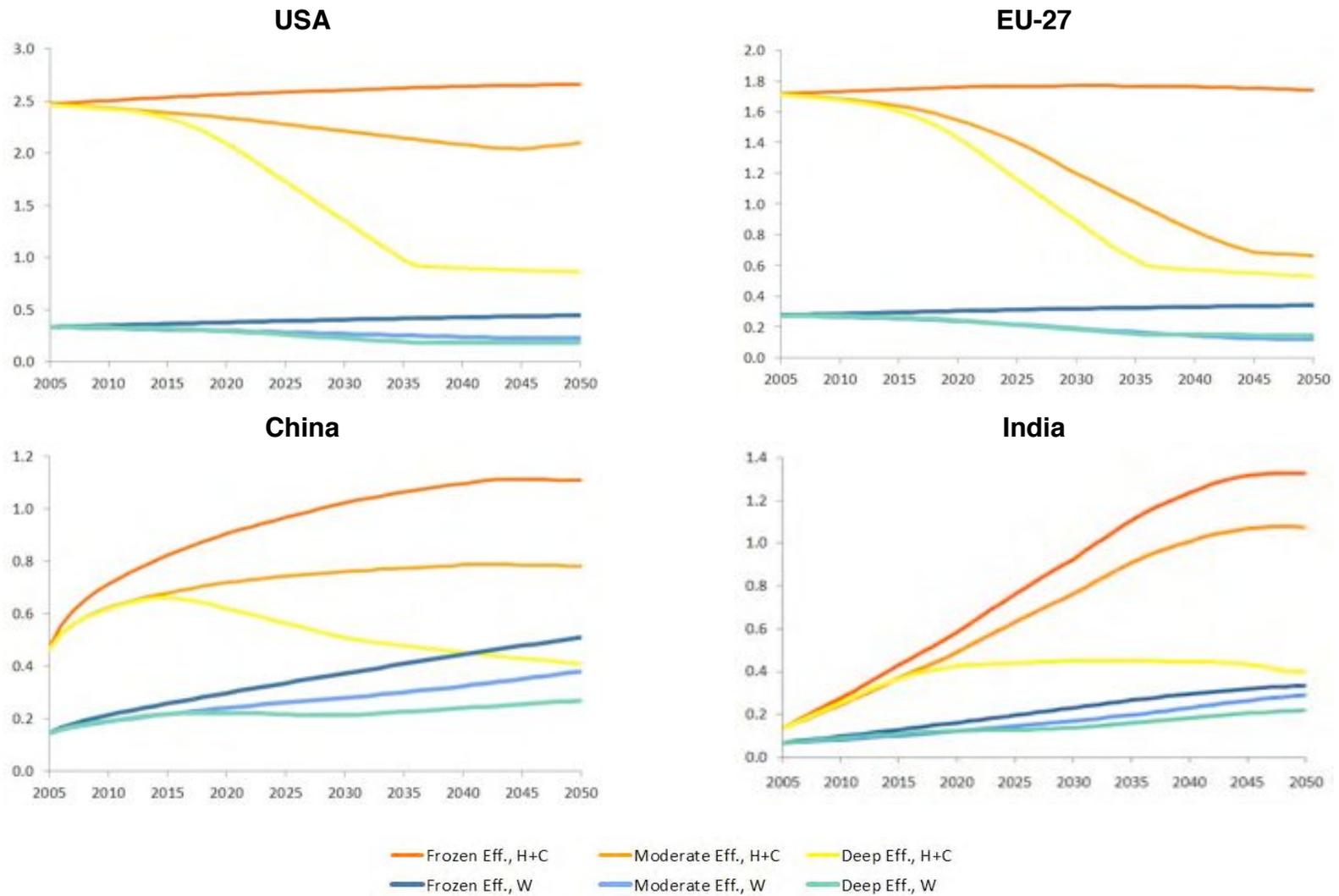


Figure 23. World CO₂ emissions from space heating & cooling and water heating for all scenarios, GtCO₂

Figure 24. CO₂ emissions from space heating & cooling and water heating for key regions for all scenarios, GtCO₂



4.4.3 Energy-related CO₂ Emissions from Space heating & Cooling and Water Heating

About 40% of global CO₂ emissions from thermal energy use can be avoided by 2050 in case of ambitious proliferation of state-of-the-art building technologies, which corresponds to almost 3 Gt of CO₂ emissions, as shown in Table 11. As for key regions, a significant potential for CO₂ savings can be seen in the US and EU-27, with a potential reduction of 1.8 and 1.4 Gt by 2050, respectively, in the Deep scenario. In China CO₂ emissions are growing in all scenarios, but to a much more modest level in comparison to India, where the growth by 2050 is more than 700% in the Frozen scenario, 564% - in the Moderate and 200% in the Deep one. Following a similar trend as total thermal energy use space heating and cooling is responsible for most of related CO₂ emissions in all analysed regions, in all three scenarios.

Table 11. Results for CO₂ emissions from space heating & cooling and water heating for all regions for all scenarios

Region	Baseline Gt CO ₂ 2005	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
		Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005
US	2.8	1.0	-63%	2.3	-17%	3.1	11%
EU-27	2.0	0.7	-66%	0.8	-61%	2.1	4%
China	0.6	0.7	11%	1.2	90%	1.6	164%
India	0.2	0.6	200%	1.4	564%	1.7	701%
Rest of the world	2.8	2.3	-18%	4.8	73%	6.0	118%
World	8.3	5.1	-38%	9.9	20%	14.0	68%

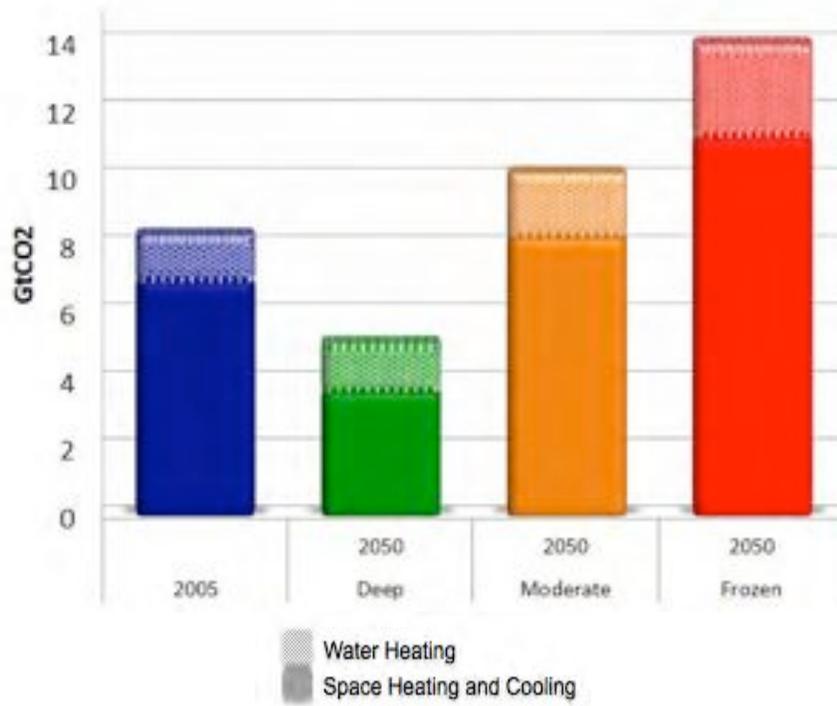


Figure 25. World CO₂ emissions by end-use

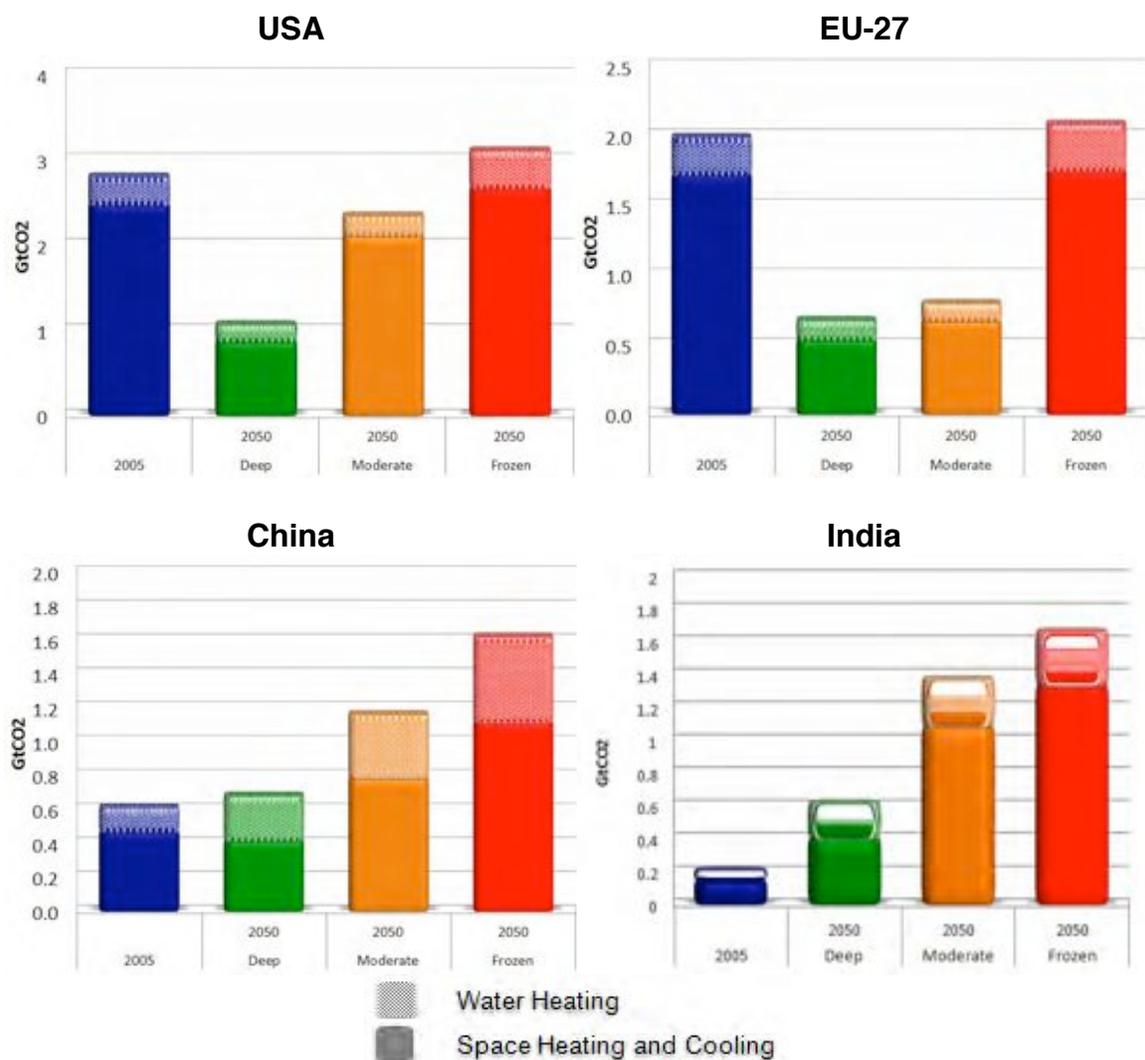


Figure 26. Total CO₂ emissions from space heating & cooling and water heating by end-uses for 4 key regions

CHAPTER 5 - SENSITIVITY ANALYSIS

5.1 Specific energy consumption

As it was mentioned above the building stock vintage is divided into categories: standard, retrofit, advanced retrofit, new and advanced new. The values of specific energy consumption intensity (for space heating & cooling) for retrofit and new buildings are important, thus a sensitivity analysis was done for advanced retrofit and advanced new buildings. The energy intensity in those buildings was decreased/increased by:

- - 10%,
- + 10%,
- + 25%,
- + 50%
- and + 100%

In reference to the values used. The sensitivity analysis was made to see the impact of specific energy consumption intensity of advanced retrofit and advanced new buildings on final energy for space heating & cooling. The results are presented for the world (Figure 27) and the four main regions (Figure 28) for the Deep Efficiency Scenario.

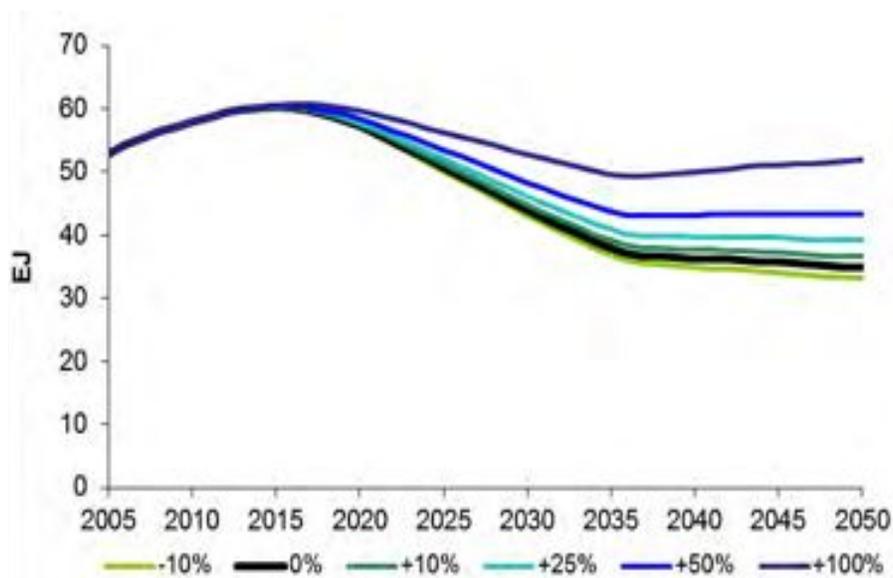


Figure 27. WORLD final energy for space heating & cooling for Deep Efficiency scenario for various specific energy consumption intensities for advanced retrofit and advanced new buildings

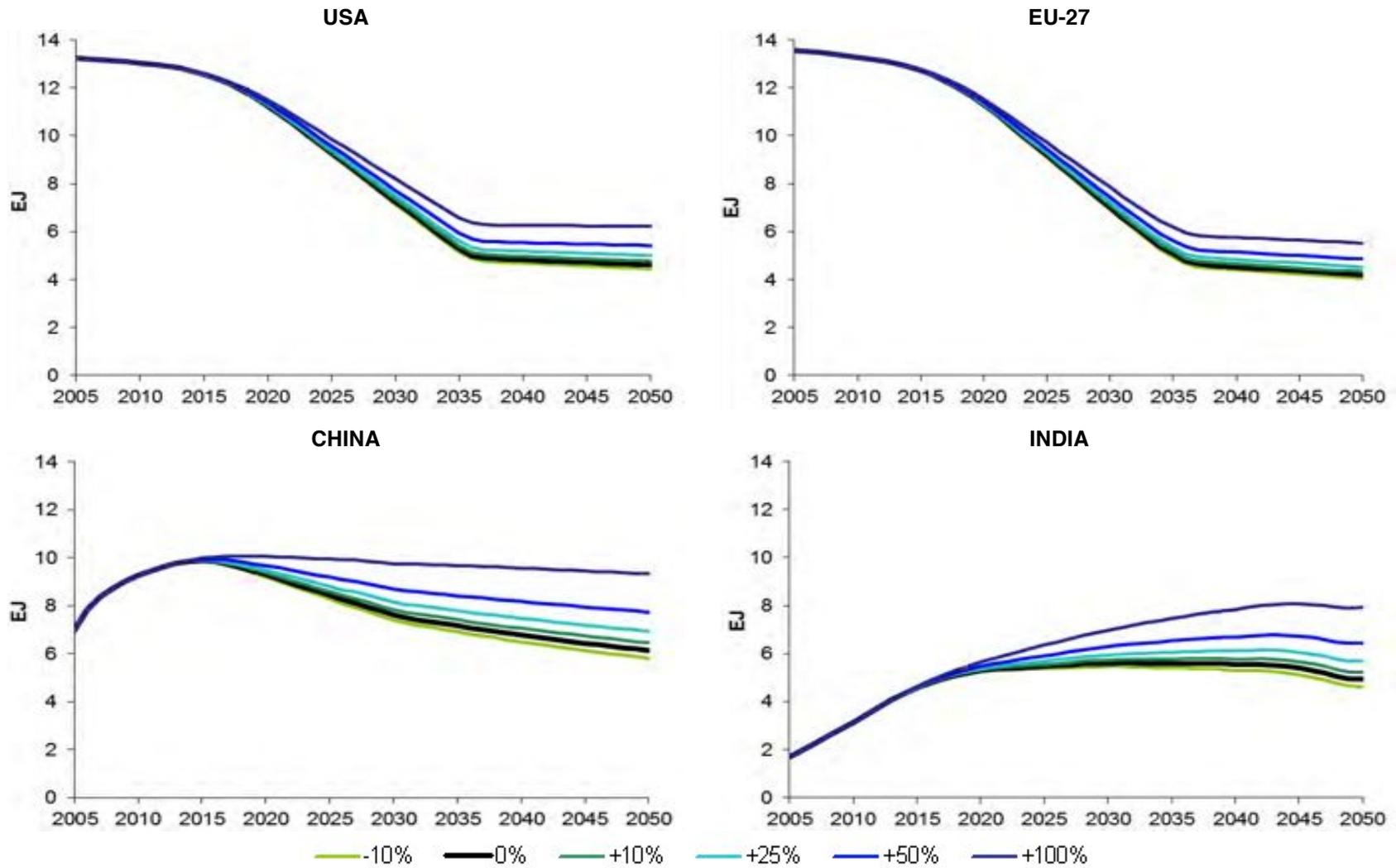


Figure 28. Final energy for space heating & cooling for Deep Efficiency scenario for various specific energy consumption intensities for advanced retrofit and advanced new buildings for USA, EU-27, China and India

Table 12. Final energy for space heating & cooling in 2050 for various specific energy consumptions

Region	Final Energy for Space Heating & cooling in 2050 for various specific energy consumption change for advanced retrofit and advanced new buildings [%]					
	- 10%	0%	+ 10%	+ 25%	+ 50%	+ 100%
US	-3.5%	0.0%	3.5%	8.7%	17.4%	34.8%
EU-27	-3.2%	0.0%	3.2%	8.3%	16.6%	33.2%
China	-5.2%	0.0%	5.2%	13.1%	26.1%	53.0%
India	-6.0%	0.0%	6.0%	15.1%	30.2%	60.4%
World	-4.9%	0.0%	4.9%	12.2%	24.3%	48.7%

It is clear that the relation of percentage change of final energy for space heating & cooling (in advanced retrofit and advanced new buildings) in reference to specific energy consumption intensity change is nearly linear. Thus it can be stated that increase of final energy intensity for space heating & cooling by 10%, increases final energy consumption by:

- 3.5% in USA,
- 3.2% in EU-27,
- 5.2% in China,
- 6.0% in India
- and 4.9% in the world.

The highest influence of specific energy consumption intensity on final energy for space heating & cooling is in India and next in China, as the rapid increase in advanced buildings, both retrofit and new, is expected.

The bottom line is that the message that a low-energy building future is possible is a very robust finding. Even a 50% increase in the thoroughly negotiated, reviewed and adjusted figures of regional specific energy consumption figures only increase global final energy consumption by 24%, still leaving an 18% decline possible between 2005 and 2050, despite the strong increases in floor space and service levels.

5.2 Retrofit rates – Deep Efficiency Scenario

In the current model, the retrofit rate assumed for all regions, grows linearly from 1.4% in 2005 to 3.0% in 2020. After 2020 it stays at a constant level. It is very difficult to judge at what retrofit rate the bottlenecks of the construction industry and the equipment and the labour markets kick in and start to have negative effects on the whole economy. Therefore, calculations were done for various values to see how it affects total final energy (space heating & cooling and water heating). The sensitivity analysis was done, assuming that in 2020 the retrofit rate reaches:

- 1.4% (stays at the same level as in 2005),
- 2.1%,
- 3.0% (used value),
- 5.0%.

When retrofit rate is increased, the standard building stock gets replaced/upgraded faster: with a 5% rate this happens by approximately 2027, while with a 2.1% rate by approximately 2044. Regarding the figures below, to make the comparison easier, retrofitted buildings (both retrofit and advanced retrofit) are in yellowish colours. The charts below present floor area change for the four main regions for the retrofit rates 2.1% and 5.0%. It is interesting to observe that an increased retrofit rate also has a slightly higher lock-in effect, since during the transition period a higher number of buildings will be retrofitted to sub-optimal performances. As a policy implication, in an ideal case, the retrofit dynamic is accelerated only by the time when the market is ready for the advanced retrofits. This effect is very important in the US and Europe, less in China, and in India it is largely irrelevant.

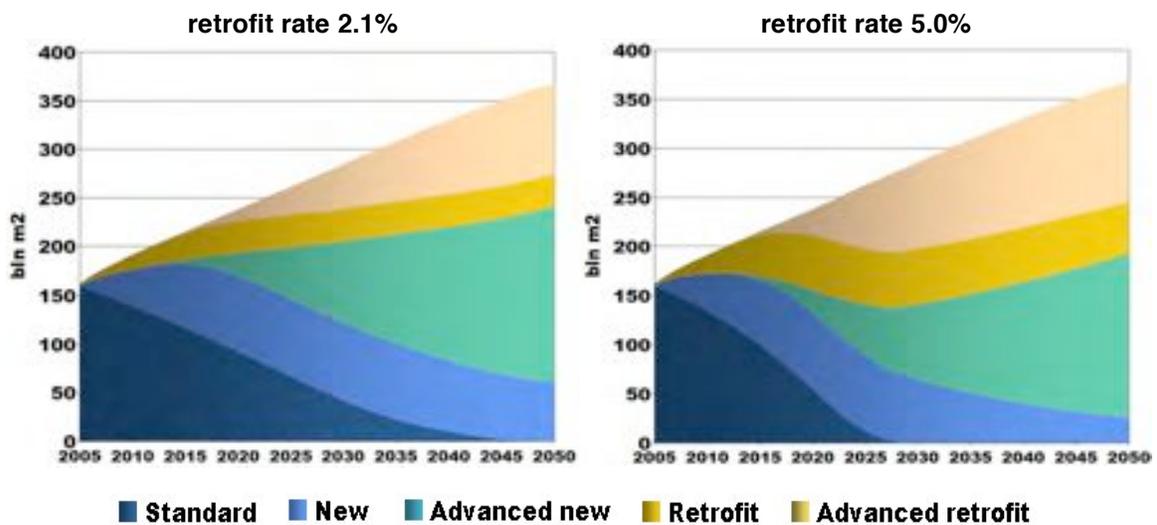
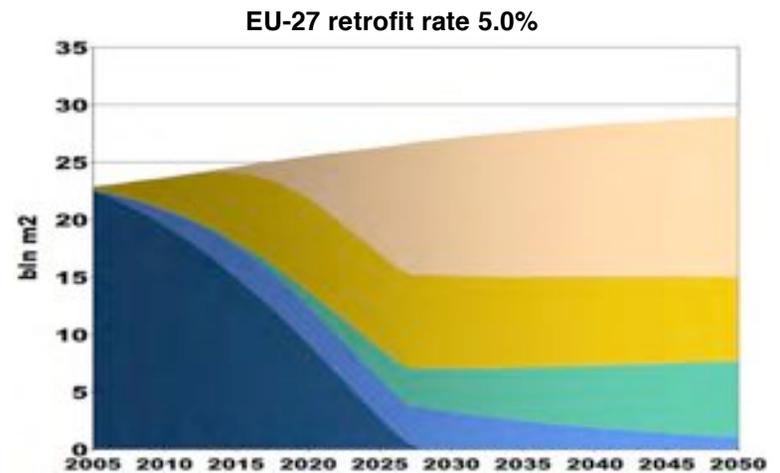
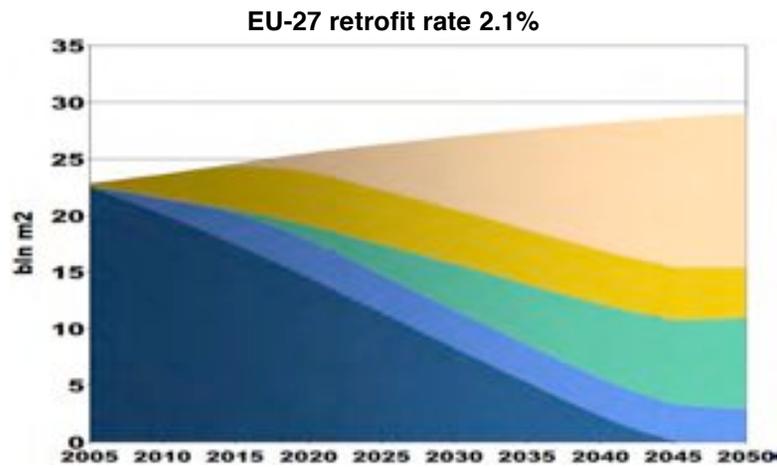
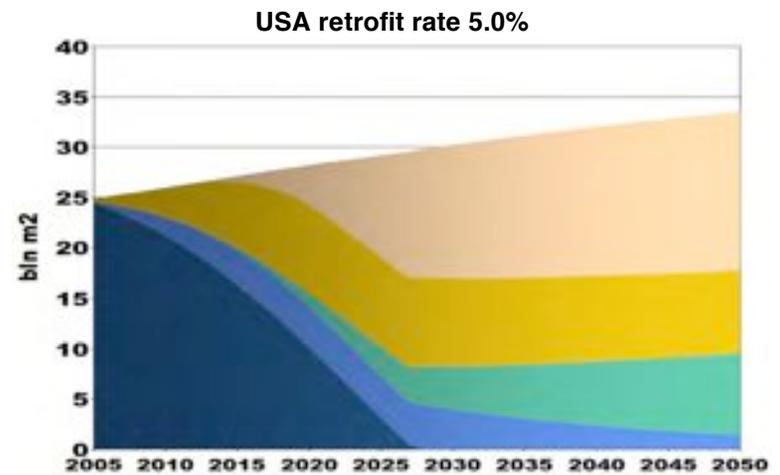
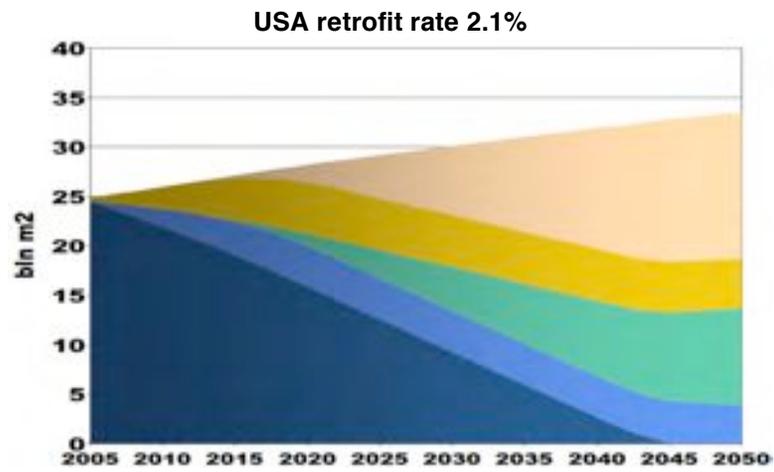
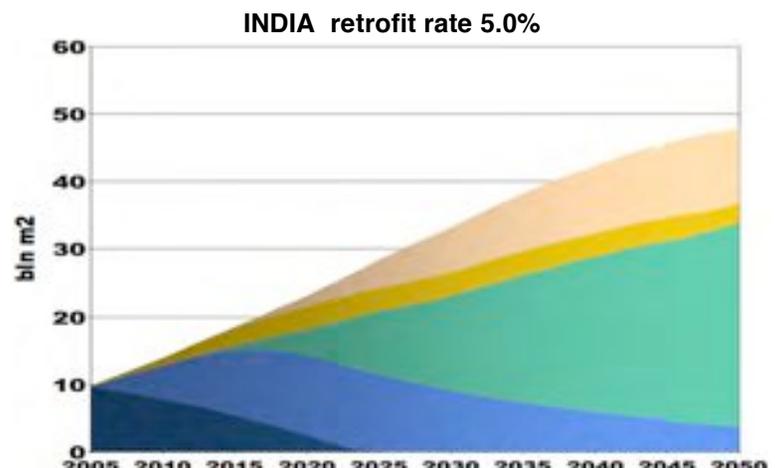
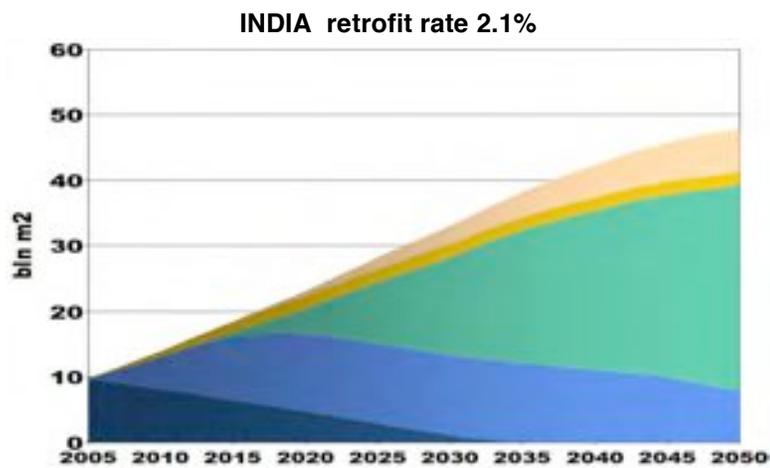
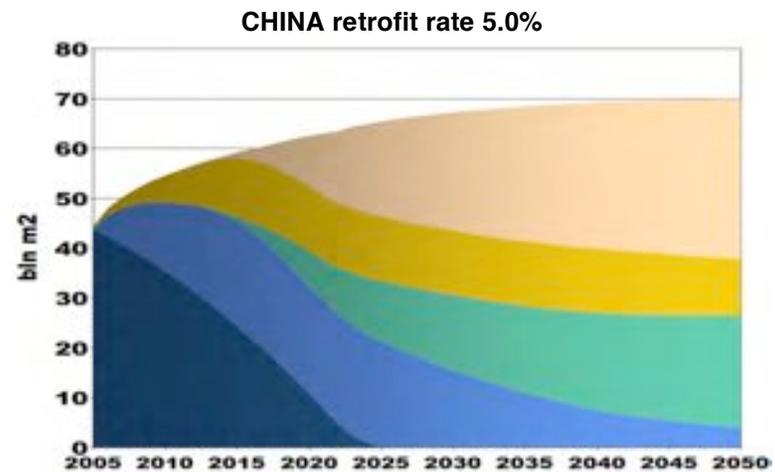
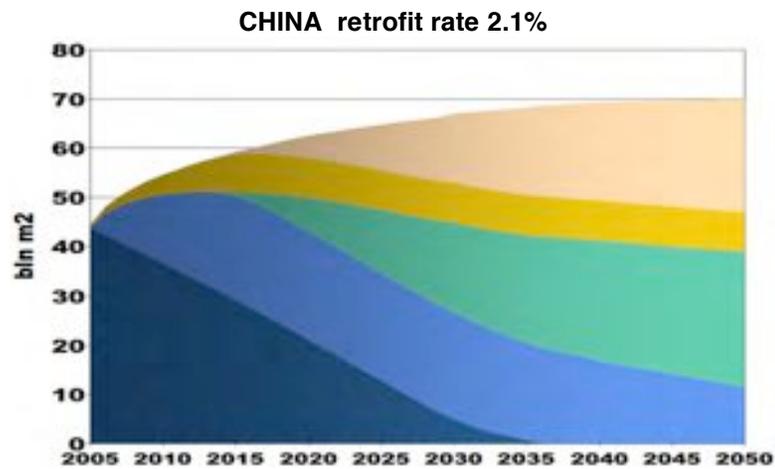


Figure 28. World floor area by vintage for retrofit rate values in 2020 of 2.1% and 5.0 for the Deep Efficiency scenario



■ Standard
 ■ New
 ■ Advanced new
 ■ Retrofit
 ■ Advanced retrofit

Figure 29. Floor area by vintage for retrofit rate values in 2020 of 2.1% and 5.0% for USA and EU-27 for the Deep Efficiency scenario



■ Standard
 ■ New
 ■ Advanced new
 ■ Retrofit
 ■ Advanced retrofit

Figure 30. Floor area by vintage for retrofit rate values in 2020 of 2.1% and 5.0% for China and India for the Deep Efficiency scenario

The largest relation between the value of retrofit rate and the floor area of retrofitted buildings is seen for developed regions – USA and EU-27 (Figure), as for these regions the number of buildings to be retrofitted is the highest. It also affects China, but for India (Figure 30) this relation is barely noticeable. Figure shows the percentage share of retrofit buildings floor area in total floor area and the year in the total final energy peaks. The values are presented for four values of retrofit rates for USA, EU-27 and the world.

Table 13. The percentage share of retrofit buildings floor area in total floor area and the year in the total final energy peaks (the Deep Efficiency scenario)

Region	Retrofit rate in 2020	Retrofit floor area as % of total floor area in 2050	The year in which the total final energy peaks
USA	1.4%	48	after 2050
	2.1%	59	2045
	3.0% (default)	65	2036
	5.0%	71	2028
EU-27	1.4%	51	after 2050
	2.1%	51	2045
	3.0% (default)	67	2036
	5.0%	73	2028
World	1.4%	27	after 2050
	2.1%	34	2045
	3.0% (default)	40	2036
	5.0%	48	2027

For the default value of retrofit rate (3.0% in 2020) in both USA and EU-27, the share of floor area of retrofitted buildings is about 65%. While if retrofit rate is assumed higher, this is 5.0%, this share is over 70%. If the retrofit value stays constant, in 2050 the share of floor area of retrofitted buildings is about 50%.

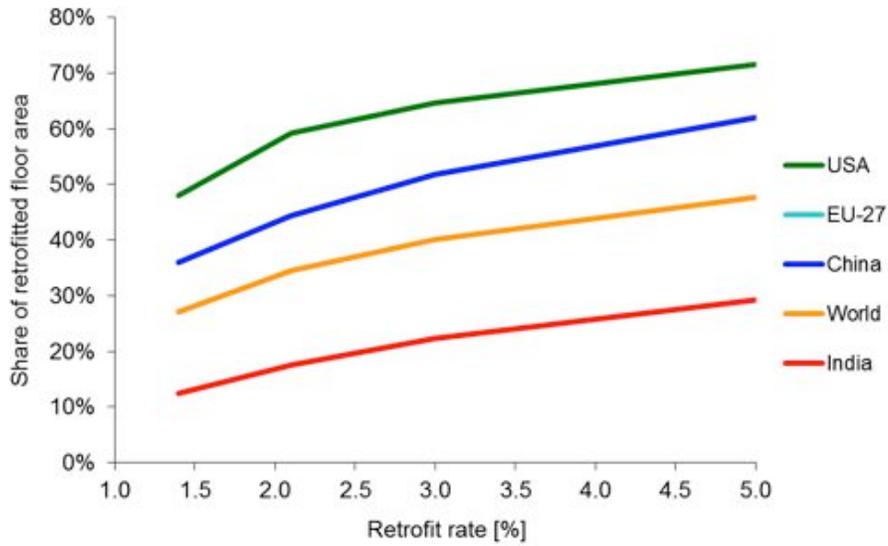


Figure 31. The share of floor area of retrofitted buildings in total floor area in 2050 (the Deep Efficiency scenario)

Next, the influence of various retrofit rates on total final energy (space heating & cooling and water heating) was analysed. The charts below show total final energy for the world and the four key regions for the various values of the retrofit rates.

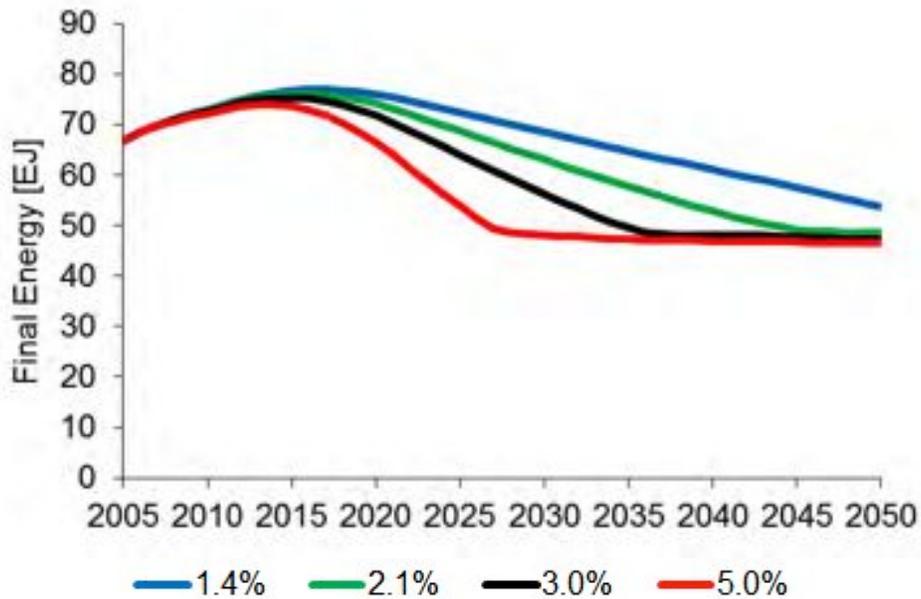
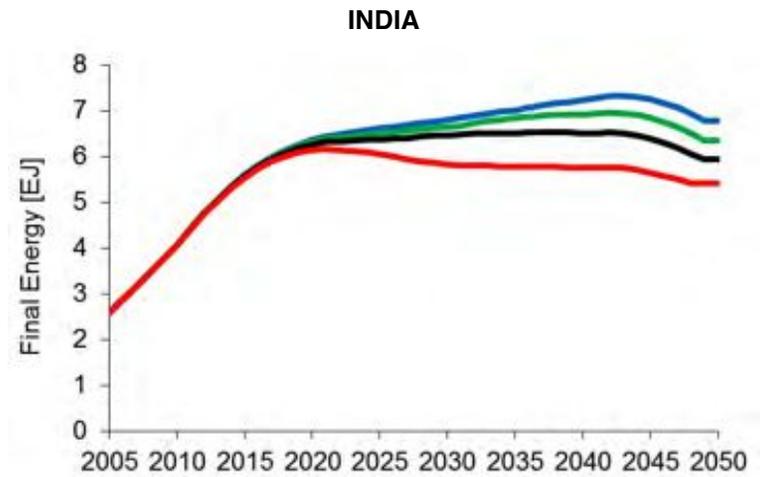
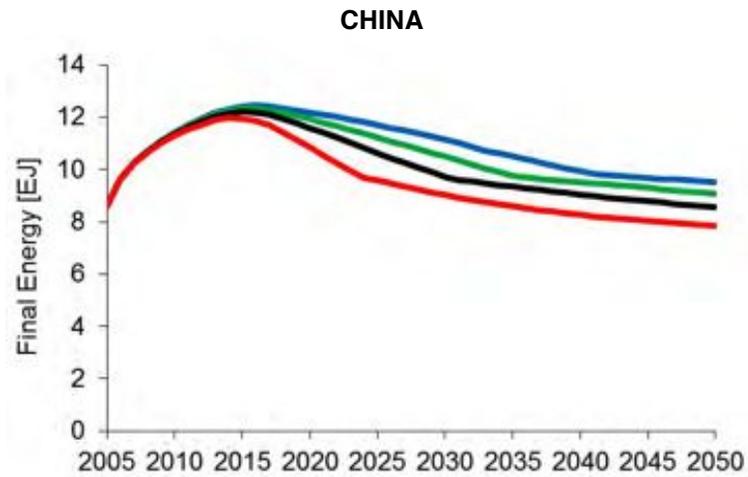
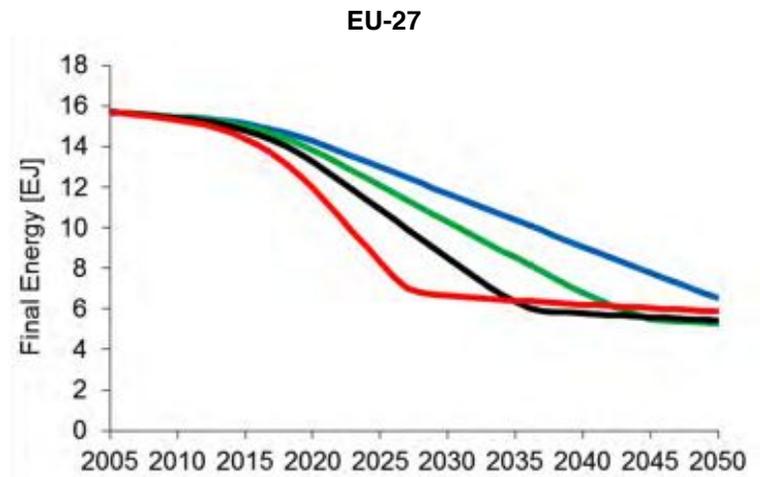
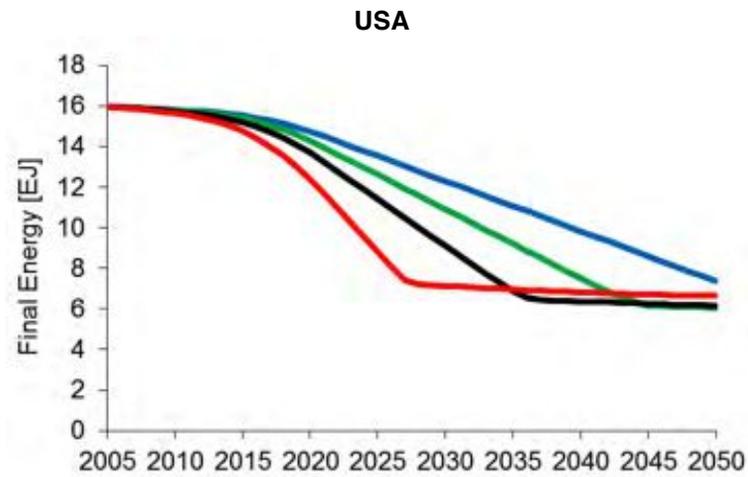


Figure 32. World total final energy for Deep Efficiency scenario for various retrofit rates for the Deep Efficiency scenario



— 1.4% — 2.1% — 3.0% — 5.0%

Figure 33. Total final energy for Deep Efficiency scenario for various retrofit rates for USA, EU-27, China and India rates for the Deep Efficiency scenario

As it can be noticed, the change of retrofit rate in 2020 affects the total final energy in 2050. It also has influences on the speed with which final energy consumption is reduced, due to the buildings' retrofit. Here total final energy peaks in 2036 with the default retrofit value of 3.0% yet there is a possibility of it peaking by 2027 if the retrofit rate of 5.0% is assumed. For USA and EU-27 the total final energy peaks in ~2036 with the default retrofit value of 3.0 [-], yet there is a possibility of it peaking by 2028 if the retrofit rate of 5.0% [-] is assumed. In case of China and India, this situation looks very different. There are no "visible" energy peaks, but there is change in total final energy in 2050 (Table 14).

Table 14. The total final energy change in 2050 to for various values of retrofit rates in relation to the default retrofit rate value (the Deep Efficiency scenario)

Region	Total final energy change in 2050 in relation to the default retrofit rate			
	1.4%	2.4%	3.0% (default)	5.0%
EU-27	20.5%	-2.4%	0%	8.3%
USA	19.5%	-1.6%	0%	7.6%
CHINA	11.2%	6.1%	0%	-8.3%
INDIA	14.2%	6.9%	0%	-8.7%
WORLD	13.6%	2.6%	0%	-1.8%

For EU-27 and USA, the increase of the retrofit rate from 3% to 5% will increase the total final energy consumption by about 8%. If it stays constant, 1.4% of the total final energy will increase by ~20% in relation to the default value.

The reason for such dynamics in the developed regions, EU-27 and USA, (increasing the retrofit rates causes the increase in the total final energy and vice versa) is the relation between the values of the energy consumption for the vintage types of building stock. In these regions the new building stock is assumed to be less energy consuming than the retrofit one. When the final retrofit rate is decreased, in the final year the amount of the retrofit building stock becomes less than in the default case, while the share of the new building stock becomes larger. However, in the case of the larger decrease the different effect starts to prevail: when the total floor area starts to decrease because of the fall of the predicted population, some part of the previously built new building floor is, first, demolished, and then the share of the rest equal to the final retrofit rate is retrofitted. Consequently, in the end the amount of the retrofit building becomes larger than in the default case, and the new one is less.

For China, for the retrofit value in 2020 of 1.4% (like in 2005), the total final energy in 2050 is by 11% larger in reference to 3% of the default value of retrofit rate. If this value is assumed higher, this is 5%, then this difference is 8.3% lower. Similar values are obtained for India.

5.3 Retrofit rates – Moderate Efficiency Scenario

In the current model, the retrofit rate assumed for all regions, grows linearly from 1.4% in 2005 to 2.1% (in US and EU-27), 1.6% (in China) and 1.5% (in India) in 2020. After 2020 it stays at the constant level. As this is a highly uncertain value, calculations were done for various values to see how it affects total final energy (space heating & cooling and water heating). The sensitivity analysis was done, assuming the default retrofit value in 2005, this is 1.4% and lower starting value, and this is 0.7%:

- | retrofit rate in 2005 | retrofit rate in 2020 |
|-----------------------|-----------------------|
| • 0.7% (lower value) | • 2.1% |
| • 0.7% (lower value) | • 3.0%, |
| • 1.4% (default) | • 2.1% |
| • 1.4% (default) | • 3.0%, |

As the retrofit rates are higher, the floor area reaches its saturation point (e.g. the maximum share of retrofitted building stock) quicker. It is clear that the total floor area will not be affected by the change of retrofit rate. On the figures below, to make the comparison easier, the retrofitted building (both retrofit and advanced retrofit) are in yellowish colours. The charts below show the floor area and the total final energy with the same value of the retrofit rate in 2020, this is 2.1%, but various starting values of the retrofit rate, these are: 0.7% and 1.4% (default value).

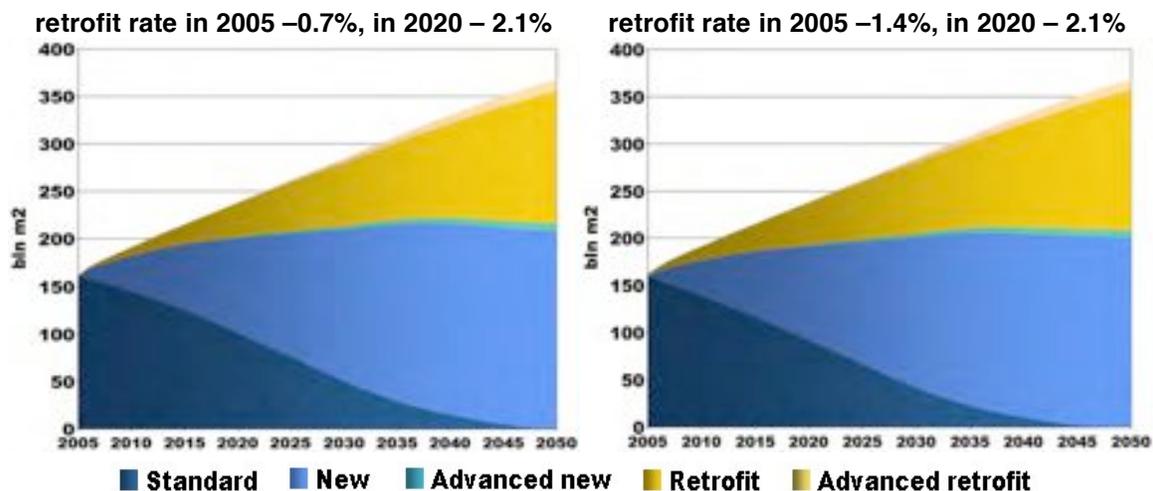
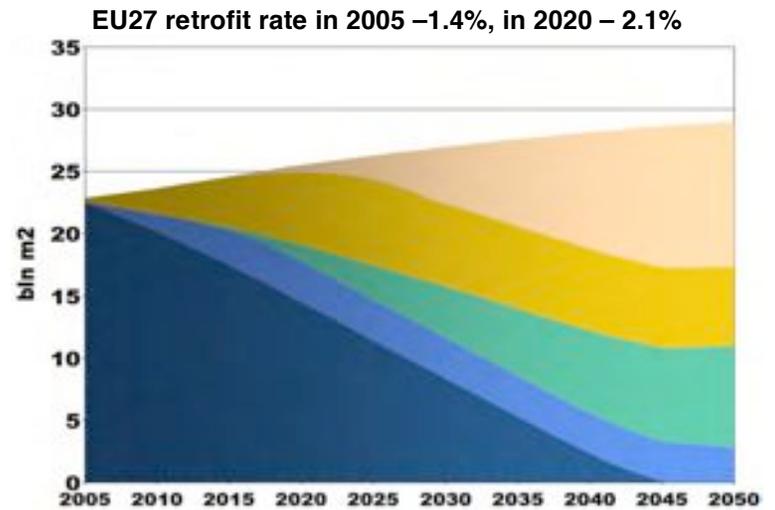
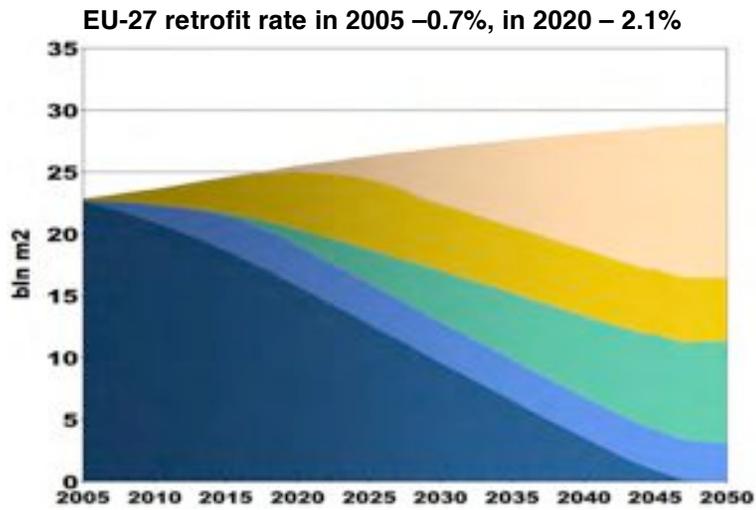
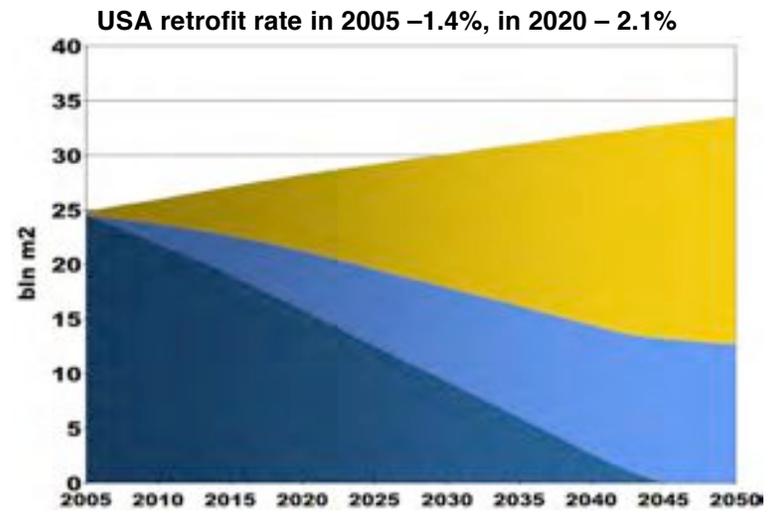
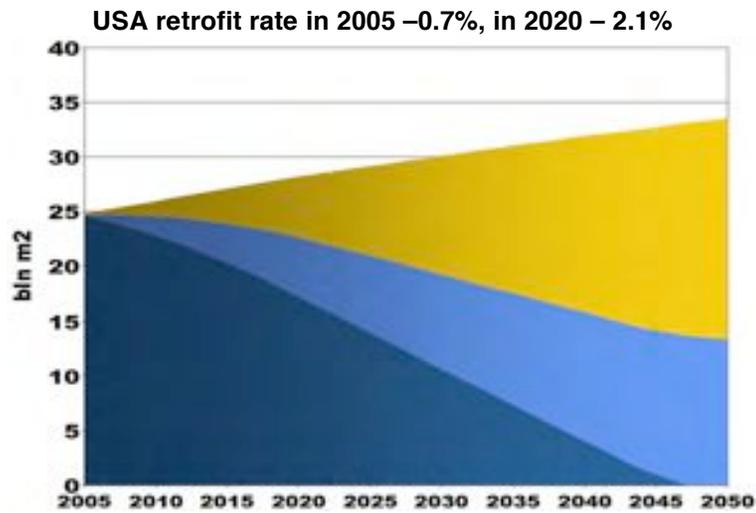
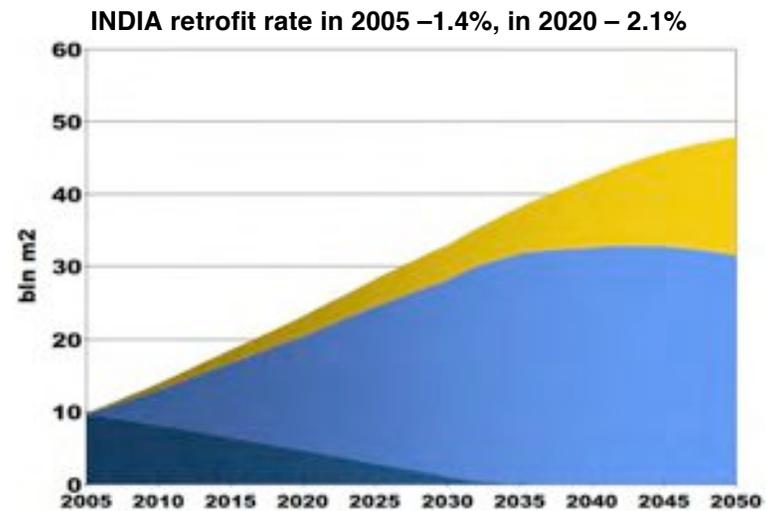
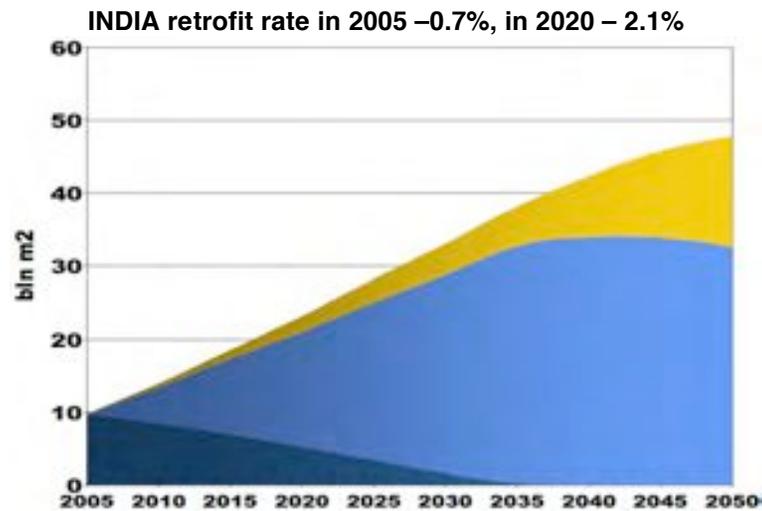
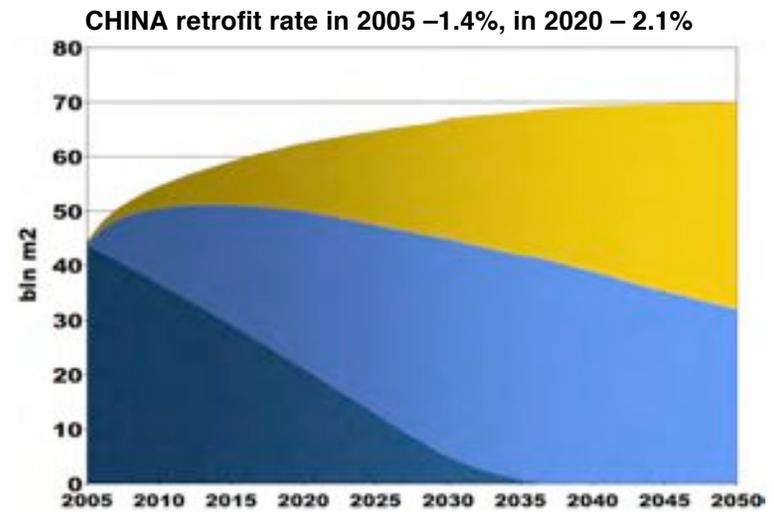
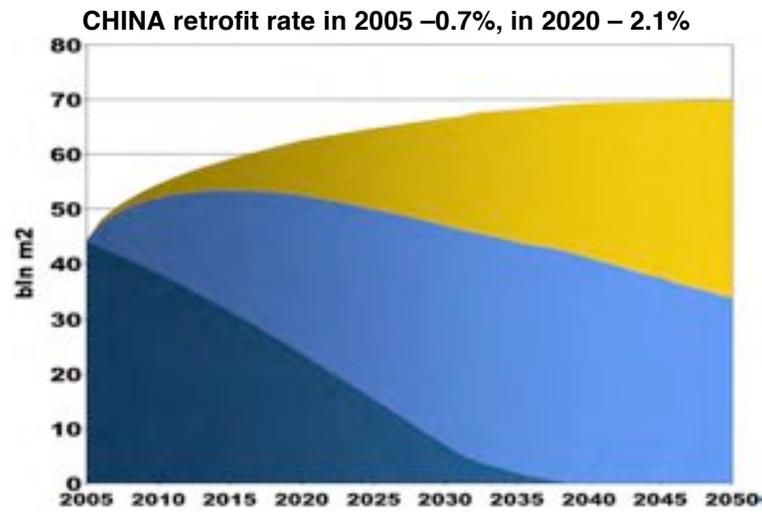


Figure 34. World floor area by vintage for retrofit rate in 2020 of 2.1% with various retrofit values in 2005, these are 0.7% and 1.4% (default) for the Moderate Efficiency scenario



Standard
 New
 Advanced new
 Retrofit
 Advanced retrofit

Figure 35. The floor area by vintage for retrofit rate in 2020 of 2.1% with various retrofit values in 2005, these are 0.7% and 1.4% (default) for USA and EU-27



■ Standard ■ New ■ Advanced new ■ Retrofit ■ Advanced retrofit

Figure 36. The floor area by vintage for retrofit rate in 2020 of 2.1% with various retrofit values in 2005, these are 0.7% and 1.4% (default) for China and India

For the world floor area, with a retrofit rate in 2020 of 2.1%, the change of the starting value in 2005 does not have a significant influence. If the retrofit rate in 2005 is assumed to be 0.7%, the global floor area of retrofit buildings is saturated in the year 2040, while if it is higher, this is 1.4% the global floor area of retrofit buildings is saturated already in the year 2035.

The largest relation between the value of retrofit rate and the floor area of retrofitted buildings is seen for developed regions – USA and EU-27 (Figure). As for these regions the number of buildings to be retrofitted is the highest. Although for India (Figure) this relation is also noticeable.

If the retrofit rate in 2005 is assumed to be 0.7%, the floor area of retrofit buildings in the USA is saturated in the year 2047, while if it is higher; this is 1.4% this area is saturated three years earlier. This relation is similar for EU-27.

Table 15 shows the percentage share of retrofit buildings floor area in total floor area and the year in which the saturation point is reached for various values of retrofit rates. The values are presented for three values of retrofit rates for the USA, EU-27 and the world.

Table 15. The percentage share of retrofit buildings floor area in total floor area and the year in which the saturation point is reached for various values of retrofit rates for the Moderate Efficiency scenario

Region	Retrofit rate in 2005	Retrofit rate in 2020	Retrofit floor area as % of total floor area in 2050	The year in which the total final energy peaks
USA	0.07%	2.1%	60	2047
	0.07%	3.0%	71	2038
	1.4% (default)	2.1% (default)	62	2044
	1.4% (default)	3.0%	73	2035
EU-27	0.07%	2.1%	61	2048
	0.07%	3.0%	66	2038
	1.4% (default)	2.1% (default)	62	2045
	1.4% (default)	3.0%	67	2038
World	0.07%	2.1%	41	2040
	0.07%	3.0%	54	2038
	1.4% (default)	2.1%	43	2035
	1.4% (default)	3.0%	55	2033

For the default value of retrofit rate, this is 2.1% in 2020 and 1.4% in 2005 in both USA and EU-27, the saturation point is reached in the year 2045 with ~60% share of floor area of retrofitted buildings. If retrofit rate is assumed higher, this is 3% in 2020, then a saturation point is already reached in the year 2035, with ~70% share of floor area of retrofitted buildings.

Next, the influence of various retrofit rates on total final energy (space heating & cooling and water heating) was analysed. The charts below show total final energy for the world and the four key regions for various values of the retrofit rates.

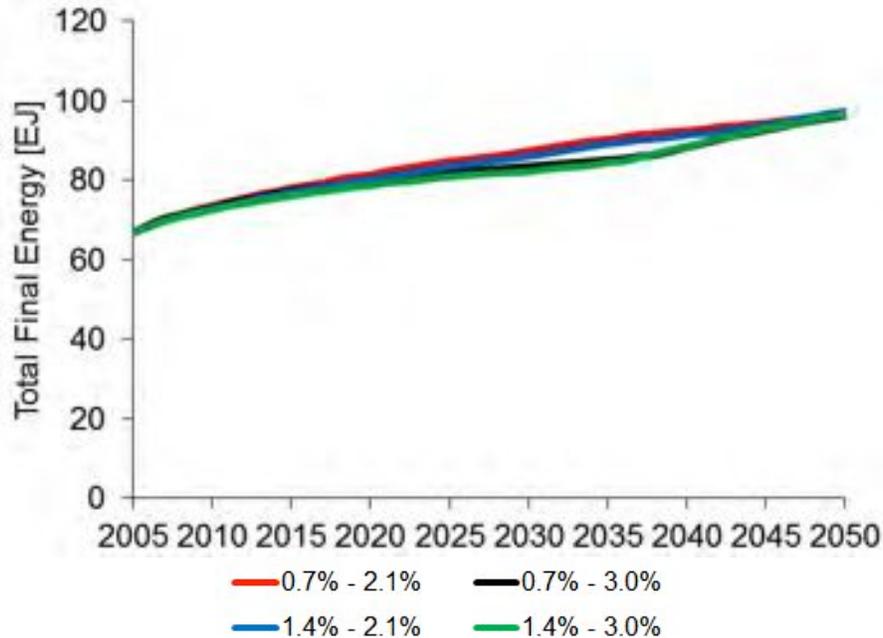


Figure 37. World total final energy for Moderate Efficiency scenario for various retrofit rates for the Moderate Efficiency scenario

As it can be seen, the change of retrofit rates does not significantly affect the value of total final energy in 2050. It mostly influences the speed with which final energy consumption is reduced, due to the buildings' retrofit. Also there is no significant change in the total final energy consumption for different values of the retrofit rate in 2005. The clear difference is visible only for the change of retrofit rate value in 2020. For the global total final energy, if the retrofit rate in 2020 of 2.1% is assumed – it peaks around the year 2040. If the retrofit rate is higher, this is 3% in 2020, then it peaks 5 years sooner, this is around the year 2035.

For the USA and EU-27 the change of retrofit rate influences the total final energy in a similar way. Here also there is no significant difference between various starting values of the retrofit rate (in 2005). The total final energy also peaks in ~2045 with the default retrofit value of 2.1% in 2020. But it can already peak in ~2035 if the retrofit rate of 3% is assumed. Like in case of floor area, the change in retrofit rates does not specifically affect total final energy in China and India.

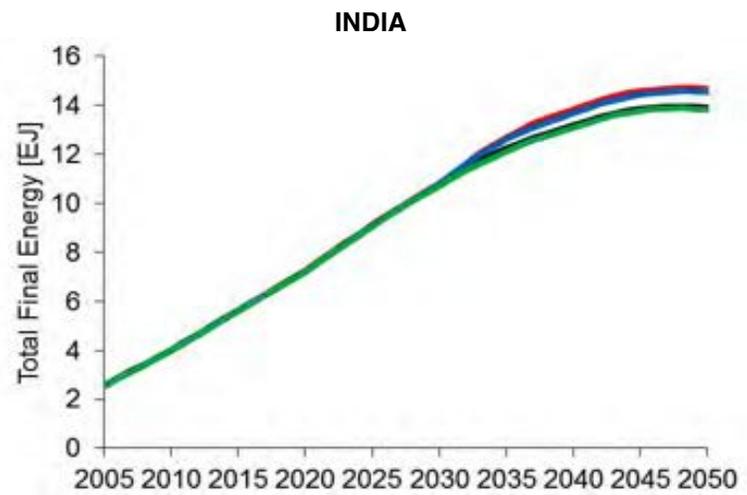
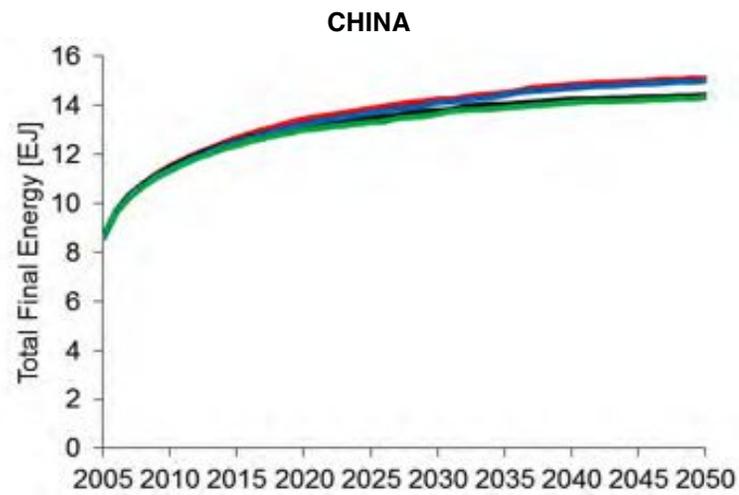
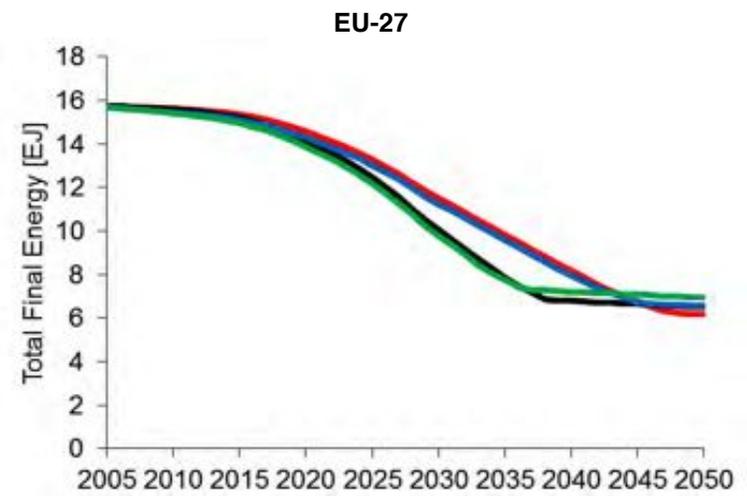
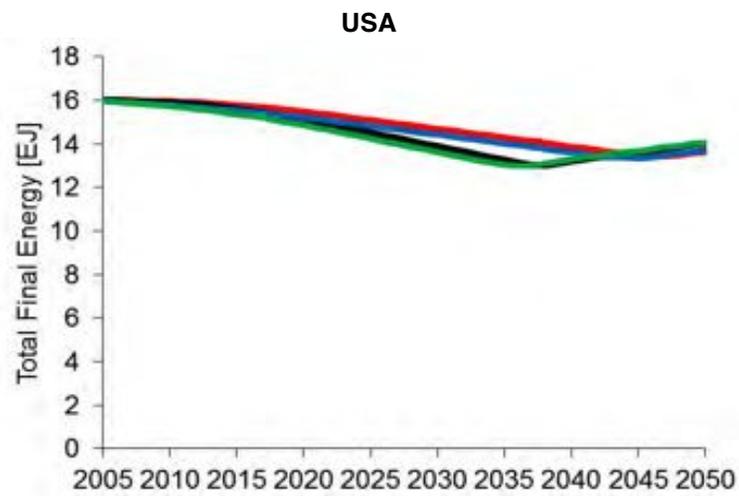


Figure.38 Total final energy for Moderate Efficiency scenario for various retrofit rates for USA, EU-27, China and India for the Moderate Efficiency scenario

5.4 Adjustment factor

In the model the adjustment factor is used to calculate the floor area of commercial and residential buildings. In case of the commercial and public buildings, the adjustment factor expresses the level of floor space productivity (GDP/floor space) reached by a given region in 2050 as compared to the floor space productivity of OECD countries (i.e. if the adjustment factor is 2, the floor space needed to produce a unit of GDP is twice as large as in OECD countries). In case of the residential buildings, adjustment factor shows the ratio of the 2050 per capita floor space in a given developing country and the respective value in OECD countries (i.e. if the factor is 0.8, then per capita floor space in the given country is 80% of the OECD per capita floor space. It is highly uncertain in the developing regions like China and India, thus only for these regions the results of sensitivity analysis are presented. Table 16 shows the values for which sensitivity analysis was done.

Table 16. The values of adjustment factors for China and India for residential and commercial buildings, for which the sensitivity analysis was done

Region	Adjustment factor [-]	
	Residential	Commercial & Public
China	0.8 [-]	
	0.9 [-] (default)	1.0 [-]
	1.2 [-]	
India	0.6 [-]	0.4 [-]
	0.7 [-] (default)	0.7 [-] (default)
	1.0 [-]	1.0 [-]

The charts below show the change influence of various adjustment factors on the total floor area. Since a different approach, not including the adjustment factor, is incorporated to model the dynamics of the floor area of commercial and public building, the sensitivity analysis of the adjustment factor for commercial and public buildings in China is not presented in the report.

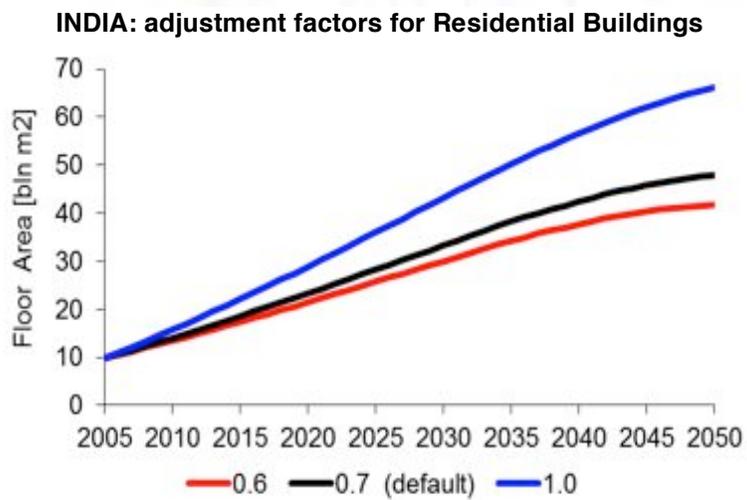
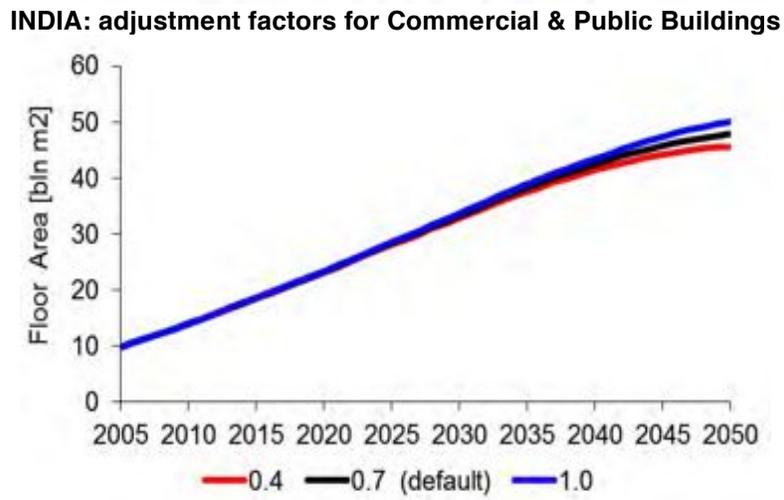
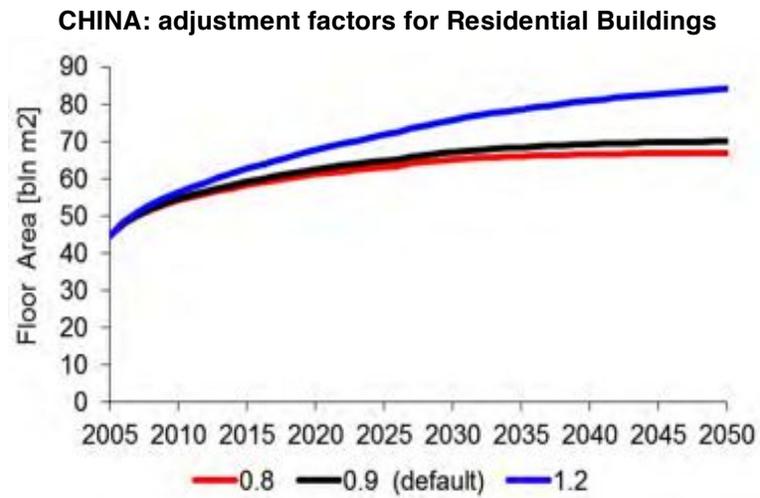


Figure 39. The total floor space for various adjustment factors for China and India, separately for residential and commercial & public buildings

The relation between the adjustment factors and floor area is close to linear (Figure). The table below shows the values of floor area increase in relation to the adjustment factor change.

Table 17. The total floor area change for China and India for residential and commercial buildings in 2005 in relation to the default value of the adjustment factor

Region	Building type	Adjustment factor change		Floor area change in 2050, bln m ²	Floor area change in 2050, %
		[-]	%		
China	Residential	by 0.3	33%	14.26	20.4%
India	Residential	by 0.3	43%	18.29	38.2%
	Commercial & Public	by 0.3	43%	2.22	4.6%

The influence on the total floor area in China has an adjustment factor for residential buildings. Its change by 0.3 [-] changes the total floor area by 20.4%. In India the greatest influence on total floor area also has an adjustment factor for residential buildings. Here the change by 0.3 [-] changes the total floor area by 38.2% (Table 17).

The total final energy for China and India for various adjustment factors for commercial and residential buildings is presented. Here, similarly to the floor area, the greatest influence of adjustment factors on the total final energy has an adjustment factor for the residential buildings in India. There is not a linear relationship between adjustment factors and total final energy.

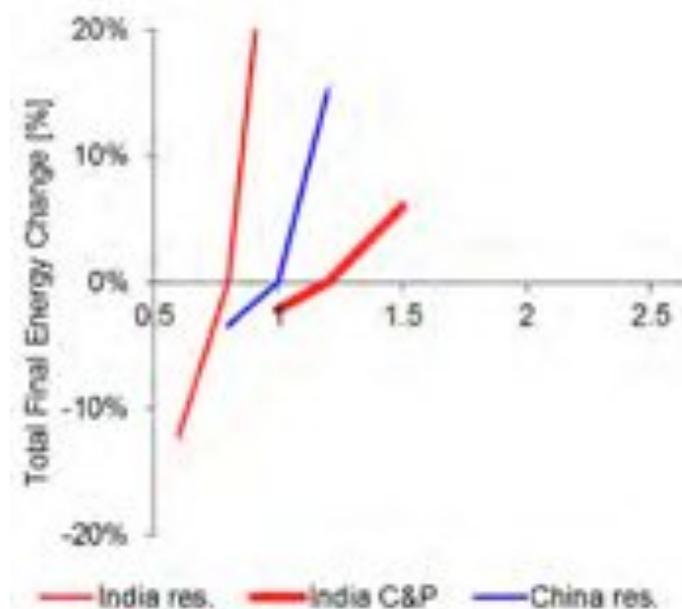
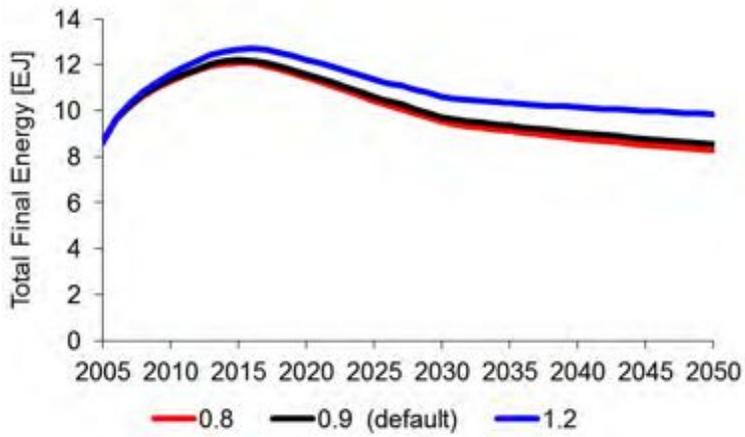
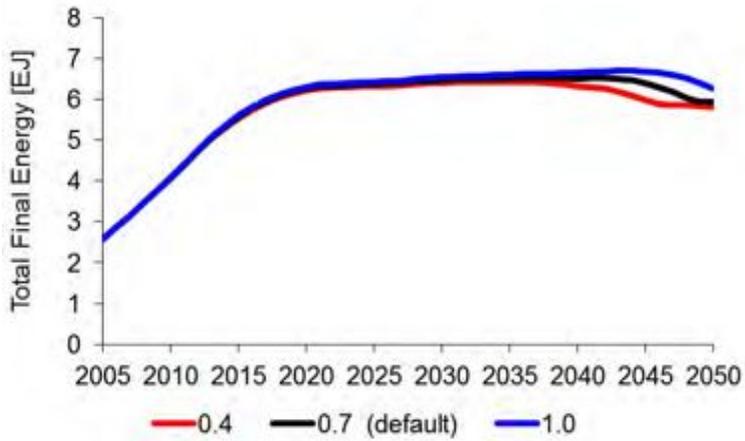


Figure 40. The percentage change of the total final energy for various adjustment factors for China and India for commercial & public and residential buildings

CHINA: adjustment factors for Residential Buildings



INDIA: adjustment factors for Commercial & Public Buildings



INDIA: adjustment factors for Residential Buildings

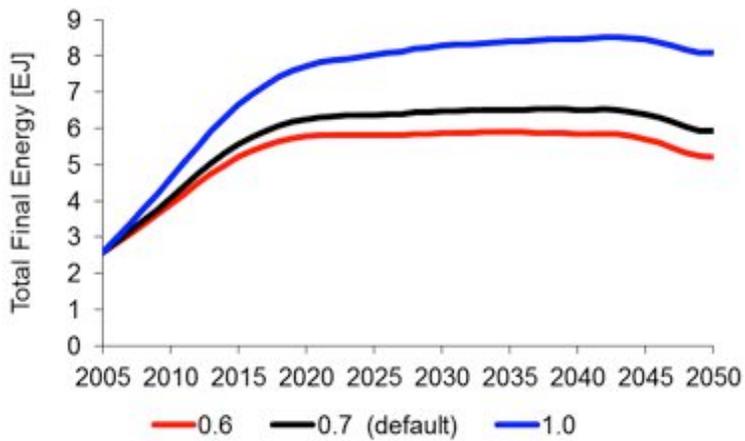


Figure 41. The total final energy for various adjustment factors for China and India, separately for residential and commercial & public buildings

Table 18. The total final energy change for China and India for residential and commercial buildings in 2005 in relation to the default value of the adjustment factor

Region	Building type	Adjustment factor change		Total Final Energy in 2050, EJ	Total Final Energy in 2050, %
		[-]	%		
China	Residential	by 0.3	33%	1.3	15.2%
India	Residential	by 0.3	43%	2.17	36.6%
	Commercial & Public	by 0.3	43%	0.35	5.9%

It can be noticed that for India, the change of adjustment factor for the residential building by 0.3 [-], this is by 43%, changes the total final energy in 2050 by 36%. For China, the change of adjustment for the residential building also by 0.3 [-], here by 33%, changes the total final energy in 2050 by 15%.

In case of commercial & public buildings, this relation is smaller. In India, the change of adjustment factor for the commercial & public buildings by 0.3 [-], this is by 43%, changes the total final energy in 2050 by nearly 6%. For China, the change of adjustment for the commercial & public buildings – similarly to the floor area – does not influence the total final in 2050. The table above shows the non-linear connection between the adjustment factors and final energy. The non-linearity is a consequence of the fact that the final energy is a sum of two components, hot-water energy and heating and cooling energy, each of which is effected differently by the change of only commercial or residential floor area. Since the adjustment factors affect the total building stock that has a non-linear impact on hot water energy, the resulting final energy could not be presented as a multiple of the adjustment factors and a function of the rest of the inputs.

5.5 Summary

In the sensitivity analysis three parameters were analysed: the final energy intensity for space heating & cooling for advanced retrofit and advanced new buildings, the retrofit rate for the “Moderate Scenario” and “Deep Efficiency” scenarios and the adjustment factor, which is used to calculate the floor area of commercial and residential buildings. The analysis was done for the world and the four GBPN regions.

The greatest influence on final energy for space heating & cooling has the final energy intensity in advanced retrofit and advanced new buildings. If they consume 50% more energy than what was assumed, the global final energy for space heating & cooling increases by ~25% and 100% of increase by ~50%. The greatest influence on the final energy is noticeable for India and China. As the increase of final energy intensity for space heating & cooling is nearly linear, the increase of 10% increases the final energy demand by 7.6% in India, by 5.3% in China, by 4.1% in USA and by 3.3% in EU-27. This makes the developing regions the most sensitive to the final energy intensity change.

The main conclusions of the final energy intensity change are:

- The correlation between the change of final energy intensity and final energy demand is nearly linear,
- The developing regions are the most sensitive to the final energy intensity change. The increase of 10% increases the final energy demand in 2050 by 7.6% in India, by 5.3% in China, by 4.1% in USA and by 3.3% in EU-27.

The change in the retrofit rate in the “Deep Efficiency” scenario influences the speed that reduces the final energy consumption, due to the buildings’ retrofit. It has the greatest influence in the developed regions like USA and EU-27. It also influences the total final energy in 2050.

The main conclusions of the retrofit rate change for the “Deep Efficiency” scenario are:

- The change of the retrofit rate changes the speed with which the final energy is reduced, due to the buildings’ retrofit,
- As the retrofit rate is higher, the floor area reaches its saturation point quicker (e.g. the maximum share of retrofitted buildings),
- As the retrofit rate is higher, the floor area reaches its saturation point quicker (e.g. the maximum share of retrofitted buildings),
- The change of retrofit rate has the largest influence on the floor area in the developed regions, these are USA and EU-27 (the values are similar), thus these two are the most sensitive to the retrofit rate change,
- If the retrofit rate is assumed 3.0% then the total final energy in the USA and EU-27 peaks in the year 2036 but if it is 5.0% then it will peak in 2026,
- The change of the retrofit rate influences the total final energy consumption in 2050.

The change in the retrofit rate in the “Moderate Efficiency” scenario influences the speed that reduces the final energy consumption, due to the buildings’ retrofit. It has the greatest influence in the developed regions like USA and EU-27. It also influences the total final energy in 2050.

The main conclusions of the retrofit rate change for the “Moderate Efficiency” scenario are:

- The change of the retrofit rate changes the speed, with which the final energy is reduced, due to the buildings’ retrofit,
- As the retrofit rate is higher, the floor area reaches its saturation point quicker (e.g. the maximum share of retrofitted buildings),
- The change of the retrofit rate has the largest influence on the floor area in the developed regions, these are USA and EU-27 (the values are similar), thus these two are the most sensitive to the retrofit rate change; although this relation is also noticeable for India,

- The change of the retrofit rate in 2005 does not have a significant influence on the floor area and total final energy. The largest influence has the retrofit rate value in 2020,
- If the retrofit rate in 2005 is assumed to be 0.7%, the floor area of retrofit buildings in the USA is saturated in the year 2047, while if it is higher; this is 1.4% this area is saturated three years earlier. This relation is similar for EU-27.

The value of the adjustment factor has the greatest influence in developing regions, like China and India for residential buildings. In China its change by 0.3 [-] changes the total floor area by 20%. In India the greatest influence on total floor area also has an adjustment factor for residential buildings. Here its change by 0.3 [-] changes the total floor area by 38%. In India the change of adjustment factor for the residential building by 0.3 [-], this is by 33%, changes the total final energy in 2050 by 36%. For China, the change of adjustment for the residential building also by 0.3 [-], changes the total final energy in 2050 by nearly 15%.

The main conclusions of the adjustment factor change are:

- The adjustment factor is highly uncertain in the developing regions, these are China and India,
- The correlation between the change of the adjustment factor and both floor area and total final energy is nearly linear,
- The increase of the adjustment factor for residential buildings by 0.3 [-] increases the total final energy in 2050 by ~15% in China and ~36% in India, what makes India more sensible for the adjustment factor change,
- The increase of the adjustment factor for commercial & public buildings by 0.3 [-] increases the total final energy in 2050 by ~6% in India.

Lessons learned from the sensitivity analysis:

The most sensitive regions, due to the change of the intensity of the final energy, are India and China. If the final energy intensity in advanced retrofit and advanced new buildings is 50% higher than was assumed, the global final energy for space heating & cooling increases by ~25% and 100% of increase by ~50%.

In the “Deep Efficiency” scenario the influence of the retrofit rate value on the speed of total final energy reduction, is noticed in the developed regions like EU-27 and the USA. Here if the retrofit rate is assumed 3.0% than the final energy peaks in 2036. But if it is 5.0% it already peaks in 2026.

The change of the retrofit rate in the “Moderate Efficiency” scenario has the largest influence on the floor area in the developed regions, these are USA and EU-27 (the values are similar), thus these two are the most sensitive to the retrofit rate change; this relation is also noticeable for India. The change of the

retrofit rate in 2005 does not have a significant influence on the floor area and total final energy in 2050. The largest influence is the retrofit rate value in 2020.

The adjustment factor is highly uncertain in the developing regions, these are China and India, and thus the value of the adjustment factor has the greatest influence on the final energy.

The sensitivity analysis of the 3CSEP HEB model, was limited by the following factors:

- Many parameters that could have influenced the results were not analysed,
- The analysis were done for the “Deep Efficiency” and “Moderate Efficiency” scenario,
- Only few values of parameters change were chosen,
- It was not clear which output should be analysed.

CHAPTER 6 – REVIEW OF EXISTING STUDIES ON MODELING ENERGY USE AND GHG EMISSIONS IN BUILDINGS

This section presents an overview of different methodologies, scopes, assumptions, scenarios and mitigation potentials of selected modelling studies and the correlation between them.

The list below presents the identified studies that hold reliable models on estimating energy use for different end-uses in the building sector. These models often cover different regions or end-uses and their projections concern various time spans.

1. BUENAS – **B**ottom-**U**p **E**nergy **A**nalysis **S**ystem, established by **L**awrence **B**erkeley **N**ational **L**aboratory, published as *“Global Potential of Energy Efficiency Standards and Labelling Programs”* in 2008 (McNeil et al. 2008)
2. BPIE – established by **B**uildings **P**erformance **I**nstitute **E**urope, published as *“Europe’s Buildings Under the Microscope”* in 2011 (BPIE 2011b)
3. ECOFYS’04 – established by ECOFYS, published as *“Mitigation of CO₂ Emissions from the Building Stock”* in 2004 (ECOFYS GmbH 2004)
4. ECOFYS’05 – established by ECOFYS, published as *“Cost-Effective Climate Protection in the UE Building Stock”* in 2005 (ECOFYS GmbH 2005)
5. ETP’08 – established by The **I**nternational **E**nergy **A**gency, published as *“Energy Technology Perspectives 2008”* in 2008 (IEA 2008)
6. ETP’10 – established by The **I**nternational **E**nergy **A**gency, published as *“Energy Technology Perspectives 2010”* in 2010 (IEA 2010a)
7. 3CSEP HEB – established by **C**enter for **C**limate **C**hange and **S**ustainable **E**nergy **P**olicy (3CSEP) for The **G**lobal **B**uildings **P**erformance **N**etwork (GBPN)
8. Greenpeace – established by **E**uropean **R**enewable **E**nergy **C**ouncil, published as *“Energy Revolution. A sustainable World Energy Outlook”* in 2010 (Greenpeace International 2010)
9. HARVEY – established by L. D. Danny Harvey, published as *“Energy and the New Reality”* in 2010 (Harvey 2010)
10. IPCC AR4 – published as the Fourth Assessment Report of the **I**ntergovernmental **P**anel on **C**limate **C**hange in 2007 (IPCC 2007)

11. LAUSTSEN – established by Jens Laustsen, as *“Reducing Energy Use in Buildings with Factor 4”*(Laustsen 2012)
12. McKinsey – established by The McKinsey & Company, as *“McKinsey Global GHG Abatement Cost Curve”*
13. WBCSD EEB – established by The **World Business Council for Sustainable Development**, published as *“Transforming the Market. Energy Efficiency in Buildings”* in 2009 (WBCSD 2009)
14. WEO’06 – established by The **International Energy Agency (IEA)**, published as *“World Energy Outlook 2006”* in 2006. The **World Energy Model (WEM)** was expanded for the *WEO-2006*(IEA 2006b)
15. WEO’08 – established by The **International Energy Agency**, published as *“World Energy Outlook 2008”* in 2008 (IEA 2008b)
16. WEO’09 – established by The **International Energy Agency (IEA)**, published as *“World Energy Outlook 2009”* in 2009 (IEA 2009)
17. WEO’10 – established by The **International Energy Agency (IEA)**, published as *“World Energy Outlook 2010”* in 2010 (IEA 2010b)
18. Wuppertal – established by Wuppertal Institute, published as *“Target 2020: Policies and Measures to reduce Greenhouse gas emissions in the EU”* in 2005 (WWF EPO 2005)

It is important to notice that the model presented by LAUSTSEN is a non-published draft but its results were published in various presentations and were discussed among the modellers. This model is important in terms of models comparison, as it is similar to 3CSEP HEB model. It is based on the same energy modelling approach; this is performance-based and bottom-up approach. It also covers all regions and the same end-uses as 3CSEP HEB; these are space heating and cooling and water heating. This is why the authors decided to present the results of LAUSTSEN model, as it is the closest to 3CSEP HEB in terms of modelling approach, end-uses and regions covered.

BUENAS model is an appliance stock model, while other models are building based models. Thus comparing the results of models with BUENAS can not be direct, as BUENAS is about standards for appliances and e.g. 3CSEP HEB model is about standards for space heating & cooling and water heating regulations, that more includes the buildings’ envelope and HVAC systems.

The models above were described and analysed according to the published reports, data and materials. Next they were compared to find the correlation between them. The models were analysed following the review methodology presented in the graph below (Figure). In the first step models’ scopes, sectors, regions and projection were analysed. The second step involved describing scenarios and their assumptions along with the strategies and measures to achieve the expected mitigation potential. In the third step methodologies were reviewed with their approaches, these were divided into *“bottom-up / top-down”*

and “component-based / performance-based”. Finally the results concerning final energy use and CO₂ emissions were compared.

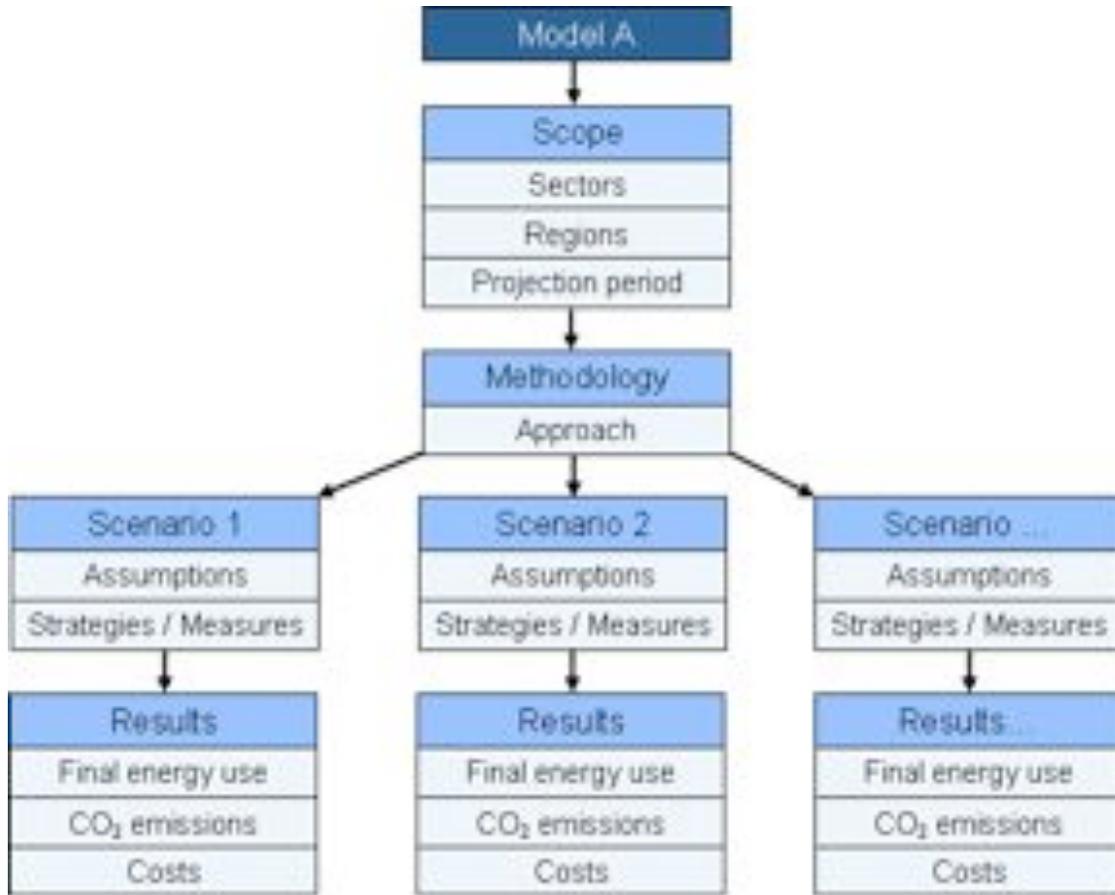


Figure 42 Review methodology

For a clear presentation of information characterizing the models, the data were placed in a tabular way. The regions, sectors, end-uses and presented results are not included in the table, but are presented in separate tables/graphs below. The primary criterion for model’s selection for comparison was a separate analysis of energy consumption in the building sector, which usually covers residential and non-residential buildings. The majority of models included other sectors like industry, transport, power generation and agriculture Table 22. Those were ETP, Greenpeace, HARVEY, IPCC AR4, McKinsey, WEO and Wuppertal. It is important to note that ETP, WEO and Wuppertal models included “Agriculture” in “Buildings” sector category.

Analysed models had various period projections. Figure shows that only 5 models have the same time span (2005-2050), which is very important in terms of models results comparisons, especially the base year. These are: WBCSD

EEB, LAUSTSEN, HARVEY, 3CSEP HEB and ETP'08. In most models analysis covers shorter time periods, this is up to 2015, 2020, 2030 or 2035. These include: Wuppertal, WEO, McKinsey, IPCC AR4, ECOFYS and BUENAS.

Table 19. Sectors analysed in the models

Sector	BUENAS	BPIE	ECOFYS'04	ECOFYS'05	ETP'08	ETP'10	3CSEP HEB	Greenpeace	HARVEY	IPCC AR4	LAUSTSEN	McKinsey	WBCSD EEB	WEO'06	WEO'08	WEO'09	WEO'10	Wuppertal	
Buildings	[Solid Blue]																		
Industry	[Solid Blue]																		
Transport	[Solid Blue]																		
Power	[Solid Blue]																		
Agriculture	[Hatched]																		

Legend:  Separate sector
 "Agriculture" sector included in "Buildings" sector

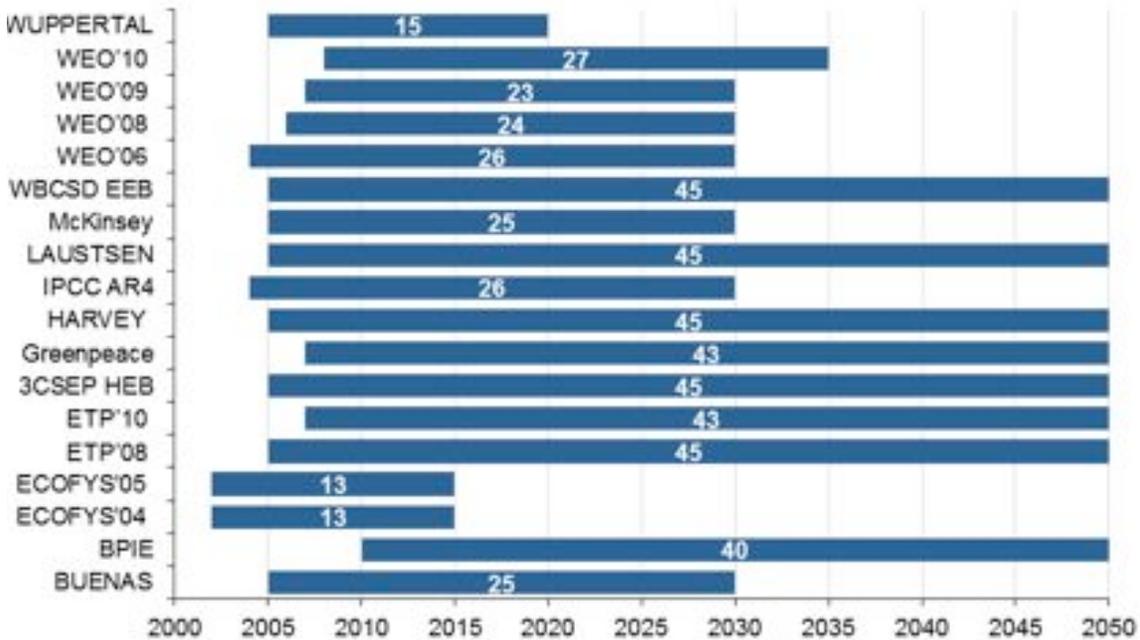


Figure 43. Projection period in analysed models, with the total number of years covered

The models analysed in this report cover different regions of the world. Empty boxes in Table 23 indicate the regions that were not included in the analysis.

Most of the models cover the entire globe, while BPIE, ECOFYS and Wuppertal models cover only Europe and in the case of WBCDS there are additional countries.

Table 20. Regions Analysed in the Models

Regions		BUENAS	BPIE	ECOFYS'04	ECOFYS'05	ETP'08	ETP'10	3CSEP HEB	Greenpeace	HARVEY	IPCC AR4	LAUSTSEN	McKinsey	WBCSD EEB	WEO'06	WEO'08	WEO'09	WEO'10	Wuppertal
North America	USA	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	Canada	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	Latin America (Mexico)	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
South America	Brazil	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
	Argentina	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
	Chile	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
Europe	Western Europe	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	Central & Eastern Europe	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	Northern Eurasia (Russia)	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
Africa	North Africa	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
	Sub-Saharan Africa	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
Asia	Middle East	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
	East Asia (Korea, Japan)	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	East Asia (China)	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
	West Asia (Israel, Turkey)	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD
	South Asia (India)	Non-OECD				Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD	Non-OECD
Oceania	Australia, New Zealand	OECD				OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD	OECD

Legend:  OECD countries
 Non-OECD countries

In terms of result comparison, these are the end-uses that are taken into account in the models.

Table 21 presents end-uses for the buildings stock covered in the models:

- Heating,
- Cooling & ventilation,
- Hot water,
- Lighting
- And appliances.

BUENAS, ETP, Greenpeace, HARVEY, IPCC AR4, McKinsey, WBCSD, WEO and Wuppertal take all these categories into account, while BPIE and ECOFYS deal only with heating and cooling. Models presented by 3CSEP HEB and LAUSTSEN include also water heating.

Table 21. End-Uses for a Building Stock in analysed models

END-USES (Building Stock)	BUENAS	BPIE	ECOFYS'04	ECOFYS'05	ETP'08	ETP'10	3CSEP HEB	Greenpeace	HARVEY	IPCC AR4	LAUSTSEN	McKinsey	WBCSD EEB	WEO'06	WEO'08	WEO'09	WEO'10	Wuppertal
Heating	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Cooling & Ventilation	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hot water	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Lighting	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Appliances & Equipment	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

6.1 Scenarios, Assumptions and Methodologies

As it is described in chapter 0 there are various approaches to building energy modelling. Table 22 summarizes the approaches used in the analysed models.

Table 22. Approaches used in the models

Approach	BUENAS	BPIE	ECOFYS'04	ECOFYS'05	ETP'08	ETP'10	3CSEP HEB	Greenpeace	HARVEY	IPCC AR4	LAUSTSEN	McKinsey	WBCSD EEB	WEO'06	WEO'08	WEO'09	WEO'10	Wuppertal	
Bottom-Up / Top-Down																			
Bottom-Up	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Top-Down	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Component-Based / Performance-Based																			
Component-Based	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Performance-Based	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

As it is clearly seen all models chosen for comparison are built on *bottom-up* approaches. The model presented by LAUSTSEN additionally used *top-down* approaches, which classifies it as a hybrid approach. In terms of

component/performance approach a majority of models are built on a *component-based* approach, while BPIE, 3CSEP HEB, HARVEY, LAUSTSEN and WBCSD are *performance-based* models.

Table 23 presents a brief description of scenarios used in the models and their assumptions. It also provides data on projected time spans in each model; this is essential in terms of comparing data. The models also contain information on strategies and measures needed to realize presented mitigation potentials. The table also shows a brief description of methodologies and key drivers, which are the major parameters of the methodology.

Table 23.Scenarios & assumptions, strategies & measures and methodologies used in analysed models with key variables used in methodologies

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
1	BUENAS 2005 ÷ 2030	0. "Baseline" – based on International Energy Outlook (IEO) baseline. Current laws and policies remain unchanged throughout the projection period 1. "EES&L" - energy efficiency improvements	- Energy efficiency improvements associated with equipment (appliances, lighting, and HVAC) in buildings by means of Energy Efficiency Standards and Labels (EES&L)	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; 3) The analysis accounts for the relationship between projected economic development and changing equipment ownership in each region. <i>Useful energy</i> is modelled (the output of heating devices, not the energy supplied to them) to heat the household in terms of <i>heating degree days</i> . <i>Useful Energy</i> (kWh/m2) = 0.0353 x HDD	1. GDP 2. Building stock 3. Urbanization 4. Population
2	BPIE 2010 ÷ 2050	0. "BAU"- the current renovation rate remains unchanged over time until 2050 at the level of 1% per year, only 40% of European a buildings stock is renovated until 2050 1a. "Slow & Shallow" –a shallow renovation path; a slow but steady acceleration in the rate of renovation; buildings will be renovated once between 2010 and 2050 1b. "Fast & Shallow" –a shallow renovation path a rapid acceleration in the rate of renovation; buildings will be renovated once between 2010 and 2050 2. "Medium" –an intermediate renovation path; and a medium rate of renovation growth; buildings will be renovated once between 2010 and 2050 3. "Deep" - the deep renovation path with the medium rate of renovation growth; buildings will be renovated once between 2010 and 2050 4. "Two stage renovation" - buildings will be renovated twice: between 2010 and 2030 and between 2031 and 2050; until 2030: an intermediate renovation path; and a medium rate of renovation growth	- Increased buildings energy efficiency - More efficient HVAC, lighting, etc. - Renewable technologies - Decarbonisation of electricity and fossil fuels, - Reducing import dependency	The scenarios illustrate the impact on energy use and CO2 emissions at different rates (percentage of buildings renovated each year) and depths of renovation (extent of measures applied and size of resulting energy and emissions reduction) from now up to 2050. The model has assessed energy saved, CO2 saved, total investment required, energy cost savings, employment impact and a range of cost-effectiveness indicators. These assessments allow policy makers the opportunity to focus on what they consider the highest priorities. The model considers features such as the age of buildings and quality of building energy performance. The model applies different discount rates, learning curves and future energy prices (based on Eurostat and Primes forecasts) in order to derive how costs will evolve from now until 2050. Two decarbonisation pathways are considered: slow and fast.	1. Building stock 2. Energy price 3. Energy use 4. Decarbonisation
3	ECOFYS04 2002 ÷ 2015	0. "BAU" - reflects the actual trends in the development of energy efficiency in the building stock. The reduction potential can be attributed to already existing energy efficiency standards. 1. "No Energy Renovation" - retrofit without energy measures. New buildings are erected according to current building regulations and replace older buildings with lower energy efficiency standard 2. "EPBD excl. certificates" - the same cycle of building renovation as in the previous scenarios. Buildings, which are subject to the Directive, are assumed to be retrofitted according to the standards set by the Directive. 3. "EPBD>1000m ^{2a} " - equivalent to the scenario "EPBD excl. certificates" but assumes in addition that certificates lead to an increased rate of energy retrofit of 40% 4. "Extended EPBD>200m ^{2a} " - like EPBD + buildings>200m ² 5. "Extended EPBD all house types" - like "Extended EPBD>200m ^{2a} " + small buildings (<200m ²)	- Building envelope; reduced transmission loss by increased insulation of walls, roof, cellar/ground floor and lower U-value - Fuel switch to an energy carrier with a lower CO ₂ emission-factor - More efficient systems	Input to the model calculation - a database containing the building stock distinguished by climatic regions, building type/size, building age, insulation level, energy supply, energy carrier and emission factors. Calculations of the development over time of the building stock as a function of demolition rate, new building activity, renovation and energy-efficiency measures in retrofits. Building stock grouped into five standard buildings with eight insulation levels. The amount of energy saving through thermal insulation determined for the model houses has been projected to the energy consumption values in the Member States and normalized for floor space. In order to find the CO ₂ emissions the average annual efficiency of heating systems have been assumed for each energy carrier depending whether it is an old or new system.	1. Building stock 2. Energy use

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
4	ECOFYS* 2002 ÷ 2015	<p>1. "EPBD" - equivalent to the scenario "EPBD excl. certificates" but assumes in addition that certificates lead to an increased rate of energy retrofit of 40%</p> <p>2. "Extended EPBD>200m²" - like EPBD + buildings>200m²</p> <p>3. "Extended EPBD all house types" - like "Extended EPBD>200m²" + small buildings (<200m²)</p>	<ul style="list-style-type: none"> - Building envelope; reduced transmission loss by increased insulation of walls, roof, cellar/ground floor and lower U-value - Fuel switch to an energy carrier with a lower CO₂ emission-factor - More efficient systems 	<p>The energy demand for heating was calculated according to the principles of the European Standard EN 832. The influence of cooling is not taken into account.</p> <p>For the calculation of the results of retrofit measures on the building envelope two situations are compared: situation before and after retrofit. To assess the financial benefit of measure to improve the thermal resistance of the building envelope a uniform average energy price and CO₂ emission factor (including all energy carriers) has been calculated for respective climate zones.</p>	<ol style="list-style-type: none"> 1. Building stock 2. Energy use 3. Energy costs
5	ETP'08* 2005 ÷ 2050	<p>0. "Baseline" – to 2030 based on WEO'07 and extended to 2050. Only policies already formally adopted and implemented are taken into account. Governments introduce no new energy and climate policies</p> <p>1. "ACT Scenarios" - CO₂ emissions are reduced by 35% below Baseline scenario level in 2050</p> <p>2. "BLUE Scenarios" - CO₂ emissions are reduced by 43% below Baseline scenario level in 2050. Requires urgent implementation of unprecedented and far-reaching new policies in the energy sector</p>	<ol style="list-style-type: none"> 1. "ACT" 2. "BLUE" <ul style="list-style-type: none"> - Use of available today technologies - Use of new and emerging technologies - Conversion of buildings to very low energy consumption, and even "zero" energy buildings - Heat pumps, solar heating - Highly efficient appliances, lighting - Fuel shift to renewables - Low-carbon electricity - Electricity is largely decarbonized in 2050 	<p>The analysis is based on a combination of four approaches:</p> <ol style="list-style-type: none"> 1. Global perspective -> based on WEO-2007 2. Country perspective -> MARKAL and TIMES models are used to assess the potential for CO₂ emissions reduction 3. Sector perspective -> based on sectors model which provide detailed simulations 4. Technology perspective -> the present and future technology options <p>ETP model belongs to MARKAL family models of bottom-up modelling tools.</p> <p>It uses cost-optimization to identify least cost mixes of technologies and fuels to meet energy service demand, given constraints like the availability of natural resources.</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. Cultural factors 4. Buildings stock 5. Energy price
6	ETP'10 2007 ÷ 2050	<p>0. "Baseline" – to 2030 based on WEO'09 and extended to 2050. Only policies already formally adopted and implemented are taken into account. Governments introduce no new energy and climate policies</p> <p>1. "BLUE Map" - sets the goal of halving global energy-related CO₂ emissions by 2050 (compared to 2005 levels) and examines the least-cost means of achieving that goal through the deployment of existing and new low-carbon technologies</p> <p>2. "BLUE CHP" - more rapid declines in the costs of fuel-cell combined heat and power (CHP) units using hydrogen</p> <p>3. "BLUE Solar Thermal" - that low-cost compact thermal storage is available by 2020 and that system costs come down more rapidly in the short term</p> <p>4. "BLUE Heat Pumps" - the development of ultra-high efficiency air-conditioners and faster cost reductions for space and water heating applications</p>	<ul style="list-style-type: none"> - Intelligent building design - High-performance buildings envelopes - Highly efficient heating, ventilation and air-conditioning systems (HVAC) - Highly efficient water heating systems - Highly efficient appliances and lighting - Efficient cook stoves - CO₂free technologies 	<p>The analysis is based on a combination of four approaches:</p> <ol style="list-style-type: none"> 1. Global perspective -> based on WEO-2007 2. Country perspective -> MARKAL and TIMES models are used to assess the potential for CO₂ emissions reduction 3. Sector perspective -> based on sectors model which provide detailed simulations 4. Technology perspective -> the present and future technology options <p>ETP model belongs to MARKAL family models of bottom-up modelling tools. It uses cost-optimization to identify least cost mixes of technologies and fuels to meet energy service demand, given constraints like the availability of natural resources.</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. Cultural factors 4. Buildings stock 5. Energy price

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
7	3CSEP HEB 2005 ÷ 2050	<p>0. "Frozen Efficiency Scenario" as Baseline Scenario - assumes that the energy performance of new and retrofit buildings do not improve as compared to their 2005 levels. Advanced new buildings are assumed only for Western Europe. Advanced retrofit buildings are not considered in any region</p> <p>1. "Moderate Efficiency Scenario" - illustrates the potential lock-in effect in building infrastructure that can be caused by accelerated and major policy efforts that compromise in performance levels</p> <p>2. "Deep Efficiency Scenario " - the best possible building design and building practices are enforced worldwide for new and renovated buildings</p>	<p>Leaves the freedom to the architects and engineers in choosing the best energy efficiency measures, as it takes into account the overall buildings energy performance</p>	<p>The model considers buildings as entire complex systems and not as a sum of their components. Concretely, national and regional building energy consumption changes are not modelled on the basis of individual energy-efficiency measures, but are calculated on the basis of marker exemplary buildings. The associated additional investment costs are used in cost calculations.</p> <p>Final energy consumption is calculated from the total floor area for a region/country, climate zone and building type with varying energy intensities among different building vintages.</p> <p>The building floor area is a primary variable, a model for floor area was constructed.</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. Energy Use 4. Technological Development 5. Building stock
8	Greenpeace 2007 ÷ 2050	<p>0. "Reference" - based on WEO 2009</p> <p>1. "[R]evolution" - a target to reduce energy related CO2 emissions by 50%, from their 1990 levels (down to a level of around 10 Gigatonnes per year by 2050)</p> <p>2. "Advanced [R]evolution" - a target to reduce energy related CO2 emissions by 80%, from their 1990 levels</p>	<ol style="list-style-type: none"> 1. "[R]evolution" <ul style="list-style-type: none"> - Significant efforts to fully exploit the large potential for energy efficiency - All cost-effective renewable energy sources for heat and electricity generation - Production of bio fuels - Energy efficient equipment 2. "Advanced [R]evolution" <ul style="list-style-type: none"> - Renewable energy sources (especially solar photovoltaic, wind and concentrating solar power plants) - Thermal insulation - Better buildings design - Replacement of old style electrical heating systems by renewable heat production 	<p>Three scenarios up to the year 2050 are outlined in this report: a Reference scenario, an Energy [R]evolution scenario with a target to reduce energy related CO2 emissions by 50%, from their 1990 levels, and an advanced Energy [R]evolution version which envisages a fall of more than 80% in CO2 by 2050.</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. CO₂ intensity 4. Energy efficiency

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
9	HARVEY 2005 ÷ 2050	<ol style="list-style-type: none"> 1. "High population, high GDP/P, low EI improvement, low C-free power" 2. "High population, high GDP/P, high EI improvement, low C-free power" 2a. "Low population, low GDP/P, low EI improvement, low C-free power" 3. "High population, high GDP/P, high EI improvement, high C-free power" 3a. "Low population, low GDP/P, high EI improvement, low C-free power" 4. "Low population, low GDP/P, high EI improvement, high C-free power" 	<ul style="list-style-type: none"> - High-performance thermal envelope - Maximize the use of passive solar energy for heating, ventilation and day lighting - Energy-efficient equipment and especially energy-efficient systems - All equipment and systems are properly commissioned and that building operators and occupants understand how they are to be used - To engender enlightened occupant behaviour 	<p>The key parameters in the accounting scheme are:</p> <ol style="list-style-type: none"> 1. the energy intensities of new and renovated buildings at the beginning of the transition period compared to the average energy intensity of all buildings that existed in 2005; 2. the energy intensities of new and renovated buildings at the end of the transition period compared to the average energy intensity of all buildings that existed in 2005; 3. the years at which the transition from the initial energy intensities to the final energy intensities starts and is completed. <p>CO2 emission is decomposed as the product of four factors: $CO2 = P \times GDP/P \times \text{energy intensity} \times \text{carbon intensity}$ [$P \times (\\$/P) \times (MJ/\\$) \times (kgC/MJ)$] P - the world population GDP - represents national, regional or total world economic output (depending on the scale of analysis) Energy intensity - an economic energy intensity → the primary energy used per unit of economic output Carbon intensity - carbon emission per unit of primary energy.</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. CO₂ intensity 4. Energy intensity 5. Building stock
10	IPCC AR4 2004 ÷ 2030	<ol style="list-style-type: none"> 0. "Baseline" – between IPCC A1B and B2 (SRES) 1. "CO₂ cost category US\$/tCO₂ <0" 2. "CO₂ cost category US\$/tCO₂ 0-20" 3. "CO₂ cost category US\$/tCO₂ 20-100" 	<ul style="list-style-type: none"> - Reducing energy consumption and embodied energy in buildings: <ul style="list-style-type: none"> *efficient lighting and day lighting, *more efficient electrical appliances and heating and cooling devices, *improved insulation, *passive and active solar design for heating and cooling, alternative refrigeration fluids, *recovery and recycle of fluorinated gases, *integrated design of commercial buildings, *solar PV integrated in buildings, *implement commissioning and improve operations and maintenance, *strong policy support, - Switching to low-carbon fuels, including a higher share of renewable energy - Controlling emissions of non-CO₂ GHG gases 	<p>The assumptions and results of 80 studies (based on bottom-up approach) were identified. Next, the results were aggregated into global and regional potential estimates, as a function of CO2 costs. Analogously, CO2 potentials as a percentage of the baseline in cost categories (US\$/tCO₂: (<0); (0;20); (20;100)) were calculated based on population weighted average potentials in the sub-regions for each cost category</p>	<ol style="list-style-type: none"> 1. Population 2. GDP 3. CO₂ intensity 4. Energy intensity 5. Building stock

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
11 LAUSTSEN	2010 ÷ 2050	<p>0. "Business As Usual" - takes into account those government policies and measures which were adopted by 2005. No further energy efficiency policies are assumed</p> <p>1. "Factor 4" – energy consumption in buildings is reduced by 75% or more by 2050</p>	<ul style="list-style-type: none"> - The best buildings envelope - Orientation and shading - Ventilation / infiltration - Reducing heating and cooling loads - More efficient HVAC systems - Use of passive energy - Renewable energy - More efficient lighting - Policy support 	<p>The model combines top-down and bottom-up approach, using data gathered globally. The objective is to see the impact of implementing appropriate best practice cases globally. There was an assumption that effective measures that could be applied on a global scale between now and 2050 currently are in progress.</p> <p>Energy use is broken down by specific uses per square meter, based on the actual space as reported, or on estimates when directly reported data are not available. Parameters to account for growth in comfort, increases or decreases in building stocks, reductions in consumption and other changes can be applied to each type of consumption in residential and commercial buildings in each region. The model is based on energy consumption for each region.</p> <p>Estimates of energy consumption in residential and commercial sectors are done separately in each of these different regions. Similarly the trends for change in comfort levels, impacts of baseline policies and assumptions about the development of new buildings or the replacement of existing buildings have been set for each region individually. The data needed to develop scenarios, have been drawn from the IEA's annual energy statistics and the energy balance in OECD and non-OECD countries.</p>	<ol style="list-style-type: none"> 1. Population 2. Building stock 3. Energy intensity
12 McKinsey	2005 ÷ 2030	<p>0. "Business-As-Usual" – emissions trajectory over time (how emissions might develop under current policies, reference case). (IEA, EPA, and Houghton) for 2030 BAU emissions</p> <p>1. "Full Technical Potential" - based on full deployment rates of GHG-efficient technologies/measures per region and over time, with a focus on measures up to €60 per tCO₂.</p>	<ul style="list-style-type: none"> - Improve buildings air tightness, - High efficiency door and windows - Insulation of attic and wall cavities - Mechanical ventilation - Retrofit to "passive" standard - Heat recovery - Heat pumps - Solar heating - High efficient appliances and electronics - Lighting - Water heating 	<p>Buildings are clustered into four groups of levers: HVAC, water heating, lighting and appliances. Items are replaced/retrofitted once they reach end of useful life or when retrofits/remodels already take place. A guiding principle in buildings sector analysis is to reduce overall heat and power demand through energy-efficiency levers (e.g. passive houses).</p>	<ol style="list-style-type: none"> 1. GDP 2. Energy price 3. Population

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
13	WBCSD EEB * 2005 ÷ 2050	<p>0. "Current Policies" - complacency and inaction leading to a failure to tackle climate change. It assumes continuation of current trends in urbanization, economic growth and energy use, with no sustained attempt to address energy efficiency.</p> <p>1. "Sleep walking" – achieves occasional advances, but these are soon lost and total energy consumption is much higher by 2050. The number of low-energy buildings grows erratically and slowly. This scenario envisages a continuation of current trends in urbanization, economic growth and energy use, with no sustained attempt to address energy efficiency. It is applied in the countries that do not do anything with regards to energy in buildings. I applies to 50% of countries in the world</p> <p>2. "Too little too late" – the development of low-energy buildings is still too slow, with energy consumption returning to current levels by 2050. There is more investment in energy efficient buildings and an acceleration of technological development. This scenario is applied in the countries which are doing something with energy in buildings, but their influence on It applies to the other 50% of countries</p> <p>3. "Transformation" - coordinated, intensive action that transforms the building sector and contributes proportionately to solving climate change. It includes the substantial energy savings necessary across the building stock. Tougher building codes are enforced for new and existing buildings; new energy and climate change policies are implemented; new design approaches and technologies are developed and applied; new skills are learned; and new financing mechanisms emerge. These are the actions that need to be taken in order to stay within the 2°C warming.</p>	<ul style="list-style-type: none"> - The right financial mechanisms - A holistic design approach, from city level to individual buildings - Integrated buildings design - Behavioural changes - Policy support 	<p>The model relies on a submarket approach to evaluate carbon generation and total energy usage in the context of adoption preferences and building system interactions. Submarkets are defined by building end use and location (climate). The EEB model answers the question on how to achieve the transformation scenario through market mechanisms and policy intervention</p> <p>It simulates the actions of decision-makers faced with a choice of investments in a range of design and construction options, projecting the market response to a mix of financial, technical, behavioural and policy packages. The energy consumption of each reference case and each potential design and construction package was calculated using a commercially available building energy analysis tool, which accounted for all complex building system interactions.</p> <p>For each type of buildings, the list of technological options (wall insulation, double glazing, heat pumps, etc.) including equipment and labor costs is prepared. Next dynamic energy modelling is done for each option separately, basing on a performance approach.</p>	<ol style="list-style-type: none"> 1. Payback period 2. Policies 3. New buildings 4. Capital availability
14	WEO'06 * 2004 ÷ 2030	<p>0. "Reference Scenario" - governments do nothing more to affect underlying trends in energy demand and supply. Only those government policies and measures that were adopted by mid-2006 are taken into account.</p> <p>1. "Alternative Policy Scenario" - policies and measures that countries are currently considering are adopted and implemented taking account of technical and cost factors, the political context and market barriers.</p>	<ul style="list-style-type: none"> - The right financial mechanisms - A holistic design approach, from city level to individual buildings - Integrated design, incentives that stimulate whole building - Behavioural changes These three have to be supported by policy frameworks, including specific regulations, taxes and subsidies, education and training, - More efficient electrical appliances - More efficient lighting - More efficient air-conditioning - Better insulation - More efficient HVAC - Solar energy - Policy support 	<p>Based on the WEM mode. The WEM makes use of a wide range of software, including specific database management tools, econometric software and simulation programs.</p> <p>In residential sector the energy consumption related to each end use is computed as the product of an intensity variable and an activity variable: the housing surface, the dwelling occupancy and the stock of appliances.</p> <p>Energy demand is a function of such variables as:</p> <ul style="list-style-type: none"> - Activity variables (GDP) - End-user process (for each sector and WEM region, a representative price (usually a weighted average) is derived taking into account the product mix in final consumption and differences between countries. International price assumptions are then applied to derive average pre-tax prices for coal, oil, and gas over the projection period) - Other variables (are used to take into account structural and 	<ol style="list-style-type: none"> 1. Population 2. GDP 3. CO₂ intensity 4. Energy prices 5. Building stock 6. Technological development

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
15	WEO'08 * 2006 ÷ 2030	<p>0. "Reference Scenario" - a future based on established trends and policies, without new initiatives by governments on energy security or climate change.</p> <p>1. "550 Policy Scenario"- assumes long-term stabilization of greenhouse-gas concentration at 550 parts per million of CO₂ equivalent. It equates to an increase in global temperature of approximately 3°C. It involves a plateauing of greenhouse-gas emissions by 2020 and reductions soon after.</p> <p>2. "450 Policy Scenario" - assumes long-term stabilization of greenhouse-gas concentration at 450 parts per million of CO₂ equivalent. It equates to an increase in global temperature of approximately 2°C. It involves much more substantial reductions after 2020.</p>	<p>1. "550"</p> <ul style="list-style-type: none"> - Full implementation of policies now under consideration in all countries (policies on lighting, electric appliances, space heating, water heating, cooking and air conditioning) - Better-insulated and designed buildings, - Solar and biomass for space and water heating - In OECD+ countries, equipment standards, building codes, building energy certification and voluntary measures are taken into account <p>2. "450" – like in WEO'09</p>		technological changes, saturation effects or other important drivers)
16	WEO'09 * 2007 ÷ 2030	<p>0. "Current Policies Scenario" - only policies already formally adopted and implemented are taken into account</p> <p>1. "New Policy Scenario" - assumes the introduction of new measures (but on a relatively cautious basis) to implement the broad policy commitments that have already been announced, including national pledges to reduce greenhouse-gas emissions and, in certain countries, plans to phase out fossil energy subsidies.</p> <p>2. "450 Scenario" - sets out an energy pathway consistent with the goal of limiting the global increase in average temperature to 2°C, which would require the concentration of greenhouse gases in the atmosphere to be limited to around 450 parts per million of carbon-dioxide equivalent (ppm CO₂-eq).</p>	<p>2. "450"</p> <ul style="list-style-type: none"> - Full implementation of policies now under consideration in all countries (policies on lighting, electric appliances, space heating, water heating, cooking and air conditioning) - Improvements in the efficiency of appliances - Improvements in machinery - Switch from less-efficient incandescent lamps to compact fluorescent lamps for lighting, - A massive shift to best available technologies for appliances, - Solar power for water and space heating - Substantial share of low-energy or low-carbon buildings in new building in the OECD+. 		
17	WEO'10 2008 ÷ 2035	<p>0. "Current Policies Scenario" - only policies already formally adopted and implemented are taken into account</p> <p>1. "New Policy Scenario" - assumes the introduction of new measures (but on a relatively cautious basis) to implement the broad policy commitments that have already been announced, including national pledges to reduce greenhouse-gas emissions and, in certain countries, plans to phase out fossil energy subsidies.</p> <p>2. "450 Scenario" - sets out an energy pathway consistent with the goal of limiting the global increase in average temperature to 2°C, which would require the concentration of greenhouse gases in the atmosphere to be limited to around 450 parts per million of carbon-dioxide equivalent (ppm CO₂-eq).</p>	<ul style="list-style-type: none"> - Strong policy intervention and measures to reduce emissions, especially after 2020 - Net-zero energy buildings - Zero-carbon footprint buildings - Mandatory building code standards - More strict requirements for appliances and equipment in buildings 		

Model	Time span	Scenarios & Assumptions	Strategies & Measures	Methodology	Key drivers
18 Wuppertal	(1990) 2005 ÷ 2020	<p>0. "Business-as-usual Scenario" - assumes continuance of existing policies and measures with no specific emphasis on climate and energy policies. This was based mainly on data and assumptions made in the most recent energy projections for Europe.</p> <p>1. "Policies and Measures Scenario, P&M" –considers the potential to increase energy efficiency and market penetration of renewable energies, a fuel switch to less carbon-intensive fossil fuels such as natural gas, and ways to mitigate rapidly increasing demand, particularly in the transport sector. It assumes a moratorium on new nuclear power plants and compliance with on going nuclear phase-out.</p>	<ul style="list-style-type: none"> - Today's best available technology will be the average fleet value in 2020 - Three-quarters of all electric light bulbs are substituted by compact fluorescent lamps -Improving energy efficiency of HVAC systems - Low-energy buildings for new developments - Highly efficient appliances 	<p>The strategies and assumptions are based on evaluation and extrapolation of detailed analyses in all sectors, for many countries, for important energy-using goods and appliances. In the scenario analysis no explicit ranking and selection of GHG mitigation potentials and strategies by cost criteria has been made, due to the problematic nature with regard to the different cost and benefit functions of actors in different countries and sectors and under different perspectives (e.g. micro-economic: company level; macro-economic: state level). Instead, potentials were selected with regard to their cost-efficiency (first on micro / company, then on macro / national level) and strategies were based in general on an implementation of about 80% of the available macro-economic potentials; e.g. the potentials which are cost efficient at a national level – calculated with long-term real interest rates typically between 3 and 5% and payback times equal to economic lifetimes of investments. Policies and strategies have been selected using expert knowledge rather than mathematical optimization algorithms</p> <p>This system uses a technology-oriented, sectoral, bottom-up approach. Corresponding to its relevance for GHG-emissions, the energy sector is modelled with the greatest detail using appliance or end-use specific sub-models for every demand sector (households, tertiary, industry, transport) and a purpose-oriented model of the transformation sector. GHG emissions in the energy sector are calculated based on the final and the primary energy balance. CH₄ and N₂O emissions in the energy sector are calculated by sub-sector using a simplified approach based on current sector-specific implied emission factors. The system applies a heuristic (expert-based) approach in order to formulate potentials and strategies and in order to estimate market penetration rates of new technologies, market shares of fuels etc. The geographical breakdown of the scenario analysis carried out here is by the EU15member states and new member states (NMS). For these two groups, specific assumptions on potentials, strategies, policies and measures have been made respectively. The basic data, economic assumptions and the main results for the BAU scenario have been derived from the latest available EU energy and transport projections.</p>	<ol style="list-style-type: none"> 1. Micro- and macro – economic potentials 2. Pay-back 3. Final energy 4. Primary energy

* Results for these models are not presented on the charts

The models list various strategies and measures to realize mitigation potential in the analysed sectors. In the building sector the most commonly mentioned strategies are:

- Building envelope changes (insulation of walls, roofs, slabs, ceilings, windows with lower U-value),
- More efficient HVAC systems, often names as *technology development* (heat pumps),
- More efficient water heating systems (using solar systems),
- Passive energy (PV, BIPV, solar panels),
- Fuel switch to renewables and to energy carriers with lower CO₂ emission factor (including low carbon electricity),
- More efficient lighting,
- More efficient appliances,
- Conversion to low-energy and zero-energy buildings,
- Integrated design approach in buildings design,
- Behavioural changes,
- Controlling emissions,
- Strong policy support.

6.2 Results Comparison

The majority of analysed models concerned final energy use/demand and/or CO₂ emissions and/or costs (investment/savings). For clarity kind of results presented in models are summarized in the table below.

Table 24. Kind of modelled units in the analysed models

Modelled units	BUENAS	BPIE	ECOFYS'04	ECOFYS'05	ETP'08	ETP'10	3CSEP HEB	Greenpeace	HARVEY	IPCC AR4	LAUSTSEN	McKinsey	WBCSD EEB	WEO'06	WEO'08	WEO'09	WEO'10	Wuppertal	
Final Energy																			
CO ₂ emissions																			
Costs																			

The results are presented only for those scenarios, for which the greatest mitigation potential is possible to achieve. For greater clarity graphs concern data only for the latest version of model. This applies to ECOFYS, ETP and WEO; for both ETP and WEO the results are presented based on a model version from 2010.

As it was presented before, the analysed models cover various end-uses. Thus it's necessary to distinguish between those, which cover all of them, and those,

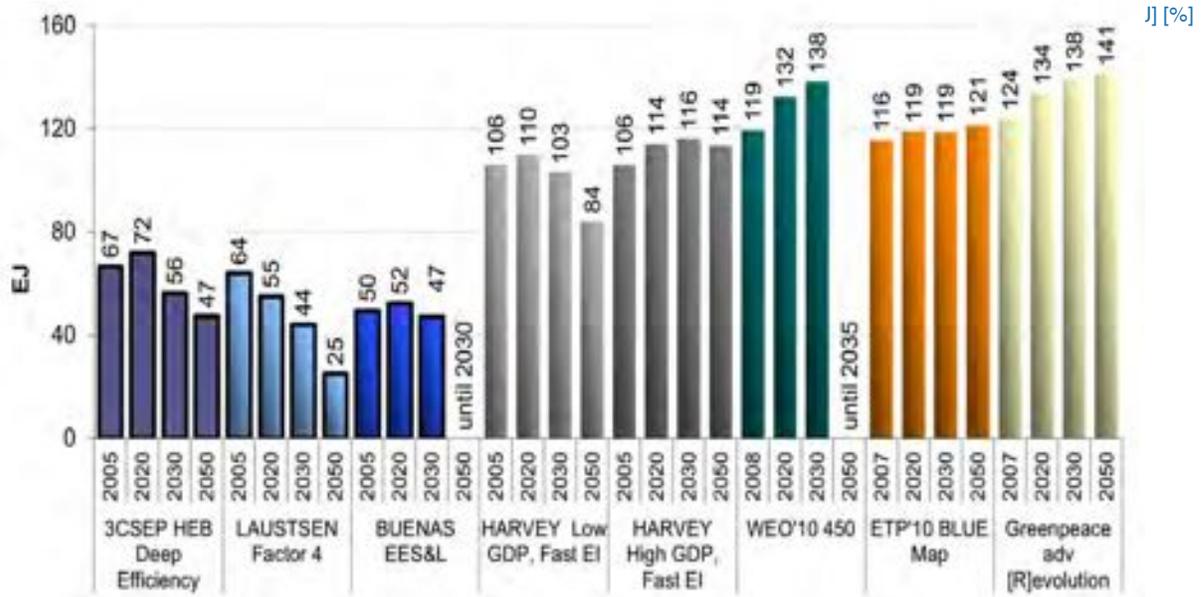
which cover just some end-uses. ECOFYS presents results for space heating only, while BPIE additionally covers space cooling. 3CSEP HEB and LAUSTSEN models include also water heating. The rest of the models cover all end-uses in buildings stock, those are: heating, cooling& ventilation, water heating, lighting and appliances. Thus they are ranked by increasing enduses coverage and are also grouped by time span (Table 25).

Table 25. Analysed Models and Scenarios

End-uses	Regions covered in the models	Scenario	End year			
Heating Cooling	Europe	*ECOFYS'05	Baseline Extended EPBD all	2015		
		BPIE	Baseline Two-stage renovation	2050		
Heating Cooling Water heating	World	3CSEP HEB	Baseline Deep Efficiency	2050		
		LAUSTSEN	Baseline Factor 4			
Heating Cooling Water heating Lightning Appliances	World	BUENAS	Baseline EES&L	2030 (2035)		
		IPCC AR4	Baseline cost: 20-100			
		McKinsey	Baseline Abatement			
		WEO'10	Baseline 450			
		ETP'10	Baseline BLUE Map			
	Europe	Wuppertal	Greenpeace	Baseline adv [R]evolution	2050	
			HARVEY	Baseline High GDP, Slow EI High GDP, Fast EI		
			Wuppertal	Baseline P&M		2020

* In this model results are presented only for space heating

To make comparison easier the bars have different filling effects that are presented in Table 29. The bars with borderlines only (no colour inside) present models which cover only space heating - ECOFYS. The bars filled with downward diagonal lines represent the models that cover space heating and cooling (BPIE). The bars filled with solid colour with thick borderline stand for the models that cover heating, cooling and water heating (3CSEP HEB and LAUSTSEN). Those ones filled with solid colours present values for total final energy for all end-uses.



6.2.1 Final Energy: World

Erreur ! Source du renvoi introuvable. presents total final energy use in building stock in base year, in 2020, 2030 and 2050 respectively. Figure presents linear trend of final energy use for mitigation and baselines scenarios until 2050 separately for models that cover space heating & cooling and water heating and for those which cover all end-uses.

Figure presents a closer look at final energy use in 2030 and 2050 for both baseline and mitigation scenarios.

and Figure show final energy difference between 2010÷2030 and 2010÷2050 respectively. They also present differences between baseline and mitigation scenario in 2030 and 2050. Results are presented both in [EJ] and [%]. In the HARVEY model, the worst mitigation scenario was assumed as a baseline one; final energy values for baseline were not reported in the publications. For 3CSEP HEB model the “Frozen Efficiency” scenario was assumed to represent the “Baseline” scenario. For BUNAS model, it was possible to extract the results only for space heating & cooling and water heating. Thus on the charts below, results presented for this model present those three end-uses only.

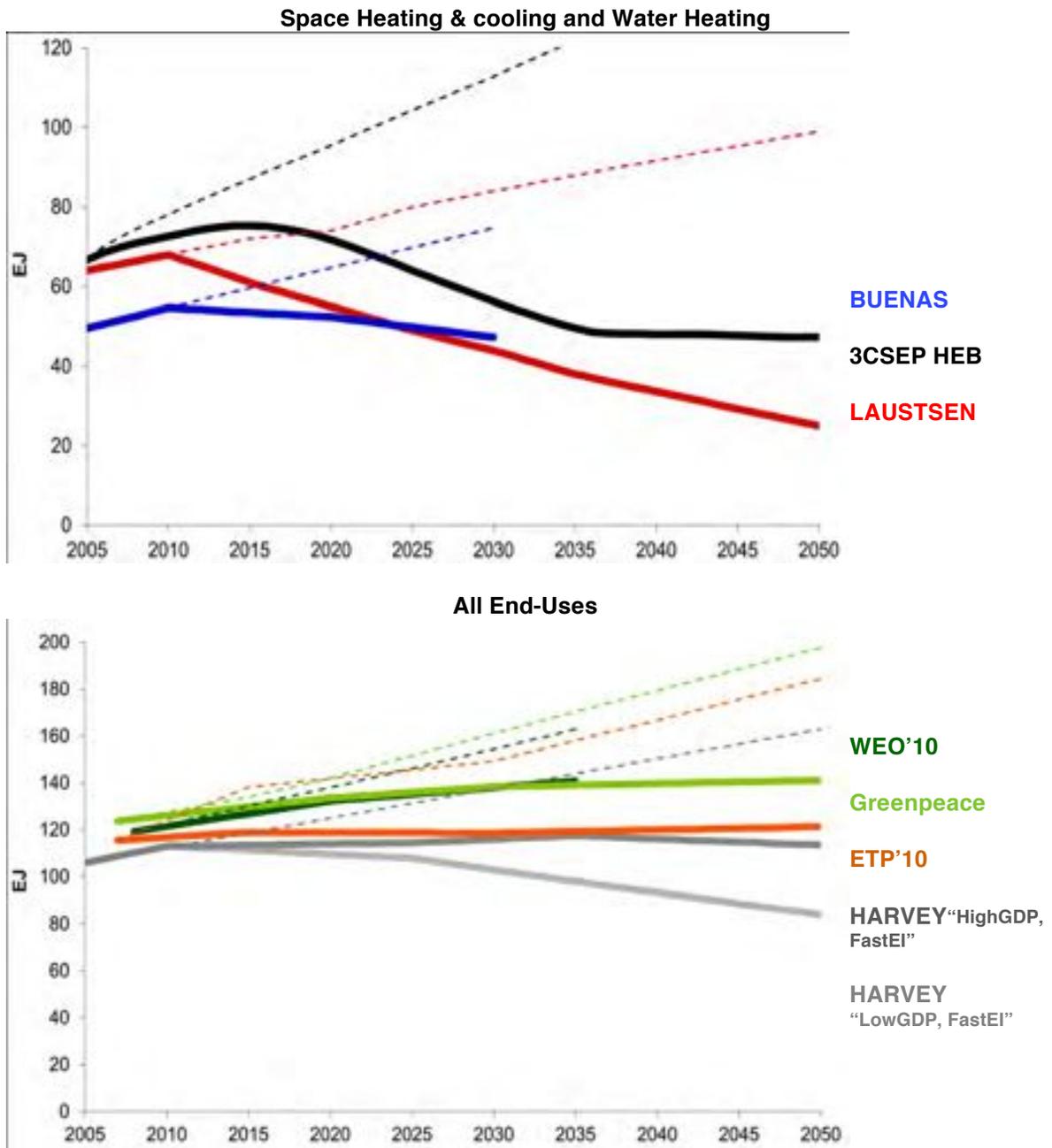
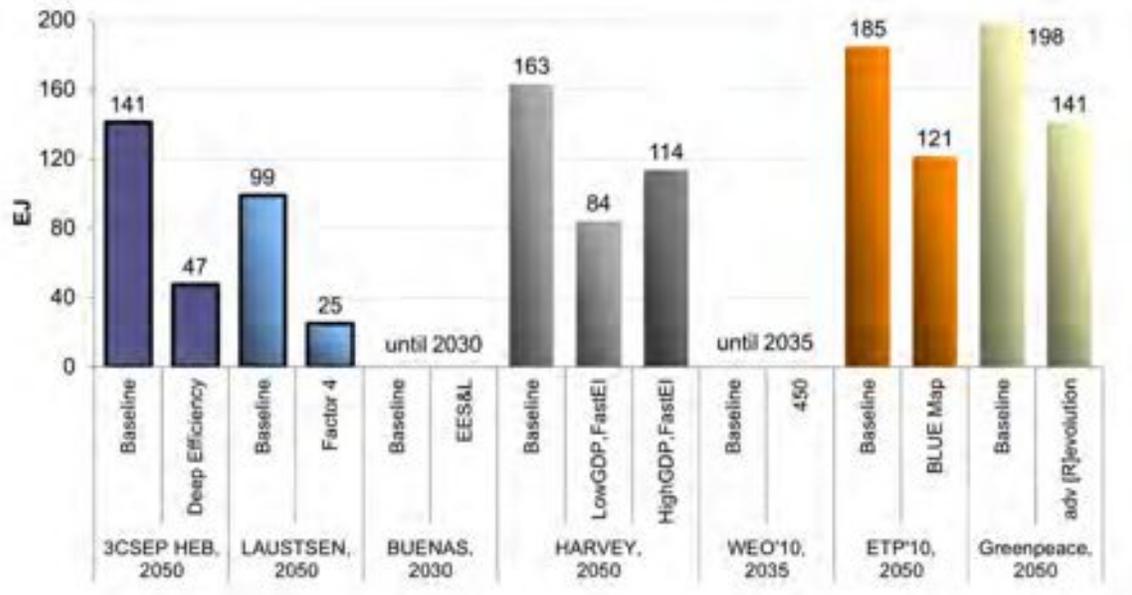
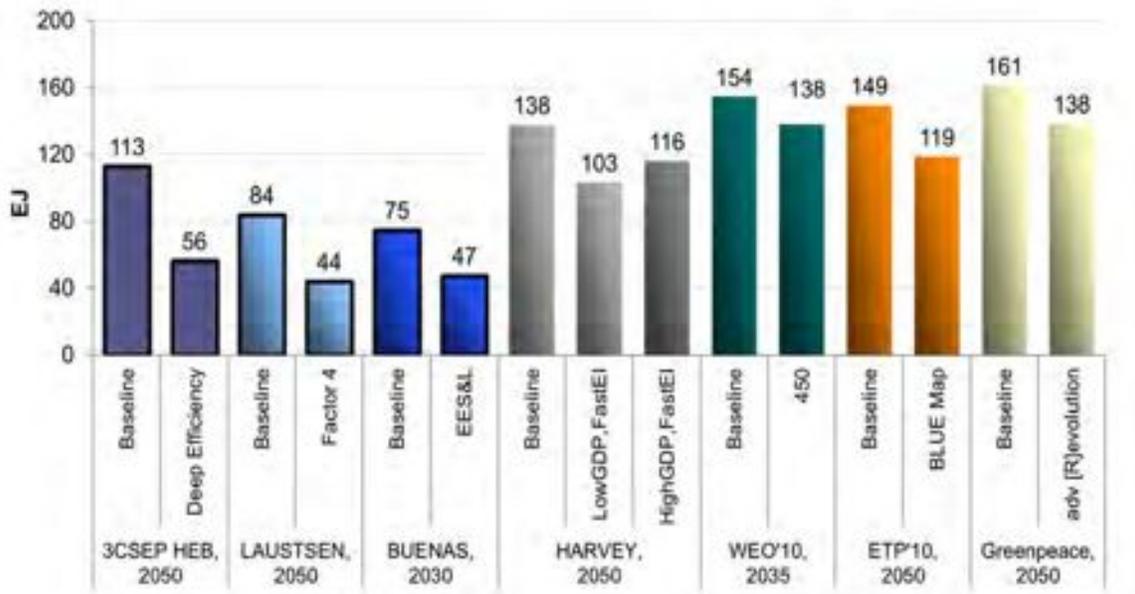


Figure 45. Linear trend of final energy use for mitigation (thick lines) and baselines (thin dashed lines) scenarios 2050 [EJ] for models that cover: a) space heating & cooling and water heating, b) all end-uses



a) final energy use in 2030 for Baseline and Mitigation scenarios



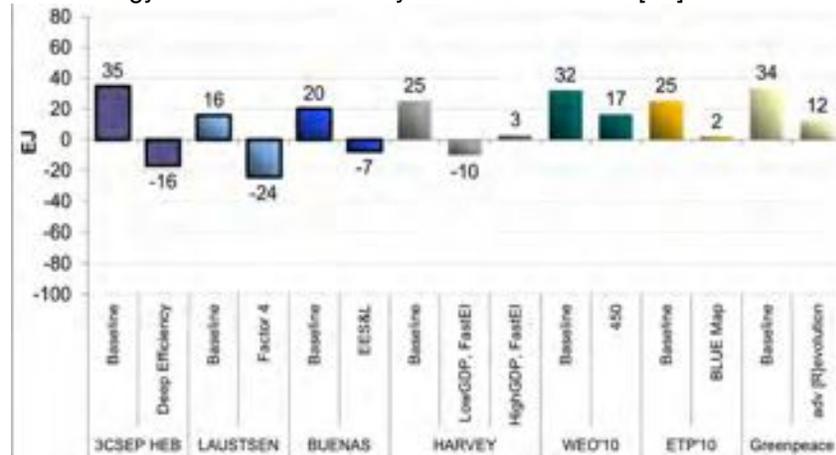
b) final energy use in 2050 for Baseline and Mitigation scenarios

H+C+W
 All end-uses

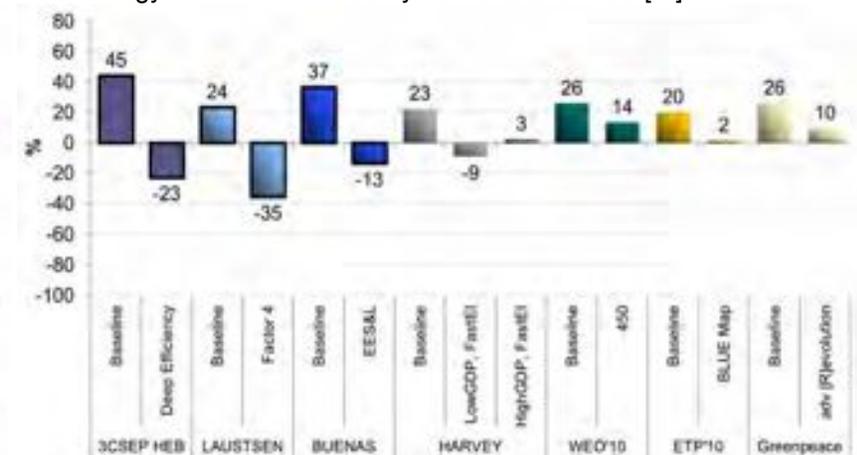
Figure 46. Final energy use for Baseline and Mitigation scenarios in 2030 and 2050 [EJ]

Figure 47. Final energy use difference between: a) 2010 and 2030 [EJ] [%], b) baseline and mitigation scenario in 2030 [EJ] [%]

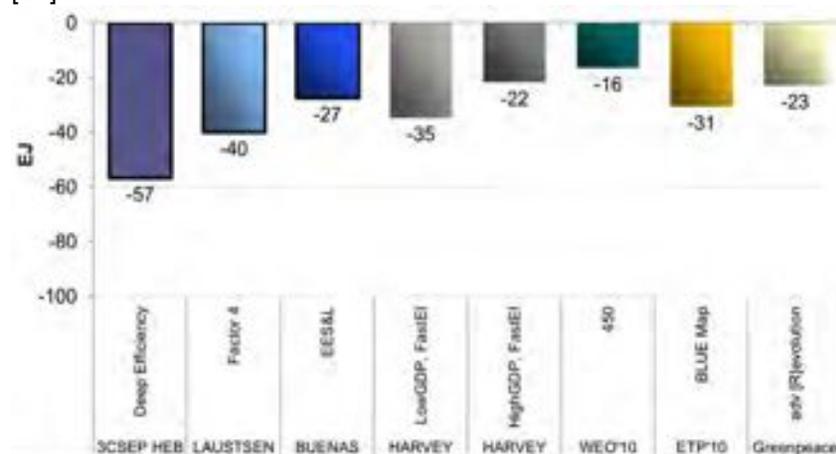
Final energy difference between year 2010 and 2030 [EJ]



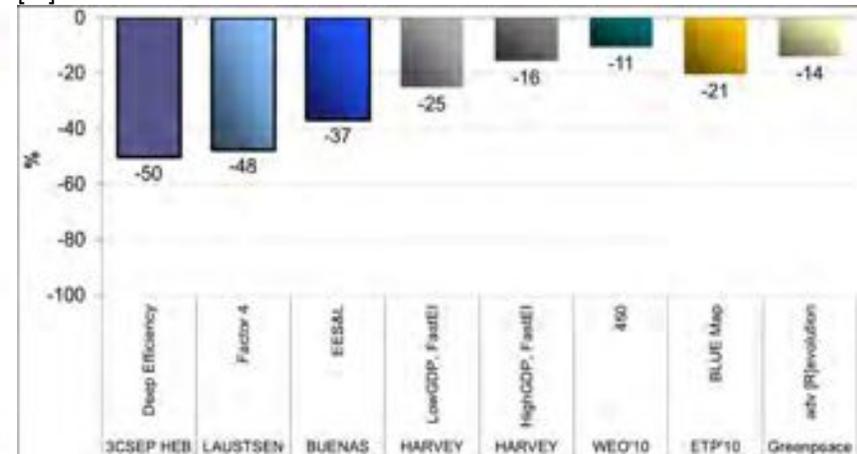
Final energy difference between year 2010 and 2030 [%]



Final energy difference between baseline and mitigation scenario in 2030 [EJ]



Final energy difference between baseline and mitigation scenario in 2030 [%]



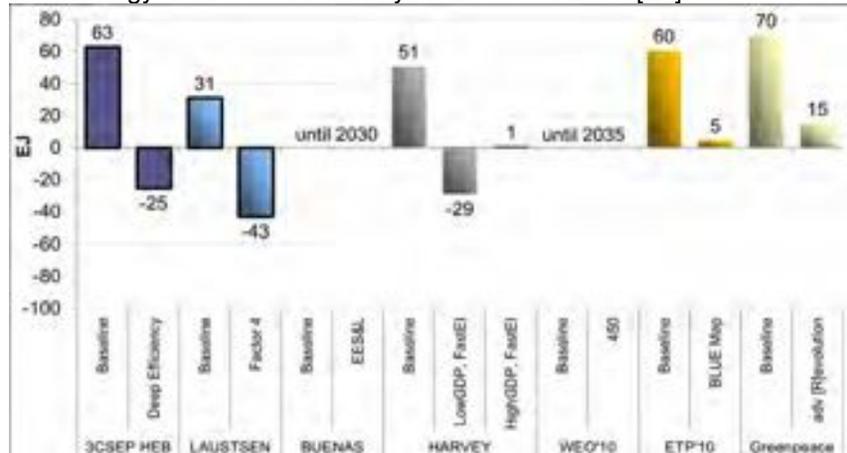
H+C+W

All end-uses

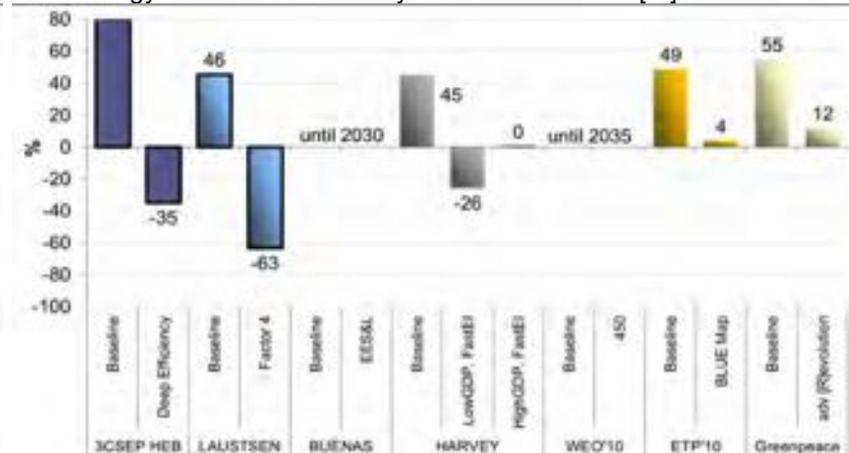
H+C+W
 All end-uses

Figure 48. Final energy use difference between: a) 2010 and 2050 [EJ] [%], b) baseline and mitigation scenario in 2050 [EJ] [%]

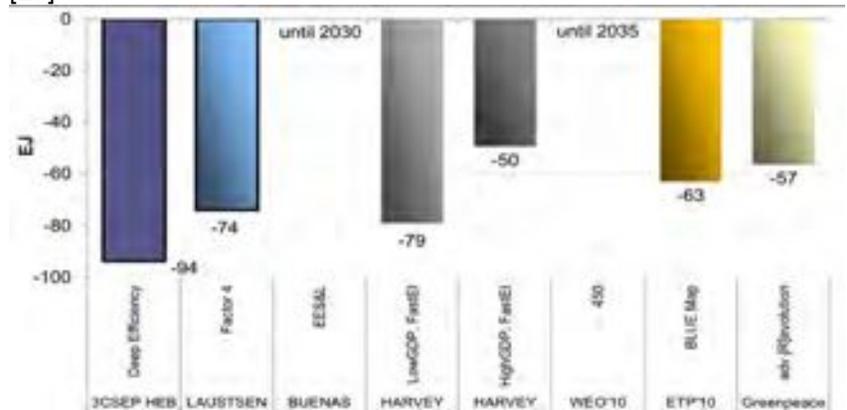
Final energy difference between year 2010 and 2050 [EJ]



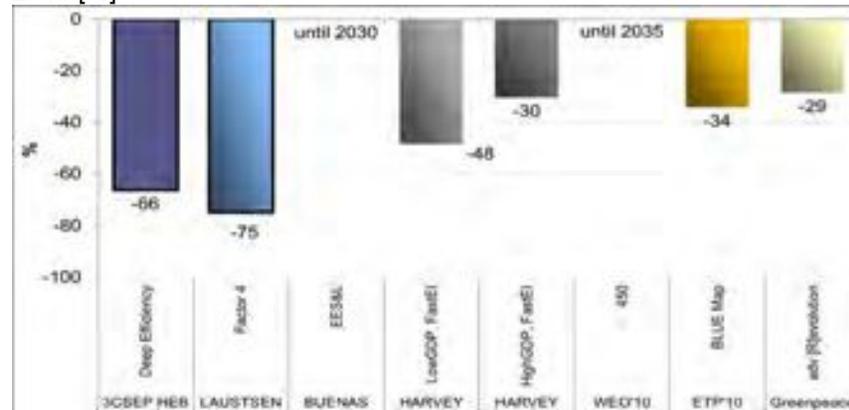
Final energy difference between year 2010 and 2050 [%]



Final energy difference between baseline and mitigation scenario in 2050 [EJ]



Final energy difference between baseline and mitigation scenario in 2050 [%]



Final energy use trends

The best mitigation scenarios of the models that cover space heating and cooling and water heating, project a decrease in final energy use in reference to their base year (see Figure 48). While almost all analysed best mitigation scenarios of the models that cover all end-uses (space heating and cooling, water heating, lighting and appliances), project an increase in final energy use in reference to their base year. Here, only HARVEY model (“Low GDP, Fast EI” scenario) projects a decrease of final energy use in reference to 2005.

Final energy use change between 2010 and 2030 year

This section analyses the results of the differences between 2010 and 2030 (see Figure 47). As it was explained above, the year 2010 was chosen as the reference year.

In models that cover three end-uses: space heating & cooling and water heating, these are: 3CSEP HEB, LAUSTSEN and BUENAS, final energy between 2010 and 2030 for baseline scenario is projected to increase by 35 [EJ], 16 [EJ] and 20 [EJ], while their mitigation scenarios will decrease by 16 [EJ] (23%), 24 [EJ] (35%) and 7 [EJ] (13%) respectively.

Final energy use for baseline scenario increases by an average value of about 30 [EJ] in the models that cover all end-uses (HARVEY, WEO’10, ETP’10 and Greenpeace). WEO’10 and Greenpeace models show similar values of final energy increase in 2030, this is: 17 [EJ] (14%) and 12 [EJ] (10%). Regarding the HARVEY (“High GDP, Fast EI” scenario) and ETP’10 (“Blue Map” scenario) models, mitigation scenarios also project similar values of final energy increase in reference to 2010: around 3 [EJ] (3%). From the models which cover all end-uses, only HARVEY “Low GDP, Fast EI” scenario projects a final energy decrease in 2030 in reference to 2010, by 10 [EJ] (9%).

Final energy use change between baseline and mitigation scenario in 2030 year

In models that cover space heating & cooling and water heating (3CSEP HEB, LAUSTSEN and BUENAS), the final energy use between their baselines and best mitigation scenarios is decreased by 57 [EJ], 40 [EJ] and 27 [EJ], which means a reduction by 50%, 48% and 37% respectively. In the models which cover all end-uses, the largest mitigation is presented by HARVEY “Low GDP, Fast EI” and ETP’10. Here final energy use in 2030 decreases by 35 [EJ] (25%) and 31 [EJ] (21%) in reference to the baseline scenario. HARVEY “High GDP, Fast EI”, WEO’10 and Greenpeace models, project the decrease of final energy consumption by 22 [EJ], 16 [EJ] and 23 [EJ], which is 16%, 11% and 14% respectively.

Final energy use change between 2010 and 2050 year

This section analyses the results of the differences between 2010 and 2050 (Figure). In models that cover three end-uses: space heating & cooling and water heating, these are: 3CSEP HEB and LAUSTSEN models, final energy for the time span 2010÷2050 for baseline scenario is projected to increase by 63 [EJ] and 31 [EJ], while their mitigation scenarios will decrease by 25 [EJ] (35%) and 43 [EJ] (63%) respectively.

In the models that cover all end-uses (HARVEY, ETP'10 and Greenpeace), final energy use for baseline scenario increases by an average value of about 60 [EJ]. Greenpeace model projects the highest increase of final energy in 2050 in reference to 2010 for mitigation scenario; this is 15 [EJ] (12%). ETP'10 shows three times lower increase; this is 5 [EJ] (4%). HARVEY ("High GDP, Fast EI" scenario) model, mitigation scenarios project nearly the same values of final energy in 2050 and in 2010. Here the difference in values is around 1.0 [EJ]. From the models which cover all end-uses, only HARVEY "Low GDP, Fast EI" scenario projects final energy decrease in 2050 in reference to 2010, by 29 [EJ] (26%).

Final energy use change between baseline and mitigation scenario in 2050 year

In models that cover space heating & cooling and water heating (3CSEP HEB, LAUSTSEN), the final energy use between their baselines and best mitigation scenarios is decreased by 94 [EJ] and 74 [EJ], what means a reduction by 66% and 75% respectively. In the models which cover all end-uses, the largest mitigation is presented by HARVEY "Low GDP, Fast EI" and ETP'10. Here final energy use in 2050 decreases by 79 [EJ] (48%) and 63 [EJ] (34%) in reference to the baseline scenario. HARVEY "High GDP, Fast EI" and Greenpeace models, project the decrease of final energy consumption by 50 [EJ] and 57 [EJ], which is by 30%.

6.2.2 CO₂ emissions: World

About 35% of current emissions from the buildings sector come directly from buildings themselves (energy-related direct CO₂ emissions), whilst the major part of 65% come indirectly from the power sector through consumption of electricity (electricity-related indirect CO₂ emissions). This is why to estimate the impact of the improvements in buildings themselves on CO₂ emissions, the analysis of GHG emissions is presented based on values received directly by final energy conversion.

The reduction in CO₂ emissions in buildings is determined by the energy saved but also by the decarbonisation of the energy supply sector. Some models assumed various emission factors during the projection period (due to increasing shares of renewables and electricity decarbonisation) it would be very hard to compare the results. That is why a constant value of emission factors was assumed for all models, except for IPCC, McKinsey, WBCSD and ECOFYS models, for which no final energy data were provided in papers. For these models values for CO₂ emissions were taken directly from papers.

As the value of emissions factor is uncertain, the results are presented with uncertainty bars above the graphs. The fixed value was assumed to be of 124 [kgCO₂/GJ], with maximum value of 147 [kgCO₂/GJ] (emissions factor recalculated from BUENAS for the first year) and minimum value of 70 [kgCO₂/GJ] (emissions factor recalculated from ETP'10 for the first year).

Figure 49 presents total CO₂ emissions in building stock in base year, in 2020, 2030 and 2050 respectively. Figure presents linear trend of CO₂ emissions for mitigation and baselines scenarios until 2030 and 2050 for a frozen emission factor of 124 [kgCO₂/GJ].

Figure 51 presents a closer look at CO₂ emissions in 2030 and 2050.

Figure 52 shows CO₂ emissions difference between 2010÷2030 and 2010÷2050 respectively. They also present differences between baseline and mitigation scenario in 2030 and 2050.

Results are presented both in [Gt CO₂] and [%]. The models for which CO₂ emissions values were calculated from the final energy using the constant emission factor were marked with *. For the rest of the models, values of CO₂ emissions were taken directly from the papers (final energy was not presented).

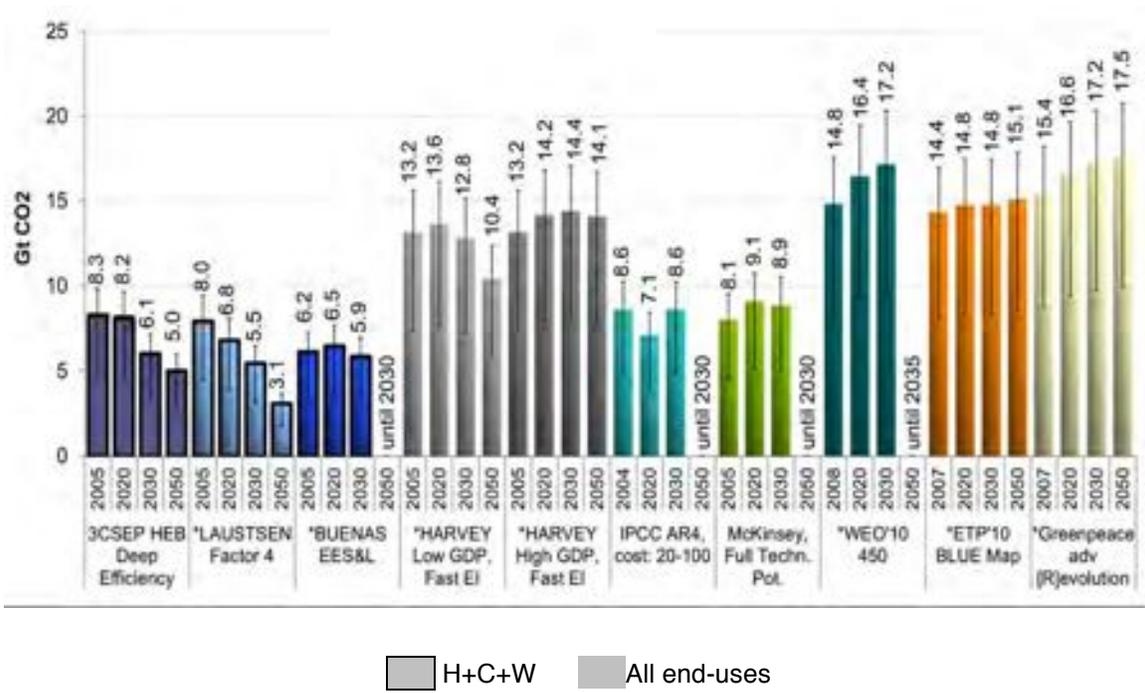


Figure 49. Building-related CO₂ emissions in 2020, 2030 and 2050 [Gt], assuming a frozen emission factor of 124 [kgCO₂/GJ]. Error bars show the variation of the emissions with emission factors of 70 [kgCO₂/GJ] and 147 [kgCO₂/GJ].

* CO₂ emissions were calculated from final energy, using a frozen emission factor.

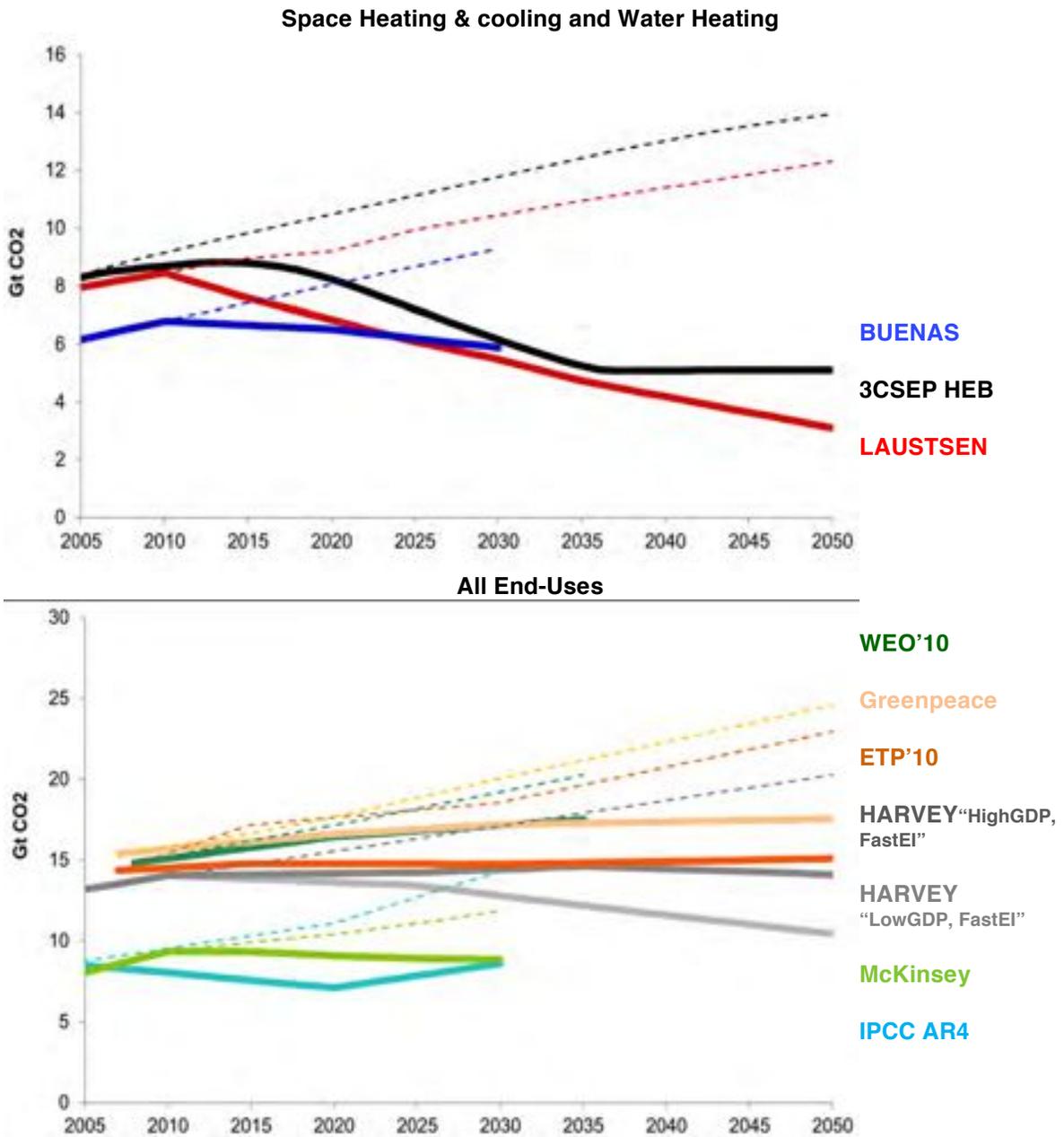
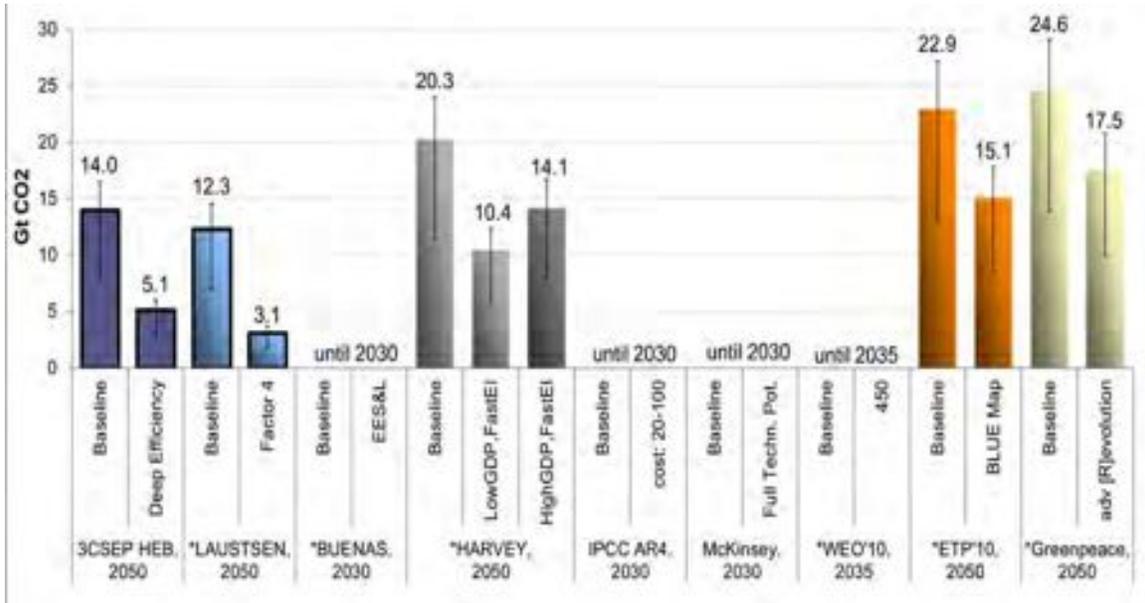
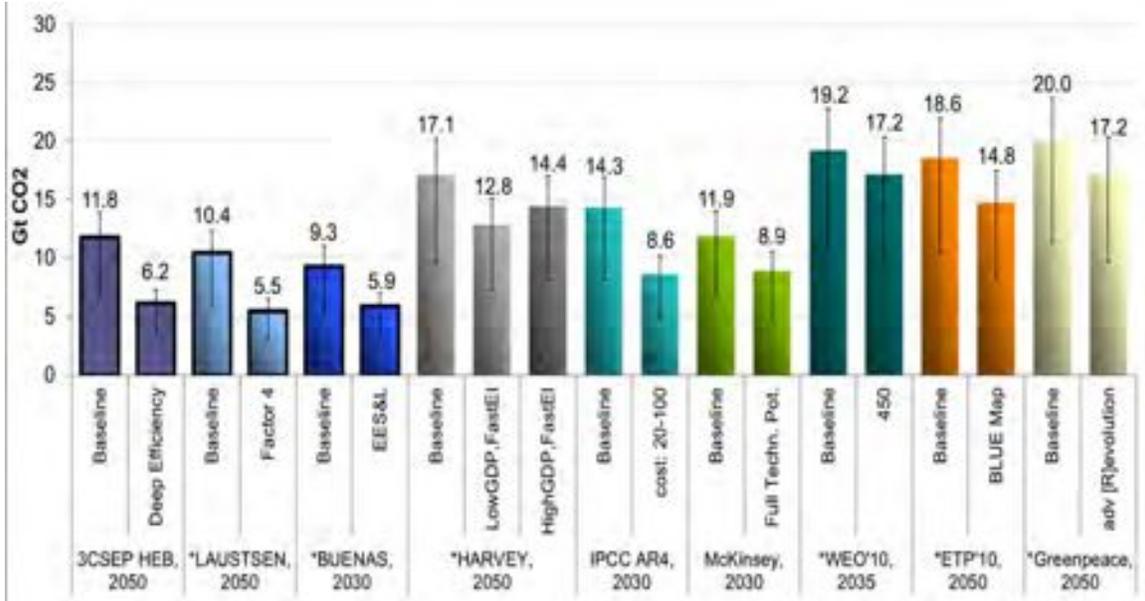


Figure 50. Linear trend of CO₂ emission for mitigation (thick lines) and baselines scenarios (thin dashed lines) until 2050 [Gt] for models that cover: a) space heating & cooling and water heating, b) all end-uses.

A frozen emission factor of 124 [kgCO₂/GJ] was assumed.



a) CO₂ emissions in 2030 for Baseline and Mitigation scenarios



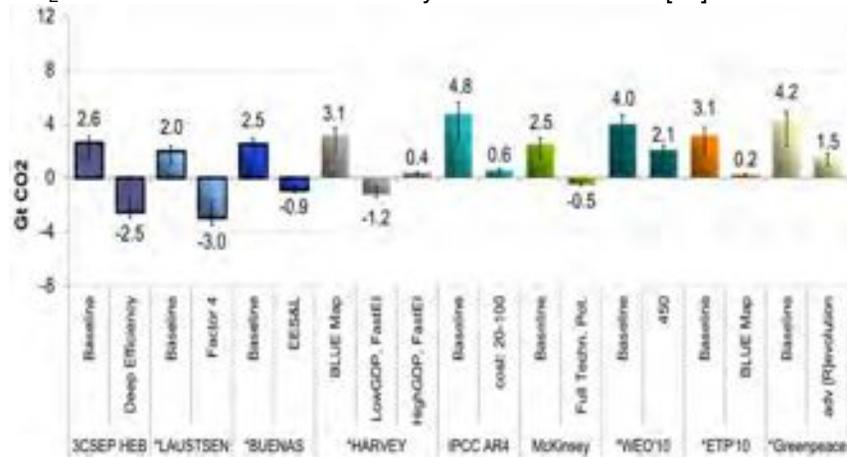
b) CO₂ emissions in 2050 for Baseline and Mitigation scenarios

■ H+C+W ■ All end-uses

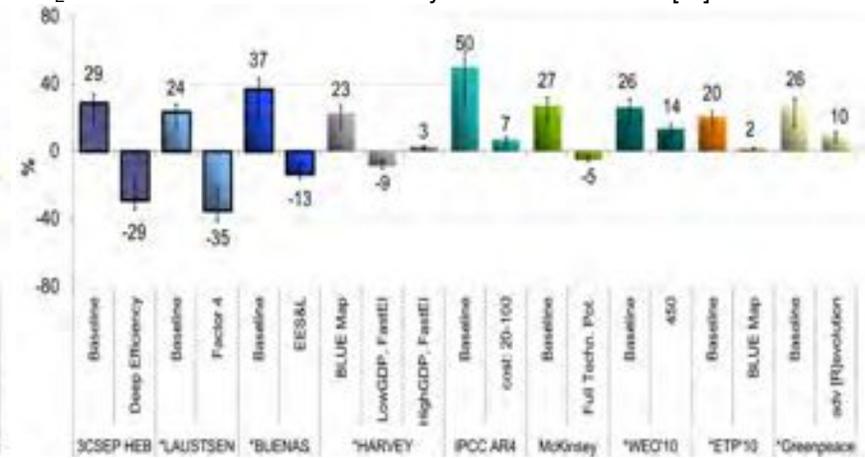
Figure 51. Building-related CO₂ emissions in 2030 and 2050 [Gt], assuming a frozen emission factor of 124 [kgCO₂/GJ]. Error bars show the variation of the emissions with emission factors of 70 [kgCO₂/GJ] and 147 [kgCO₂/GJ].

*CO₂ emissions were calculated from final energy, using a frozen emission factor.

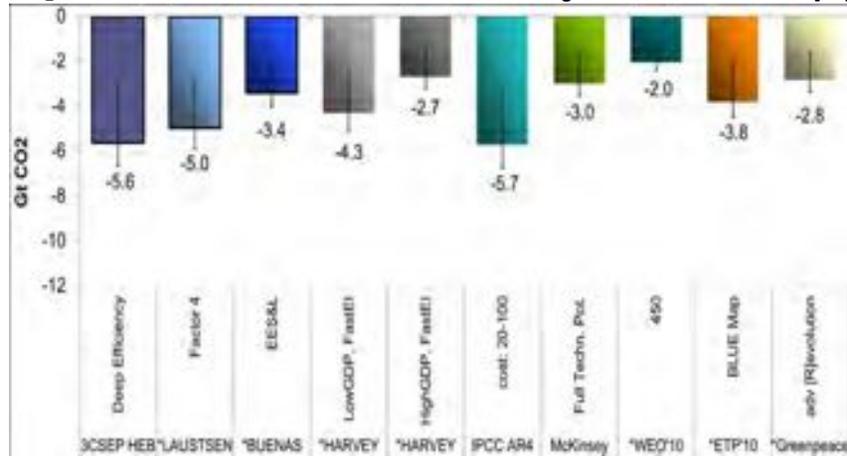
CO₂ emissions difference between year 2010 and 2030 [Gt]



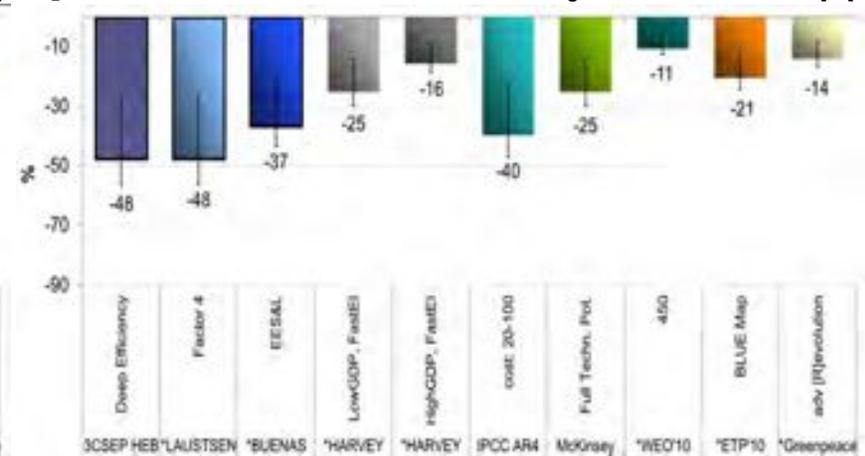
CO₂ emissions difference between year 2010 and 2030 [%]



CO₂ emissions difference between baseline and mitigation scenario in 2030 [Gt]



CO₂ emissions difference between baseline and mitigation scenario in 2030 [%]



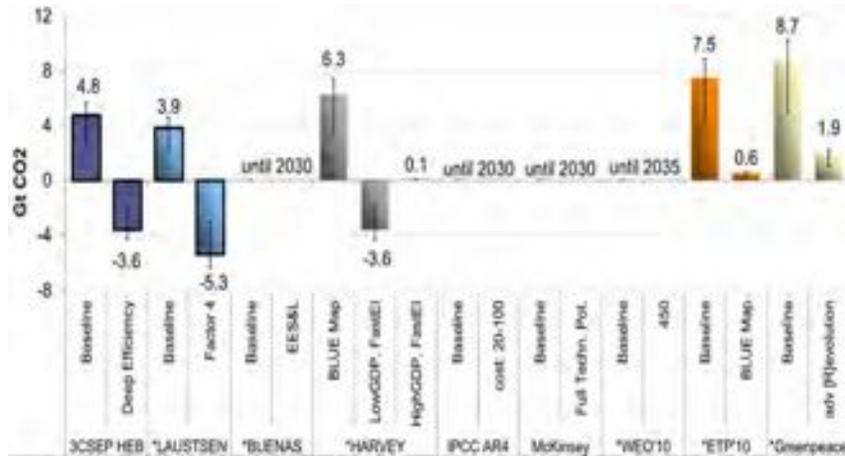
H+C+W

All end-uses

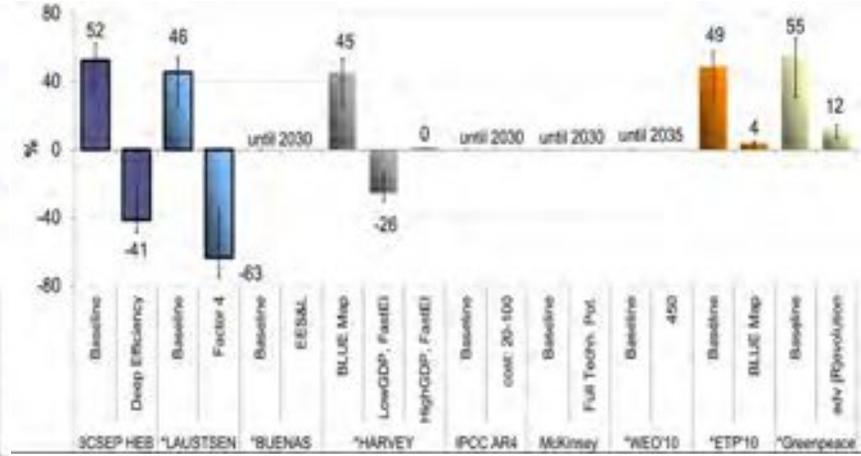
Figure 52. Global building-related CO₂ emissions difference [Gt] [%] between: a) 2010 and 2030, b) baseline and mitigation scenario in 2030, assuming a frozen emission factor of 124 [kgCO₂/GJ]. Error bars show the variation of the emissions with emission factors of 70 [kgCO₂/GJ] and 147 [kgCO₂/GJ].

* CO₂ emissions were calculated from final energy, using a frozen emission factor.

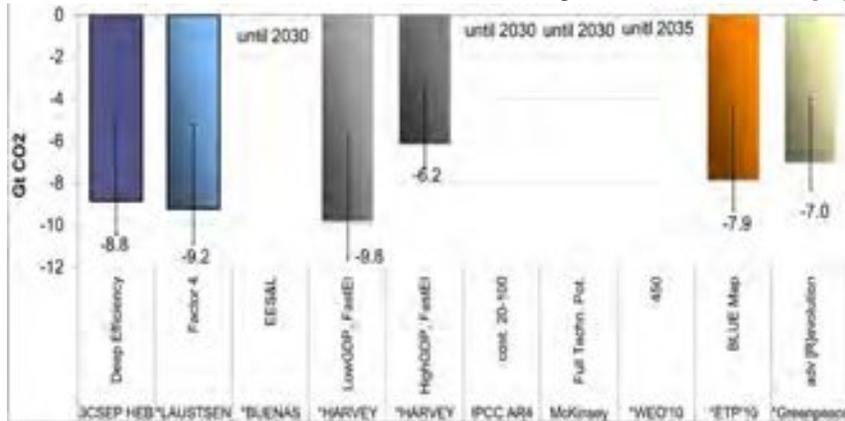
CO₂ emissions difference between year 2010 and 2050 [Gt]



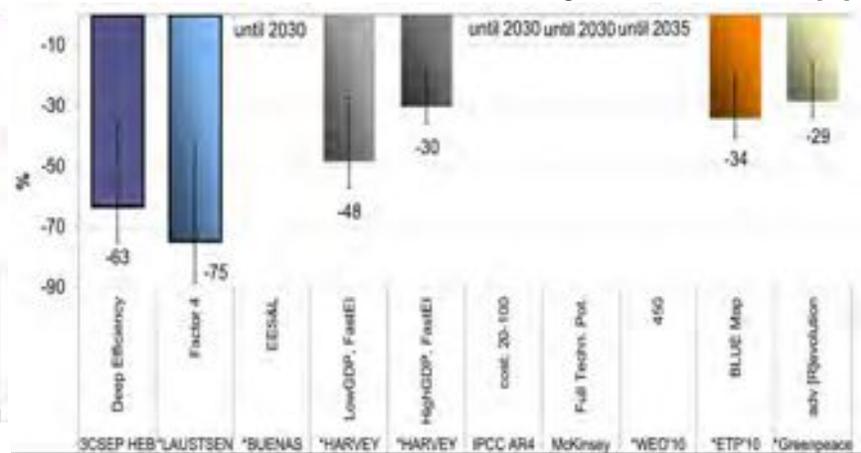
CO₂ emissions difference between year 2010 and 2050 [%]



CO₂ emissions difference between baseline and mitigation scenario in 2050 [Gt]



CO₂ emissions difference between baseline and mitigation scenario in 2050 [%]



H+C+W

All end-uses

Figure 53. Global building-related CO₂ emissions difference [Gt] [%] between: a) 2010 and 2050, b) baseline and mitigation scenario in 2050, assuming a frozen emission factor of 124 [kgCO₂/GJ]. Error bars show the variation of the emissions with emission factors of 70 [kgCO₂/GJ] and 147 [kgCO₂/GJ]. * CO₂ emissions were calculated from final energy, using a frozen emission factor.

CO₂ emissions trends

As the CO₂ emissions values were calculated from final energy values, it is clear that the values will show the same trend as final energy.

The best mitigation scenarios of the models that cover space heating & cooling and water heating (3CSEP HEB, LAUSTSEN, BUENAS), project decrease of CO₂ emissions in reference to their base year (similar trend to final energy consumption).

Only for IPCC and McKinsey models CO₂ emissions were not calculated from final energy use, as the models did not present it. Thus these are the values taken directly from the publications. Most of the analysed best mitigation scenarios of the models that cover all end-uses (space heating & cooling, water heating, lighting and appliances), project increase of CO₂ emissions in reference to their base year. Only HARVEY “Low GDP, Fast EI” shows decrease of CO₂ emissions in 2050 in reference to the base year. IPCC model projects nearly the same CO₂ emission value in 2030 as in 2005.

CO₂ emissions change between 2010 and 2030 year

In this section the results of differences between 2010 and 2030 are analysed (see Figure). As it was explained above the year 2010 was chosen as the reference year.

In 3CSEP HEB, LAUSTSEN and BUENAS models, which cover space heating & cooling and water heating, CO₂ emissions between 2010 and 2030 for baseline scenario is projected to increase by 2.6 [Gt], 2.0 [Gt] and 2.5 [Gt], while their mitigation scenarios will decrease by 2.5 [Gt] (29%), 3.0 [Gt] (35%) and 0.9 [Gt] (13%) respectively.

In the models that cover all end-uses of CO₂ emissions as baseline scenarios increase by an average value of about 3.5 [Gt]. The smallest increase of CO₂ emissions for mitigation scenarios in reference to 2010 are projected by: HARVEY “High GDP, Fast EI” 0.4 [Gt] (3%), IPCC 0.6 [Gt] (7%) and ETP’10 0.2 [Gt] (2%). HARVEY “Low GDP, Fast EI” scenario and McKinsey models project decrease of CO₂ emissions of 1.2 [Gt] (9%) and 0.5 [Gt] (5%) respectively. The best mitigation scenarios in WEO’10 and Greenpeace models show CO₂ emissions reduction (in reference to 2010) of 2.1 [Gt] (14%) and 1.5 [Gt] (10%).

CO₂ emissions change between baseline and mitigation scenario in 2030 year

In models that cover space heating cooling and water heating (3CSEP HEB, LAUSTSEN, BUENAS), the CO₂ emissions of best mitigation scenarios in reference to baseline scenarios are decreased by 5.6 [Gt], 5.0 [Gt] and 3.4 [Gt], which means a reduction by 48%, 48% and 37% respectively. In the models that cover all end-uses the largest mitigation potential is presented by IPCC. Here CO₂ emissions in 2030 decreases by 5.7 [Gt] (40%) in reference to the baseline scenario. McKinsey and ETP'10 present similar results; here CO₂ emissions in 2030 are reduced in reference to their baseline scenarios by 3.0 [Gt] (25%) and 3.8 [Gt] (21%) respectively. CO₂ emissions in both the WEO'10 and Greenpeace models are reduced by 2.0 [Gt] (11%), and 2.8 [Gt] (14%) respectively.

CO₂ emissions change between 2010 and 2050 year

This section analyses the results of differences between 2010 and 2050 (see Figure). In the 3CSEP HEB and LAUSTSEN models, which cover space heating & cooling and water heating, final energy for baseline scenario is projected to increase by 4.8 [Gt] and 3.9 [Gt], while their mitigation scenarios will decrease by 3.6 [Gt] (41%) and 5.3 [Gt] (63%) respectively.

In the models that cover all end-uses (HARVEY, ETP'10 and Greenpeace), CO₂ emissions for baseline scenario increases by an average value of about 7.2 [Gt]. The mitigation scenarios for ETP'10 and Greenpeace project that CO₂ emissions will increase in reference to 2010 by 0.6 [Gt] (4%) and 1.9 [Gt] (12%). For HARVEY "High GDP, Fast EI" scenario, CO₂ emissions are projected to stay at nearly the same level as in 2010. But HARVEY "Low GDP, Fast EI" scenario project the decrease of CO₂ emissions in 2050 in reference to 2010 of 3.6 [Gt], which is of 26%.

CO₂ emissions change between baseline and mitigation scenario in 2050 year

In models that cover space heating & cooling and water heating (3CSEP HEB and LAUSTSEN), the CO₂ emissions between their baselines and best mitigation scenarios is decreased by 8.8 [Gt] and 9.2 [Gt], what means reduction by 63% and 75% respectively. In the models which cover all end-uses the largest mitigation is presented by HARVEY "Low GDP, Fast EI" scenario. Here CO₂ emissions in 2050 decreases by 9.8 [Gt] (48%) in reference to the baseline scenario. HARVEY "High GDP, Fast EI", ETP'10 and Greenpeace models project, that CO₂ emissions will be 6.2 [Gt] (30%), 7.9 [Gt] (34%) and 7.0 [Gt] (29%) respectively lower than baseline scenarios in 2050.

6.2.3 Comparison by regions

This section shows the comparison of final energy and CO₂ emissions values for chosen regions: EU-27 (Figure), US (Figure), China (Figure) and India (Figure).

Models that presented values for final energy separately for EU-27 region were:

- BPIE, Two-stage Scenario (space heating & cooling),
- 3CSEP HEB, Deep Efficiency Scenario (space heating & cooling and water heating),
- ETP'10, Blue Map Scenario (all end-uses),
- WEO'10, 450 Scenario (all end-uses),
- Wuppertal, P&M Scenario (all end-uses).

CO₂ emissions for EU-27 were presented by:

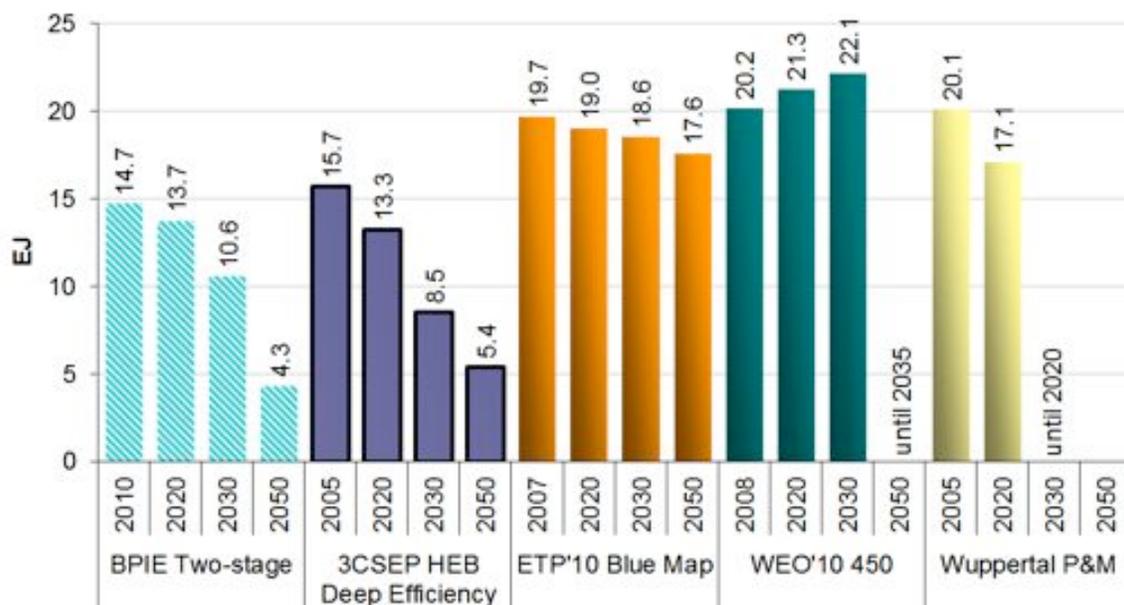
- ECOFYS'05 (space heating)
- McKinsey (all end-uses).

Models that presented values for final energy separately for US, China and India were:

- 3CSEP HEB, Deep Efficiency Scenario (space heating & cooling and water heating),
- ETP'10, Blue Map Scenario (all end-uses),
- WEO'10, 450 Scenario (all end-uses),

McKinsey presented CO₂ emissions for these regions.

For models that presented values of final energy in the papers, CO₂ emissions were calculated directly from final energy using the constant emission factor of 124 [kgCO₂/GJ]. On the charts those models were marked with *. In all models values are presented for best mitigation scenarios.



EU-27

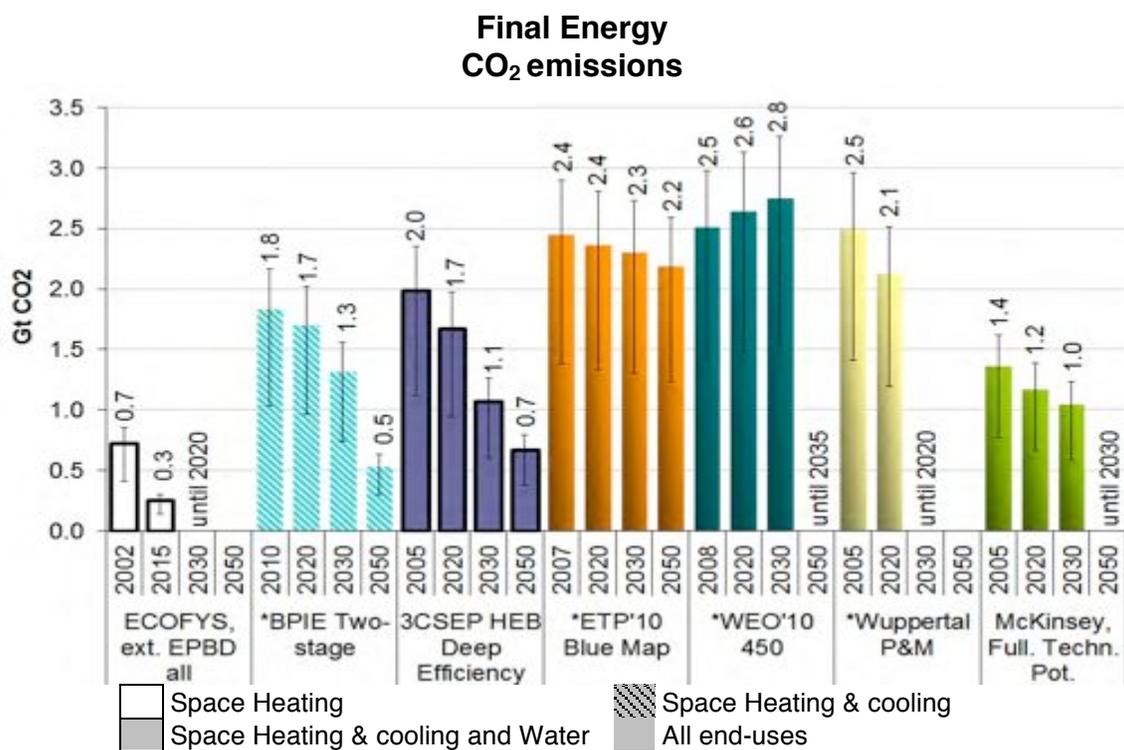


Figure 54. EU-27 final energy [EJ] use and CO₂ emissions [Gt CO₂] in base year, 2020, 2030 and 2050
 *CO₂ emissions were calculated from final energy, using a frozen emission factor.

EU-27 Final Energy

In the BPIE “Two-stage” model that concerns space heating & cooling the final energy consumption decreased by 4.2 [EJ] (28%) by 2030 (with reference to 2010). By 2050 the final energy use decreased by 10.4 [EJ] (71%).

In the 3CSEP HEB “Deep Efficiency” model that concerns space heating & cooling and water heating the final energy use decreased by 6.9 [EJ] (45%) by 2030 (with reference to 2010). By 2050 the final energy use decreased by 10.0 [EJ] (65%).

In ETP’10 “Blue Map” model that concerns all end-uses the final energy use decreases by 1.0 [EJ] (5%) by 2030 (with reference to 2010). By 2050 the final energy use is reduced by 1.9 [EJ] (10%). The WEO’10 “450” model projects that final energy use will increase by 1.8 [EJ] (9%) in 2030 (with reference to 2010). Wuppertal projection time is up to 2020. The “P&M Scenario” models that final energy use can be reduced by 2.0 [EJ] in 2020, what is by 11%.

When comparing these values to the baseline scenario projections we see that by 2030 the final energy use can be reduced by: 3.5 [EJ] (25%), 8.0 [EJ] (48%), 5.8 [EJ] (24%) and 1.4 [EJ] (6%) in BPIE, 3CSEP HEB, ETP’10 and WEO’10 respectively. By 2050 the BPIE, 3CSEP HEB and ETP’10 models present that final energy use can be reduced by: 9.11 [EJ] (68%), 11.08 [EJ] (67%) and 10.89 [EJ] (38%) in respectively.

EU-27 CO₂ emissions

ECOFYS’05 “Extended EPBD to all buildings” model, which covers only space heating, shows that by 2015 CO₂ emissions can be reduced by 0.4 [Gt]. This means there will be a 60% reduction in reference to 2002.

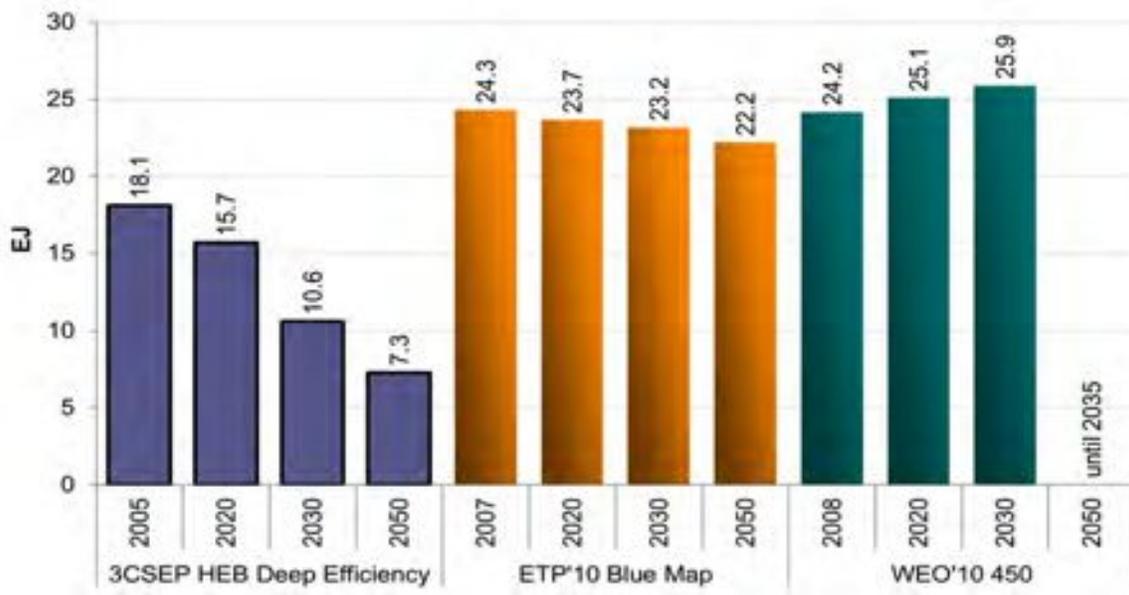
In the BPIE “Two-stage” model that concerns space heating & cooling CO₂ emissions consumption decreased by 0.5 [Gt] (28%) by 2030 in reference to 2010. By 2050 it is decreased by 1.3 [Gt] (71%).

In the 3CSEP HEB “Deep Efficiency” model that concerns space heating & cooling and water heating CO₂ emissions decreased by 0.9 [Gt] (45%) in 2030 in reference to 2010. By 2050 it is decreased by 1.3 [Gt] (65%).

In ETP’10 “Blue Map” model (all end-uses covered) CO₂ emissions decreases by 0.1 [Gt] (5%) in 2030. By 2050, CO₂ emissions are reduced by 0.2 [Gt] (10%). The WEO’10 “450” model projects that CO₂ emissions will increase by 0.2 [Gt] (9%) in 2030 in reference to 2010. Wuppertal projection time is up to 2020. The “P&M Scenario” models that CO₂ emissions can be reduced by 0.4 [Gt], which is 11%. McKinsey “Full Technical Potential” model projects that by 2030 CO₂ emissions can be reduced by 0.3 [Gt] (20%) in 2030.

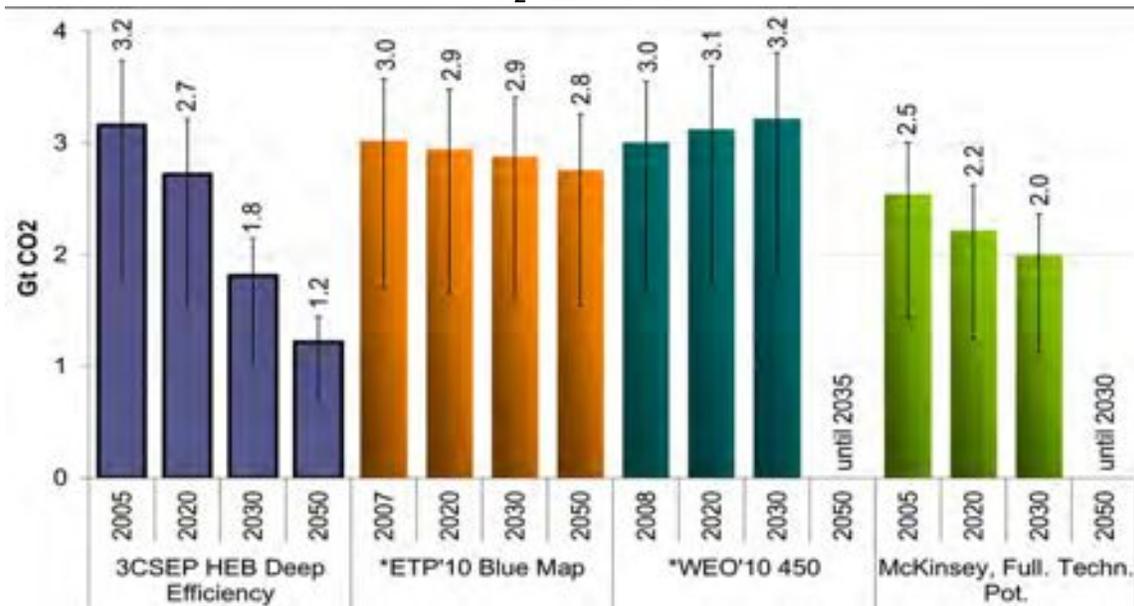
Comparing the values to the baseline scenarios projections, the BPIE, 3CSEP HEB, ETP’10, WEO’10 and McKinsey models predict that by 2030 CO₂

emissions can be reduced by: 0.4 [Gt] (25%), 1.0 [Gt] (49%), 0.7 [Gt] (24%), 0.2 [Gt] (6%) and 0.4 [Gt](30%) respectively. In 2050 the BPIE, 3CSEP HEB and ETP'10 models predict that CO₂ emissions can be reduced by: 1.13 [Gt] (68%), 1.41 [Gt] (68%) and 1.35 [Gt] (38%) respectively.



NAM

Final Energy CO₂ emissions



Space Heating & cooling and Water
 All end-uses

Figure 55. NAM final energy [EJ] use and CO₂ emissions [Gt CO₂] in base year, 2020, 2030 and 2050

*CO₂ emissions were calculated from final energy, using a frozen emission factor.

NAM Final Energy

In the 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) by 2030 the final energy use is decreased by 7.3 [EJ] (41%) in reference to 2010. By 2050 it is decreased by 10.6 [EJ] (59%).

In ETP’10 “Blue Map” model (all end-uses covered) the final energy use decreases by 1.0 [EJ] (4%) by 2030. In 2050 the final energy use reduces by 2.0 [EJ] (8%). The WEO’10 “450” model projects that the final energy will be increased by 1.6 [EJ] (6%) in 2030, with reference to 2010.

Comparing the values to the baseline scenarios projections, in 2030 final energy use can be reduced by: 9.1 [EJ] (46%), 5.2 [EJ] (18%) and 1.6 [EJ] (6%) in 3CSEP HEB, ETP’10 and WEO’10 models respectively. In 2050 final energy use can be reduced by: 13.2 [EJ] (64%) and 9.6 [EJ] (30%) in 3CSEP HEB and ETP’10 respectively.

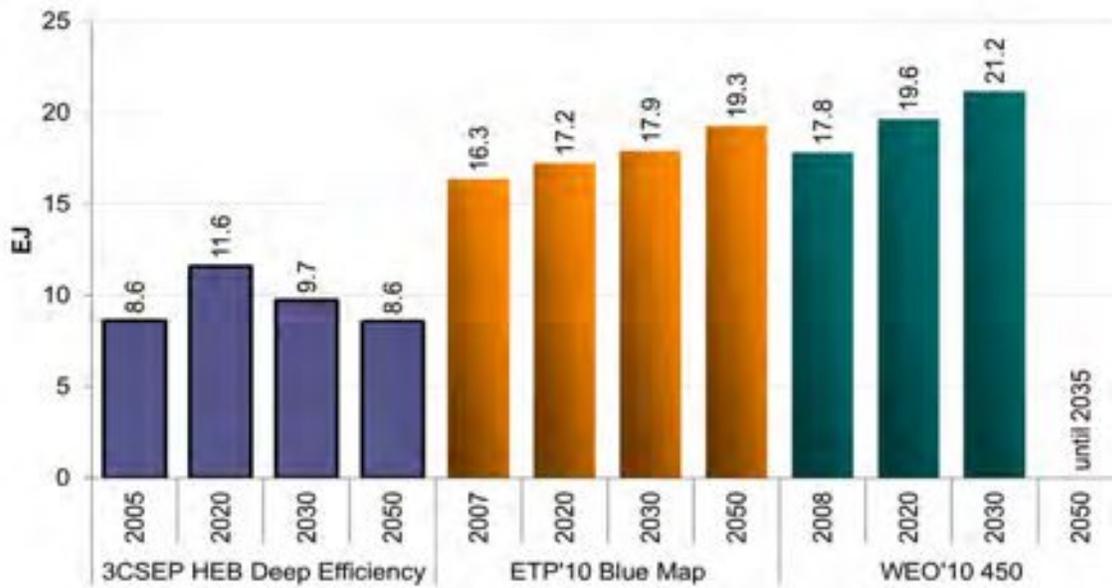
NAM CO₂ emissions

In the 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) in 2030 CO₂ emissions will decrease by 1.3 [Gt] (42%) in reference to 2010. By 2050 it decreases by 1.9 [Gt] (61%).

ETP’10 “Blue Map” and McKinsey models (all end-uses covered) project a decrease of CO₂ emissions in 2030 in reference to 2010. This is by 0.1 [Gt] (4%) and 0.4 [Gt] (18%) in 2030 and by 0.2 [Gt] (8%) in 2050.

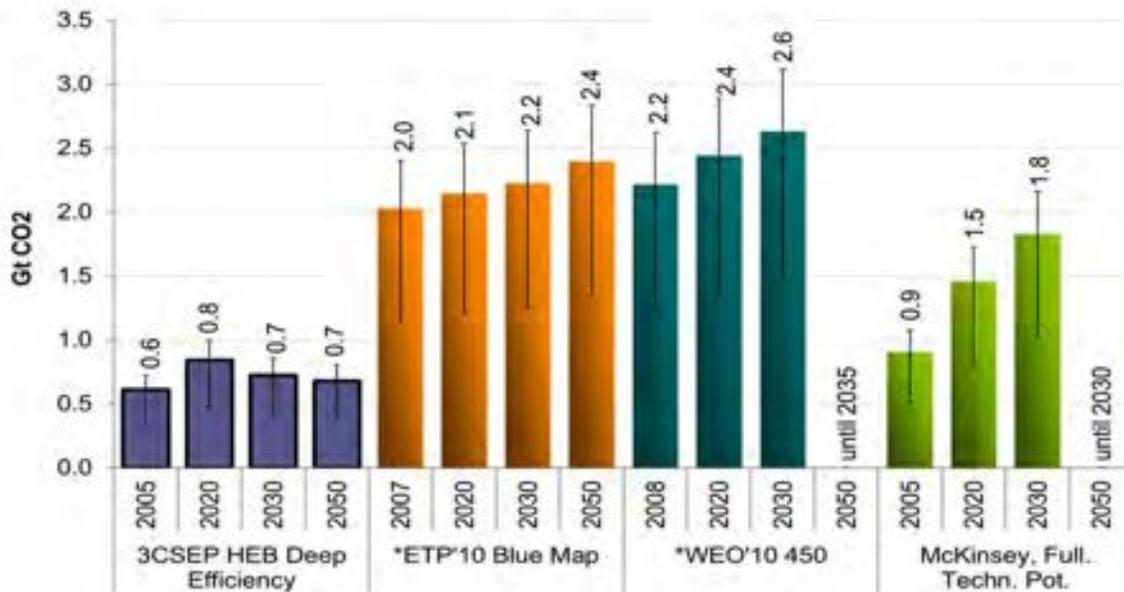
The WEO’10 “450” model projects that CO₂ emissions will increase by 0.2 [Gt] (6%) in 2030, with reference to 2010.

Comparing the values to the baseline scenarios projections, in 2030 CO₂ emissions can be reduced by: 1.6 [Gt] (47%), 0.6 [Gt] (18%), 0.2 [Gt] (6%) and 0.7 [Gt] (26%) in 3CSEP HEB, ETP’10, WEO’10 and McKinsey models respectively. In 2050 CO₂ emissions can be reduced by: 2.31 [Gt] (65%) and 1.20 [Gt] (30%) in 3CSEP HEB and ETP’10 respectively.



CHINA

**Final Energy
CO₂ emissions**



Space Heating & cooling and Water
 All end-uses

Figure 56. CHINA final energy [EJ] use and CO₂ emissions [Gt CO₂] in base year, 2020, 2030 and 2050

*CO₂ emissions were calculated from final energy, using a frozen emission factor.

CHINA Final Energy

In the 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) by 2030 the final energy use is decreased by 1.6 [EJ] (14%) in reference to 2010. By 2050 it is decreased by 2.8 [EJ] (25%).

In the ETP’10 “Blue Map” model (all end-uses covered) in 2030 final energy use increases by 1.4 [EJ] (8%). In 2050 it increases by 2.7 [EJ] (16%). The WEO’10 “450” model projects that the final energy use will increase by 3.0 [EJ] (17%) in 2030 in reference to 2010.

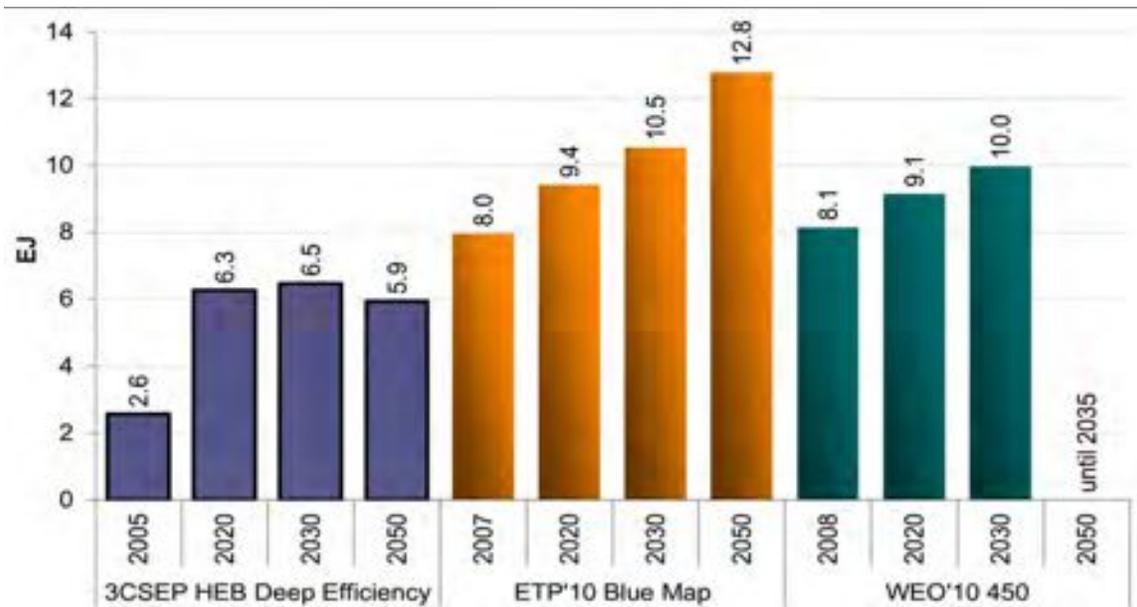
Comparing the values to the baseline scenarios projections, in 2030 final energy use can be reduced to: 9.8 [EJ] (50%), 6.5 [EJ] (27%) and 3.1 [EJ] (13%) in the 3CSEP HEB, ETP’10 and WEO’10 models respectively. In 2050 final energy use can be reduced by: 13.76 [EJ] (62%) and 12.13 [EJ] (39%) in the 3CSEP HEB and ETP’10 models respectively

CHINA CO₂ emissions

In the 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) CO₂ emissions is decreased by 0.1 [Gt] (11%) in 2030 and by 0.2 [Gt] (16%) in 2050 in reference to 2010.

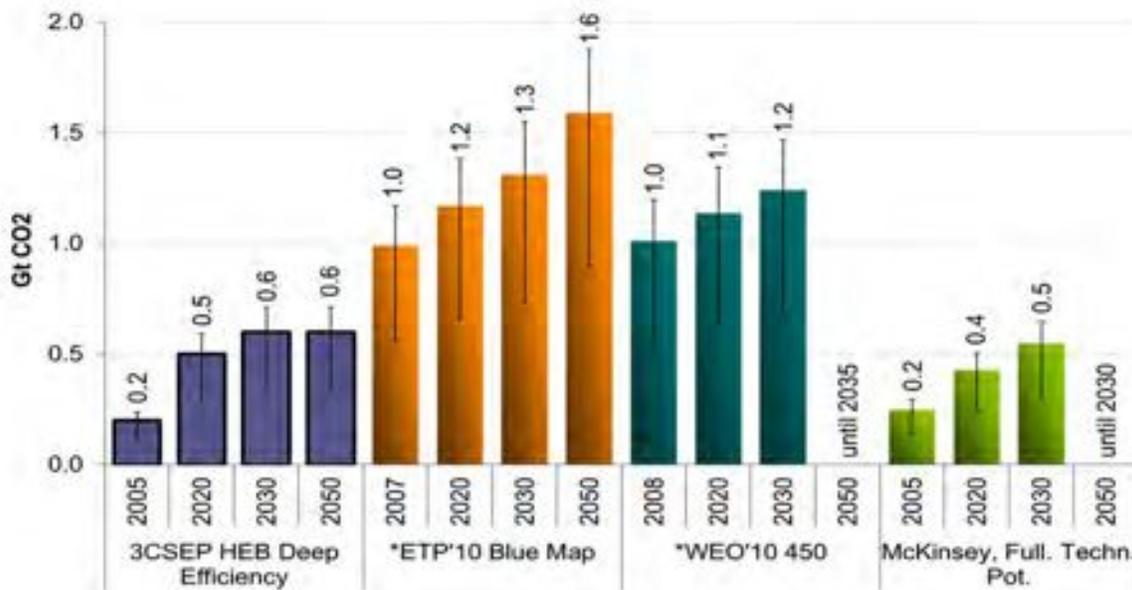
ETP’10, WEO’10 and McKinsey models (all end-uses covered) project an increase of CO₂ emissions in 2030 in reference to 2010. This is by 0.2 [Gt] (8%), 0.4 [Gt] (17%) and 0.7 [Gt] (67%) in 2030. In 2050 in ETP’10 it will increase by 0.3 [Gt] (16%).

Comparing the values to the baseline scenarios projections, in 2030 CO₂ emissions can be reduced by: 0.7 [Gt] (48%), 0.8 [Gt] (27%), 0.4 [Gt] (13%) and 0.6 [Gt] (25%) in the 3CSEP HEB, ETP’10, WEO’10 and McKinsey models respectively. In 2050 CO₂ emissions can be reduced by: 0.94 [Gt] (58%) and 1.51 [Gt] (40%) in the 3CSEP HEB and ETP’10 models respectively.



INDIA

**Final Energy
CO₂ emissions**



Space Heating & cooling and Water
 All end-uses

Figure 57. INDIA final energy [EJ] use and CO₂ emissions [Gt CO₂] in base year, 2020, 2030 and 2050
 *CO₂ emissions were calculated from final energy, using a frozen emission factor.

INDIA Final Energy

In 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) in the final energy use increases by 2.4 [EJ] (59%) in 2030 and by 1.9 [EJ] (46%) in 2050 in reference to 2010.

In ETP’10 and WEO’10 models (all end-uses covered) the final energy use increases by 2.2 [EJ] (27%) and 1.7 [EJ] (20%) respectively in 2030. In 2050 the ETP’10 model predicts that it increases by 4.5 [EJ] (54%).

Comparing the values to the baseline scenarios projections, in 2030 final energy use can be reduced by: 7.6 [EJ] (55%), 2.0 [EJ] (16%) and 0.8 [EJ] (8%) in the 3CSEP HEB, ETP’10 and WEO’10 models respectively. In 2050 final energy use can be reduced by: 14.7 [EJ] (71%) and 3.74 [EJ] (23%) in the 3CSEP HEB and ETP’10 models respectively.

INDIA CO₂ emissions

In 3CSEP HEB “Deep Efficiency” model (space heating & cooling and water heating) the CO₂ emissions increase by 0.2 [Gt] (73%) by 2030 in reference to 2010. In 2050 it increases by 0.3 [Gt] (81%).

ETP’10, WEO’10 and McKinsey models (all end-uses covered) project an increase of CO₂ emissions in 2030 in reference to 2010. This is by 0.3 [Gt] (27%), 0.2 [Gt] (20%) and 0.2 [Gt] (78%) in 2030. In 2050 in ETP’10 it will increase by 0.6 [Gt] (54%).

Comparing the values to the baseline scenarios projections, in 2030 CO₂ emissions can be reduced by: 0.4 [Gt] (47%), 0.28 [Gt] (16%), 0.1 [Gt] (8%) and 0.2 [Gt] (25%) in 3CSEP HEB, ETP’10, WEO’10 and McKinsey respectively. By 2050, CO₂ emissions can be reduced by 0.67 [Gt] (61%) and 0.47 [Gt] (23%) in the 3CSEP HEB and ETP’10 models respectively.

6.3 Results Comparison

The results presented in the analysed studies were compared. First the results for the final energy were analysed. Here 3CSEP HEB results hold significant compatibility for the base year with other models that cover the same end-uses; this is between 50-67 [EJ]. Also the models that cover all end-uses show similar value of final energy in the base years, this is between 106-124 [EJ]. For the best mitigation scenarios the results are different, as various measures and strategies were taken under consideration in various models. Generally, the models which cover space heating & cooling and water heating, the best mitigation scenarios project the decrease of final energy by 13-35% in 2030 and by 35-63% in 2050 in reference to 2010. In case of models that cover all end-uses final energy is projected to increase in reference to 2010. By 2030 final energy is projected to increase by 2-10%, and in 2050 up to 12%. Only one model, which cover all end-uses projects final energy decrease in 2050 in relation to 2010.

In case of the comparison of CO₂ emissions, the models present various trends by 2050. Because some models assumed various emission factors during the projection period (due to increasing shares of renewable energy sources and electricity decarbonisation) the CO₂ emissions had different trends than the final energy. Also emission factors used in the models were not presented in the majority of papers. Thus, to make the comparison possible the fixed value of emission factor was used for all models (it eliminates the influence of electricity decarbonisation). As the value of emissions factor is uncertain, the results were presented with uncertainty bars above the graphs. Also here 3CSEP HEB results are in the great compatibility in the base year with other models that cover the same end-uses, this is between 6.2-8.3 [Gt CO₂]. Also the models that cover all end-uses show similar value of CO₂ emissions in the base years, this is between 13.2-15.4 [Gt CO₂]. Only the models for which the values of CO₂ emissions were taken when they were presented in the papers (not converted from final energy using the same emission factor like in other models) show lower values of CO₂ emissions. For the best mitigation scenarios the results are different, as various measures and strategies were taken under consideration in various models, which cover all end-uses projects final energy decrease in 2050 in relation to 2010.

The sections below present the results for the best mitigation scenario for the world and four key regions and the main strategies and measures assumed in the models.

WORLD

In case of the global models that cover space heating & cooling and water heating, these are: 3CSEP HEB, LAUSTSEN and BUENAS model, the methodologies used are similar only for first two models. Both 3CSEP HEB and

LAUSTSEN models are built on the performance-based and the bottom-up approach (LAUSTSEN is the hybrid model that also uses top-down approach). The LAUSTSEN model, the “Factor 4” scenario presents the best mitigation potential out of all analysed models. Here in 2050 the final energy use can be reduced by 75% in reference to the baseline scenario, what means that in relation to 2010 it can be reduced by 63%. The assumption made in LAUSTSEN “Factor 4” scenario methodology was that the effective measures that could be applied on a global scale between now and 2050 are currently in progress. The most important strategy to achieve such potential in the buildings sector is to implement appropriate best practice cases globally. While in the best mitigation potential scenario in 3CSEP HEB model (“Deep Efficiency”) it is assumed that the best possible design and building practices are enforced worldwide for new and renovated buildings.

All the global models that cover all end-uses, these are: HARVEY, WEO, ETP and Greenpeace model are built on the bottom-up approach. Only the HARVEY model is built on the performance-based approach, while three other models are built on the component-based approach. Here only the HARVEY model “Low GDP, Fast EI” scenario shows mitigation potential in relation to 2010 - final energy can be reduced by 26%. The three other models show final energy increase in relation to 2010 – final energy increase up to 12%. The most important strategies and measures that need to be implemented to realize the mitigation potential in HARVEY “Low GDP, Fast EI” scenario are: high performance thermal envelope, use of passive systems, energy-efficient HVAC equipment, occupant behavioural changes.

The GHG emissions values presented in the models comparison section were calculated from direct conversion from final energy, using the same constant emission factor for all models. The energy savings determines CO₂ emission reduction but also by the decarbonisation of the energy supply sector. Because some models assumed various emission factors during the projection period (due to increasing shares of renewables and electricity decarbonisation) it would be very hard to compare the results. That is why a constant value of emission factors was assumed for all models, except for IPCC, McKinsey and ECOFYS models, for which no final energy data were provided in papers. For these models values for CO₂ emissions were taken directly from papers. Thus the trends in CO₂ emissions reduction are the same as for final energy. In case of models that cover space heating & cooling and water heating here also LAUSTSEN “Factor 4” scenario presents the highest potential of 75% (9.2 Gt) of CO₂ reduction in 2050 in reference to the baseline scenario, what means reduction by 63% (5.3 Gt) in reference to 2010.

All the best mitigation scenarios of the global models, except for the HARVEY model, show an increase of CO₂ emissions in 2050 in reference to 2010 - up to

12%. Only HARVEY “Low GDP, Fast EI” scenario – model built on the performance-based approach – shows the possible reduction by 26% (3.6 Gt) in 2050 in reference to 2010, what means the reduction by 48% (9.8 Gt) in reference to the baseline scenario in 2050.

In **EU-27** region, the possible CO₂ emissions reduction presented by 3CSEP HEB “Deep Efficiency” scenario (the model covers space heating & cooling and water heating) is of 65% (1.3 Gt) in 2050 in reference to 2010, what means the reduction by 68% (1.4 Gt) in 2050 in reference to the baseline scenario. From the models that cover additionally lighting and appliances & equipment, the largest CO₂ mitigation potential in 2030 in reference to 2010 is presented by McKinsey “Full Technical Potential” scenario – this is by 20%, what means the reduction by 30% in 2030 in reference to the baseline scenario. In 2050 ETP’10 “BLUE Map” scenario presents the possible CO₂ emissions reduction of 38% in reference to the baseline scenario, what means the reduction of 10% in 2050 in reference to 2010.

For the **USA** region the CO₂ emissions reduction presented by 3CSEP HEB “Deep Efficiency” scenario is of 61% (1.9 Gt) in 2050 in reference to 2010, what means the reduction by 65% (2.3 Gt) in 2050 in reference to the baseline scenario. From the models that cover additionally lighting and appliances & equipment, the largest CO₂ mitigation potential in 2030 in reference to 2010 is presented by the McKinsey Model “Full Technical Potential” scenario – this is by 18%, this means the reduction by 26% in 2030 in reference to the baseline scenario. In 2050 ETP’10 “BLUE Map” scenario presents the possible CO₂ emissions reduction of 8% in reference to 2010, this means the reduction of 30% in 2050 in reference to the baseline scenario.

For **China** the CO₂ emissions in 2050 presented by the 3CSEP HEB model “Deep Efficiency” scenario (space heating & cooling and water heating) decrease by 16% (0.1 Gt) in 2050 in reference to 2010, this means the reduction by 39% (0.94 Gt) in 2050 in reference to the baseline scenario. From the models that cover additionally lighting and appliances & equipment, the smallest increase of CO₂ emissions in 2050 in reference to 2010 is presented by ETP’10 “BLUE Map” – this is by 16%, this means the reduction by 39% in 2050 in reference to the baseline scenario.

For **India**, the CO₂ emissions, presented by 3CSEP HEB “Deep Efficiency” scenario, increase by 81% (0.3 Gt) in 2050 in reference to 2010, what this means is the reduction of 63% (1.04 Gt) in 2050 in reference to the baseline scenario. From the models that cover additionally lighting and appliances & equipment, the smallest increase of CO₂ emissions in 2030 in reference to 2010 is presented by WEO’10 “450” scenario – this is by 20%. In 2050 ETP’10 “BLUE Map” scenario presents the CO₂ emissions increase of 54% in reference to 2010.

For the global models that cover space heating & cooling and water heating the best mitigation potential out of all analysed models is presented by the LAUSTSEN model. In case of the global models that cover all end-uses, the best mitigation potential is presented by HARVEY model. The comparison of the results proves that even though the models use various assumptions, methodologies and measures, they come to the common conclusions, presenting the results in a similar range of values.

Taking into account only those models that cover space heating & cooling and water heating, the studies that project the highest CO₂ mitigation potential in 2050, in reference to 2010, are LAUSTSEN “Factor 4” and 3CSEP HEB “Deep Efficiency” model. Taking into account those models that additionally cover electricity, the studies that project the highest CO₂ mitigation potential, in 2050 in reference to 2010, are HARVEY “Low GDP, Fast EI” and ETP’10 “BLUE Map”. In 2030 these are McKinsey “Full Technical Potential” and WEO’10 “450”. The sections below present the main strategies and measures that need to be taken to realize the mitigation potential.

The main objective of the **LAUSTSEN “Factor 4”** model is to see the impact of implementing appropriate best practice cases globally. There is an assumption that effective measures that could be applied on a global scale between now and 2050 currently are in progress. The main strategies and measures assumed in this study are:

- The best buildings envelope,
- Orientation and shading,
- Ventilation / infiltration,
- Reducing heating and cooling loads,
- More efficient HVAC systems,
- Use of passive energy,
- *Renewable energy,
- More efficient lighting,
- Policy support.

*The “ Factor Four” scenario included renewable energy in two cases: in connection to initiatives to reach zero energy buildings, for new buildings where there was no separation on the way a zero was obtained in the end, either by efficiency or by renewable energy. Solar water heaters were also used to reduce energy for hot sanitary water. It was especially expected that renewable energy would impact on the longer term as efficiency measures starts to reach very high levels. Therefore the values are not directly comparable with the 3CSEP HEB model.

In the **3CSEP HEB “Deep Efficiency”** model the performance of whole systems (e.g. whole buildings) is studied and these performance values are used as inputs in the scenarios. This scenario demonstrates how far today’s state-of-the-art construction and retrofit know-how and technologies can take us in reducing building energy use and CO₂ emissions, while also providing full thermal comfort in buildings. In essence, the techno-economic energy efficiency potentials in the building sector are determined. Except for a small fraction of heritage buildings, exemplary building practices are implemented worldwide for both new and renovated buildings. Over the 10-year period from 2013 to 2023 advanced buildings increase their market share from 0% in 2013 to close to 100% (depending on the share of non-retrofit table buildings) in all regions. The transition period allows markets and industries to prepare for the large-scale deployment of the exemplary building construction technologies, materials and know-how.

Ambitious building policies can also be implemented and the necessary supporting institutional framework introduced. After 2023, most renovations and newly built structures will be of a very low energy design just as existing exemplary buildings in the same (or a similar) climate zone. For regions where the best building design practices have not yet been proven, e.g. in most of the developing world, the energy consumption figures for each building category are transferred from the same climate zones to other regions. There are no main strategies and measures assumed in this study as this model leaves the freedom to the architects and engineers in choosing the best energy efficiency measures, as it takes into account the overall buildings energy performance (see section 0).

The **HARVEY “Low GDP, Fast EI”** model assumes that no change in the energy intensity of new buildings occurs until at least 2010. It is assumed that all buildings undergo a significant renovation between 2005 and 2050 in which maximum advantage is taken of the opportunity to reduce energy use. A transition from the current energy intensity of new and renovated buildings to a much lower energy intensity is assumed to occur sometime between 2010 and 2050. The main strategies and measures assumed in this study are:

- Focus on a high-performance thermal envelope,
- Maximization of the use of passive solar energy for heating, ventilation and day lighting,
- Highly energy-efficient equipment and especially energy-efficient systems,
- Being ensured that all equipment and systems are properly commissioned and that building operators and occupants understand how they are to be used,
- Changed occupant behaviour.

The **ETP’10 “BLUE Map”** scenario shows that the buildings sector can play a substantial role in securing a more sustainable energy future. In this scenario most of the savings comes from energy efficiency, from the switch to low- and

zero-carbon technologies and from the decarbonisation of the electricity used in the sector (not included in the results presented in the charts), especially:

- Intelligent building design,
- High-performance buildings envelopes,
- Highly efficient heating, ventilation and air-conditioning systems (HVAC),
- Highly efficient water heating systems,
- Highly efficient appliances and lighting,
- Efficient cook stoves,
- CO₂ free technologies.

A guiding principle in the **McKinsey “Full Technological Potential”** model is to reduce overall heat and power demand through energy-efficiency levers (e.g. passive houses). The “Full Technical Potential” scenario is based on full deployment rates of GHG-efficient technologies/measures per region and over time, with a focus on measures up to €60 per tCO₂. The main strategies and measures assumed in this study are:

- Improve buildings air tightness,
- High efficiency door and windows,
- Insulation of attic and wall cavities,
- Mechanical ventilation,
- Retrofit to “passive” standard,
- Heat recovery and heat pumps,
- Solar heating,
- High efficient appliances and electronics,
- Lighting.

The **WEO’10 “450”** assumes that all policies now under consideration will be fully implemented, reinforced and extended. It also assumes that until 2020 the OECD countries will adopt domestic policies and measures to generate and sell emissions credits. After 2020 those assumptions are extended to Other Major Economies (China, Russia and Middle East). The main strategies and measures assumed in this study are:

- Buildings envelope,
- Switch from oils and gas boilers to electricity-based systems,
- National policies and measures aimed at energy efficiency and renewables,
- PV,
- Solar water heater,
- Biomass,
- Geothermal-based heating,
- Heat pumps.

Lessons learned from the models comparison:

- Models that cover space heating & cooling, water heating and electricity present less ambitious CO₂ mitigation potential than models that do not cover electricity (lighting and appliances),
- Among the models which cover space heating & cooling and water heating, the studies that project the highest CO₂ mitigation potential in 2050, in reference to 2010, are LAUSTSEN “Factor 4” and 3CSEP HEB “Deep Efficiency” model,
- Taking into account those models that additionally cover electricity, the studies that project the highest CO₂ mitigation potential, in 2050 in reference to 2010, are HARVEY “Low GDP, Fast EI” and ETP’10 “BLUE Map”. In 2030 these are McKinsey “Full Technical Potential” and WEO’10 “450”.

The most important limitations when examining the correlation between the models constraints encountered, that substantially limited the analysis of correlation were:

- The values not presented in consistent way (e.g. only as charts, what required reading the values directly from the them,
- The values were presented in various units,
- The studies use various baseline scenarios, this made the mitigation potential in the reference to different scenarios less reliable,
- The results were not broken down by end-uses,
- The description of the methodology of calculations was not detailed enough,
- Most models didn’t have detailed messages concerning the measures and strategies to achieve the mitigation potential,
- The majority of studies did not present the values for emission factors and/or primary energy factors, which are needed to convert final to primary energy,
- The majority of the studies did not present the values for fuel shares,
- There was a lack of transparency, which made it less possible to see how some models came to the presented values and conclusions,
- The 3CSEP HEB model is much more transparent than most of the analysed studies, this is a very strong point for this report.

CHAPTER 7 – POLICY RELEVANT MESSAGES

The main outcome of this report is the demonstration of a significant potential for energy use and CO₂ emissions reduction in the building sector. With state-of-the-art technological measures implemented worldwide (as assumed in the Deep Efficiency Scenario), it is possible to reduce absolute final thermal energy use in the building sector by more than one third by 2050 and the related CO₂ emissions can be almost halved even taking into account significant increase in global floor area (127% increase from 2005 to 2050).

This pathway is very ambitious in its assumptions and requires strong political support. However, if energy efficiency improvement is moderate, almost 80% of global final thermal energy savings can be locked-in by 2050 in the world building infrastructure. Without actions (if the energy performance of the global building sector remains at its current level), energy use will almost double in the analysed period. The lock-in problem originates from the fact that if moderate performance levels become the standard in new and/or retrofit buildings, it can either be impossible or extremely uneconomic to further reduce energy consumption in such buildings for many decades to come and in some cases, for the entire remaining lifetime of the building. The results of the study show that in case the mitigation efforts in the building are moderate, the lock-in problem will take place in all key regions, making the realization of energy saving potentials impossible in the mid-run.

However, even a very ambitious proliferation of energy efficient best practices is insufficient to achieve vital global greenhouse gas reduction targets. In other words, despite the radical transition to very energy efficient buildings worldwide, the building sector will still not contribute enough to climate change mitigation goals.

Therefore, reducing building energy demand has to be accompanied by the decarbonisation of energy supply and significant behavioural and lifestyle changes. To decarbonize energy supply, a wide proliferation of renewable energy technologies seems to be essential. Behavioural and lifestyle changes can help to limit floor space growth, avoid unnecessary energy consumption, and increase the efficiency of energy systems in buildings.

The major increase in energy use and related CO₂ emissions will come from the developing world due to rapid economic development, expanded access to energy services and population growth. Global building floor area is projected to increase by almost 127% by 2050 with most of this growth coming from developing countries. How such an expansion will affect building energy use and GHG emissions greatly depends on the energy performance of the buildings constructed in the next 40 years, the energy carriers used in these buildings, and

the ways how energy will be utilized in these buildings. In developed countries the depth of building renovation is also crucial, as retrofit buildings have the largest share of total building stock by 2050. If “deep” renovation becomes a common practice, it will result in significant energy savings through retrofitting existing buildings. However, if moderate level of renovation remains dominant, this opportunity will be lost and potential energy savings will be locked in retrofitted buildings for several decades. Therefore, in order to promote “deep” renovation ambitious building codes and standards, which include provisions for energy performance of retrofit buildings, have to be implemented and effectively enforced and preferably accompanied by various incentives for energy efficient renovation (e.g. grants, subsidies, tax deductions, etc.).

In developing regions new building stock has the dominant role and, therefore, most of potential energy saving may come through construction of new energy efficient buildings. It can be achieved through enforcement of stringent building codes, requiring high levels of energy performance for new construction, in combination with building certification and labelling, technology transfer, training of building specialists and financial incentives. However, in order to stimulate a substantial transition of the building sector to a more advanced level of energy performance, a holistic approach is needed for both developed and developing countries. This approach should include measures and policies for both new and existing buildings, including energy efficiency improvements and installation of renewable energy technologies.

OECD countries are responsible for the largest share of current energy consumption, so it is impossible to achieve ambitious global reduction targets without their major contributions. In the cold and moderate climate zones where most rich countries are located, relative emissions reduction potentials are enormous. It is also clear that urban areas will be responsible for most of the growth in energy use (85% in the Frozen Efficiency Scenario), both in developed and developing countries. In developed countries most of the population is already living in cities while in developing regions urbanization is expected to increase the number of city dwellers by 2820 million, which is approximately 35 times the population of Germany.

In developing regions, urban and rural lifestyles are very different. In cities, access to energy services is better due to better infrastructure and higher living standards; so energy demands are usually higher too. The analysis shows that approximately 70% of the potential growth in thermal energy use can be attributed to the cities of developing countries. Therefore, measures for building energy performance improvement and the related policy instruments should be focused on urban areas in developing regions.

A notable exception – where rural regions are absolutely crucial – is the replacement of inefficient stoves in India. This is particularly important to increase

the efficiency of water heating in most developing regions (besides all other environmental and health co-benefits).

The four focus regions of this report – the US, China, India and the EU – are responsible for more than 60% of global final thermal energy use. Reduction potentials in the EU and the US are above 60%; CO₂ savings can be measured in gigatons (1.8 and 1.3Gt, respectively). In China, the explosive growth of floor space can be off set by energy efficiency improvements. In India, it is a great success if thermal energy use just doubles.

CHAPTER 8 - CONCLUSIONS

The presented study aimed at (1) analysing existing key energy models for the building sector and (2) estimating best-case potential mitigation of building energy related CO₂ emissions by 2020, 2030 & 2050.

The first aim has been achieved through a detailed review and comparison of key existing models related to energy use and CO₂ emissions from buildings, including comparison of methodologies, assumptions, mitigation strategies, data and results. The comparison of the results proves that even though the models use various assumptions, methodologies and measures, they come to the common conclusions illustrating a significant mitigation potential in buildings, and presenting the results in a similar range of values.

The second aim required the elaboration of a comprehensive model (referred to in the report as 3CSEP HEB Model – Center for Climate Change and Sustainable Energy Policy High Efficiency Buildings Model) on estimating energy use for space heating, cooling and water heating of the building sector for the world and four key regions (US, EU-27, China and India) from 2005 till 2050. Within 3CSEP HEB model three main scenarios has been analysed and mitigation potential has been estimated illustrating that by 2050 about 40% of global CO₂ emissions related to thermal energy use can be avoided through ambitious energy efficiency improvement in buildings. However, if the actions for realization of this potential are not taken urgently more about 80% of thermal final energy savings will be locked in the building for uncertain time.

Although the present study presents enormous research efforts to conduct as detailed and robust analysis as possible within a very ambitious timeframe, there are certain gaps in knowledge, which should be taken into consideration.

8.1 Gaps in knowledge

Uncertainties in energy and CO₂ scenarios are substantial. Data collection in most developing country regions (which are very important) is extremely difficult, making assumptions for scenarios then introduce new uncertainties, and it is not easy to compare scenario results with other (similarly uncertain) model predictions due to methodological issues. Below the most important sources of uncertainties are listed for each of the research steps.

Data collection:

- Very limited data availability in developing country regions (especially by building types, end-uses, etc.). From India, for example, there is no data about any exemplary buildings.

- Data transfer for one region to another and from one climate zone to another (used to fill data gaps) does not take into account the features of the region where the data are transferred.
- Due to a very detailed climate classification, with a large number of climate zones, it was impossible to find energy use data for each climate zone, therefore, calculation of missing data on energy intensities was made by applying coefficients, depending on the level of cooling, heating and dehumidification energy needs. Such an approach is rather uncertain, as no data exist on such coefficient.
- Data availability is bias in the case of all major regions (more data from the more developed parts of the region)
- There is an insufficient description of data collection methodologies in the case of many datasets, hence, problematic comparison or combined use of different datasets (e.g. energy intensity with reference to total floor area or conditioned – heated or cooled – floor area)
- Limited accuracy of data points (e.g. emission factor)

Assumptions:

- Inherent uncertainty of a large number of parameters
- Insufficient region-specificity and applicability of global classifications (climate classification, building types, etc.)
- Insufficient information about the most important region-specific parameters that affect input values (e.g. district heating infrastructure in regions, slums, etc.)
- Controversial information from different sources, disagreement between experts, mistakes in published scientific reports
- Due to the complexity of the issue and the limited time and resources, certain assumptions had to be kept simple even though better solutions do exist (e.g. in the case of the share of MF and SF buildings in urban areas). Limited options for sensitivity analysis (very large parameter space)
- Lack of justification for some assumptions: for example, floor area per capita growth in developing countries to OECD levels or portion of OECD level (so-called adjustment factor) or growth of commercial floor area proportionally to GDP dynamics. However, more reliable information on this kind of dynamics has not been found during the limited timeframe of the project; regional experts also have not provided better judgments regarding this matter.
- Fixed emission factors. This assumption is made in order to evaluate the effect of energy demand reduction in buildings and does not take into account changes on supply side, thereby, not considering its potential decarbonisation.
- Analysis only of direct emissions. Data on indirect emissions is usually scarce and, therefore, the study takes into account only direct CO₂ emissions (not other GHGs), thereby, not including emissions from

utilization of unsustainable biomass, which has a significant share of fuel mix in developing countries (e.g. China). This may lead to underestimation of total CO₂ emissions for some regions.

Models comparison:

- The lack of transparency, which made it not possible to see how some models came to the presented values and conclusions
- Most models did not have sufficiently detailed messages concerning the methodology, measures and strategies to achieve the mitigation potential
- The studies used various baseline scenarios, what made the mitigation potential in the reference to different scenarios less reliable
- Values not presented in consistent way, e.g. only as charts (what required reading the values directly from the them), various units
- Different end-uses covered by models, the results not broke down by end-uses
- The majority of studies did not present the values for emission factors and/or primary energy factors, which are needed to convert final to primary energy
- The majority of studies did not present the values for fuel shares
- Different projection periods of models

The 3CSEP HEB model is much more transparent than most of the analysed studies, what is a very strong point of this report.

Sensitivity analysis

- Many parameters that could influence the results were not analysed
- The analysis were done only for the “Deep Efficiency” and “Moderate Efficiency” scenarios
- Only few values of parameters change were chosen
- It was not clear which output should be analysed

Methodology and scope:

- Analysis of final energy. As the minimization of primary and final energy use requires different measures, and the real-life optimum is between these options depending on the decarbonisation rate of energy supply, it would be important to analyse strategies for these two cases separately. However, the analysis of primary energy scenarios is out of the scope of the study.
- Analysis of only three end-uses. Only energy use for space heating, cooling and water heating are considered in this study. It would be

- important to include modelling of energy use from lighting and appliances; however, it was impossible due to time and resources limitation.
- Inseparable results for space heating and cooling. The results for space heating and cooling are presented together as the input data on building energy intensities is usually reported together for heating and cooling and, generally, it was very difficult to find building energy data with a detailed split by end-use or information on shares separately for space heating and cooling in total building demand.
 - Focus on energy efficiency. The study focuses on the potential for energy use reduction through an ambitious improvement of energy efficiency in buildings. However, other crucial factors for fossil fuel energy demand reduction, such as utilisation of renewable energy in buildings and life style change are not considered in the current study. In order to evaluation full mitigation potential for GHG emission reduction for the building sectors, these aspects have to be taken into account.
 - Universal methodology for all regions. The limitation of this approach is that regional features sometimes play a major role in the final outcomes. For example, in China and Japan zonal heating of the house is a common practice, which reduces considerably the heated floor space of a building. However, as the model considers floor area per capita for all regions as the data on such peculiarities are usually unavailable. This may cause overestimating of energy use for a region. However, major efforts were made to take such key features into account, according to the information provided by regional experts without a major change in the modelling logic
 - Universal climate zones classification and thermal comfort requirements for all regions. Climate zones classification was based on HDD18° and CDD10°, according to US standards, however, in some regions (e.g. China) the perception of thermal comfort is considerably different from the one existing in the developed countries. For example, according to Jiang (pers.com.), in some parts of China during heating season the indoor temperature is around 10 to 16 °C in most of time.
 - Utilization of population and GDP projections as the main drivers for residential and commercial building floor area dynamics. Although UN projections for population and GDP are used in the model, building floor area dynamics not always directly correlated with these parameters. For example, addition of new individuals to the population does not always mean addition of new floor space to the economy; and vice versa, decrease in population does not necessarily mean removal of building floor space. However, in the latter case it is true for the model in terms of energy use decrease.
 - Fixed energy intensities. Energy intensities for different building types and vintages remain fixed during the whole period of the analysis. The study distinguishes between five vintages with different level of building energy performance. The modelling logic presumes that the values of energy

intensities for space heating and cooling do not change in terms of absolute numbers (e.g. new or retrofit buildings consume the same amount of energy for space heating and cooling in 2005 and 2050), however, in ambitious scenario the share of advanced buildings, which consume much less energy, grows, ensuring overall energy use reduction. However, it is more likely that energy performance of conventional buildings will be increased gradually before it reaches the advanced level.

8.2 Directions for further research

Taking into account outlined gaps in knowledge there is a number of areas for further research and improvement of the model:

- Extending the scope of the study by including into analysis other end-uses, such as lighting and appliances
- Separate modelling of space heating and cooling in order to evaluate the contribution of each end-use into total building energy use and mitigation potential
- Modelling potential for fossil fuel energy use and CO₂ emissions reduction through utilization of renewable energy technologies in the building sector
- Modelling potential for fossil fuel energy use and CO₂ emissions reduction through possible life changes towards a more sustainable pattern
- Further research on building floor area dynamics, addition of other important drivers, besides population, GDP and increase in floor area per capita for developing countries
- Collection and update of energy use data on state-of-the-art buildings in different regions and climate zones
- Estimation of investment costs and energy cost saving of different scenarios
- More extensive regional analysis for the key regions of interest. This study has shown that in order to obtain robust results, a deep analysis for each region has to be conducted, which is possible only in case of comprehensive communication with regional experts and a review process. Regional analysis has to include the following:
 - Detailed data collection for all main parameters (energy intensities, floor area per capita, commercial floor area, retrofit rates, demolition rates, etc.)
 - Existing climate classification(s)
 - Variation in building types including age of the building stock
 - Distribution between single-family and multifamily buildings in urban and rural areas and their shares in the building stock
 - Perception of thermal comfort, existing heating and cooling practices
 - Utilised energy carriers for heating, cooling, water heating and fuel mix
 - Investment costs of different energy efficiency measures during construction and renovation

- More data on slums and informal dwellings in and India are needed
- More data on the projections of slums development/reduction are needed
- More data on the assumptions and methodologies are needed, which were used in the analysed models – to find the better correlation between the measures and strategies needed to be taken to realize the mitigation potential
- The common baseline for all models is needed
- More input parameters should be analysed in the sensitivity analysis

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About GBPN The Global Buildings Performance Network (GBPN) is a globally organised and regionally focused network whose mission is to advance best practice policies that can significantly reduce energy consumption and associated CO₂ emissions from buildings.