Cutting the energy use of buildings: How deep can the planet go?

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Abstract

While it is a well-accepted fact in the energy efficiency expert community that reducing energy use in the building sector is one of the most effective and cost-effective ways for climate change mitigation, the magnitude of the real opportunities has rarely been quantified in a rigorous manner. Reliable figures on the real contribution of the building sector to climate change mitigation and meeting other global societal goals are crucial in the arena of a broad portfolio of different alternatives, strongly competing for their market shares.

The Centre for Climate Change and Sustainable Energy Policy (3CSEP) at the Central European University has been assessing and synthesizing various global research initiatives in this field for over a decade, including leading efforts for the IPCC's 4th and 5th Assessment Reports, the Global Energy Assessment, and now for the newly established Global Building Performance Network. In a rigorous, detailed modelling exercise based on a novel and comprehensive methodology, new mitigation scenarios on global and regional building energy use and related CO_2 emissions have been constructed, rooted in the latest building science and using best practice experiences.

The results of this modelling work attest that buildings can play a crucial role: despite growing population, welfare and increased energy service levels in buildings, global final energy use for heating, cooling and water heating in 2050 can be reduced by one-third as compared to 2005 levels. In contrast, the research highlighted that present policy trends are still very far from reaching such ambitions: about 80 % of cost-effective energy savings will be locked-in for decades, where only a fraction of this potential can ever be harvested and at much greater costs. The paper clearly demonstrates the urgency of ambitious policy efforts, actions in the developing world, urban areas and specific building types.

Introduction

Global greenhouse gas (GHG) emissions have grown by about 70 % between 1970 and 2004 (IPCC 2007) and are projected to continue growing in the future. Buildings are one of the key sectors contributing significantly to global emissions and, therefore, climate change. Such contribution is expected to increase, taking into account expansion of building areas, energy-consuming equipment and access to modern energy services (IEA 2008).

The global building sector (residential, commercial and services) accounts for about 25–40 % of total global energy demand (IEA 2009; IEA 2010a; Greenpeace International 2010) and about 30 % of global energy-related CO_2-emissions (IPCC 2007; IEA 2009; IEA 2010a; IEA 2010b). Buildings produce GHG emissions during all stages of their life cycle including construction, operation, maintenance and demolition (ECOFYS 2004). Operation stage is usually the most emission-intensive, accounting for nearly 80 % of the total CO_2 emissions in residential buildings worldwide (WBCSD 2009). Thermal energy end-uses have the largest portion in global total building energy use: over half is utilised for space heating and coolin g and another 10–20 % used for satisfying water heating needs. Therefore, thermal energy uses account for approximately two thirds of the total final energy use and are in the focus of this

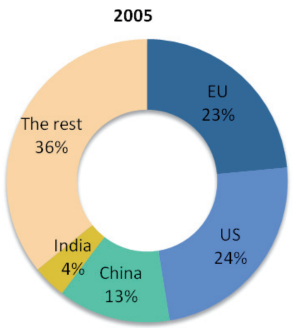

Figure 1. Share of building final thermal energy use by key world region in 2005 (based on study results).

paper (i.e. lighting and appliances are not taken into account in the analysis).

At the same time the building sector provides the largest cost-effective mitigation potential. Despite this tremendous opportunity to reduce energy consumption and emissions from buildings, there are few studies that focus on the global building sector and rigorously quantify its potential.

Energy efficiency improvement in buildings in combination with switching from fossil fuels to renewable energy sources and energy carriers with lower a CO_2- emission -factor (including low carbon electricity generation) can make an impact, along with behavioural changes and strong policy support. These are all low cost CO_2 measures, which make the building sector very important in terms of global mitigation potential.

This paper presents a novel effort to evaluate the importance of the global and regional building sectors in mitigating climate change by means of scenario analysis, to provide a scientific basis for developing policy instruments in order to realize energy savings potentials in the mid-term future.

On the regional scale the paper focuses on four key regions: US, EU-27, China and India. Together, these regions are responsible for more than 60 % of the 2005 global final building thermal energy use (see Figure 1). The model also analyses 11 big regions, which together cover the glob. The results for these regions are presented only as aggregated for the world.

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. Although this paper does not present the results for the costs of these scenarios, only the data on building energy performance for the best-practices cost-effective in a particular region have been used.

The paper is going to answer several main questions:

- How much energy can be saved through worldwide proliferation of present building energy efficient best-practices?
- How much energy savings will be "locked in", if moderate political and technological efforts remain dominant?
- What should be the focus of policy actions in the global and regional building sector?

Methodology and key assumptions

In order to answer the three key questions from above the research team at the Centre for Climate Change and Sustainable Energy Policy (3CSEP[1]), Central European University (CEU) has elaborated a sophisticated High Energy Building (3CSEP-HEB) model commissioned by the Global Building Performance Network (GBPN[2]) for analysing energy and CO_2 emissions trends in buildings at the global and regional levels till the mid-century. The model focuses on building energy use for space heating and cooling (SH&C), as well as water heating. For detailed information regarding the model's methodology, flow chart and assumptions, see Urge-Vorsatz et al. (2012).

This model is novel in its methodology as compared to earlier global energy analyses, as it is based on the performance-oriented approach to buildings energy analysis. Under this approach a building (or an aggregated building type) is considered as an integrated, holistic system with its performance being the key parameter of the analysis and important input data. The overall energy performance of buildings for SH&C is examined, regardless of the individual measures applied in each building. For water heating, on the contrary, the diversity of possible solutions is taken into account and for each individual technology, an average achievable efficiency is assumed.

The 3CSEP-HEB model effectively combines a bottom-up framework with top-down features through analysing detailed technological information for a particular sector of economy and utilising macroeconomic (GDP) and socio-demographic data (population, urbanization rate, floor area per capita, etc.). Besides global estimates, the model provides the results for 11 aggregated regions, described in (Urge-Vorsatz, Eyre, et al. 2012) and separately for US, China, India and each of 27 EU Member States. In this paper the term "region" refers to both regions and countries considered in the model, if it is not specified otherwise.

One of the unique features of the 3CSEP-HEB model is a comprehensive multi-level building classification. Depending on a settlement type, buildings are divided into urban and rural. According to the building type, buildings are distinguished between residential (single-family or multifamily) and commercial and public (C&P) buildings (offices, educational buildings, restaurants and hotels, retail and others). Buildings are located in different climate zones, depending on region-specific climatic conditions. A rigorous geo-spatial analysis has been used in order to create a novel climate classification, based on specific patterns in heating degree days, cooling degree days, average temperature and humidity in order to capture differences in energy needs for space heating, cooling and dehumidification all over the world. Such a classification provides the justification of the assumptions for building energy performance in the investigated locations where the reported data is missing.

Buildings belong to one of five building vintages, based on their thermal energy performance: standard, new, advanced new, retrofit, advanced retrofit. Standard buildings are those ones, which had been built prior to the analysed period (earlier than 2005), and, therefore, include old energy-intensive building stock. New buildings include the ones constructed during

1. www.3csep.ceu.hu
2. http://www.globalbuildings.org/

a particular year within the analysed period. Correspondingly, retrofit buildings are those renovated during a particular year. The same logic is applied to advanced new and advanced retrofit buildings, with the only difference that their specific energy consumption for SH&C is much lower. Advanced buildings represent regional best-practices, meaning new or retrofit buildings with ambitious level of energy performance (with typically 70–90 % lower energy consumption for SH&C). It is assumed that if this performance level is reached in a certain building, it can be replicated in other buildings belonging to the same building type and climate zone.

The crucial part of the model is the estimation of the building floor area for each year. The outlined building vintages and types participate in the annual building stock dynamics, including demolition and renovation of standard buildings and new construction of new and advanced new buildings.

The main drivers for residential floor area dynamics are region-specific floor area per capita (which remains constant for developed countries and grows in developing countries with time) and population projections. Total floor area is split into urban and rural parts, according to the urbanization rate for each region. The overall building floor area is calculated for each climate zone and building type by applying population shares calculated by means of GIS (geographic information system) analysis.

Estimation of the commercial floor area is determined by GDP (Market Exchange Rate) projections. C&P floor area of the region in 2005 is divided by GDP in 2005 and this constant multiplied by GDP for each year to result in the C&P floor area demanded by each region. For exact data on population and GDP projections, as well as, floor area per capita in different regions see Urge-Vorsatz et al. (2012).

Floor area estimations for a particular region, climate zone, building type (including urban/rural division) and building vintage are utilised to calculate the total energy use for SH&C through multiplication by data on specific energy consumption. An enormous effort has been made to collect detailed data on building energy performance for various locations and building types. Collected data come from a great variety of sources (databases, publication, official statistics, expert interviews, etc.). For extensive list of the sources used and the data collection procedures utilised, please, refer to Urge-Vorsatz et al. (2012). However, due to insufficient data availability for all required data-points and limited data precision, certain assumptions have been made to fill in gaps and improve the data quality. The key assumptions are:

- Retrofit buildings consume 30 % (in Moderate and Deep Efficiency Scenario) and 10 % (in Frozen Efficiency Scenario) less final energy for SH&C than standard buildings;
- Most of the data for the energy performance of advanced buildings are in the range of 15–30 kWh/m^{2}yr;
- Energy use of (advanced) retrofit buildings is usually higher than of (advanced) new ones;
- New buildings' energy performance is at the level of a local Building Code or conventional practice.

For water heating energy use, regional technology mix assumptions and the assumed efficiencies of the technologies in these mixes are used together to determine regional average efficiency levels. Therefore, key data for water heating energy use calculation till 2050 include: 2005 residential and C&P hot water energy use values, average efficiencies of water heating technologies and the volume of hot water consumption. Final hot water energy demand is also affected by consumption levels, to account for which the floor area was used as a proxy. Water saving technologies with a potential to reduce consumption are considered when future technological efficiencies are determined.

In the 3CSEP-HEB model future trends in building energy use, CO_2 emissions and floor area are analysed under three alternative scenarios: Deep Efficiency Scenario, Moderate Efficiency Scenario, and Frozen Efficiency Scenario. The scenarios are built on the assumptions for different levels of advanced buildings' proliferation in the building sector, renovation rates, ambitions of policy efforts, etc. (see Table 1).

Results

LOW-ENERGY FUTURE IS POSSIBLE FOR THE BUILDING SECTOR

The results of the scenario analysis have reaffirmed that buildings are the key sector for climate change mitigation, which can follow a low-energy pathway in a feasible way.

The scenario assessment has shown that by 2050, global final thermal[3]energy use in buildings can be reduced by about one-third as compared to 2005 values through implementing already proven and cost-effective energy efficient best-practices and technologies (Deep Efficiency Scenario). It can be done without compromising economic growth and increase in living standards with 127 % increase in floor area as well as a significant increase in thermal comfort levels by the mid-century. Although there are no insuperable technological barriers, ambitious policy efforts are required to achieve this goal.

A hypothetical "frozen" action scenario demonstrates drastically different results: 111 % increase in building energy use increases. However, even if today's policy tendencies are put in force, global building energy use will still increase by about a half of 2005 levels, as shown by Moderate Efficiency Scenario, emphasizing a significant gap between what is possible to achieve and what can be reached with current policy trends.

URGENT AND AMBITIOUS POLICY ACTIONS ARE CRUCIAL

The gap mentioned above means that 80 % of the 2005 thermal final energy use will be locked-in by 2050 due to the long buildings' lifetime and relatively slow major retrofit cycle of the built infrastructure (especially for SH&C – see Figure 3). The size of the lock-in effect is considerable in all regions. Therefore, if ambitious climate mitigation actions are not taken immediately, it will not be possible to utilize much of this unlocked potential, unless only at excessive costs.

As for the regions, in the EU-27 effective implementation of current building policies are able to capture a large fraction of the cost-effective potentials, however, all other regions are

3. In this paper "thermal" energy use refers to energy use for space heating, cooling and water heating.

heading towards a significant lock-in. In the US, approximately half of 2005 final energy use can be locked in by 2050; in China, approximately two-thirds; and in India over 400 %. In India this points to the crucial importance of ambitious building codes, with effective enforcement and requirements for high energy performance.

The high lock-in risk demonstrates the crucial importance of early policy action, strategic policy planning, as well as the principal importance of ambitious levels of energy performance in building codes for new construction and renovation. Reducing building energy use by the mid-century in a meaningful way requires worldwide building codes to adopt performance levels demonstrated by best-practices in a particular climate zone and building type, even if it is not yet common on the local market. Well-designed policies have to support accelerated transformation of the construction industry and markets in order to realise energy savings in the building sector by mid-century.

Table 1. Key characteristics of the three scenarios.

Parameter	Deep	Moderate	Frozen
Main features of final energy use for SH&C	Wide proliferation of building best-practices in construction and renovation	Compliance with national building codes and current enforced energy efficiency policies (e.g in EU – EPBD)	Energy performance of new and retrofit buildings do not improve as compared to their 2005 levels
Main feature for water heating energy use	Solar systems and/or advanced heat pumps gain large significance	Water heating efficiency measures are not more ambitious than currently existing programs	The fuel mix and efficiency of water heaters do not change
Share of advanced buildings	By 2022 advanced will replace most of conventional new and retrofit buildings on the market	In most of the regions no advanced buildings are assumed, except for (EU, Western Europe and North America)	Advanced buildings assumed only in Germany as 5% and in Austria as 10% of their new building stock; no advanced retrofit buildings
Energy performance of advanced buildings	Passive house level (15–30 kwh/m^2/yr)	Passive house level (15–30 kwh/m^2/yr)	Passive house level (15–30 kwh/m^2/yr)
Energy performance of conventional buildings	New buildings correspond to regional building codes or averages; retrofit consume 30% less than standard buildings	New buildings correspond to regional building codes or averages; retrofit consume 30% less than standard buildings	New buildings consume 10-20% more than the national building codes or averages; retrofit consume 10% less than standard buildings
Renovation rate	Till 2019 – 1.4%, from 2020 – 3% for all regions	Till 2019 – 1.4%, from 2020 – higher level (1.5–2.1%, depending on the region)	Fixed at 1.4% for all regions
Policies considered	Strong political efforts are need to encourage such an ambitious market transformation	Current policy trends (e.g. EPBD recast in EU-27 and local building codes in other regions)	No policy interventions

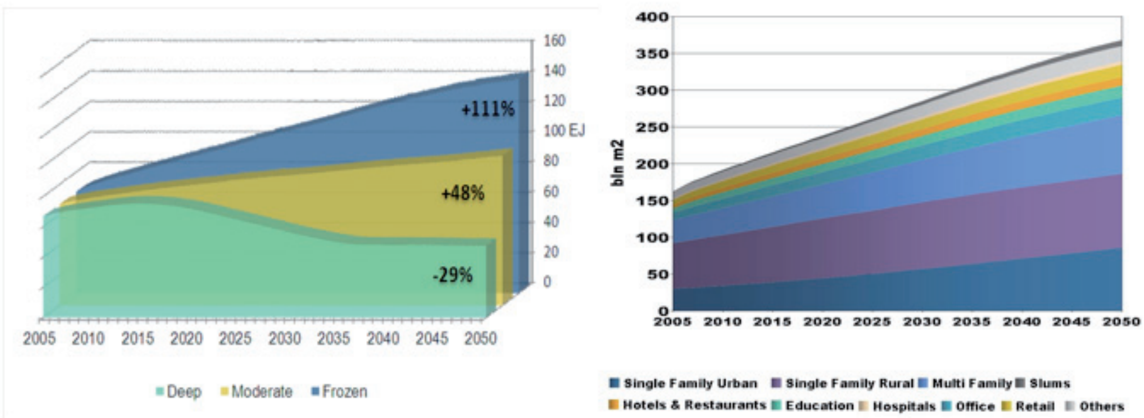

Figure 2. World final thermal energy for three scenarios, contrasted by floor area by building type. Note: For the final thermal energy, percentage figures show the change in 2050 in relation to 2005.

Contents Keywords Authors

FOCUS ON NEW BUILDINGS IN DEVELOPING COUNTRIES IS NECESSARY

The scenarios show that the greatest growth in the final thermal building energy use and related GHG emissions will take place in developing countries due to rapid economic development, increases access to energy services and population growth. Most of the increase in the final thermal building energy use will come from the fast growing economies, such as China and India. Floor area in these countries is projected to increase significantly by 2050, which will require construction of numerous new buildings. The extent at which such expansion will affect building energy use and related emissions greatly depends on the energy performance of the buildings constructed during the next 40 years and the way energy services will be used in these buildings. Figure 4 shows trends in in China and India for floor area and building energy use for SH&C. It also demonstrates the amount of energy savings in case buildings are constructed and renovated to high energy performance levels (China: -12 %, India: +188 % in relation to 2005). If moderate levels of building energy efficiency improvement remain dominant in these regions it will make a drastic increase in thermal building energy use inevitable by 2050 (China: +68 %, India: + 680 % in relation to 2005).

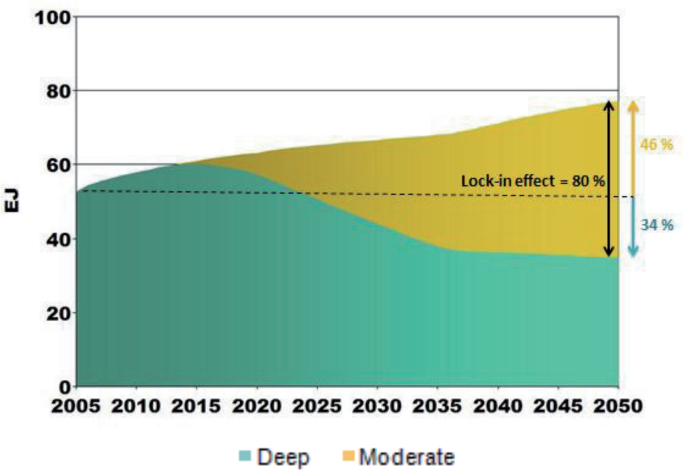

Figure 3. The lock-in effect: World final energy use for SH&C for Moderate and Deep Efficiency scenarios.

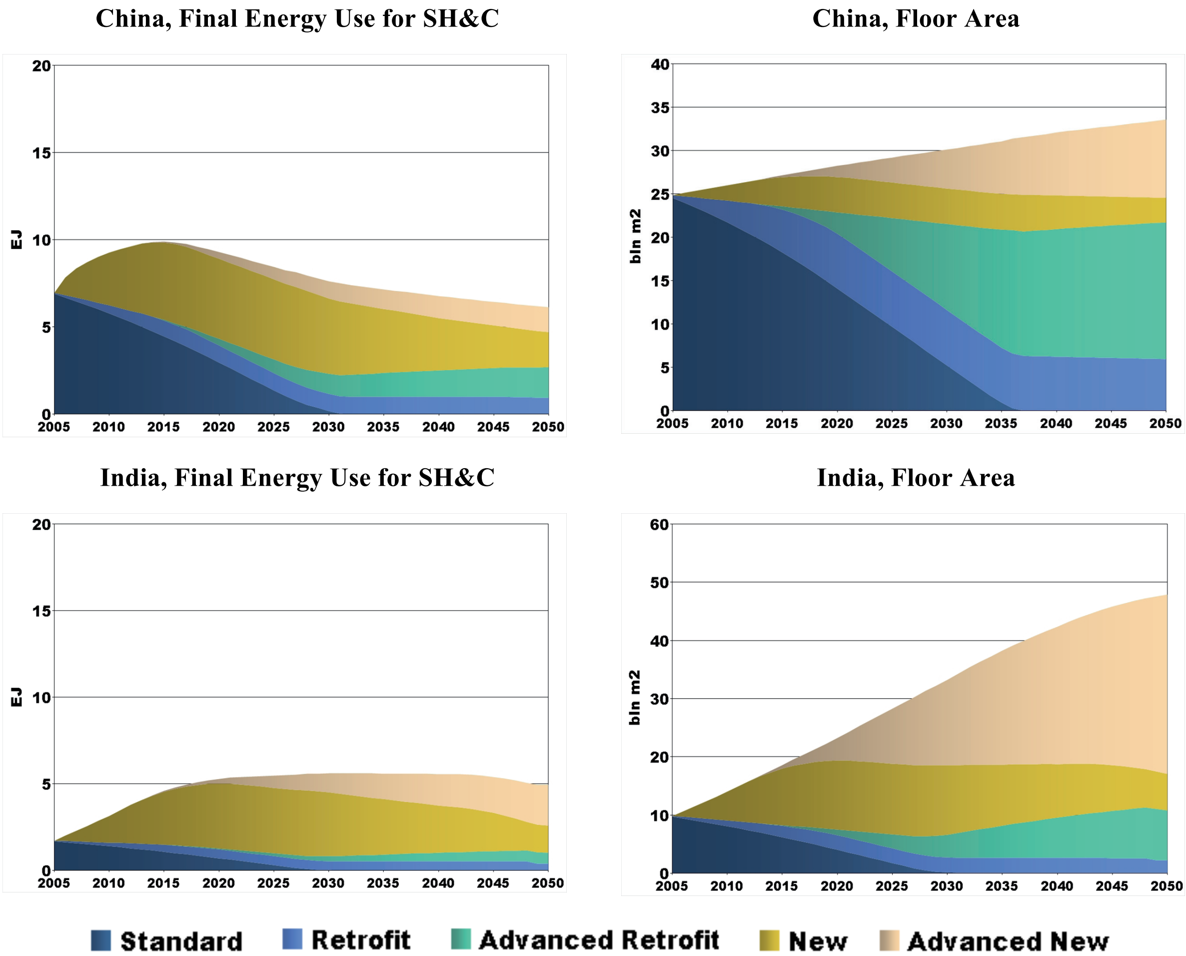

Figure 4. Floor area and energy use for SH&C in China and India in Deep Efficiency Scenario.

FOCUS ON EXISTING BUILDINGS IN DEVELOPED COUNTRIES IS ESSENTIAL

In developed countries depth of building renovation is most crucial, as most of the buildings that determine energy use and emissions levels by 2050 already exist. Therefore, the focus of the policy actions in developed countries, such as US and EU, should be put on existing building stock, deep renovation and acceleration of the renovation rates (see Figure 5).

In US the proliferation of the state-of-the-art building practices by 2050 can result in 65 % of energy saving potential. Slightly higher level of energy savings, up to 69 %, can be reached by the EU-27. The Moderate Efficiency scenario, on the contrary, demonstrates a significant difference in the potentials for these two regions. While in the US most of the savings are likely to be lost, if policy trends maintain their current level of ambition, resulting in a very modest energy saving potential by 2050 (-15 %), in the EU-27 a significant part of the potential can be realized through effective implementation of EPBD recast (-61 %). However, this amount of energy savings in the EU is possible to obtain only if EPBD enforces all Member States to construct and especially renovate their buildings to low energy standards (about 25 kWh/m²year of final SH&C energy use).

FOCUS ON EFFORTS IN CITIES

For the first time the 3CSEP-HEB model has quantified the role of cities in building energy use: buildings in urban areas are responsible for about 70 % of the total thermal energy use in 2005, despite the fact that the rural population is still larger at the global level and for many regions (see Figure 6).

As population living in urban areas all over the world is increasing with time, respective floor space is also growing together with thermal energy use to satisfy higher living standards and energy needs. By the end of the analysed period 85 % of growth in building energy use will come from urban areas, 70 % of which – from developing countries. Therefore, urban policies in developing countries are especially crucial for low-carbon building future.

Policies and programs implemented at the city level can play an equally important or even larger role in restraining building thermal energy use as those introduced by national governments, and are often easier to implement. Policies aimed at reducing building energy use in urban areas can include: optimized urban planning and zoning, building permission conditions, mitigating heat island effect, promoting energy cascading opportunities, preferential property tax regimes, etc.

ACTIONS TARGETING SPECIFIC BUILDING TYPES ARE VITAL

The results of the modelling exercise have showed that the importance of different building types for energy use and emissions reduction varies greatly by region (see Figure 7).

Residential buildings are responsible for the greatest part of the final thermal energy use of the world (75 % in 2005, 70 % in 2050 in Deep scenario), as well as of most of the regions and scenarios. In 2005 single-family (SF) buildings used 54 % of

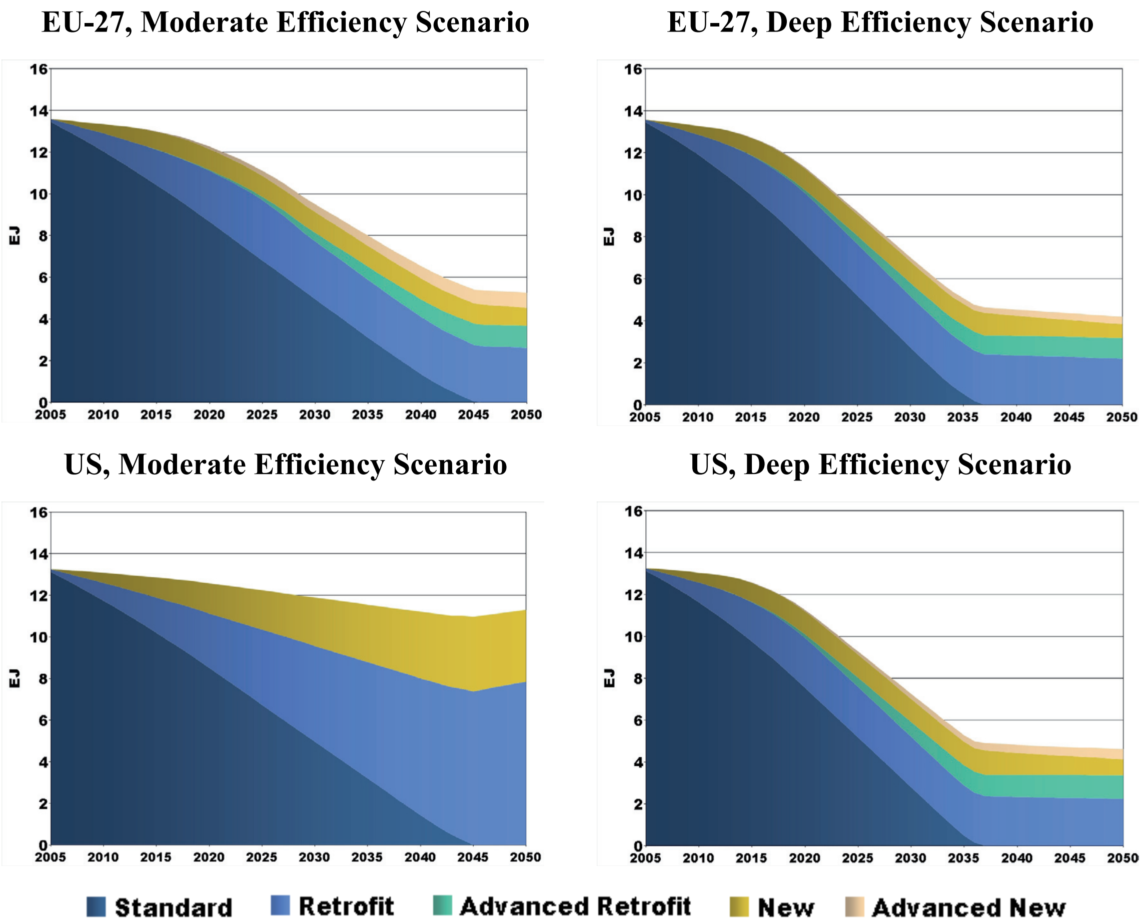

Figure 5. Final energy use for SH&C in EU-27 and US in Moderate and Deep Efficiency Scenarios.

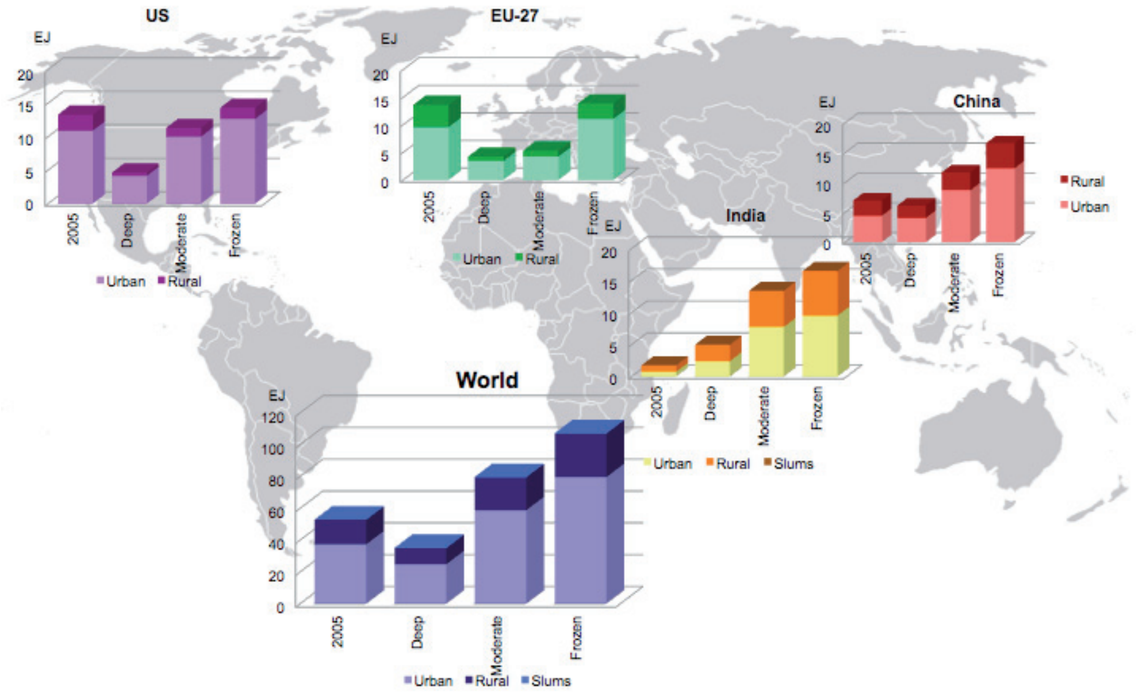

Figure 6. Final thermal energy in 2005 (first column) and 2050 (three scenarios: last three columns) in rural and urban areas for world and four selected regions.

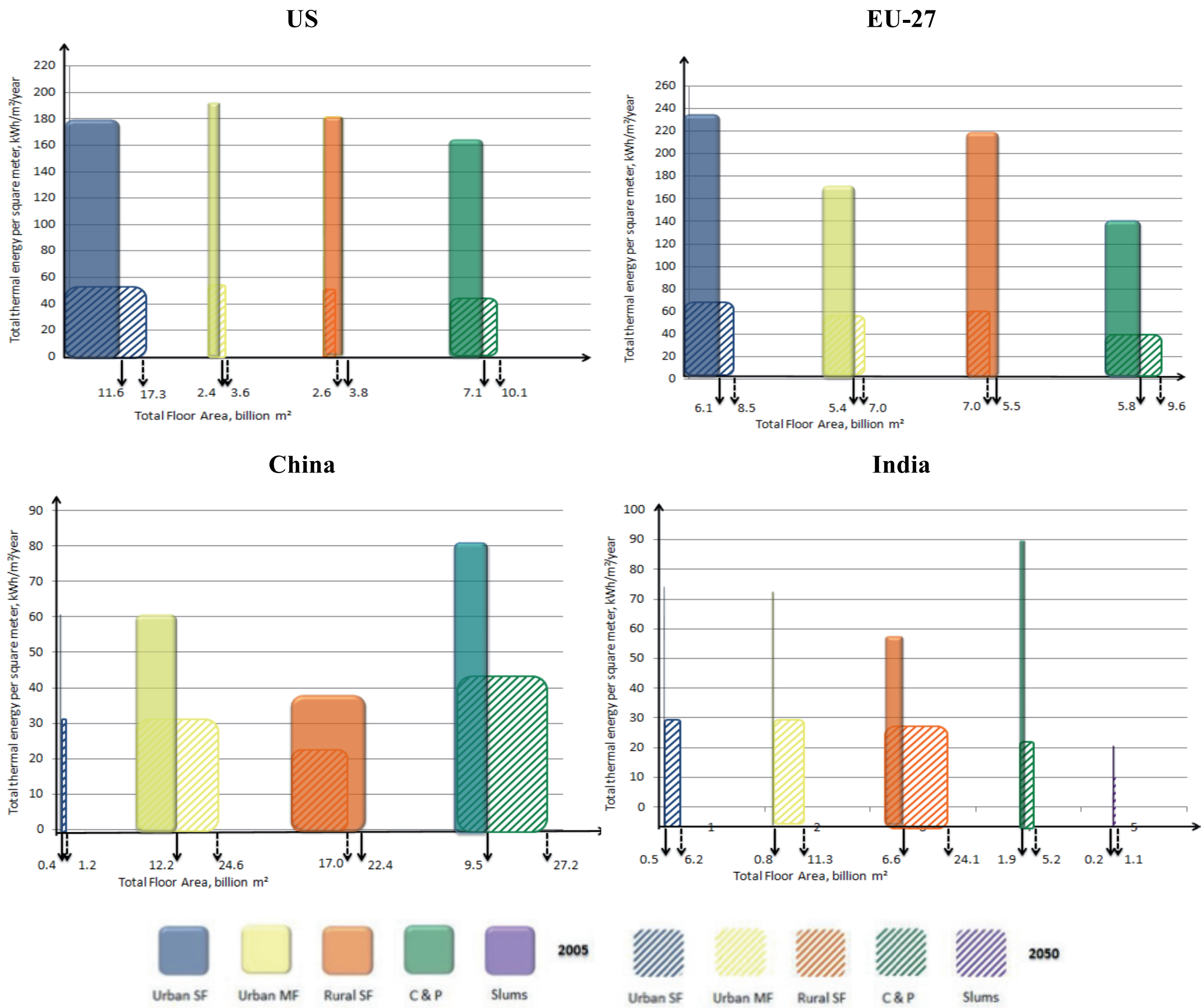

Figure 7. Final energy mitigation potential for DEEP scenario between 2005 and 2050 by building type for four regions.

Table 2. Results for final thermal energy for all key regions and 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%

global building thermal energy, while multifamily (MF) buildings added another 21%. Deep Efficiency scenario shows that the opportunity to reduce global final thermal energy use by 2050 in single-family houses is 37 %, and 22 % in multifamily buildings.

In the US, urban SF buildings are responsible for approximately half of final thermal building energy use, commercial and public buildings for 27 % of it, while shares of rural SF and MF buildings are not significant. In contrast, in China, commercial buildings dominate and their contribution is growing by the mid-century, followed by urban multifamily buildings, urban SF are almost playing no role, and the importance of rural buildings is declining. In India, energy use from SF rural buildings dominates despite increasing urbanization, with MF buildings growing from 9 % to 25 % of all thermal building energy use between 2005 and 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 a 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.

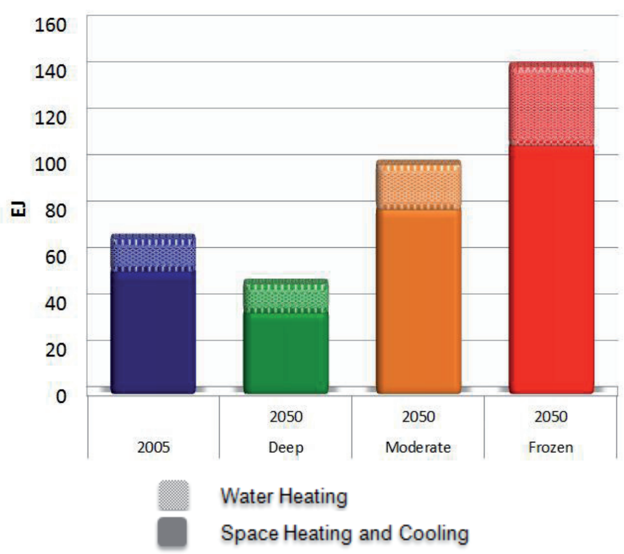

Figure 8. World total final thermal energy in buildings by end-use for three scenarios.

SUMMARY OF GLOBAL AND REGIONAL RESULTS FOR THERMAL ENERGY USE AND RELATED CO_2 EMISSIONS

Table 2 presents the summary of the results for total final thermal energy use for the world, for the four selected regions and three scenarios.

In the analysed regions and on the global scale (see Figure 8) space heating and cooling are a more energy-consuming end-use than water heating, consuming in the range of 65–87 % of the total for different regions and scenarios and about 80 % for the world.

The global energy saving potential by 2050 in relation to 2005 for total final thermal energy use is 29 % (see Table 2). In case building space heating, cooling and water heating do not achieve the level of state-of-the-art practices in the coming 10 years, Moderate Efficiency pathway will bring 48 % increase in total thermal energy use, while under Frozen Efficiency scenario this growth is immense – 111 % by 2050.

In the four key regions Deep Efficiency scenario presents the lowest level of the thermal energy use (see Table 2). If "moderate" efficiency measures are dominant in the building sector instead of "deep" ones, it will result in increasing thermal energy use by 2050, except for the EU-27, mostly due to the implementation of EPBD recast.

Frozen Efficiency case demonstrates the greatest growth in the thermal energy use, as there are no policy interventions and technological improvements, which could mitigate this growth. India, as a fast growing economy, demonstrates the greatest increase in its thermal energy consumption under all three scenarios among other presented regions. However, in Deep Efficiency scenario this growth is much lower than in Moderate and especially in Frozen scenarios: 131 % vs. 491 % vs. 701 %, respectively.

The trends in energy-related CO_2 emissions are similar to the ones in building final thermal energy use both on the global (see Figure 9) and regional scales.

Table 3 presents values for CO_2 emissions from thermal energy use in 2005 and 2050 and the percentage difference in three scenarios in relation to 2005.

About 40 % of global CO_2 emissions from thermal energy use in buildings can be avoided by 2050 in case of ambitious proliferation of state-of-the-art energy efficient building technologies, which corresponds to almost 3 Gt of CO_2 emissions, as shown in Table 3.

In the Frozen Efficiency scenario CO_2 emissions grow in all regions to different levels. Emissions' growth in developing

Table 3. Results for CO_2 emissions related to the thermal energy use for all regions and scenarios.

Region	Baseline	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
	GtCO2 2005	GtCO2 2050	Δ% to 2005	GtCO2 2050	Δ% to 2005	GtCO2 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%

countries, especially in India is the highest. However, in the Moderate Efficiency scenario there is a CO_2 emission reduction by 2050 in developed regions: 17 % in the US and 61 % in the EU-27, in China and in India emissions are growing considerably.

In the Deep Efficiency scenario developed regions show a high potential for CO_2 emission reduction. The results for the US and the EU-27 demonstrate that more than 60 % of CO_2 emissions in these regions can be avoided by 2050, which corresponds to 1.8 and 1.4 Gt of avoided CO_2 emissions, respectively. In China CO_2 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.

Discussion

This section is devoted to demonstrate the robustness and feasibility of the 3CSEP-HEB model's results. It is done by means of sensitivity analysis, comparison of the results to a number of selected models and presentation of the model's key limitations.

RESULTS OF SENSITIVITY ANALYSIS

Any modelling exercise presumes certain level of uncertainty usually caused by gaps in data and modelling assumptions. In this paper the results of a sensitivity analysis are presented for two input parameters: specific energy consumption for advanced retrofit/advanced new buildings and the retrofit rates.

The results have demonstrated that even large variations in the specific energy consumption figures for advanced new and advanced retrofit buildings do not change the scenarios' key outcome. This illustrates that significant energy savings in the building sector are possible even despite considerable increase in energy service levels and floor area (see Figure 10).

Variations in the retrofit rates influence the time to reach the achievable lowest energy use for the overall building stock: the higher the rate, the faster the energy saving potential can be realised (see Figure 11). However, according to the results, a large acceleration in retrofit rates is not desirable, as it leads to higher lock-in effect: during the transition period a higher number of buildings will be retrofitted to sub-optimal performance levels. Therefore, it is advised for policy development to accelerate the retrofit dynamic only when advanced retrofits dominate the market.

RESULTS OF MODEL COMPARISON

The findings presented in this paper are in line with the results presented in other modelling and scenario studies. Eighteen global and selected regional studies that present estimations of energy saving and/or CO_2 reduction potential in the building sector have been reviewed in order to compare to the estimations produced by the 3CSEP-HEB model. The sources used for the comparison include studies by IEA, IPCC (IPCC 2007), WBCSD (WBCSD 2009), LBNL (McNeil et al. 2008), Greenpeace (Greenpeace International 2010), McKinsey (McKinsey 2009), as well as scenarios developed by D. Harvey (Harvey 2010) and J. Laustsen (Laustsen 2012). Most of the studies have different projection periods, assumptions, methods, which aggravates precise comparison and requires caution during analysis of the results.

In all models building energy use is projected to grow significantly (by 60–90 % of the 2005 value by 2050) in the next few decades in case there are no or limited mitigation actions. The final energy demand for thermal energy needs, i.e. heating/cooling/hot water, is likely to grow even more considerably (for more details see (Urge-Vorsatz, Petrichenko, et al. 2012). There are significantly larger opportunities for bringing thermal energy use down compared to other building end-uses. The analysis has illustrated that under mitigation scenarios total building energy use stays roughly constant or even increases by 2050. On the contrary, models focusing on thermal energy uses demonstrate the opportunity of significant reductions – up to 60 % reduction by 2050, as compared to 2005. Similar trends can be observed in energy-related CO_2 emissions trends.

MAIN LIMITATIONS

Substantial uncertainties in energy and CO_2 scenarios are mostly related to the gaps in data. Data collection in most developing country regions is extremely difficult and assumptions to fill these data gaps are hard to accurately justify. It is not possible for the presented model to capture region-specific features related to building practices and energy consumption, also during data transfer from the region or climate zone to another. The accomplishment of the presented modelling exercise has also been aggravated by controversial information from different sources, disagreement between experts, etc.

The 3CSEP-HEB model does not directly present the results for primary energy (although it is taken into account when calculating CO_2 emissions), which may limit the opportunity of analysis and policy recommendations. The model considers

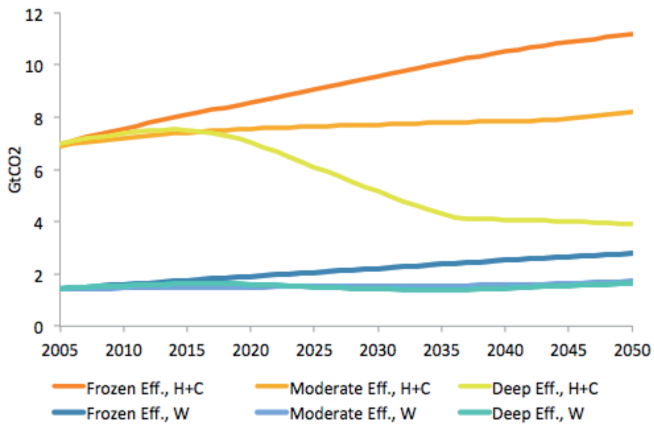

Figure 9. World CO_2 emissions related to the thermal energy use for all scenarios, $GtCO_2$.

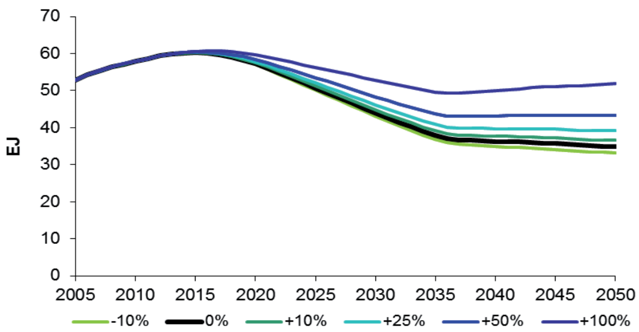

Figure 10. World final energy use for SH&C for the Deep Efficiency scenario for various specific energy consumption intensities for advanced retrofit and advanced new buildings.

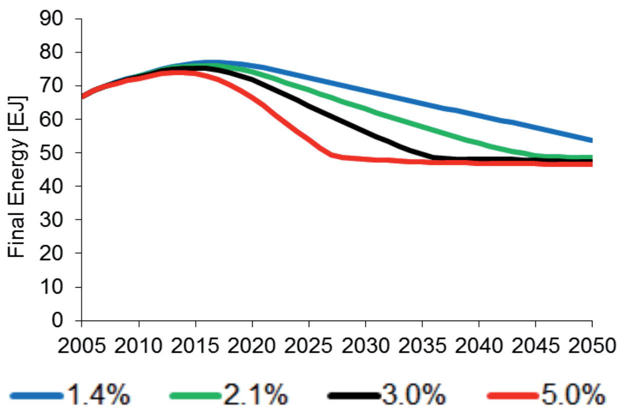

Figure 11. World total final thermal energy for various annual retrofit rates for the Deep Efficiency scenario.

only thermal energy end-use. It would be important to include into the analysis energy use from lighting and appliances; however, this would require different modelling logic and involvement of much more significant resources. Currently the model focuses exclusively on the potential for energy use reduction through an ambitious improvement of energy efficiency in buildings, omitting analysis of other crucial factors, such as utilisation of renewable energy in buildings and life style change. Fixed energy intensities are another important limiting factor. The modelling logic presumes that the values of energy intensities for space heating and cooling do not change in terms of absolute numbers; only the share of advanced buildings grows in Deep Efficiency scenario, 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.

Conclusion

The paper has presented results of the comprehensive model (referred as 3CSEP-HEB model) on estimating energy use for space heating, cooling and water heating and related CO_2 emissions from the global and regional building sectors with a specific focus on US, EU-27, China and India for the period from 2005 till 2050. Within the 3CSEP HEB model three scenarios have been analysed and mitigation potential has been estimated illustrating that by 2050 through worldwide proliferation of state-of-the-art energy efficient technological measures, it is possible to reduce absolute final thermal energy use in the building sector by one third by 2050 and 40 % of the related CO_2 emissions can be avoided even taking into account significant increase in global floor area (127 % increase from 2005 to 2050). A detailed review of key existing models related to energy use and CO_2 emissions from buildings has demonstrated that despite great variations in modelling logic, assumptions and input, significant mitigation potential can be achieved within a similar range of values by mid-century.

However, if the actions for the realization of this potential are not ambitious and/or urgent enough, about 80 % of global thermal final energy savings will be locked in the building sector for decades. The lock-in risk is present in all key regions, making the realization of the potential impossible in the mid-term. It means that if moderate levels of building performance will become standard in new and/or retrofit buildings for the next decade or longer, later on it can either be impossible or extremely economically unfeasible to further reduce energy consumption in such buildings due to long building lifetime and renovation cycles.

Avoiding the lock-in issue and following the ambitious pathway requires strong political support. Without policy actions (if the energy performance of the global building sector remains at its current level), energy use will almost double by the end of the analysed period. Radical transition to highly energy efficient building practices is an essential step to achieve vital global greenhouse gas reduction targets in the building sector. However, in order to further reduce greenhouse gas emissions from buildings, this step has to be accompanied by the decarbonisation of energy supply (through wide proliferation of renewable energy technologies, potentially building-integrated renewables) and major behavioural and lifestyle changes.

The major increase in energy use and related CO_2 emissions will come from the developing world due to rapid economic development, expanded access to energy services, population and floor space growth. The expansion of the floor area in the building sector will require the focus of policy efforts on new construction. New stringent building codes should be effectively enforced and introduced in combination with building certification and labelling, technology transfer, training of building specialists and financial incentives.

In developed countries the depth of building renovation is crucial, as retrofit buildings have the largest share in the total building stock. Therefore, "deep" renovation has to become a common (and preferably, the only possible) practice. Otherwise, domination of moderate or "shallow" renovation will lock in potential energy savings in retrofitted buildings till the next major renovation. "Deep" renovation should be promoted through ambitious building codes and standards, which have to be effectively implemented and enforced and preferably accompanied by various financial incentives (e.g. grants, subsidies, tax deductions, etc.).

Urban and rural lifestyles (especially in developing regions) are traditionally very different. In cities, access to energy services and energy consumption is usually higher due to better infrastructure and higher living standards. The scenarios' results show that approximately 70 % of the potential growth in thermal energy use can be attributed to the cities of developing countries. Therefore, urban areas in developing regions should become the focus for building energy performance improvement and related policy development.

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