Best Practice Policies for Low Carbon & Energy Buildings

Based on Scenario Analysis

Extended Summary

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CONTENTS

Please, see the Main Report (MR) and the Annex of the Report in separate documents

EXTENDED SUMMARY

1.1 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).

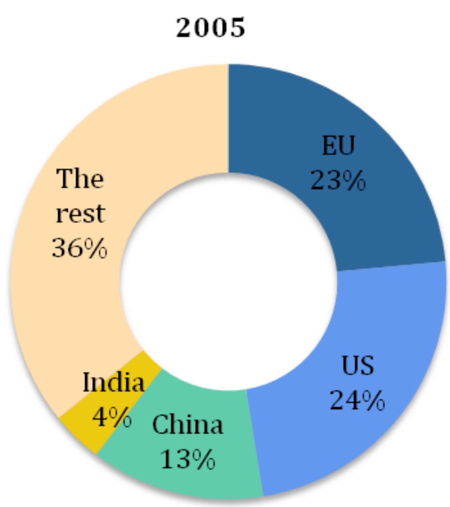


Figure 1. Share of building final thermal energy use by key world region in 2005.

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 how certain policy decisions can have significant consequences, as well as to demonstrate the vast potential in energy savings to policy-makers. 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 the "deep" scenario.

While buildings can contribute to climate change mitigation through a number of strategies, including reduced demand for services (such asthrough behavioral changes), improved technological and systemic efficiency, as well as improved carbon efficiency, this report focuses on the efficiency "lever" of mitigation, i.e. technological and systemic energy efficiency, and few interventions from the other two key levers (behavior and renewable) 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.

Description of the three scenarios used in the analysis:

The deep efficiency scenario demonstrates how far today's state-of-the-art construction and retrofit know-how and technologies can take the building sector in reducing (the growth of) energy use, while also providing full thermal comfort in buildings. In essence, we determine the techno-economic energy efficiency potentials in the building sector, assuming that today's best practices become the standard. The scenario also assumes an accelerated retrofit dynamic after a transitionary decade. The energy efficiency of water heating also increases much more rapidly than before the modeled period: improved stoves in developing countries, condensing gas heaters, water saving technologies become common, rapid penetration of solar water heaters, deployment of efficient heat pump systems, as well as waste heat recovery are the pillars of the hot water element of this scenario.

A frozen efficiency scenario has been used as a reference scenario. While it is a clearly hypothetical future, it demonstrates where the world would be without policy and market developments – the consequences of inaction. Concretely, this 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 levels of energy performance than in the Moderate scenario due to lower compliance with Building Codes. Retrofits rate are assumed to be constant throughout the analyzed period at the level of 1.4%. For water heating it is assumed that the fuel mix and efficiency of water heaters do not change during the analyzed period.

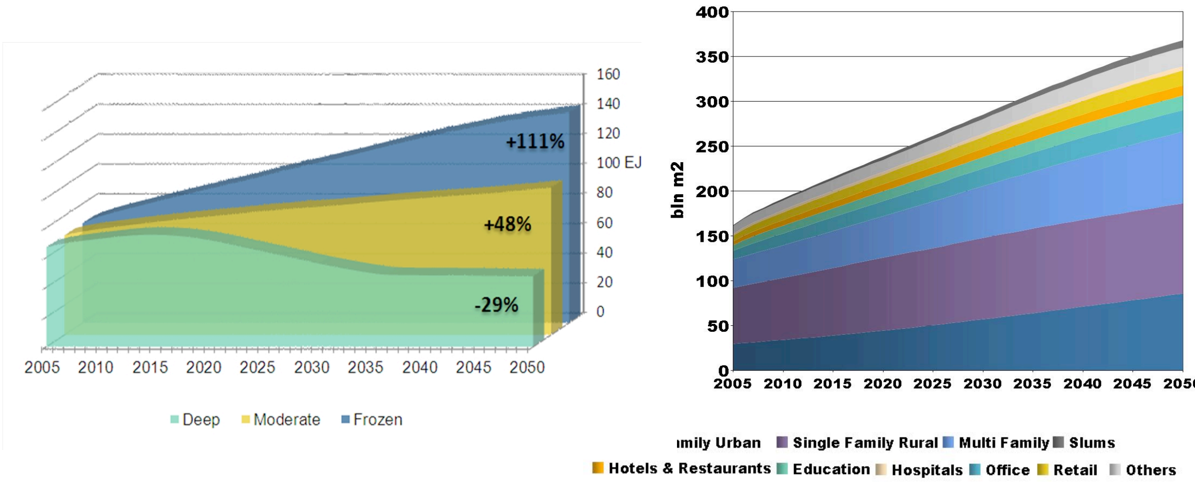
The rationale for the **moderate efficiency scenario** is to illustrate the development of building energy use under recent policy trends. It is still an ambitious scenario as it also assumes an increase in retrofit dynamics (typically from 1.4% to 2.1% in the EU-27, China – 1.6% and India – 1.5%) as well as widespread building codes. 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: 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. Water heating efficiency measures are not more ambitious than currently existing programs such as the boiler scrappage scheme in the UK and the "efficient stove initiative" in India.

Initially the focus of this Extended Summary is on the report's key findings, the key assumptions and methods that are used in the scenario analysis are then summarized and finally the key results of the four focus regions are presented. It is important to emphasize that while the main aim of the report is CO2 emission mitigation, the discussion in the report, and thus the Summary for Decision Makers, 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 decarbonization trends, and such figures may camouflage 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.

1.2 Key Global Findings: Potentials for Climate Change Mitigation

The research has reaffirmed the hypothesis: buildings are one of the key levers 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.

As the sensitivity analysis demonstrates, the findings are very robust despite the uncertainties in input data and achievable individual performance levels.



World floor area by building type

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 bulding type.

These findings are in line with those of other studies. We have reviewed 18 global and selected regional[1] studies that assess energy saving or CO2 reduction potential in the building sector, including those from the IEA, WBCSD, Greenpeace, and McKinsey[2]. Although most studies have different projection periods, assumptions, methods and thus their results should be compared with caution, a few trends are clear:

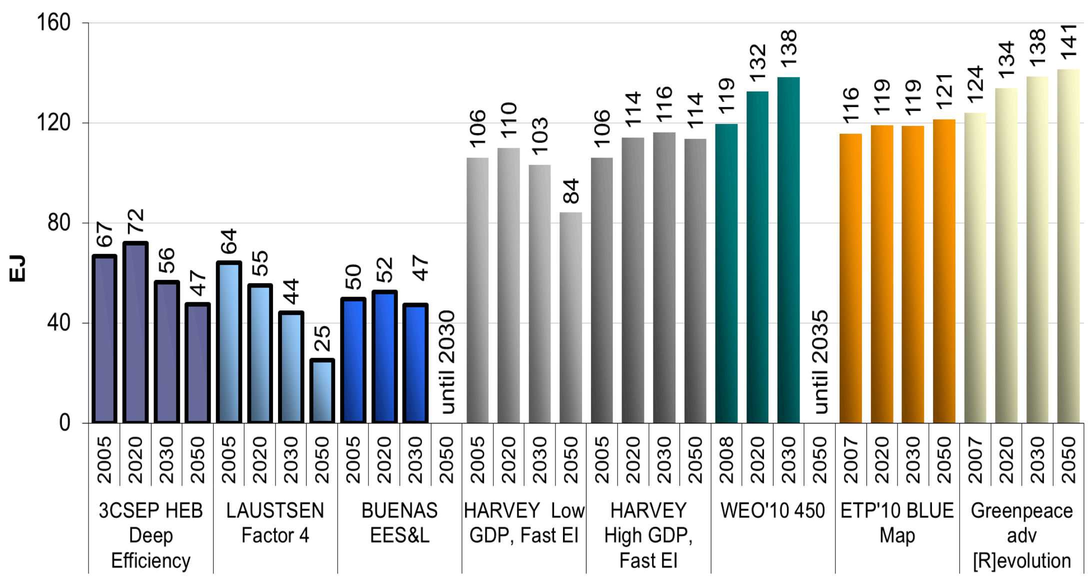
- Building energy use is projected to grow significantly in the next few decades. Without action, total building final energy use, and thus corresponding emissions, is expected to grow by 60 – 90% of the 2005 value by 2050, as demonstrated by different reference scenarios (Figure 2), from about 110 EJ to approximately 165 – 200 EJ (see Figures 46, 47 and 48b in the Main Report.). The final energy demand for thermal energy needs, i.e. heating/cooling/hot water is likely to grow even more dynamically without action: two of the three models already show over a 50% increase by 2030 in the reference scenarios (see Main Report Figure47).

- Improved efficiency alone will not bring the sector's emissions anywhere near what is needed for reaching ambitious climate targets. As Figure 1 demonstrates, even the most ambitious scenarios are only able to compensate for the increase in service demand, i.e. total final energy use

[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.

at best stays constant until 2050 for the entire sector (see also Main Report Figures 47, 51, 52). 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 behavioral and lifestyle change.

- There are significantly larger opportunities for bringing heating/cooling energy use down compared to other building end-uses. As Figure 3 demonstrates (further demonstrated by several more models in the Main Report Figure 56), while total building final energy use stays roughly constant or even increases in most ambitious scenarios, models focusing on thermal energy uses demonstrate the possibility of major absolute reductions – up to 60% reduction by 2050, as compared to 2005 (Laustsen model).



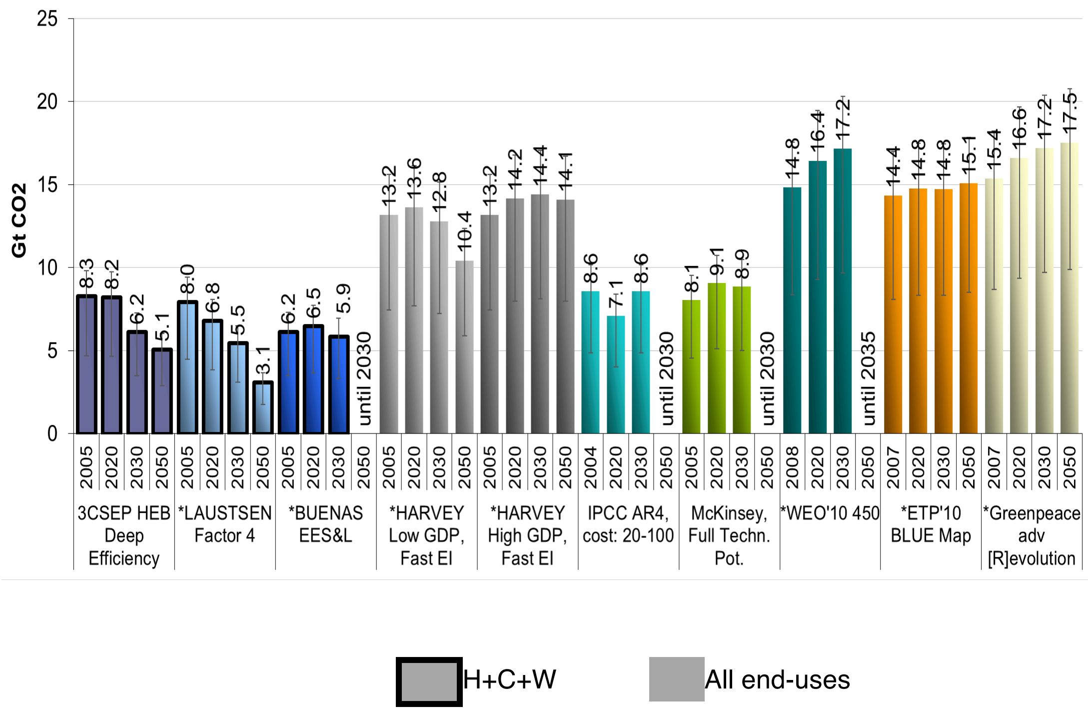


Figure 3. Global building final energy demand (a) and CO2 (b) projections by various models, 2005 - 2050

- Policies focusing on holistic/systemic opportunities in buildings are likely to achieve much more significant reductions than those focusing on individual building components. As Figure 3 also demonstrates[3], along with the Main Report's Figures 49 and 56, analyses that considered whole building, systemic options rather than component-by-component measures were able to identify substantially larger energy use reduction opportunities. Although further work is needed; this research indicates that it is likely that performance-based building policies are 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. For example, for models focusing on thermal uses, the global CO_2 emissions in 2030 reference to 2010, are projected to be reduced by an average of 13% in case of "short-time" models, while "long-time" models project an average reduction of 34%. This points to the crucial importance of strategic, long-term policy-making and the stability of policy structures, as opposed to policies aimed at the short-term. While this is

[3] Performance-based models are 3CSEP-HEB, Laustsen, Harvey, BPIE and Ecofys. It is interesting to point out that among the models examiningexaming total building energy use, only Harvey projected a reduction in energy use by 2050 in his ambitious scenario – the only model among total-building-energy-use-models that used a performance-based approach.

difficult in a short-term political election-cycle reality, infrastructure is built for the long-term and thus requires policy continuity.

1.3 Key Global Findings: Insights from the Scenario Analysis

The message from the scenario analysis is clear: a low energy pathway is feasible for thermal building energy uses (Figure 5). Globally, by one-third of today's final building thermal energy use can be reduced 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 by 46% by 2050, instead of declining. Due to of the long-term presence and relatively slow major retrofit cycle of the built infrastructure, this results in 80% of the 2005 thermal final energy use being locked-in by 2050 **(**Figure 4**)**. Unlocking this energy savings potential in the future will either be extremely expensive, or technologically unfeasible for several more decades. This is because once infrastructure has been constructed or retrofitted to suboptimal performance levels, some upgrades become impossible (such as changing orientation, community morphology, etc.), while others become very expensive due to the reduced size of remaining potential, through substantial fixed costs (such as scaffolding, or early replacement of components). 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**.** Instead, mitigation options from other sectors will need to "jump in" to achieve the emission reductions otherwise possible from the built environment. These are likely to be much more expensive than if the original, full potentials were captured in the first construction/retrofit cycles.

Since the moderate scenario already represents today's best policies and policy intentions,

is very alarming. It shows that even by fully implementing today's best policy directions, building energy use will increase substantially. This 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.

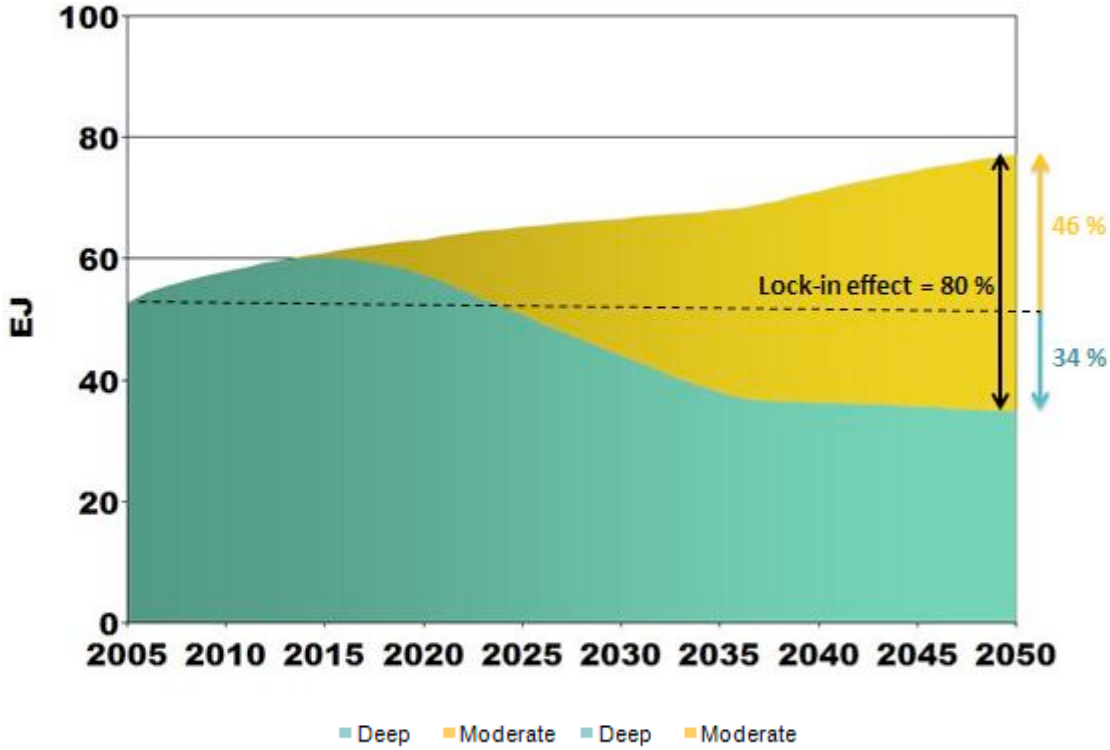


Figure 4. The lock-in effect: World final energy use for space heating and cooling for Moderate Efficiency and Deep Efficiency scenarios.

The research demonstrates the crucial importance of immediate action and the high cost of delay. For instance, the time it takes for the construction industry and markets to adopt and supply today's state-of-the-art technology on a mass scale is very important. This is demonstrated in the Main Report Figure 11 for the deep scenario: although floor area that is added or retrofitted during the next decade – the period of assumed transition – is a small share of 2050's floor area, this small area's energy consumption dominates, or compares to, the energy consumed by all the rest of floor area added and retrofitted during the remaining period until 2050. To be more specific, looking at the deep scenario, the conventional buildings (standard, new and retrofit) will have 23 % of the total floor area by 2050 and will be responsible for 48 % of the total energy consumption, while the share of the advanced buildings (advanced new and advanced retrofit) is 77 % of the 2050 floor area and their energy consumption is limited to only 52 % of the total. Therefore immediate action, as well as an accelerated transformation of the construction industry and markets is of paramount importance for determining 2050 emissions.

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 growth and increased quality of life. 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, 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.

A novelty of this report is that the role of urban vs. rural buildings in energy use, as well as mitigation potential, is assessed for the first time at a resolution that includes large regional and also building type resolutions. As Figure 5 demonstrates, buildings in urban areas have70% and already contribute the dominant share of building energy use in all world regions, despite the fact that the rural population is still larger. The share of building energy use in urban areas for the four key regions are US: 82%, EU-27: 70%, China: 63% and India: 41 %. With increasing urbanization this trend continues, and by 2050 the lion's share of building energy use will take place in urban areas; 85% of growth in building energy use during the projection period comes from urban areas, 70% of it from cities in developing countries. The only region where rural building thermal energy use continues to play an important role is India. 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 floorspace growth, sprawl and energy performance levels are especially crucial for a low-carbon building world[4].

Another novelty of the report is the first quantification of slum thermal energy use. While energy and floorspace data on slums are very uncertain, it is a robust conclusion that albeit a significant share (up to 60%) of urban population lives in slums in several regions, they do not contribute significantly to world thermal building energy use with a 0,06 % of total heating/cooling building energy use, and thus to reduction opportunities. This is not likely to change until the mid-century, despite the expected growth in slum populations. On the

[4] Public buildings and communities should aim to have very ambitions energy saving targers. These can be reached by means of mandatory rating and disclosure policies and can motivate communities, owners and buyers to upgrade their buildings to be energy-efficient

positive side, the desirable development and upgrading of slums can go far before their GHG emissions become important from a mitigation perspective.

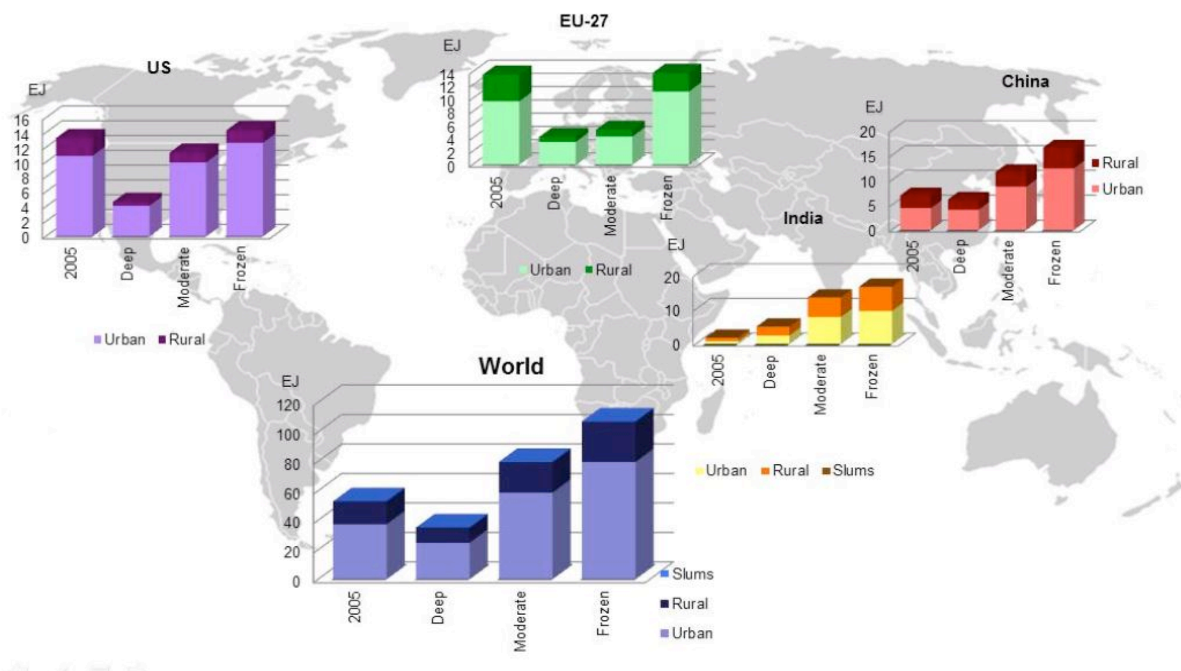


Figure 5. Final Thermal Comfort Energy in Rural and Urban buildings for the world and four key regions under the three scenarios

With regard to building types, final energy use as well as reduction opportunities from residential buildings dominate in all regions and scenarios, with 75% of 2005 thermal energy use in this subsector, declining to 70% by 2050 in the deep scenario. Worldwide, the building type responsible for the single largest final thermal energy use and thus emission reduction opportunities are single-family (SF) houses, using 54% of all world thermal energy demand, with multifamily buildings adding another 21%. Therefore it is important for SF buildings go reduce their energy use to 49% by 2050, with MF building energy use share remaining roughly constant. However, the importance of building types is extremely variable by region, as detailed in the next section.

1.4 Key Findings: Further Major Regional Messages

While the feasibility message is universal, there are very large regional differences (see Figure 6). 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%, CO_2 savings can be measured in gigatons (1.8 and 1.3Gt, respectively). In China, the explosive growth of floor space can be offset by energy efficiency improvements. In India, it is already a success if thermal energy use just doubles. 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.

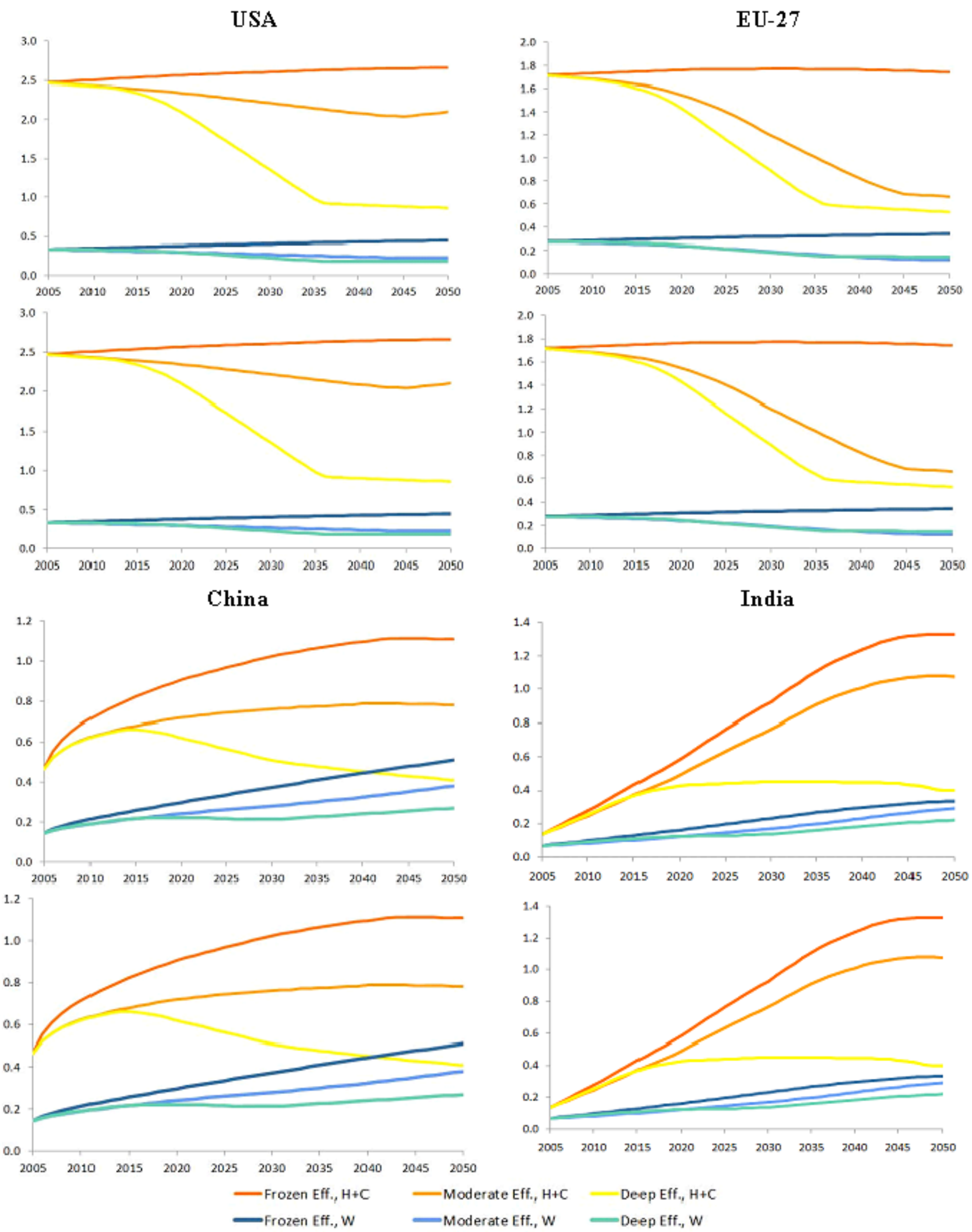


Figure 6 CO_2 emissions from space heating & cooling and water heating for four world regions for t he three scenarios in GtCO2, assuming no decarbonization of fuels.

Hot water represents a smaller contribution to 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% (For instance, see Figure 6), except for India, where it is 35% today. This share, i.e. water heating's role in final energy demand, is expected to increase in all scenarios and regions, except in India where it will grow less dynamically than heating and cooling and thus its share declines.

The research in the report highlighted that in 2050 the building thermal energy use in the USA and Europe will mainly be determined by the retrofitted building stock, whereas in China and India (esppecially the latter) the key driver is new construction, thus new construction requires the main policy attention. While policies in Europe are already strong for new construction, the major impact is offered by very low energy retrofits with an accelerated retrofit dynamic.

The size of the lock-in effect is considerable in all regions (see Main Report Figure 22, see also the difference between the yellow and orange lines on Figure 6 above), except for the EU. It is difficult to quantify precisely the impacts of present policies and policy directions due to many uncertainties and limitations in the available time/resources of this project for such a complex task to be precisely implemented. Thus the exact numbers should not be overused for quantitative conclusions, but rather, the trends provide useful insights. These figures attest that while the EU-27 policies and policy directions have the potential of capturing a rather large fraction of the cost-effective potentials for reducing thermal energy demand in the building sector, all other regions are still heading towards a significant lock-in risk. 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 developing ambitious building codes in terms of energy performance (see Main Report Figure 15).

The importance of building type is extremely variable by region, as mentioned above (see, for instance, Figure 7). The figures in the regional summaries below show the energy reduction potential in the different building types in different regions, illustrated by floor area size and energy performance. 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 China, commercial buildings dominate (especially towards the end of the period), followed by urban multi-family buildings, urban SF almost playing no role, and rural buildings declining in their importance. In India, energy use from SF rural buildings dominates 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.

With regard to commercial building types, data were more reliable for the US and EU. Within these regions, in the US, “other” commercial building energy use is even larger than that of all multifamily buildings with 12% share. Health care, education, catering and hotels, retail and offices each contribute an approximate 3% to building thermal energy use, with little change throughout the period. In the EU, each of the six commercial building types has an approximate 2 – 4% share, slightly increasing throughout the period. In India, retail alone uses 11% of all building thermal energy. In China, although relying on less robust data, offices use 10% of all building thermal energy, growing to 15% by 2050. The growing importance of commercial buildings, paticularly in India and China needs to be highlighted and be treated as a crutial factor in addressing GHG emissions globally.

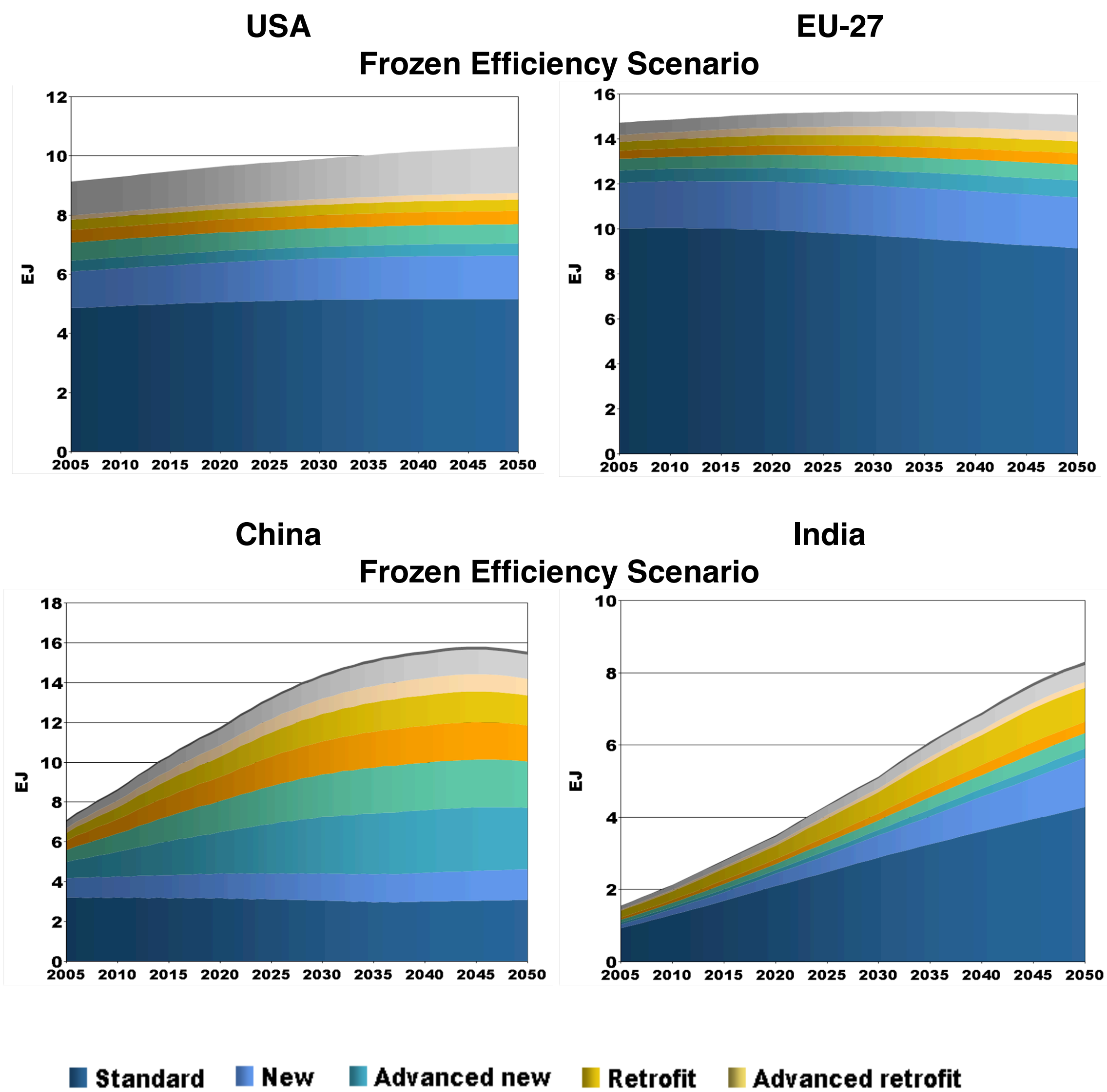


Figure 7. Final energy for space heating and cooling by building type

1.5 Key Messages from the Sensitivity Analysis

As some of the input parameters for the models were uncertain, a sensitivity analysis was carried out. Three parameters were selected for the analysis: specific energy consumption for advanced retrofit and advanced new buildings, the retrofit rate, and the adjustment factor (which is used to calculate the floor area of commercial and residential buildings).

The Main Report's Figure 27 demonstrates 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:

A low-energy pathway is possible, and it is possible to reduce global building energy consumption despite a significant increase in service levels and floor area.

Even a 50% increase in specific energy consumption figures assumed for advanced new and retrofit buildings (that were set region-building type and climate-specifically based on already existing best practices and a very broad, several-stage expert review) increases the deep scenario's 2050 values by only 24%. Even in such a case, the global building sector energy use still declines by 18% by 2050. Therefore, it can be concluded, that the findings of the deep scenario are very robust despite the uncertainties in concrete figures in achievable advanced new and retrofit specific energy consumption values.

When sensitivity to retrofit rates is considered, the conclusion is that it decreases the time to reach the achievable lowest energy use (after which it continues to increase). With a 5% rate this happens in approximately 2027, while with a 2.1% rate by approximately 2044. However, the sensitivity analysis also demonstrated that a too large acceleration in retrofit rates is not desirable. 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 when the market is ready for advanced retrofits.

The moderate scenario is mostly unaffected by the retrofit rate (see Main Report Figures 39 and 40), Europe is the only region where a slight delay can be observed. This holds a very important policy message: if performance levels in building codes and retrofits remain far from state-of-the-art levels, accelerating building retrofits will not bring major climate benefits.

Adjustment factors are used in the model to estimate the maximum ratio of floorspace intensity (per capita for residential and per GDP for commercial) to be reached in developing countries as compared to those in OECD countries – i.e. some sort of saturation factors or self-caps for developing country floorspace intensities. However, these are very uncertain in the future. The sensitivity analysis of adjustment factors (Figure 8) showed that residential energy use in India is the most sensitive to change in the adjustment factor, with Chinese residential energy use following, Chinese commercial energy use is more inelastic to the choice of sensitivity rate.

This has a very important policy implication. Especially in India, but also in China, policies to encourage limitations in residential floorspace 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. Beyond energy or climate reasons, unlimited floorspace growth in these countries will inevitably result in land shortages and problems. Beyond uncertainty analysis, encouraging limitations in personal floorspace is an important policy in other regions, too; although it is more challenging with an existing building stock.

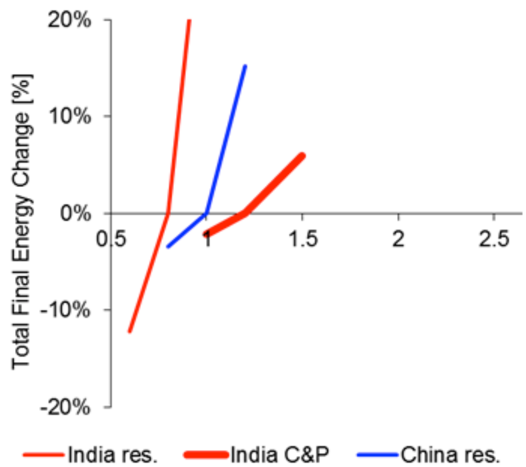


Figure 8 The percentage change of the total heating/cooling final energy for various adjustment factors for China and India for commercial & public and residential buildings.

1.6 Model Description and Key Assumptions

In this final part of the Summary for Decision Makers, we present the background information on the model that was used for the assessment, as well as its key assumptions.

Figure 9 illustrates the modeling logic. To produce practical results globally, 17 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). In addition, some parts of the model also reflect detailed feedback from regional experts, and this is a crucial advantage in the case of regions where reliable data is sparse (e.g. China). The high level of methodological transparency distinguishes the model from most of its peers and enables continuous collaborative improvement.

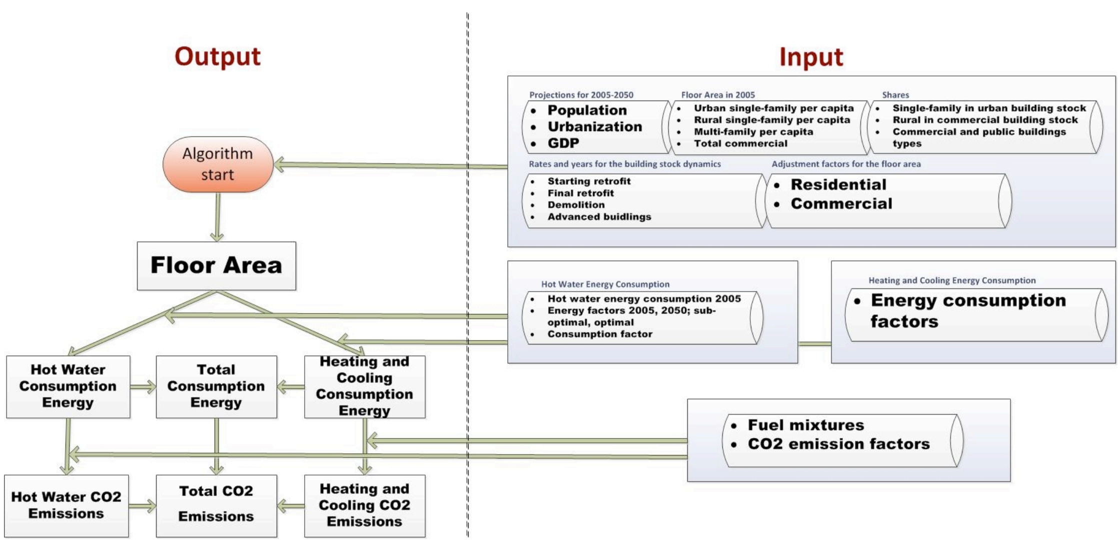


Figure 9. Flowchart representing the modeling logic for 3CSEP-HEB.

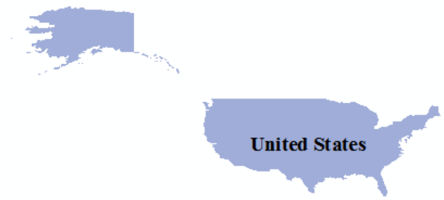
1.7 Selected Limitations

A modeling effort of this magnitude and detail, squeezed into such a short time period, will always have major limitations. These are detailed in the main report. Most importantly, the main limitation was the poor data availability that posed a very serious challenge. In some regions (especially developing ones), most parameters were largely uncertain; and in the case of some parameters (e.g. heated floor area or hot water energy consumption) large uncertainties were encountered in most regions.

Secondly, some of the assumptions limit the applicability of results. To correctly account for the role of improved energy efficiency in emissions mitigation, a constant fuel mix is used to calculate CO_2 emissions in all scenarios for space heating and cooling (not for water heating, because improvement very often means a change in the fuel mix there). In this way, emission reductions from energy efficiency and reductions due to the decarbonization of energy supply are not mixed; the potentials of efficiency can be clearly seen. In some cases, this results in a distortion of absolute emission values, especially because several developing regions have large shares of traditional bio-energies in their fuel mix. As indirect emissions from the use of bio-fuels are not considered in the calculations (the quantification of these emissions is very controversial), CO_2 emissions in most developing regions are underestimated. Thus, energy, and not CO2, projections should be considered as the most important scenario outcomes.

REGIONAL SUMMARIES

2.1 USA



Of all world regions, North America has the highest energy consumption in the buildings sector relative to its population. With approximately 90% of both population and consumption, the United States can do most to mitigate the related disproportionate CO2 emissions that totaled 2.8Gt in 2005 (Figure 10). Without major changes, however, the country is on track for even higher emissions (Table 1). The US population is over 300 million and grows by almost 3 million a year, while its residential floor area per capita is still unmatched by any other major country. The commercial building stock is also very large due to the historically high levels of economic activity. The energy performance of buildings can be largely improved; until now only a handful of very low energy buildings were built. Nevertheless, these buildings and their European counterparts located in similar climate zones testify that exemplary performance and low energy scenarios are possible from a techno-econoic perspective. The energy pathways chosen by the United States will not only have a strong influence on GHG emissions, but probably also serve as a model for many other regions of the world.

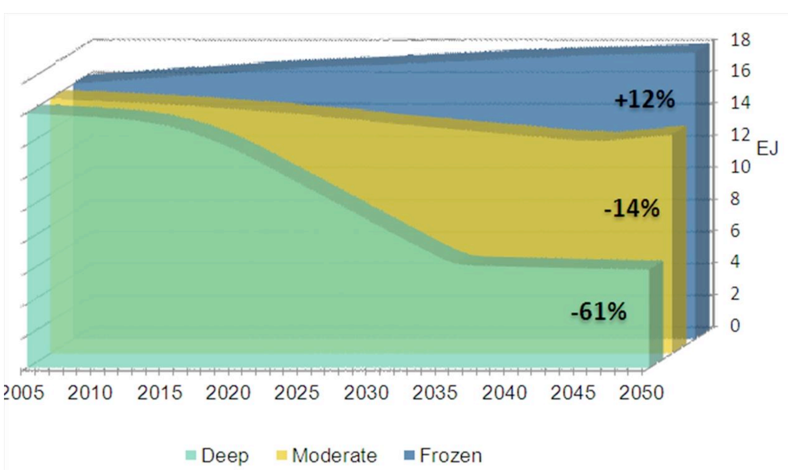


Figure 10. US total final energy for three scenarios, as a percentage of 2005 values.

Table 1. US Total final energy and total CO2 emissions in 2005, 2020, 2030 and 2050 and mitigation potential in reference to 2005 for all scenarios

Scenarios: Final energy (EJ), CO_2 emissions (Gt)	2005	2020	2030	2050	Δ% (2005-2020)	Δ% (2005-2030)	Δ% (2005-2050)
Deep Efficiency Scenario							
Final energy for SH&C	13.3	11.3	7.3	4.6	-15%	-45%	-65%
Final energy for WH	2.7	2.4	1.9	1.6	-10%	-31%	-43%
Total Final energy	16.0	13.7	9.1	6.2	-14%	-43%	-61%
Total CO_2 emissions	2.8	2.4	1.6	1.1	-15%	-44%	-62%
Moderate Efficiency Scenario							
Final energy for SH&C	13.3	12.6	11.9	11.3	-5%	-10%	-15%
Final energy for WH	2.7	2.6	2.5	2.4	-3%	-7%	-11%
Total Final energy	16.0	15.2	14.4	13.7	-5%	-10%	-14%
Total CO_2 emissions	2.8	2.6	2.5	2.3	-6%	-11%	-17%
Frozen Efficiency Scenario							
Final energy for SH&C	13.3	13.8	14.0	14.3	4%	5%	8%
Final energy for WH	2.7	3.1	3.3	3.6	14%	21%	34%
Total Final energy	16.0	16.9	17.3	17.9	5%	8%	12%
Total CO_2 emissions	2.8	2.9	3.0	3.1	5%	7%	11%

* SH&C – space heating and cooling, WH – water heating

If unabated, annual emissions may rise by more than 300 Mt CO2 until 2050 due to the additional 1.9 EJ of energy use. Compensating this growth (which is in the order of the Latin American buildings sector's current emissions) and achieving a reduction of nearly 500 Mt CO_2 (2.3 EJ) by improving energy efficiency by approximately 30% is necessary. However, through the proliferation of very high-performance buildings (not yet considering renewable), it is possible to save more than 60% (9.8 EJ) and reduce annual GHG emissions by 1.7 Gt CO2. Roughly 70% of this reduction can be realized by 2030. The technologies required to achieve these ambitious goals are not uniform. Measures like super insulation in the cold parts of the country or solar water heating in the sunny regions will need to gain significance. Improving performance in different building types will pose different challenges and offer different opportunities.

The following figures in each of our regions show the potential for energy savings by 2050, decomposed by the activity level (the development in floor area, horizontal) and energy efficiency drivers (the development of average specific energy consumption, vertical). Each rectangle shows the building thermal energy use of the particular building type in 2005 or 2050.

These figures demonstrate which drivers are most responsible for the development of the energy use in the particular building type. For instance, for US rural buildings the substantial potential is due almost solely to the improvement in building energy efficiency (Figure 11), while Figure 12 demonstrates that despite the significant assumed reduction in individual specific energy consumption in urban buildings, total urban building energy use will significantly increase due to the massive growth in the floorspace of this building type.

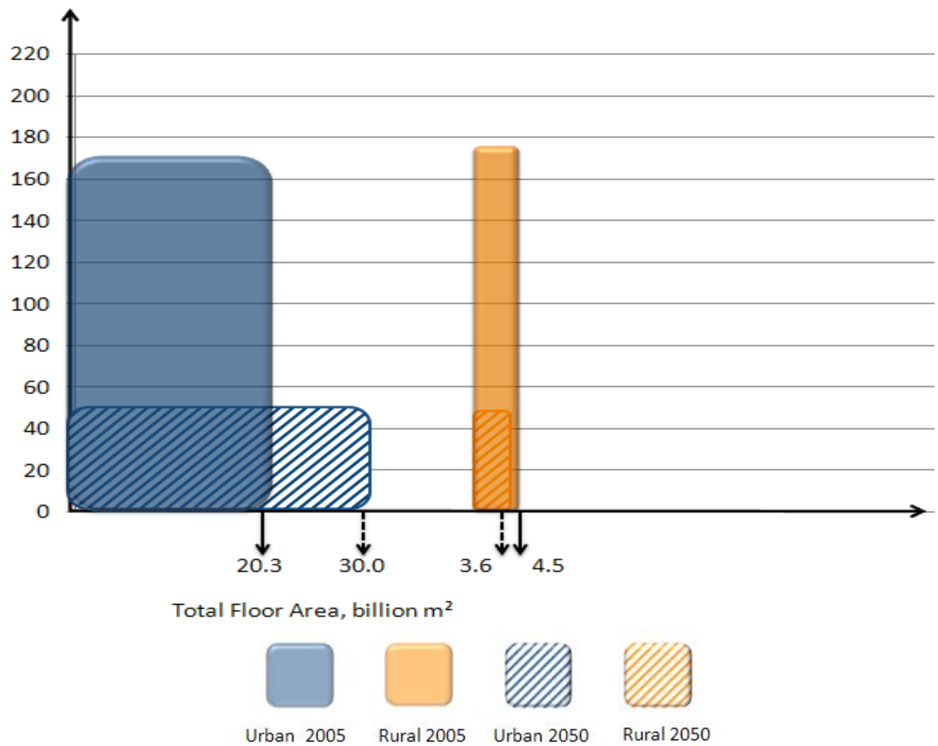


Figure 11. US potential for total final thermal energy savings by 2050

From an energy consumption point of view, the urban-rural distinction is not as crucial in the US as it is in developing regions because of the smaller differences between lifestyles. In fact, even building types are often similar: the vast majority of rural and a significant proportion of urban buildings are single-family houses. Accordingly, it is crucial to reduce the energy consumption of individual single-family homes by 80-90% to reap the over 60% reduction potential in this building category. Potentials for other building types are similarly large, since a relatively balanced floor space growth is expected and saving potentials of individual buildings in different categories are not very different. If the transition to low energy technologies is accompanied by a shift to smaller residences and energy saving behavior, reductions can be even greater.

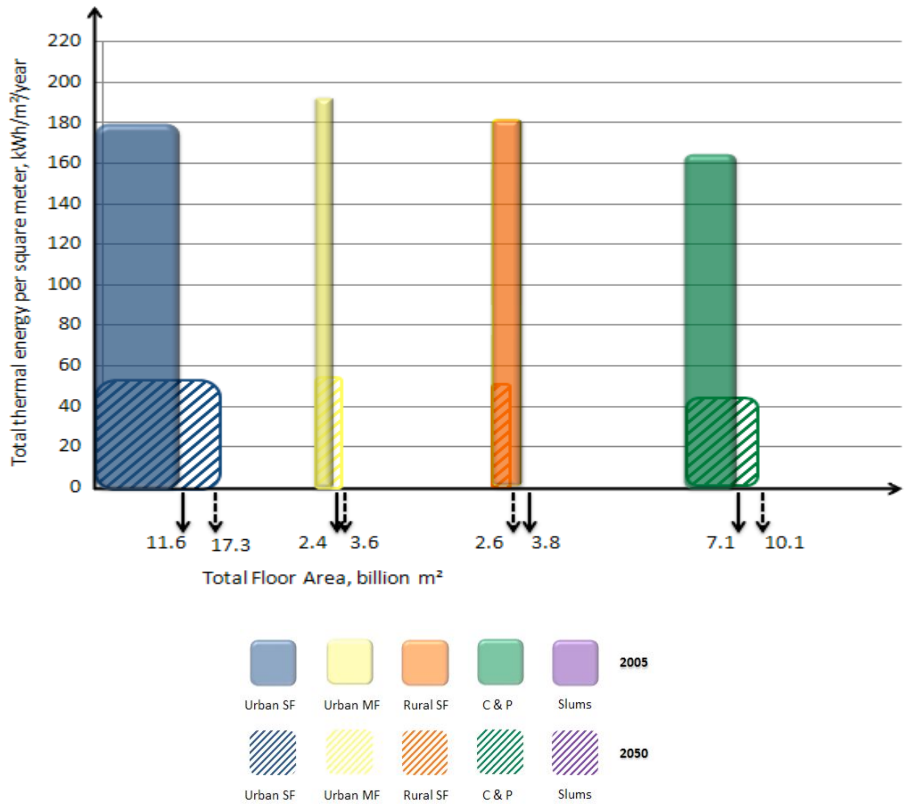
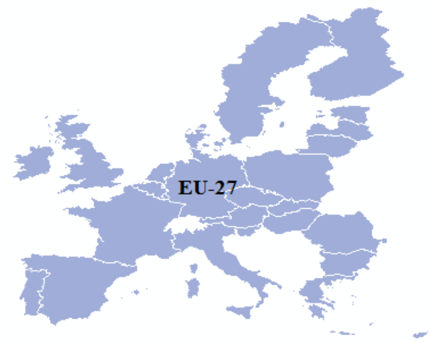


Figure 12. US final energy mitigation potential for DEEP scenario between 2005 and 2050

2.2 EU-27



The European Union is the region where recent developments of very high-performance buildings are the most dynamic. In the GHG mitigation scenarios energy consumption data from a large number of exemplary buildings can be used. The absolute techno-economic reduction potentials are very large, because the average level of energy efficiency is low, the cumulative floor area is not changing rapidly, and thermal comfort is already provided to the vast majority of Europeans. Due to the large existing building stock and the very significant share of the population living in moderate and cold climate zones where thermal energy needs are substantial, approximately a quarter of the current global final energy consumption for heating, cooling and water heating takes place in the region. Accordingly, there is no viable sectoral climate change mitigation scenario without radical energy savings in European buildings and deep cuts in the related CO_2 emissions.

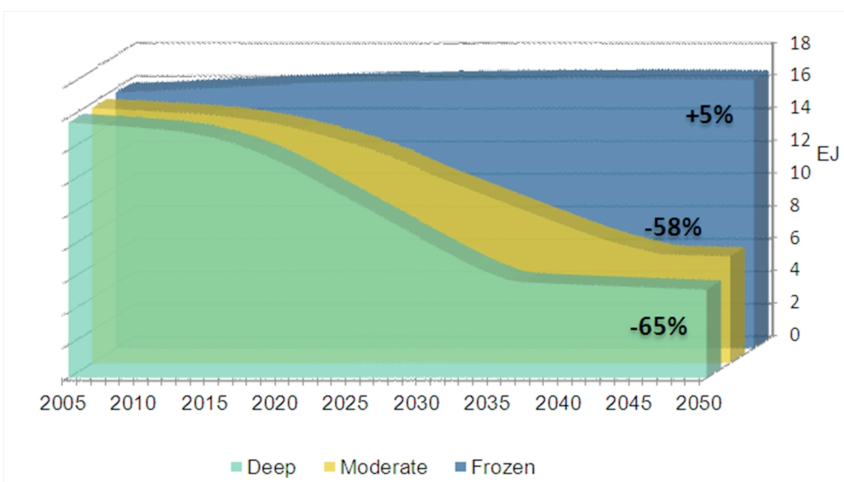


Figure 13. EU-27 total final thermal energy for three scenarios, as a percentage of 2005 values.

Table 2. EU-27 Total final energy and total CO2 emissions in 2005, 2020, 2030 and 2050 and mitigation potential in reference to 2005 for all scenarios

Scenarios: Final energy (EJ), CO_2 emissions (Gt)	2005	2020	2030	2050	Δ% (2005-2020)	Δ% (2005-2030)	Δ% (2005-2050)
Deep Efficiency Scenario							
Final energy for SH&C	13.6	11.3	7.0	4.2	-17%	-48%	-69%
Final energy for WH	2.1	1.9	1.5	1.2	-8%	-29%	-42%
Total Final energy	15.7	13.3	8.5	5.4	-16%	-46%	-65%
Total CO_2 emissions	2.0	1.7	1.1	0.7	-16%	-46%	-66%
Moderate Efficiency Scenario							
Final energy for SH&C	13.6	12.3	9.5	5.3	-10%	-30%	-61%
Final energy for WH	2.1	2.0	1.7	1.3	-4%	-17%	-39%
Total Final energy	15.7	14.3	11.2	6.6	-9%	-28%	-58%
Total CO_2 emissions	2.0	1.8	1.4	0.8	-10%	-30%	-61%
Frozen Efficiency Scenario							
Final energy for SH&C	13.6	14.0	14.0	13.8	3%	3%	2%
Final energy for WH	2.1	2.4	2.5	2.7	11%	17%	25%
Total Final energy	15.7	16.3	16.5	16.5	4%	5%	5%
Total CO_2 emissions	2.0	2.1	2.1	2.1	4%	5%	4%

* SH&C – space heating and cooling, WH – water heating

As it can be seen from Figure and Table 2 it is possible to reduce final energy consumption by half by 2030 and by two-thirds by 2050. While there is a slight increase of GHG emissions in the Frozen Efficiency Scenario, the 'Moderate Efficiency Scenario' is not moderate in Europe. The aim of this scenario is to demonstrate where current policies lead, and it is clear that the level of ambition of the European 'Energy Performance of Buildings Directive' is close to the optimum. The conclusion from the two low energy scenarios is unambiguous: a radical reduction of emissions (1.2-1.3Gt per year) is possible with the currently available advanced technologies that are already transforming housing markets in Austria or Germany. With measures used in thousands of existing high efficiency houses and improved water heating (e.g. solar collectors or heat pumps), climate change mitigation goals can be assisted while also alleviating the region's chronic dependence on imported fossil fuels. However, this transformation is not possible without very ambitious national targets, policies, and building codes: deep retrofitting and high efficiency new buildings are necessary in all residential, commercial and public building categories.

Figure 14 shows that, like the US, the urban floor area will increase in the EU-27. This new floor area gives space for great saving potentials in final thermal energy use. Figure 15 shows that floor area in urban residential buildings (single family and multi-family) and commercial and public buildings will increase, yet if the deep scenario is adopted the saving potentials can be seen in all types of buildings in both urban and rural areas.

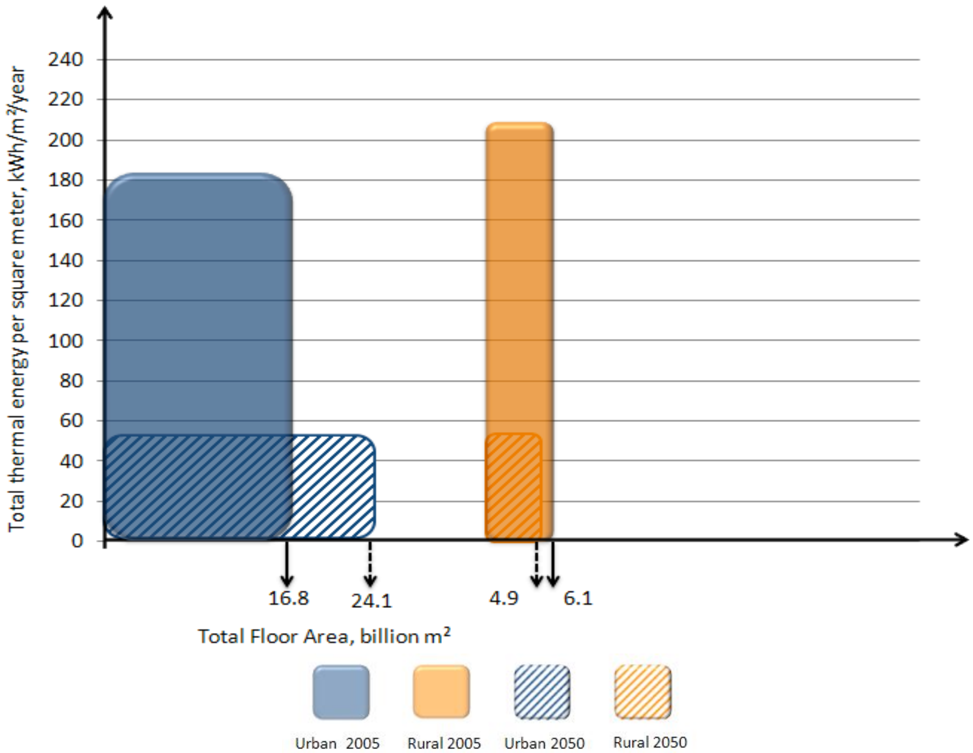


Figure 14. EU-27 potential for total final thermal energy savings by 2050

Just as in the USA, continued urbanization makes it easier to reduce total energy use in rural areas. Since rural and urban lifestyles are not very different, priorities depend more on building types. Due to the dominance of single-family buildings in the residential building stock and their relative inefficiency, these buildings offer the largest absolute savings potential. At the same time, the standard solutions applicable in the retrofit projects of multi-family buildings and the higher cost-efficiency of their retrofitting can make apartment buildings the first targets of large-scale national energy efficiency programs. According to the different building activities, thermal energy saving opportunities are somewhat different in commercial and public buildings, but the potentials are similarly large. Hospitals, whose energy intensity is very high partly because of their high hot water consumption, can be targeted first. In all different building categories, inefficiency and readily available technologies offer large savings and call for rapid action.

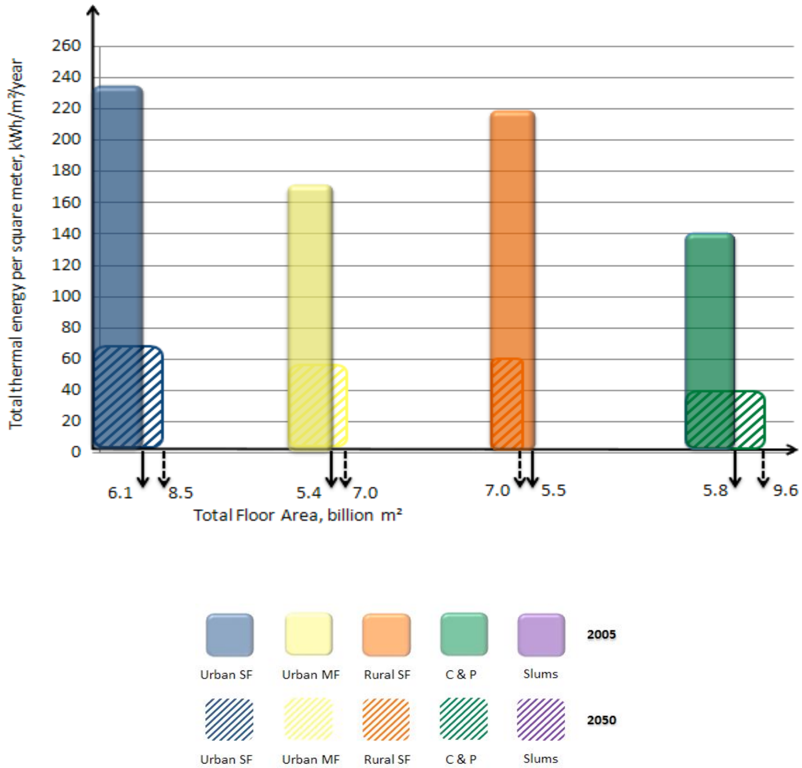


Figure 15. EU-27 final energy mitigation potential for DEEP scenario between 2005 and 2050

2.3 CHINA

China's role in the energy scenarios does not need a lengthy introduction. The building sector of the world's most populous country and economic superpower is booming. Between 2005 and 2050, China's urban population is expected to swell by nearly 500 million. At the same time, the projected reduction of rural population is close to 400 million. The magnitude of change in the building sector is almost inconceivable. Heating, cooling, and water heating are provided to hundreds of millions who previously lacked thermal comfort. In parallel with the fundamental change in residential housing, the world's largest economy with its whole building infrastructure is being created. The fact that low thermal energy pathways still exist can be attributed to three crucial factors: the relatively mild climate of the most densely populated regions (this is why energy use is not skyrocketing even faster in the Frozen Efficiency Scenario), the relatively low consumption values per capita (e.g. hot water consumption, due partly to water scarcity), and efficiency. The uncertainties of the scenarios shown in (figure 16) are substantial: even start values taken from statistics or research studies are sometimes unreliable, let alone predictions about China between 2040 and 2050. Nevertheless, the trends are very clear and give enough justification for a massive push for low energy building policies.

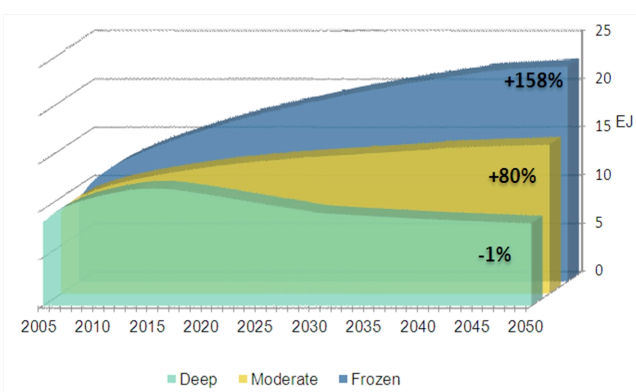


Figure 16. China total final thermal energy for three scenarios. Percentage figures are comparisons to 2005 values.

Table 3.China total final thermal energy and related CO2 emissions in 2005, 2020, 2030 and 2050 and mitigation potential in Frozen Efficiency to 2005 for all scenarios

Scenarios: Final energy (EJ), CO_2 emissions (Gt)	**2005**	**2020**	**2030**	**2050**	**Δ% (2005-2020)**	**Δ% (2005-2030)**	**Δ% (2005-2050)**
Deep Efficiency Scenario							
Final energy for SH&C	7.0	9.3	7.6	6.1	33%	9%	-12%
Final energy for WH	1.6	2.3	2.1	2.4	41%	28%	48%
Total Final energy	8.6	11.6	9.7	8.6	35%	13%	-1%
Total CO_2 emissions	0.6	0.8	0.7	0.7	38%	18%	11%
Moderate Efficiency Scenario							
Final energy for SH&C	7.0	10.7	11.4	11.7	54%	64%	68%
Final energy for WH	1.6	2.6	3.0	3.8	59%	80%	131%
Total Final energy	8.6	13.4	14.3	15.5	55%	67%	80%
Total CO_2 emissions	0.6	1.0	1.0	1.2	57%	71%	90%
Frozen Efficiency Scenario							
Final energy for SH&C	7.0	13.5	15.3	16.6	94%	119%	137%
Final energy for WH	1.7	3.4	4.2	5.7	103%	154%	247%
Total Final energy	8.6	16.9	19.5	22.3	95%	126%	158%
Total CO_2 emissions	0.6	1.2	1.4	1.6	96%	127%	164%

* SH&C – space heating and cooling, WH – water heating

The shape of the Frozen Efficiency scenario in Table 3 can be explained by the most important trends affecting residential and commercial and public floor space. The Chinese population is expected to peak around 2030 with only slight changes in floor space per capita values afterwards. Economic growth is expected to be continuous, but increasing productivity of floor space per unit can stop the growth of commercial and public floor area before the end of the studied period. In line with these trends, approximately 80% of the projected growth in energy consumption and emissions are predicted to take place before 2030 in the less ambitious scenarios. As Table 3 shows, negative trends can be reversed in the Deep Efficiency scenario, reaching approximately 2005 emission levels by by 2050. Total building related emissions in Chinese cities increase in all scenarios, but the difference between the scales of growth is substantial. To prevent energy consumption climbing to levels higher than those of the EU or the US in 2005, efficiency is a must.

There are building types where energy use is projected to remain roughly constant by 2050 despite the efficiency gains, due to the increase in floorspace (such as Chinese urban building energy use). In other areas, such as Chinese rural energy use (Figure 17), little reduction in specific energy consumptions can be expected, so the potential is limited despite the almost stagnation of floorspace.

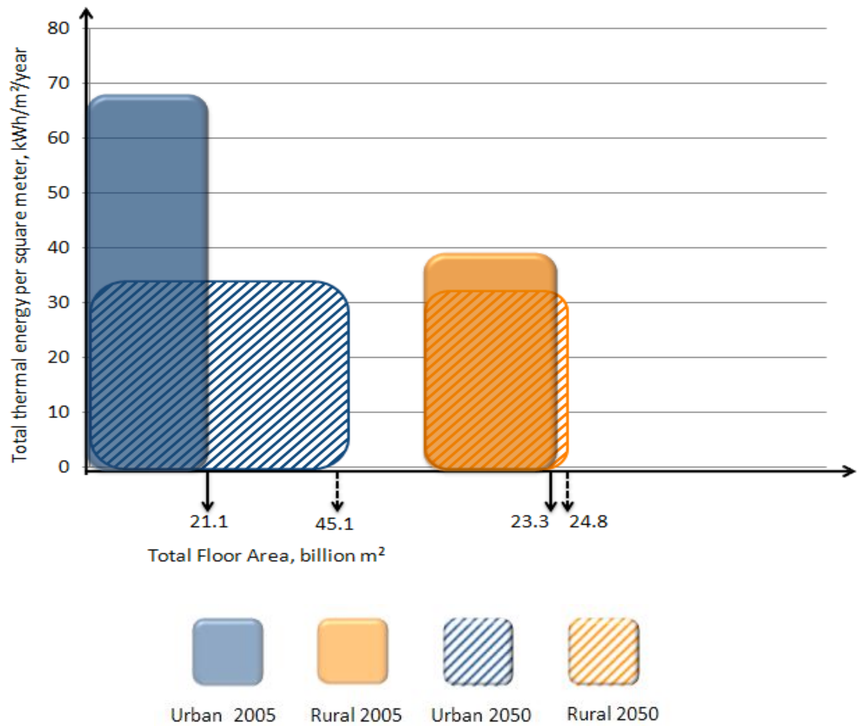


Figure 17. China potential for total final thermal energy savings by 2050

Apparently, the reduction of urban energy use is a top priority, and it is sure that technological and lifestyle decisions will determine future energy trends together (Figure 17). It is explained in the report how the important role of changes to lifestyles is considered in the case of China.

As for priorities by building types, uncertainties are substantial. Even in the Deep Efficiency scenario, it seems impossible to cut emissions in the commercial and public sector because of the very large floor space growth. In residential buildings, low energy solutions for space heating and cooling and major programs that can increase the share of solar water heaters from 10% to 60% can reduce energy consumption. As the number of multi-family buildings will swiftly increase, it will be harder to decrease the total consumption in this building category (Figure 18). However, it is absolutely essential to concentrate on large apartment buildings and the commercial and public category to have reasonable chances to stop the growth of energy consumption and CO_2 emissions.

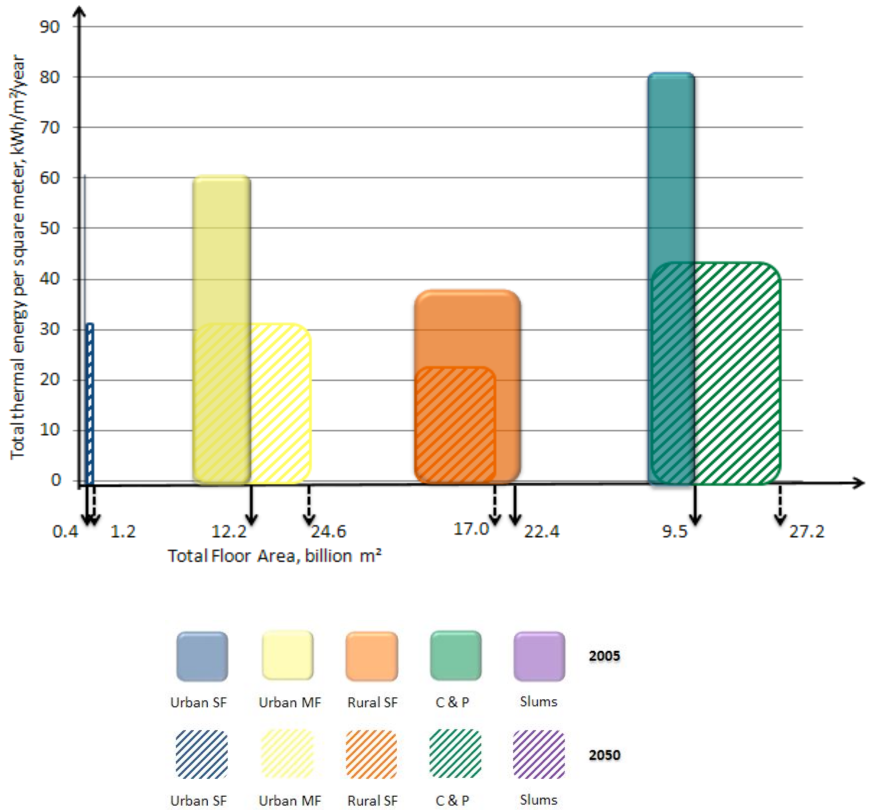


Figure 18. China final energy mitigation potential for DEEP scenario between 2005 and 2050

2.4 INDIA

The largest relative growth of energy use is expected to take place in India. The analyzed time period will bring rapid social and economic changes to the country. According to projections, total population growth can be close to 500 million with an even larger increase in cities and a 5-10% reduction in rural areas. As households are getting smaller and consumption per capita increases as lifestyle changes, the speed of growth in housing needs to surpass the pace of population growth. Together with a commercial and public sector that is rapidly expanding, this is expected to result in a more than fivefold growth of total floor area by 2050. In addition, comfort levels are also expected to improve (which means more cooling and dehumidification plus better hot water services when needed), so energy needs will certainly increase. At the same time, the supply side of the energy system will also change considerably, so assuming a constant fuel mix distorts emissions predictions. However, this assumption (which is used for all regions in the report) helps to correctly capture the importance of measures affecting energy efficiency. The only exception is water heating, where efficiency improvements cannot be separated from fuel mix changes. We also note that Indian emissions are largely underestimated, because indirect emissions from the use of biomass are not considered. However, Figure19 clearly shows the possible trends of Indian building-related energy use.

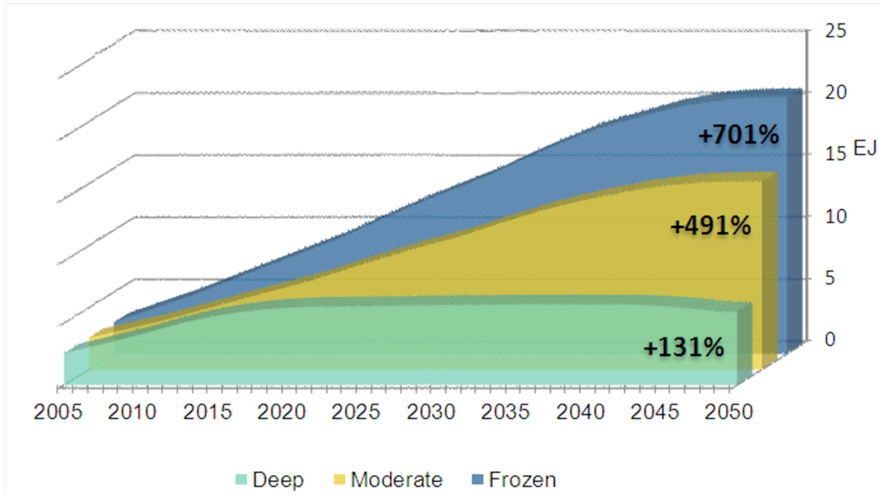


Figure 19. India total final thermal energy for three scenarios

Table 4. India total final thermal energy and related CO2 emissions in 2005, 2020, 2030 and 2050 and mitigation potential in Frozen Efficiency to 2005 for all scenarios

Scenarios: Final energy (EJ), CO_2 emissions (Gt)	2005	2020	2030	2050	Δ% (2005-2020)	Δ% (2005-2030)	Δ% (2005-2050)
Deep Efficiency Scenario							
Final energy for SH&C	1.7	5.3	5.6	4.9	209%	227%	188%
Final energy for WH	0.9	1.0	0.9	1.0	14%	2%	16%
Total Final energy	2.6	6.3	6.5	5.9	144%	152%	131%
Total CO_2 emissions	0.2	0.5	0.6	0.6	166%	186%	200%
Moderate Efficiency Scenario							
Final energy for SH&C	1.7	6.1	9.5	13.4	257%	453%	680%
Final energy for WH	0.9	1.1	1.3	1.8	32%	57%	110%
Total Final energy	2.6	7.2	10.8	15.2	182%	322%	491%
Total CO_2 emissions	0.2	0.6	0.9	1.4	197%	352%	564%
Frozen Efficiency Scenario							
Final energy for SH&C	1.7	7.3	11.5	16.5	323%	569%	858%
Final energy for WH	0.9	2.0	2.9	4.2	136%	236%	387%
Total Final energy	2.6	9.3	14.4	20.6	260%	458%	701%
Total CO_2 emissions	0.2	0.7	1.2	1.7	261%	458%	701%

*SH&C – space heating and cooling, WH – water heating

As it can be seen from Table 4, even in the case of a very ambitious efficiency improvement, energy consumption will more than double by 2050. Without action, it can grow to levels 6-7 times higher than it was in 2005. The near-linear shape of the projections in the Frozen and Moderate Efficiency Scenarios, shown in (figure 19), stem from the continuous long-term trends, but the lack of details (in the calculations, as compared to other regions) can also be attributed to the dearth of knowledge about the Indian building sector. Data on the current energy consumption of buildings is largely unavailable, and knowledge about the techno-economic potentials of very high efficiency buildings is extremely limited (no sufficiently documented exemplary buildings were found). Moreover, the country is totally different from regions where reliable data exist (e.g. the EU or the US) in terms of both climate conditions and energy needs. Therefore, in the lack of raw data or reliable transfer coefficients, India's assumptions are the most uncertain among the key regions. However, due to the momentous trends explained above, some priorities are clear. In light of the incredible urbanization process, it is evident that all efforts are necessary to curb building-related energy use in cities (Figure, blue area). Concentrating on slums is also crucial, because the number of slum dwellers is expected to rise very quickly.

Figure 20 demonstrates that despite the significant assumed reduction in individual specific energy consumption in buildings, total building energy use will significantly increase due to the massive growth in the floorspace in both urban and rural areas.

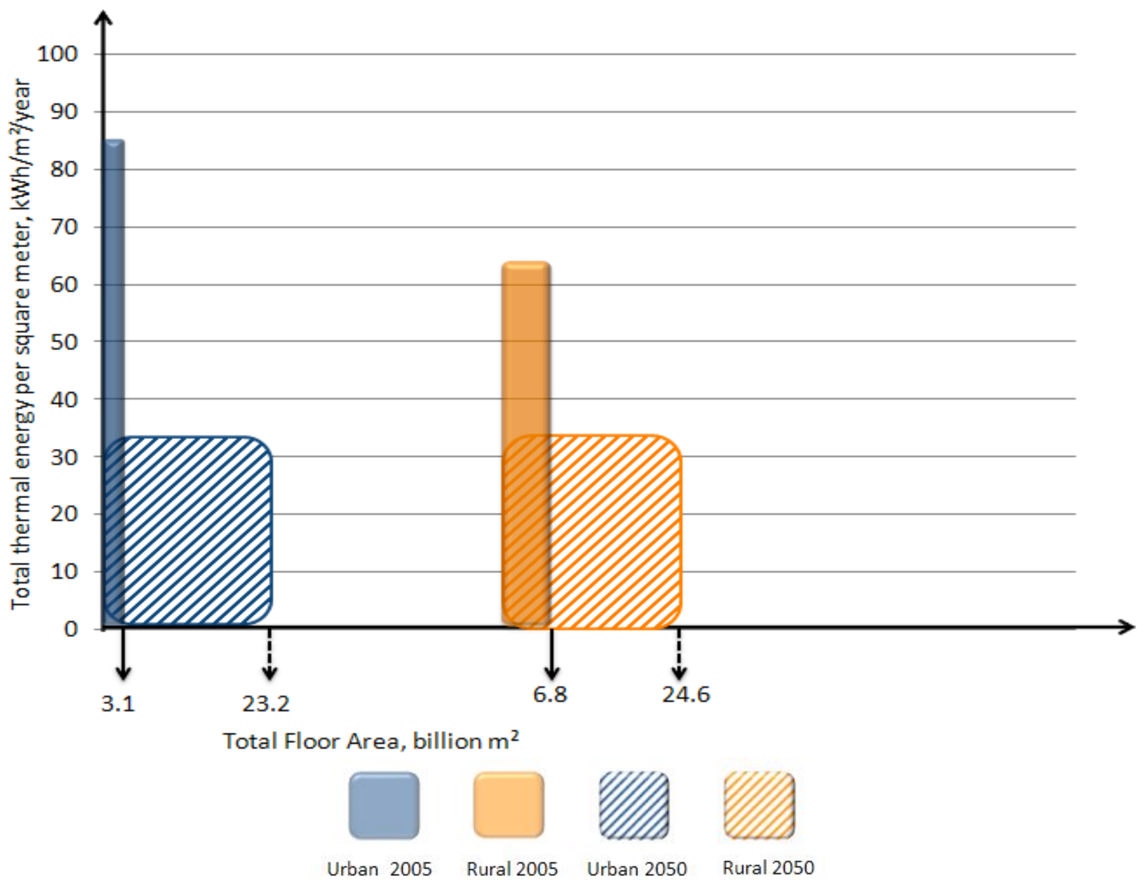


Figure 20. India potential for total final thermal energy savings by 2050

With regards to building types, multi-family buildings will be increasingly important. In a country with a traditionally high share of single-family buildings, this change must be handled effectively to secure a low energy future (Figure 21). Besides, limiting the growth of slums and improving stoves in rural areas can have a large number of co-benefits apart from the reduction of energy use. Due to the current dominance of single-family buildings, the approximately 80% relative growth in this category is by far the largest growth in absolute terms (1.3 EJ), so this building type needs the most attention. Priorities in the case of commercial and public buildings are largely unknown.

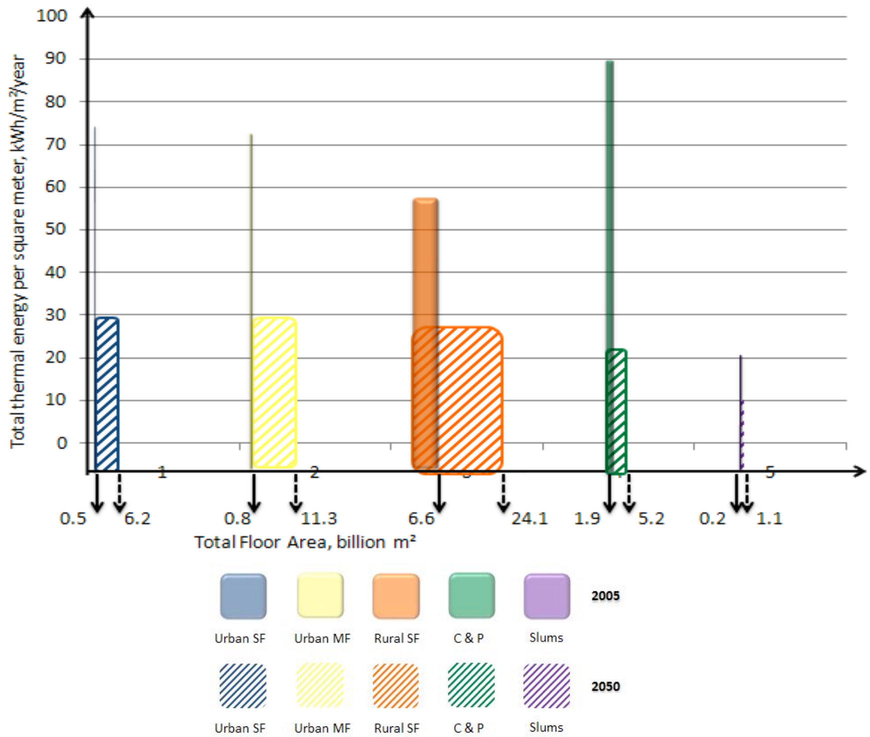


Figure 21. India final energy mitigation potential for DEEP scenario between 2005 and 2050