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Energy use in buildings in a long-term perspective

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Energy services in and related to buildings are responsible for approximately one-third of total global final energy demand and energy-related greenhouse gas emissions. They also contribute to the other key energy-related global sustainability challenges including lack of access to modern energy services, climate change, indoor and outdoor air pollution, related and additional health risks and energy dependence.The aim of this paper is to summarize the main sustainability challenges related to building thermal energy use and to identify the key strategies for how to address these challenges. The paper's basic premises and results are provided by and updated from the analysis conducted for the Global Energy Assessment: identification of strategies and key solutions; scenario assessment; and the comparison of the results with other models in the literature. The research has demonstrated that buildings can play a key role in solving sustainability challenges: close to one-third of 2005 building energy use can be eliminated by the proliferation of state-of-the-art construction and retrofit know-how in each world region, while maintaining wealth and amenity increases. In contrast, approximately 80% of this 2005 energy use will be locked in by the middle of the century if policies are not sufficiently ambitious in targeting regionally specific state-of-the-art performance levels.

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Introduction and background

Energy for services consumed in or related to buildings worldwide was responsible for 122EJ final energy in 2010, or 33% of total final energy use; 54% of electricity [1,2]; almost 9 Gt of corresponding CO_2 emissions, or around one third of total energy-related such emissions [3,4]; with more than 15% of halocarbon gas emissions, among others [5]. Therefore, building energy use is a major contributor to energy-related global challenges to sustainable development. For instance, approximately two million deaths and 41.6 million disability-adjusted life year (DALY) losses were attributable to indoor cooking in 2008 worldwide [6–8]; with women and children in developing countries disproportionately affected [9]. Other global energy-related challenges to sustainable development, such as (in)sufficient energy resources to fuel economic development, (lack of) access to modern energy services for everyone, climate change, other environmental pressures such as indoor and outdoor air pollution, related and additional health risks and damages, and energy dependence and insecurity — are all significantly influenced by the quantity and quality of energy we need for serving our activities in and related to buildings.

The aim of the Global Energy Assessment [10••] was precisely to explore these challenges and their solution space in depth. More concretely, the GEA embraced a set of normative targets that were accepted by its authors as basic criteria that need to be met for a more sustainable and equitable energy future for human development. These include the maintenance of certain levels of economic growth; the stabilization of global climate change at a maximum of 2 °C above pre-industrial levels to be achieved in the 21st century; enhanced energy security through the diversification and resilience of energy supply; the reduction in air pollution; universal access to modern energy services to all by 2030; and minimization of ancillary risks of the energy systems. This paper also adopts these normative goals as an assessment framework.

Aim of the paper

With this background, the aim of the paper is to synthetize the key challenges energy use related to buildings pose to environmental sustainability in the long-term perspective, as well as the key strategies through which changes in building energy use can contribute to solving these challenges. In this context, the paper provides a review of scenarios for how global building energy use may develop in more sustainable development pathways in the medium term. This informs policy processes and academic work on how much buildings can potentially contribute to the solutions seen through the lens of quantitative indicators.

In harmony with the concept of the 2013 Energy System section of this journal and similarly to other papers in this section, the paper starts from the main relevant premises of the Global Energy Assessment [10••], with updating, reassessing, and in key sections expanding its findings related to the building sector based on the recent literature. Because of the length limitations, its scope focuses primarily on technological and systemic solutions, leaving the discussions of the policies that can catalyze the wide adoption of these solutions to another paper in this issue [11].

The key challenges energy use in buildings is posing in the long-term perspective

The primary challenge building energy use is posing to sustainable development is the vast amounts of energy resources our activities and service demands in buildings require for their satisfaction. This energy consumption growth is driven by a composite of many factors: population growth, reduction in household size, growing affluence, increased personal requirements for indoor space and increasing demands for improved thermal comfort levels, a dynamically multiplying variety of electricity-provided services, primarily in the areas of information, communication and media services; and increasing amounts of time spent by using (or wasting...) these services. As the figures reviewed in the introductory sentences above show, these energy services comprise a significant share in our total demand for energy resources. Electricity is the most important: building-related energy services constituted approximately 54% of global final electricity demand in 2010 [2]. Therefore, the largest challenge is how [sustainable] energy resources will continue to be available in the long term to fuel the energy service needs by the increasing amenities in buildings for an increasingly wealthy, growing global population. The section below on scenarios explores what energy levels such growing demands translates into quantitatively.

While electric equipment ownership, usage and comfort levels are dynamically increasing and even reach levels in many developed countries at which the energy to power the actually consumed energy services may be smaller than the wasted amounts that are used to 'power' no useful services — about 3 billion people do not have any access to modern energy services [12,13]. These include 2.8 billions who have to rely on polluting solid fuels for cooking and other household energy needs [14] and the 1.6 billion who lack access to electricity [15,12,13]. In the sub-Saharan African and South Asian regions up to 90% of all households depend on solid biomass fuels [16]. Women, children and infants are the main victims of indoor air pollution, as they are directly exposed to smoke in unventilated kitchens rooms [17,18].

Indeed, indoor air pollution from burning solid fuels is the one of the top ten factors for global burden of disease [19], causing more than two million premature deaths a year [17] and serious health problems, such as difficulty in breathing, stinging eyes, chronic respiratory diseases and mental deficiency [9,20]. Although significantly less, indoor and outdoor air pollution from building-related energy use also affects populations in developed countries. Outdoor air pollution benefits locally from the high reliance on electricity; nevertheless, these large power generation activities emit significant amounts of air pollutants elsewhere, including carbon-dioxide, thus playing a large role in causing climate change [18,21]. A significant dependence of the world population on biomass fuels, which constitute close to one third of world building primary energy demand and may continue to grow, according to projections [22], is also one of the major anthropogenic causes of deforestation worldwide [23].

Indoor air quality is a crucial factor also for modern buildings with full access to energy services. As buildings are responsible for a significant share of the energy consumption, reduction of cooling and heating loads in buildings through improvement of the air tightness is one of the main strategies to reduce building energy use. However, airtight buildings without adequate ventilation cause health problems, known as sick building syndrome (SBS) [24]. SBS is a combination of general, respiratory, mucosal, and skin symptoms temporally associated with work in and/or occupation of specific buildings [25,26]. Such building-related symptoms are usually caused by inadequate air change rate and poor building maintenance, which may lead to microbial exposure [25], [27–29] and increased concentration of various chemicals (e.g. VOCs) that are released into building interiors by materials of construction, furnishings, adhesives, paints, cleaners, combustion fumes, copier toners, and personal products [24,26]. At the same time, most of today's high-performance buildings rely on sophisticated ventilation systems that not only eliminate these problems but have major other health benefits such as reduced flu and cold transmission.

Energy security is also affected from building energy services: particularly in locations where resources are imported for power production or heating. For instance, the lion's share of the European Union 40% of energy that is consumed in its building sector is imported [30•]. Therefore, reducing building energy demand contributes strongly to energy security improvements. For example, studies have shown that a comprehensive deep retrofit program could reduce January natural gas imports in Hungary by over 60%, making the country significantly less vulnerable to gas supply disruptions that have had

Table 1

Summary table for the key challenges posed by energy use in buildings and their relation to sustainable development

Challenges	Relation to sustainable development
Increase in demand for energy services	Global energy consumption is growing, driven by many factors → sustainable solutions are needed, on one hand, in order to limit this growth and/or make energy services less harmful for environment and, on the other, — to provide high quality energy services to a larger number of people
Indoor air pollution	There is a significant dependence of the world population on biomass fuels, which causes indoor pollution and leads to various health problems → solutions are needed to switch from inefficient usage of biomass to low-carbon energy sources
Sick building syndrome	Certain building-related symptoms usually caused by inadequate air change rate and poor building maintenance → high quality ventilation should be ensured during buildings' design
Energy dependency	In many countries energy consumed in the building sector is imported → reduction in building energy demand and utilization of local renewable energy sources are needed to improve energy security
Fuel poverty	The inability of households to afford adequate energy services, or a disproportionate financial burden to pay for such services → reduction in building energy demand is needed to make energy services more affordable
Urban heat island effect	Higher urban temperatures in the city centers than in the surrounding rural or suburban areas → better built and operated buildings are needed

threatening consequences during political incidences among its Eastern neighbors during the past decade [31,32].

Another key challenge related to building energy use is fuel poverty — that is, the inability of households to afford adequate energy services, or a disproportionate financial burden to pay for such services [33]. The three key causes of fuel poverty are general poverty, high (relative) domestic fuel prices and the energy inefficiency of dwellings [33–35], with the latter as the primary reason in several seriously affected countries. Among the effects are social welfare losses as well as occasionally serious physical and mental health risks [36]. Only in England and Wales 27,000 deaths per year are attributed to fuel poverty [37].

Densely built urban areas in warmer climates may suffer from the urban heat island (UHI) effect, resulting in, among others, higher urban temperatures in the city centers than in the surrounding rural or suburban areas [38]. The air temperature in the cities can be as much as 5 °C higher than these other areas [39]. The UHI effect has multiple negative effects: increased energy use for cooling [40,39] and related CO_2 emissions [38], abated air quality [41], human discomfort, physical and psychological health risks [38,39,42–44], alter local weather patterns [41]. Therefore, UHI has a major impact on the quality of people's life, environment and infrastructure and can be mitigated by better built and operated buildings [45•].

The key challenges discussed above and their relation to the sustainable development are summarized in Table 1.

There are other challenges that this paper has no space to go into, such as non-CO_2 GHG emissions related to refrigeration and insulation in buildings; health effects from other energy use patterns than described above; major indirect energy demand created and related emissions induced through the proliferation of especially urban buildings mainly in developing countries, etc. Another crucial challenge to account for is embodied energy, that is, energy required to produce, transport, utilize and dispose building materials and technologies. As embodied energy may be significant in some energy efficient and low-carbon buildings (sometimes even higher than in conventional buildings), due to utilization of additional technologies and materials, it is necessary to apply a life-cycle approach for buildings' construction and renovation [46,47].

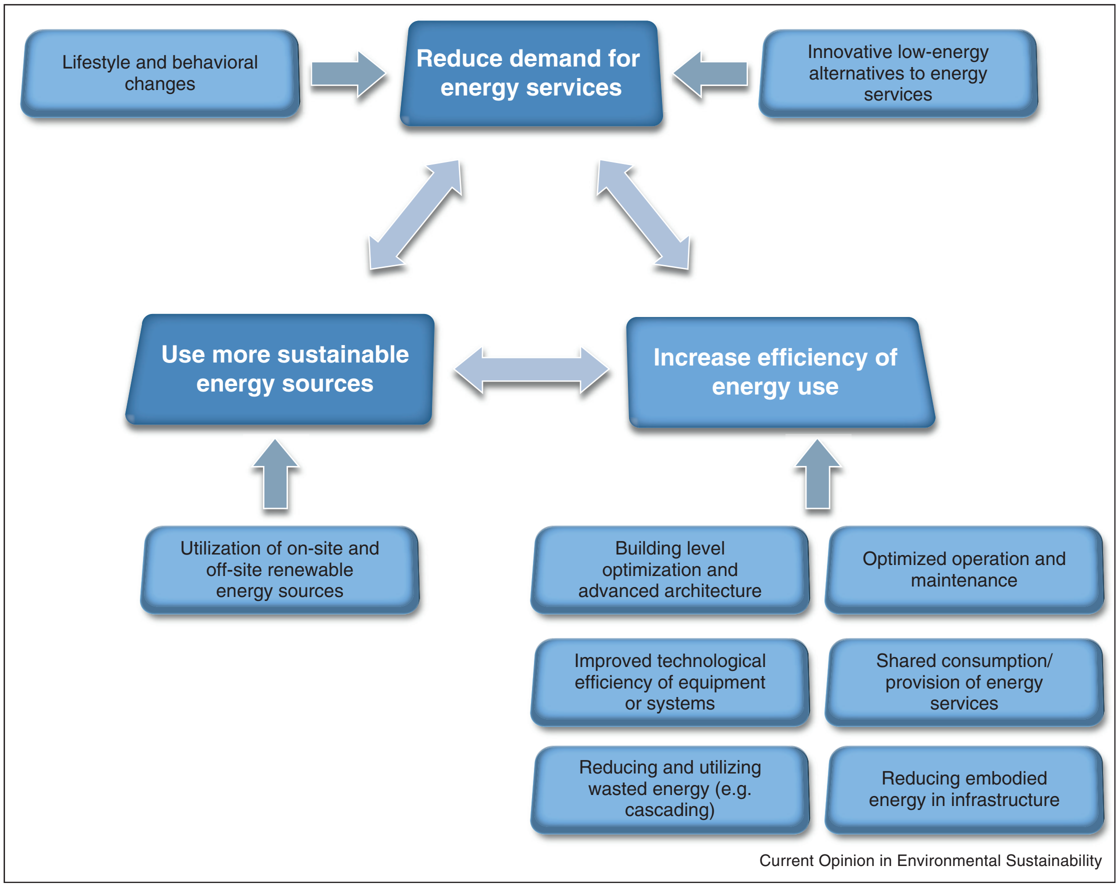
The following section will focus on how the multiple stresses discussed above can be mitigated through more sustainable utilization of energy resources in buildings.

Main solution strategies to these challenges in the long-term perspective

The key strategies to address these multiple challenges to sustainable development from building energy use comprise the combination of first, reducing the demand for relevant energy services, second, increasing the efficiency of energy use that satisfies these services; and third, using more sustainable, cleaner energy sources that fuel these energy needs. Each of these strategies includes a variation of steps and activities (see Figure 1).

In short, the key towards a more sustainable energy use in buildings and mitigating all building energy related challenges outlined above is to reduce the requirements in building operational energy to the point where these needs can be met through renewable and emissions-free energy sources; preferably from locally generated sources when available and can be produced in a sustainable manner. If all sustainability challenges are considered,

Figure 1



Key strategies and steps to address challenges related to energy use in buildings. Source: based on [48].

as a general but not absolute rule, the first priority is for reducing the need for energy services while providing equal or higher comfort; then, reducing the energy needs to provide the same (or increased) services; and finally, to satisfy the remaining small energy demand by sustainable resources. In developed countries where energy service levels are very high, some research and policy discussions also suggest that perhaps the levels of energy services could be considered to be capped or even reduced in some cases through different measures; and this maybe inevitable in the longer run to solve our sustainability challenges. This paper does not focus on this latter option, while the GEA has devoted a chapter to the exploration of these rarely discussed options [49].

Significant (up to 90%) reductions in building energy use in comparison to conventional ones in new low-energy buildings can be achieved in almost any location of the world through the application of the Integrated Design Process (IDP). Key principles of IDP involve the consideration of building orientation, form, thermal mass; the specification of a high-performance building envelope and other measures to reduce heating and cooling loads; the maximization of passive heating, cooling, ventilation and daylighting; the installation of efficient systems to meet remaining loads; the utilization of energy efficient and properly sized individual energy-using devices; and ensuring that systems and devices are properly commissioned [48]. Using principles of this approach during renovation, it is also possible to achieve more than 50% reductions in the energy use of existing buildings, up to even 90–95%. Once gross energy requirements have been reduced considerably, it is sometimes possible to supply most or all of the remaining energy needs with on-site or locally produced renewable energy generation or other renewable electricity sources [10••]. Combination of energy efficiency measures with local renewable energy supply can allow a building to become nearly zero-energy, net zero energy or even energy positive (incase there is excess of renewable energy supply).

Buildings that are constructed or retrofitted according to the IDP principles usually provide high-quality indoor environment due to combination of air-tightness with improved ventilation and HVAC systems, thereby eliminating the risk of indoor air pollution and health risks. According to the literature, better ventilation and indoor air quality reduce cases of colds and flu by 9–20% in the general population in US, which could provide annual savings of $6–14 billion [50]. Because of improved daylighting, lighting, and temperature and ventilation control, reduced indoor pollutants, and improved air quality in high performance buildings labor productivity rises by about 6–16% and students' test scores shows ~20–26% faster learning in schools [51].

As high performance buildings are becoming more and more cost-effective and are declining in capital costs, they potentially can offer alternative, sustainable living environment for the people who do not have access to high quality energy services. Utilization of renewable energy sources and efficient appliances and equipment (including cooking stoves) contributes to tackling the problem of burning traditional fuels and related issues for human and environmental health [17,18,52].

Efficient and clean-burning cookstoves can produce perhaps the most important benefits for sustainable development in the world's buildings in the next decades, by eliminating or reducing the two million deaths and 41.6 million DALY losses [6,17]. While a fuel switch for fossil-fuel using stoves may result in an ultimate increase in commercially traded energy use and GHG emissions, it typically reduces unsustainably harvested biomass use and thus often deforestation as well as black carbon emissions — that is a strong greenhouse agent. These are in addition to the significant social and gender benefits of reducing the time spent on collecting fuel-wood and cooking and making it available for productive uses.

Deep retrofitting exiting buildings occupied by households experiencing fuel poverty, which result in sustantial energy savings ('deep' retrofits), can tackle fuel poverty problem with high cost-effectiveness and multiple co-benefits [53,54•,55•]. Besides obvious positive environmental effects buildings retrofitted in this way offer a significantly lower energy bills, which will improve financial situation of the benefiting households [56,57].

Buildings can contribute to addressing the UHI effect challenge, too, if the low-energy buildings integrate cool or green roofs, high albedo building materials, increased vegetation and water bodies (i.e. ponds) on and/or around the building site. These technologies can lower the building surface and air temperatures, decrease the corresponding sensible heat flux to the atmosphere [40,45•], and, therefore, reduce energy use for cooling, as well as peaks in energy use [58]. Consequently, integration of green areas [58,59,60•] and water bodies [61,60•] into urban spaces cool the environment and, thus, mitigate the heat island effect [41].

Outlook for building energy use in the long-term: insights from the Global Energy Assessment

In order to assess the importance of the buildings sector in solving sustainable development related challenges a research team from the Centre for Climate Change and Sustainable Energy Policy (3CSEP) at CEU, including the authors of this paper, have been conducting comprehensive scenario analysis for several years. This work started under the umbrella of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [5] and was further developed during the preparation of the Global Energy Assessment in harmony with its overarching scenarios [48], together with the UNEP's Sustainable Buildings and Climate Programme. The model was significantly elaborated and extended under the initiative of the Global Building Performance Network (GBPN) in 2011–2012 [62••]. As a result of its close relationship to GEA scenarios, certain input data (e.g. projections for population, urbanization, GDP) for this model are shared with the MESSAGE model developed by International Institute for Applied Systems Analysis (IIASA) for the GEA (see, for example [6,63,64]). Results of the present study were harmonized with the results of the main GEA energy supply scenarios through several iterations [6].

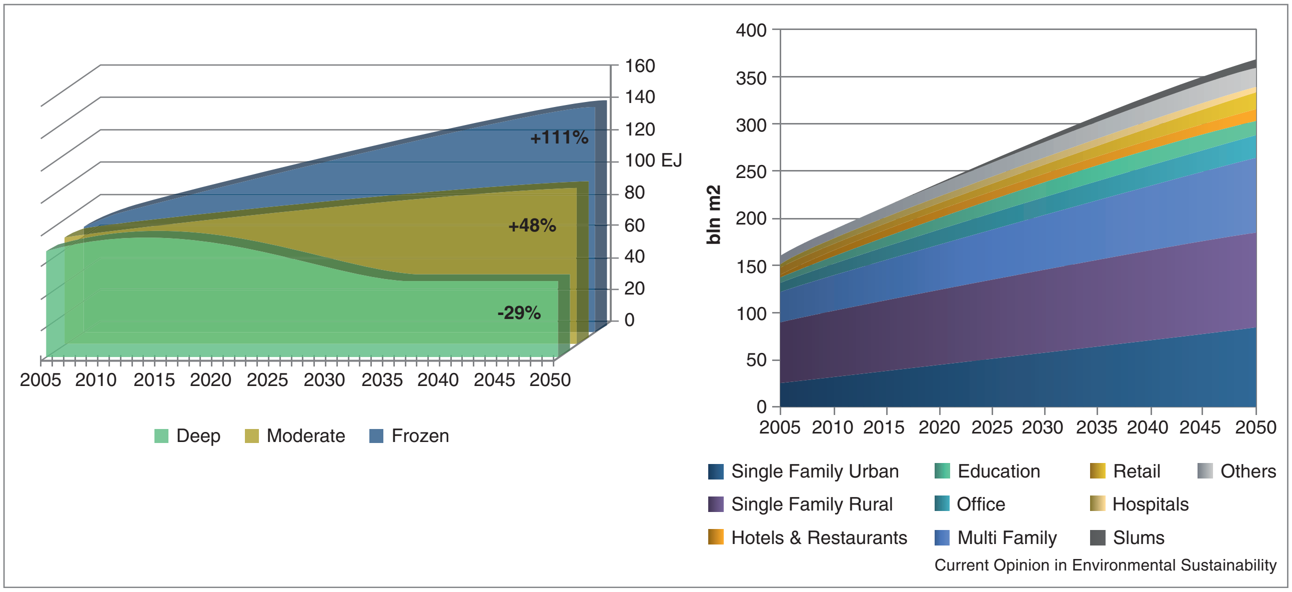
As more than a half of the global building final energy is used for space heating and cooling and another 10–20% for water heating, this study focused on thermal energy uses (i.e. energy use for lighting, cooking and appliances are not considered in this analysis).

The scenarios developed in this study are policy-relevant techno-economic scenarios, which do not aim at forecasting the future, but are devoted to present the potential trends of building energy use under different decision regimes. The key purpose of the scenario assessments is to demonstrate the vast potential in energy savings to policy-makers and a dangerous risk to loose this opportunity if policy actions are not ambitious enough.

Three scenarios were elaborated in order to illustrate:

(1) How far the building sector can contribute to ambitious climate change mitigation goals through wide proliferation of energy efficient building best-practices ('Deep efficiency' scenario);
(2) How in contrast a hypothetical future building energy use will look like if no energy efficiency improvement and policy interventions will take place in the building sector ('Frozen efficiency' scenario);
(3) How much energy savings can be achieved through moderate policy actions and whether they will be sufficient to realize long-term mitigation targets ('moderate efficiency' scenario).

Figure 2



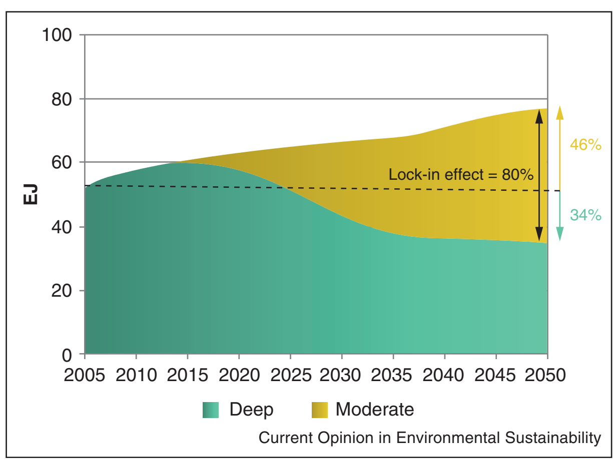
World total final building thermal energy for three scenarios, contrasted by floor area development during the same period. For the final energy, percentage figures show the change of the scenario in 2050 as compared to 2005. Floor area is by main building type.
Source: Authors' own elaborations, for more details see [62••].

The scenarios are built on a comprehensive building stock model, which captures key process in the building, such as construction, renovation and demolition. The key drivers for residential building floor area dynamics are population and floor area per capita, for commercial — GDP. Total building floor area is calculated for each region, climate zone, building type and vintage. It is multiplied by respective specific energy consumption values (in kWh/m^2 yr) to obtain final thermal energy use for each region, climate zone, building type and vintage. Specific energy consumption values have been obtained from numerous data sources, publications and personal communications. From these results energy-related CO_2 emissions are calculated by applying on regional emission factors for respective fuels. More information on methodology, assumptions and data can be found in publically available report (see [62••]).

The results of the analysis clearly demonstrated that buildings are one of the key levers in mitigating climate change and solving other sustainability challenges related to energy production. 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 global floor area as well as a significant increase in thermal comfort levels and living conditions in developing countries.

On the contrary, the hypothetical no-action 'frozen' scenario will bring 111% increase in final thermal energy use in the global building sector. Figure 3 also demonstrates through the Moderate scenario the insufficiency of modest policy trends: if today's policy plans and efforts are implemented in developed countries, global building energy use will still increase by about a half of 2005 levels (+48%, moderate scenario, Figure 2). This outcome indubitably shows a significant gap between what level of

Figure 3



World lock-in effect for final energy use for space heating and cooling for Moderate Efficiency and Deep Efficiency scenarios.
Source: Authors' own elaborations, for more details see [62••].

energy savings is possible to achieve using already well-known practices and where even today's policy efforts are taking us.

The risk of the lock-in effect

The gap between Deep and Moderate scenarios discussed above represent a major lock-in risk. Traditionally, the concept of the lock-in effect is considered in relation to the technologies' development or links between technological and environmental change [65–68]. The 3CSEP team has for the first time quantified the energy lock-in risk for a concrete infrastructure related delay [48,62••,69•].

In the current context the lock-in effect takes place because in case a building is constructed or retrofitted to an energy-efficiency level that is far from the state-of-the-art level, it either physically cannot be brought up to the cutting edge performance levels until it stands; or, it will be extremely uneconomic until the next retrofit/construction cycle due to significantly increased (additional) costs, combined with withered energy savings.

Accordingly, in this paper we calculate the lock-in risk as the difference in the thermal energy use levels achieved under two scenarios: Moderate Efficiency and Deep Efficiency — in relation to the base year (2005).

Figure 3 demonstrates that the lock-in risk for the building sector is very significant. If present standards prevail for new construction, combined with moderate efficiency levels for renovation, 80% of 2005 final heating and cooling energy will be locked-in by 2050 despite ramped up retrofit dynamics and already growing ambitions in new building codes.

The level of magnitude of the lock-in effect varies among different regions, but usually presents a significant risk for potential energy savings. For selected regions the values of calculated lock-in effect for space heating and cooling energy use are the following: US — 53%, China — 63%, India — 414%. These results clearly demonstrate urgency and necessity of effective policy development in the building sector in these countries. In EU-27 a relatively small lock-in effect results from the assumption that the EPBD is effectively implemented in all Member States and already improves energy performance of most new and retrofitted buildings in the 2020–2050 period even in the Moderate scenario.

While from an energy savings perspective the lock-in effect is less problematic since energy saving can be achieved in the next renovation or construction cycles, and lower savings levels still represent positive developments as considered to the baseline case, the urgency of climate change and early emission reductions mean that the potentially locked-in 80% of 2005 thermal energy demand levels can seriously jeopardize ambitions to reach low climate targets for decades. From a climate change perspective, it is essential that buildings deliver maximized energy savings in the midterm, which requires ambitious and urgent policy actions.

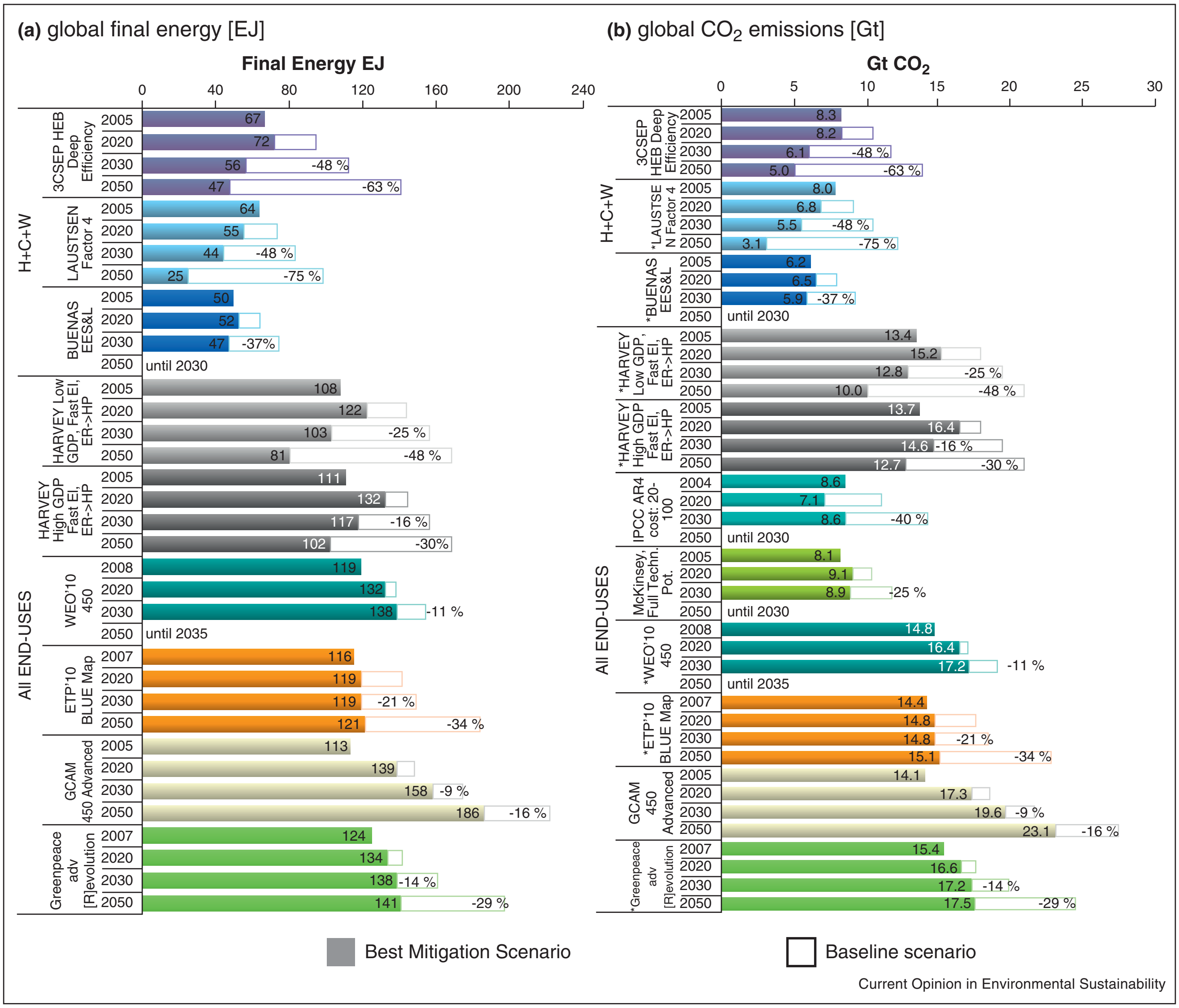
Outlook for building energy use in the long-term: insights from other models

This section presents a comparison of the scenarios presented above with other similar models in the literature. For this purpose, we have reviewed 18 global and regional studies on the medium-term final energy consumption reduction and/or CO_2 emissions mitigation strategies in the building sector that are presented in detail in Urge-Vorsatz *et al.*, 2012 [62••]. In this paper we only present the global review. This covers the results of High Efficiency Buildings (HEB) developed by the 3CSEP [62••], building energy use model developed by J. Laustsen (J. Laustsen, Technical Director, Global Buildings Performance Network, *personal communication*, 2012), Bottom-Up Energy Analysis System (BUENAS) [70], Global Climate-Oriented Building Energy Use Scenarios developed by D. Harvey (D. Harvey, in preparation. 'Global Climate-Oriented Building Energy Use Scenarios'. *Energy Policy*), World Energy Outlook (WEO) [71], Energy Technology Perspective [22], Greenpeace [72], IPCC [5], McKinsey [73] and Global Change Assessment Model (ObjECTS GCAM, Joint Global Change Research Institute. URL: http://www.globalchange.umd.edu/models/gcam/). Although the models had different projection periods, assumptions and methodologies, their comparison suggests similar conclusions.

As we can see from the medium-term trends (Figure 4a) the baseline scenario, if such was constructed, of final energy (thus the corresponding CO_2 emissions) is expected to grow by ~60% of the 2005 value by 2050 (ETP'10, Greenpeace, Harvey), meaning an increase from about 115 EJ to close to 200 EJ if all end-uses are considered. At the same time, if only final energy demand for thermal energy needs, that is, heating/cooling/hot water is considered, the 2005 final energy is likely to grow even more dynamically; the value is expected to double by 2050 (3CSEP HEB). As space heating (H), cooling (C) and water heating (W) all together can contribute to around 60–70% of a building's total energy consumption it makes these end-uses particularly important in terms of strategies and measures to reduce the energy demand. The other end-uses are electricity related, thus the changes here are very dependent on power sector decarbonization.

It is disquieting that even the results for the most ambitious scenarios show the global final energy *increase* in reference to their 2005 values. The exception here is the Harvey model's 'LowGDP, FastEI, ER to Heat Pumps'

Figure 4



Global final energy use [EJ] and CO_2 emissions [Gt] in base year, 2020, 2030 and 2050 for the baseline scenario and the best mitigation scenario together with percentage value of final energy reduction in 2030 and 2050 in reference to the baseline scenario. *For these models CO_2 emissions were not presented in papers but were calculated directly from final energy.

scenario that projects the possibility of final energy decrease of 25% of the 2005 value. In contrast, larger relative reductions can be observed for the models that cover only the thermal energy needs. Here final energy can be reduced by up to 60% of the 2005 value (e.g. Laustsen, 'Factor 4' scenario).

Similar trends can be noticed for CO_2 emissions (Figure 4b). As the analyzed models assumed different developments in emission factors and fuel shares in time (and thus power sector decarbonization), to make the comparison possible and impartial, and to show the role of the building sector rather than the supply sector, a constant emission factor of 124 [kgCO_2/GJ] was assumed for all models and years. Again, the assessed models that cover only thermal energy demand present the largest CO_2 emissions mitigation possibilities, which is up to 75% in 2050 in relation to the baseline scenario. Among the models that cover all end-uses, there is one mitigation scenario which shows that keeping the CO_2 emissions value in 2030 at the same level as in 2005 is possible (IPPC AR4).

An important finding from the model comparison is that studies that cover a longer term (until 2050) achieved higher reductions than studies focusing on the shorter-term (until 2030) (Buenas, IPCC, McKinsey, WEO'10) — pointing to how crucial is a strategic, long-term vision for the sector. It also points to the importance of stable, long-term and consistent policies for a sector where infrastructure prevails and determines emissions for many decades or even centuries. Another key finding is that despite the assumed broad and deep proliferation of state-of-the-art building technologies and know-how, energy use still declines only by app. one-third by the middle of the century. This means that in order to reach stringent climate goals, policies pushing for energy-efficiency improvements need to go hand-in-hand with those pushing the other levers such as switching to low-carbon fuels (renewable or decarbonized electricity) and encouraging behavioral and lifestyle changes.

Conclusions

The purpose of this paper was to synthetize the key challenges energy use related to buildings pose to sustainable development in a longer-term perspective, as well as the key strategies through which changes in building energy use can contribute to solving these challenges. In this context, the paper provided a review of scenarios for how global building energy use may develop in more sustainable development pathways in the medium term.

The paper demonstrated that energy used for services in buildings is responsible for an important part of our global sustainable development challenges, including large shares of greenhouse gas and other climate forcing agent emissions, over a million deaths and dozens of millions of DALYs annually, exacerbated indoor and outdoor air quality; among other more general energy-related challenges such as energy dependence. It showed that without targeted actions these problems will become much worse with building energy use expected to grow by over 110% by 2050. In contrast, if today's state-of-the-art become standard practice, building thermal energy use can decline by as much as a third as compared to its 2005 levels by 2050. Similar results were shown by several models. Energy for non-thermal building energy services is projected to be able to be reduced in a less dynamic manner: total building energy use typically stagnates even in most ambitious model scenarios.

The projected potential improvements in thermal and cooking energy have been shown to be able to address many important challenges, including the cooking-related mortalities and morbidities, energy and fuel poverty, GHG emissions, air quality, energy security, social, gender and economic well-being. However, the paper also pointed out that without sufficiently ambitious performance levels embraced by policies, there is also a significant lock-in risk, comprising as much as 80% of 2005 building thermal energy demand levels by 2050. The scenario and scenario comparison analyses pointed to the importance of a strategic, long-term vision for this sector where infrastructure prevails and determines emissions for many decades or even centuries. Finally, the paper pointed out that while improved efficiency may take the sector very far in reaching sustainable development objectives, it will alone not be able to solve some of the larger challenges such as climate change, and thus it is important to also place an emphasis on building-integrated renewables (or switching to low-carbon fuels) as well as behavior, culture and lifestyle.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

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