

TECHNICAL ASSESSMENT FOR BUILDING ENERGY EFFICIENCY RETROFITTING

(BUILDINGS)

(BUILDINGS, ENERGY, ENERGY EFFICIENCY, RETROFITTING)

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*Note: For some of the technical reports, the result section is not yet updated. Kindly refer to the model for the latest results.

PROJECTDRAWDOWN

27 GATE 5 RD., SAUSALITO, CA 94965

INFO@DRAWDOWN.ORG

WWW.DRAWDOWN.ORG

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EXECUTIVE SUMMARY

In the United States and the European Union, buildings account for about 40% of total energy consumption, while in China buildings currently consume 28% of total energy demand with total consumption growing dramatically. Cooling, heating, lighting and other operational services, as well as appliances, are responsible for a large portion of the energy being used in the existing buildings sector.

High building energy consumption results in financial, social and environmental costs, including:

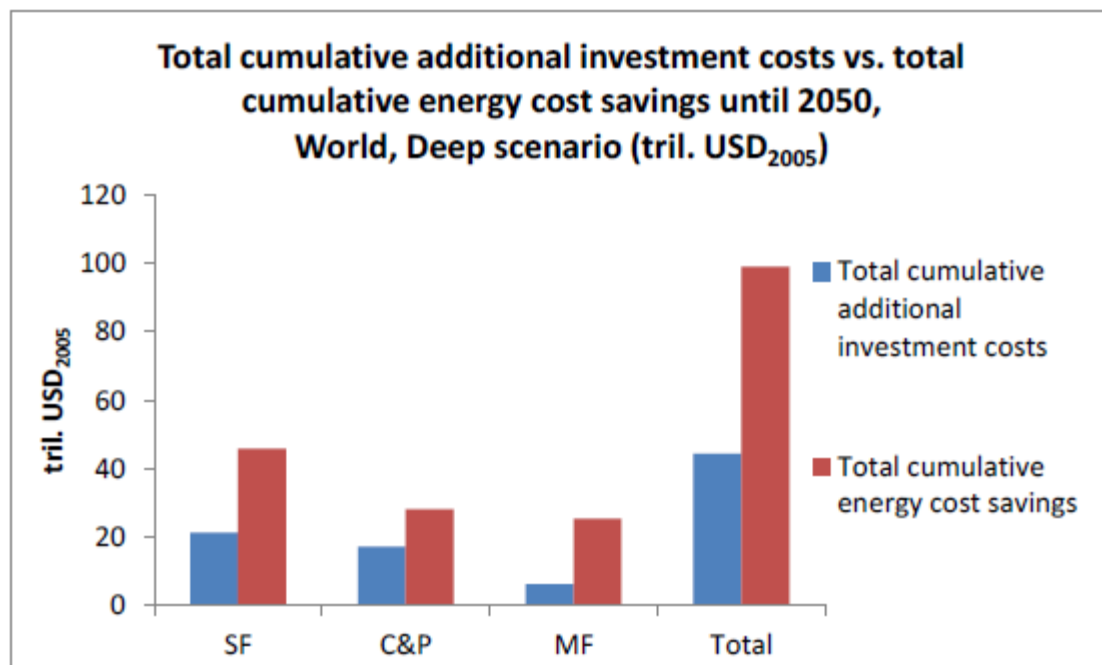
- Emissions of carbon, SO₂, NO_x and PM - which can be harmful to human health - as a result of electricity generation from power plants;
- Expensive construction or upgrading of infrastructure as the utility sectors in many countries struggle to keep up with growing energy demand;
- Greater exposure and vulnerability to fuel price fluctuations as high consumption increases concerns around energy security; and
- Direct financial losses to those footing the energy bills as a result of inefficiency.

Improving building energy efficiency is one of the most cost-effective and fastest ways to reduce electricity demand and associated fuel imports, while indirectly slashing carbon emissions as well as improving local air quality and public health. While many initiatives focus on new buildings, in most countries the majority of the buildings that will make up the urban environment by the year 2030 already exist today. In some cities like New York this percentage is as high as 85%.

Energy efficient buildings are also believed to be healthier buildings, resulting in lower health-related absenteeism or productivity drops. Energy Efficient buildings are increasingly used for public relations and brand management, contributing to a company's 'social license to operate', while the green credentials can often also be used to satisfy reporting, procurement or investment requirements. A retrofitted building is therefore less likely to lose value and be subject to functional obsolescence. For all these reasons, retrofitting for the world's existing commercial, industrial and residential buildings is compelling.

Building retrofits can be undertaken in a myriad different ways, initiated by either the building owner or manager, the tenant or an external party, and with a suite of different financing models. The most suitable measures can also vary considerably depending on the climate and the building location, shape and form. Most building retrofits focus on either passive design measures such as improving the building envelope (e.g. installing better insulation and double pane glazing) and active design measures to improve the efficiency of lighting, HVAC (heating, ventilation and air conditioning), water heating and plug loads.

Building retrofits are anticipated to be cost-effective on a global level and for four major regions considered (EU, USA, China and India) with total cumulative energy cost savings under a 'deep efficiency scenario' exceeding the total cumulative additional investment costs and providing a return on investment of 124% by 2050.



Total cumulative additional investment costs versus total cumulative energy cost savings until 2050 for the world as a whole under a Deep Efficiency / OP scenario

Building the case for an energy retrofit in many cases also means proving the value of investing in energy savings beyond the simple 'energy cost savings' story. To do so, it is helpful to tap into what really motivates key decision-makers and show them how energy efficiency can contribute to those goals. The rise of better financing and contracting models that mitigate or eliminate the risk and burden of high upfront cost and somewhat uncertain operational cost savings, as well as schemes that provide incentives to utilities to help their customers save rather than consume more energy are also increasingly important drivers for greater uptake of building energy efficiency retrofitting. In addition, a number of global trends are likely to drive interest in building retrofitting. For example, new risks have emerged, such as increased volatility of fuel prices for electricity generation and energy insecurity from dependencies on scarce fossil resources and the locations from which these are sourced.

In order to accelerate the uptake of building retrofitting a number of hurdles common to many countries must be addressed, including:

- Low cost of electricity, particularly compared to property rents and land prices, with energy costs accounting for only a small percentage of overall business costs or household expenditure;
- Insufficient government policies and regulations, resulting in market inefficiencies as well as energy consumption not being considered a key issue by the private sector;
- Real or perceived high upfront costs for more energy efficient buildings;
- Split benefits between landlords and tenants, where landlords have little incentive to reduce the building's energy use since tenants pay a major portion of the overall building's energy costs and thus reap most of the benefits of the upgrade;
- Lack of awareness of the hidden costs of high energy consumption and how to best approach a building retrofit from a technical and financial perspective;

- Access to capital, as many types of retrofit programs and financing models are relatively new and capital providers who have limited exposure to such types of investment consider the risks of lending to be fairly high;
- Legal or structural challenges, such as mortgage covenants which prevent the accumulation of further debt or changes to the structure of the building without explicit consent of the lender; and
- Insufficient demand for buildings with green credentials.

To assess the CO₂ reduction potential and financial cost-benefits of building retrofits, Project Drawdown looked to adoption scenarios and methodology developed by the Global Buildings Performance Network (GBPN) and the Central European University (CEU). This research analyzes the total thermal energy use and associated CO₂ emissions under Frozen, Moderate and Deep Efficiency scenarios for the world's building stock in a number of key regions (EU, USA, China and India) up to the year 2050, as well as the cumulative additional costs versus the cumulative energy cost savings.

The GBPN and CEU research focus is on thermal energy, i.e. space heating and cooling as well as hot water provision, since over half of global final energy use in buildings can be attributed to space heating and cooling while water heating is responsible for an additional 10-20% of energy use. Project Drawdown considers the Frozen Efficiency scenario to be equivalent to our Reference Case (REF) scenario, while the Deep Efficiency scenario is equivalent to our Optimistically Plausible (OPT) scenario.

For the calculation of energy related CO₂ emissions, the GBPN and CEU research converted energy end-use to primary energy using primary energy factors, and subsequently applied CO₂ emission factors for the different key types of fuels used in the generation of energy. For the cost analysis, cost-effective best practices of building energy performance which can be replicated for similar climatic conditions and building types were identified.

The GBPN and CEU research concluded that about 40% of global CO₂ emissions from thermal energy use attributable to buildings can be avoided by 2050, compared to a 2005 baseline, in case of an ambitious uptake of state-of-the-art building technologies, which corresponds to almost 3 Gt in CO₂ emission reductions.

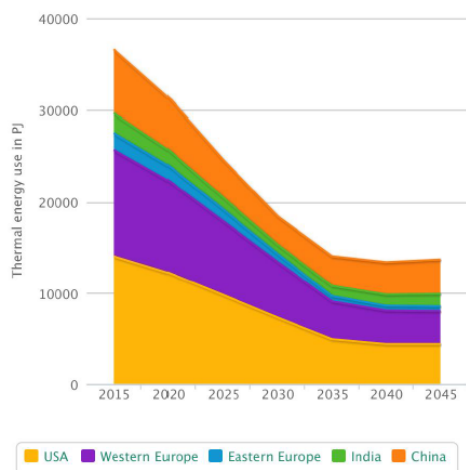
Region	Baseline Gt CO ₂ 2005	Deep Efficiency		Moderate Efficiency		Frozen Efficiency	
		Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005	Gt CO ₂ 2050	Δ% to 2005
US	2.8	1.0	-63%	2.3	-17%	3.1	11%
EU-27	2.0	0.7	-66%	0.8	-61%	2.1	4%
China	0.6	0.7	11%	1.2	90%	1.6	164%
India	0.2	0.6	200%	1.4	564%	1.7	701%
Rest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

Combined CO₂ emissions from space heating, cooling and water heating in 2050 compared to 2005 under 3 efficiency scenarios

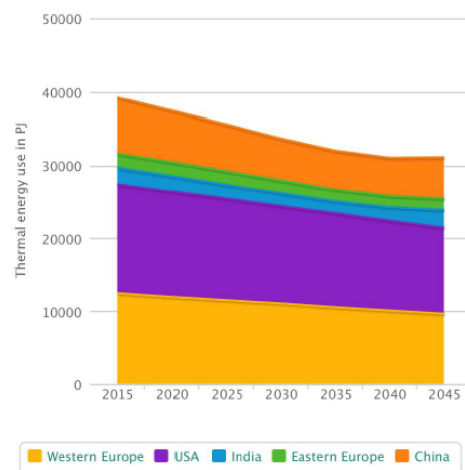
As for key regions, a significant potential for CO₂ savings can be seen in the USA and EU, with a potential reduction of 63% (1.8 GT) and 66% (1.3 Gt) by 2050, respectively, under the Deep Efficiency/OPT

scenario. In China, CO2 emissions grow in all scenarios, although at a much more modest level in comparison to India, where the growth in CO2 emissions by 2050 could be as high as 700% under the Frozen Efficiency/REF scenario. Space heating and cooling is responsible for the majority of the related CO2 emissions in all regions and under all three scenarios.

Deep efficiency - Total thermal energy use, Urban & Rural / All buildings, Total for existing buildings



Frozen efficiency - Total thermal energy use, Urban & Rural / All buildings, Total for existing buildings



Thermal energy use 2015 to 2045 in existing buildings under a Deep Efficiency / OP and Frozen Efficiency/REF scenario for the USA, Western and Eastern Europe, China and India

Deep Efficiency/OPT building retrofits are anticipated to be cost-effective on a global level and for the four major regions considered (EU, USA, China and India) with total cumulative energy cost savings exceeding total cumulative additional investment costs, providing an accumulated ROI of 124% by 2050.

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	21.2	45.9
Commercial & public buildings (C&P)	17.1	28.1
Multi-family buildings (MF)	6.1	25.3
Total	44.3	99.2

Total cumulative additional investment costs and total cumulative energy cost savings until 2050 at world level under a Deep Efficiency / OP scenario

Much lower cost-effectiveness would be achieved under the Moderate Efficiency scenario, while in some regions, such as the US, the cumulative additional investment costs up to 2050 could even exceed the savings. As such it's clear that pursuing a Deep Efficiency/OPT scenario would not only provide the greatest carbon reduction benefits but also financially result in the highest return on investment.

1 LITERATURE REVIEW

1.1 INTRODUCTION

The International Energy Agency predicts that by 2030 cities will be using 73% of global energy while housing 60% of the world's population.¹ Increasingly, cities across the globe are recognizing their ability to develop and implement meaningful policies that address climate change and energy security at the local level. Buildings form the fabric of the world's rapidly growing urban landscapes. In order for cities to accommodate their tremendous increases in population and energy demand in a sustainable manner, it is imperative that energy efficiency in new as well as existing buildings be addressed head on.

In the United States and the European Union buildings account for about 40%² of total energy consumption, while in China, which is currently the home of the most megacities³ of any country in the world, buildings currently consume 28% of total energy demand with total consumption growing dramatically. In some cities such as Hong Kong buildings are even responsible for 90% of all electricity consumed⁴. Cooling, heating, lighting and other operational services as well as appliances are responsible for a large portion of the energy being used in the existing buildings sector.

High building energy consumption is costly in many ways. To just name a few impacts:

- Carbon as well as ambient air emissions, particularly SO₂, NO_x and PM which can be harmful to human health, are emitted as a result of electricity generation from power plants;
- In many countries the utility sector increasingly struggles to keep up with growing energy demand through the construction or upgrading of expensive infrastructure;
- High consumption increases concerns around energy security and leads to greater exposure and vulnerability to fuel price fluctuations;
- Energy inefficiency leads to direct financial losses to those footing the energy bills.

Improving building energy efficiency is one of the most cost-effective and fastest ways to reduce electricity demand and associated fuel imports, while indirectly slashing carbon emissions as well as improving local air quality and public health. While many initiatives focus on new buildings, in most countries the majority of the buildings that will make up the urban environment by the year 2030 already exist today. In cities like New York this percentage is as high as 85%.⁵

Nonetheless, many people fail to associate the mentioned impacts with high energy consumption in the buildings sector. Also, factors such as low electricity prices in many countries, upfront costs and split incentives work against creating the necessary incentive for building owners/managers and tenants to voluntarily pursue building energy efficiency retrofits.

¹ International Energy Agency (2008). World Energy Outlook 2008 – Global Energy Trends to 2030.

² Derived from <http://www.eia.gov/tools/faqs/faq.cfm?id=86&t=1> and <http://ec.europa.eu/energy/en/topics/energy-efficiency/buildings>

³ Megacities are typically defined as areas of continuous urban development of over 10 million people

⁴ Electrical and Mechanical Services Department (2013). Hong Kong Energy End Use Data 2013

⁵ City of New York (2015). PlaNYC Green Buildings and Energy Efficiency. Available at <http://www.nyc.gov/html/gbee/html/about/about.shtml>

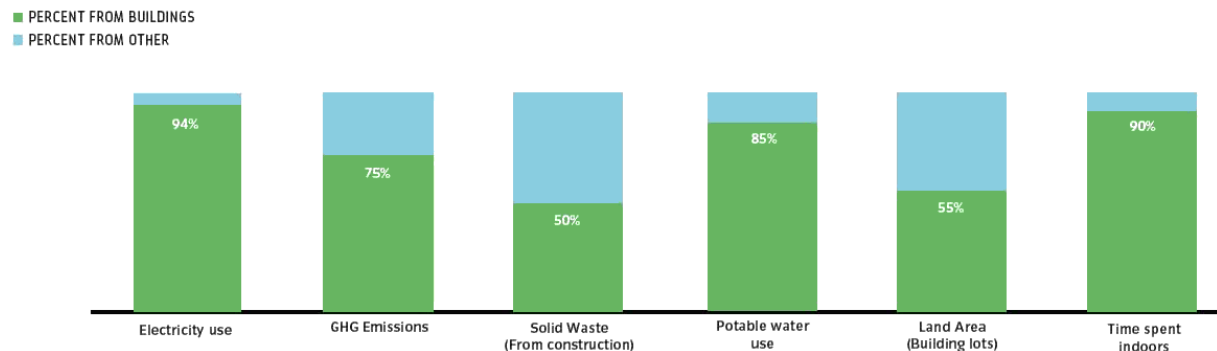


Figure 1 Impact of buildings in New York City on total electricity use, GHG emissions generated and other resource uses⁵

Building retrofits can be undertaken in a myriad of different ways - initiated by either the building owner or manager, the tenant or an external party - and with a suite of different financing models. The most suitable retrofit measures vary considerably depending on the climate and the building location, shape and form. Nonetheless, most building retrofits focus on passive design measures such as improving the building envelope (e.g. installing better insulation and double pane glazing) and active design measures, including lighting, HVAC (heating, ventilation and air conditioning), service water heating and plug loads.

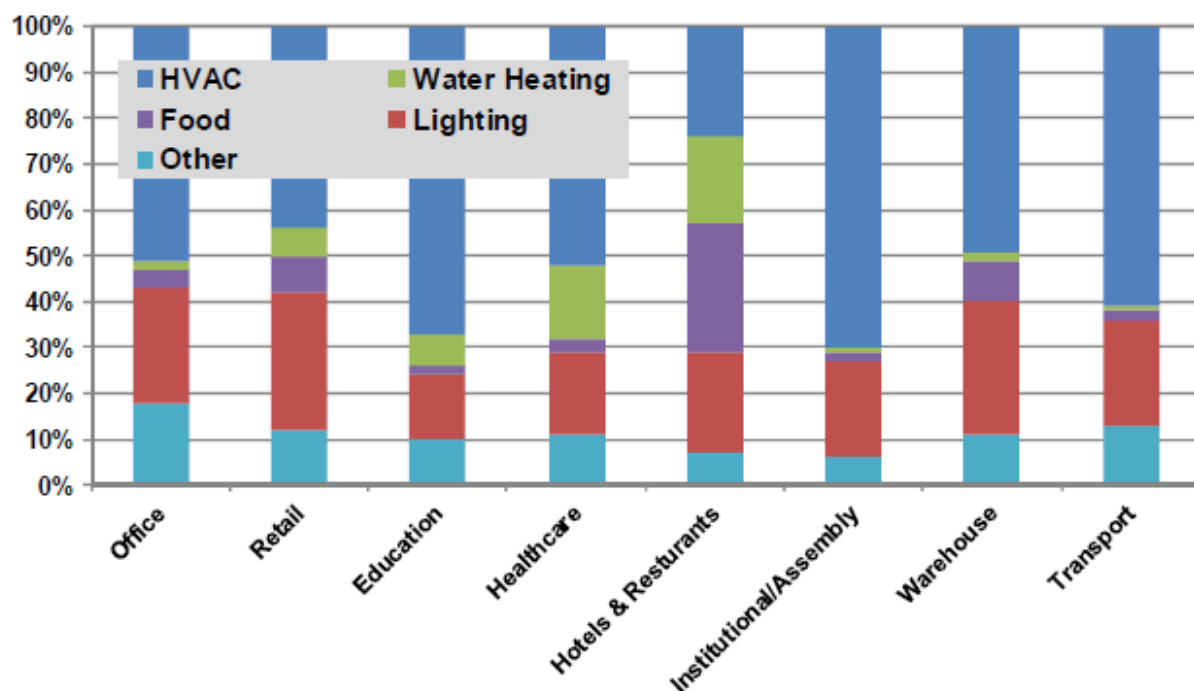


Figure 2 Energy consumption patterns by building type, world averages (2011 data)⁶

We see the greatest uptake in building energy efficiency in regions that have considerable heating or cooling demands as a result of climate, combined with relatively high energy prices and a strong push from stakeholders such as national or municipal governments or non-profit organizations like Green Building Councils. This includes the European Union and the United States.

⁶ Pike Research (2012). Energy Efficiency Retrofits for Commercial and Public Buildings - HVAC, Lighting, Commissioning, Control, Solar Energy, Water Management, Building Envelope, and ESCOs: Global Market Analysis and Forecasts.

In other regions such as Asia and the Middle-East, there have been major annual increases in building energy demand due to rapid uptake of air conditioning systems (because of high cooling loads and increasing wealth), low (subsidized) electricity prices, and limited awareness of and capacity to drive energy efficiency improvements. Nonetheless, these regions in recent years have shown a surge in the interest and efforts to promote and incentivize building energy efficiency. A good overview of current trends in green building for new and existing buildings (retrofits) in different parts of the world is provided by the 2013 report on *World Green Building Trends – Business Benefits Driving New and Retrofit Market Opportunities in over 60 Countries*.

Generally, there is a lack of literature that quantifies the global potential for GHG emission mitigation from energy efficiency improvements in the world's existing building stock. Urge-Vorsatz, et al in 2007 examined 80 collected national or regional studies estimating the CO₂ mitigation potential in five continents and came to the GHG emission reduction potentials from a technical, economic and market perspective shown in **Error! Reference source not found..** Since most studies reviewed covered a limited number of measures or options, the estimates provided are low estimates of the real mitigation potential.⁷

Economic Region	Country or country groups considered	GHG reduction potential	As % of national baseline for buildings
Developed Countries	USA, EU-15, Canada, Greece, New Zealand, Australia, Republic of Korea, UK, Japan, Germany	Technical:	21-54%
		Economic:	12-25%
		Market:	15-37%
Economies in transition	Hungary, Russia, Poland. As a group: Latvia, Lithuania, Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, Czech Republic	Technical:	26-47%
		Economic:	13-37%
		Market:	14%
Developing countries	Argentina, Brazil, China, Ecuador, Thailand, Pakistan, Middle East as a group	Technical:	18-41%
		Economic:	13-52%
		Market:	23%

Table 1 Estimated GHG reduction potential from building retrofits based on 80 national or regional studies (2007)⁷

The fifth IPCC report (2014) provides a few broad generalizations for the energy reduction potential of building retrofits including:⁸

- Detached single-family homes achieving reductions in of 50 – 70% in total energy use under a comprehensive deep retrofit package;

⁷ Urge-Vorsatz, D., Danny Harvey, L.D., Mirasgedis, S. and Levine, M.D. (2007). Mitigating CO₂ emissions from energy use in the world's buildings. Building Research & Information 35, pp. 379–398

⁸ Oswaldo, L., Urge-Vorsatz, D., Ahmed, A., Akbari, H., Bertoldi, P., Cabeza, L., Eyre, N. et al (2014). Buildings, in Working Group III contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Climate Change 2014: Mitigation of Climate Change, chapter 9. Geneva: Cambridge University Press

- Multi-family housing (such as apartment blocks) achieving reductions of 80 - 90 % in space heating requirements for several projects, while relatively modest envelope upgrades in countries such as China achieve reductions of 33 – 50 % in cooling energy use and 65% reductions in heating energy use;
- Commercial buildings achieving 25 – 50% savings in total HVAC energy use through equipment and control system upgrades; and 30-60% reductions in lighting energy use through lighting upgrades.

Building retrofits are anticipated to be cost-effective on a global level and for the four major regions considered (EU, USA, China and India) according to *Monetary Benefits of Ambitious Building Energy Policies* (2015) with total cumulative energy cost savings under a 'deep efficiency scenario' exceeding total cumulative additional investment costs and providing a return on investment of 124% by 2050. However, the same report found that more shallow building efficiency programs do not provide a positive return on investment but merely break even. This research suggests that it is significantly more financially beneficial to promote very high performance buildings than to focus on accelerated investment into a more limited set of energy efficiency improvements ('moderate efficiency scenario') during building retrofit or construction.⁹

Region	Deep efficiency scenario		Moderate efficiency scenario	
	Total cumulative additional investment costs	Total cumulative energy cost savings	Total cumulative additional investment costs	Total cumulative energy cost savings
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
EU-27	5.1	9.8	5.0	7.5
USA	4.3	8.3	5.6	2.8
China	6.8	11.9	6.5	6.2
India	5.0	11.8	3.6	3.7
RoW ¹	23.3	42.2	24.00	14.8
World ²	44.3	99.2	44.6	42.0

Notes: 1 - RoW - Rest of the World; 2 - Note, that the region World is not a simple sum of the four major regions and RoW region, but rather a sum of the 11 world regions. Therefore there are differences in World and sum of the four major regions.

Figure 3: Cumulative additional investment costs and energy cost savings from a deep and moderate efficiency scenario⁹

Total revenue worldwide for energy efficiency retrofits in commercial and residential buildings amounted to US\$80.3 billion dollars in 2011, with North America, Western Europe and Asia-Pacific dominating the retrofit market. In all three regions, the majority of retrofits comprised retail and office buildings. Within the North-American market, the United States represented 90% of revenues, while Germany, France and the United Kingdom combined represented 84% of the market. In Asia-Pacific, China lead the market with 47% followed by Japan and Korea.⁶

⁹ Ürge-Vorsatz, D. Reith, A., Korytárová, K., Egyed, M. and Dollenstein, J. (2015). *Monetary Benefits of Ambitious Building Energy Policies*

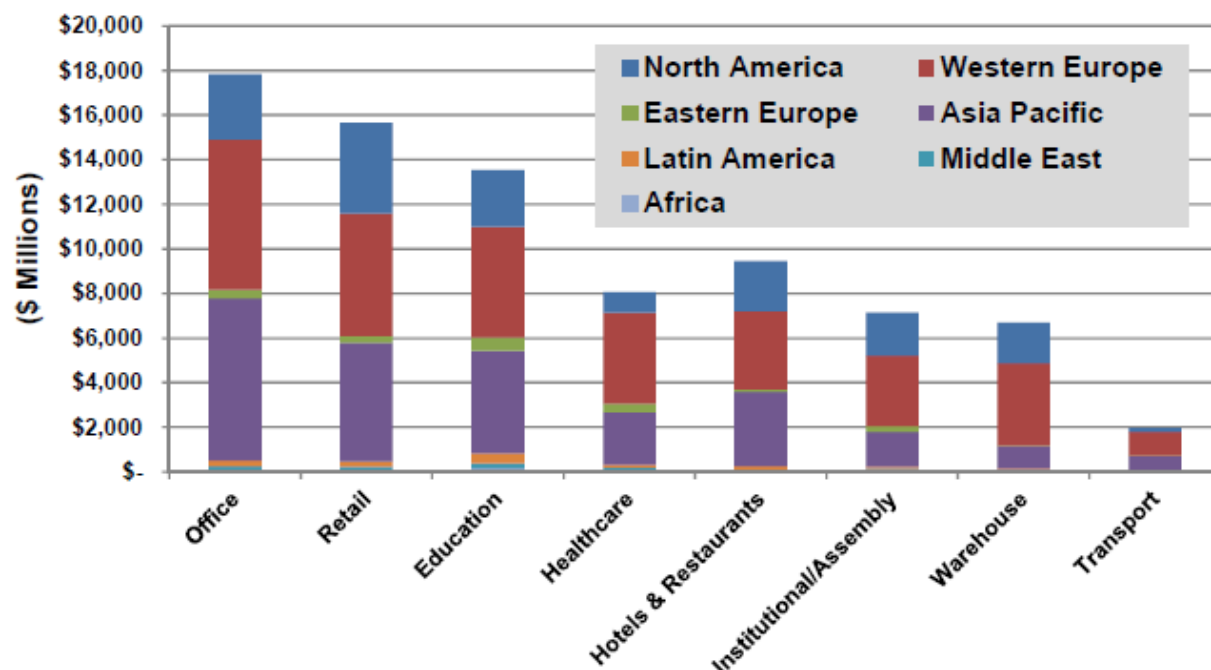


Figure 4 Energy efficiency retrofit revenue by building type and region (2011 data)⁶

1.2 ADOPTION PATH

Building retrofits are often associated with relatively high upfront capital and installation costs as well as minor to major temporary disruption of the building occupants' daily activities. Depending on the package of energy efficiency measures pursued, the maturity of the retrofitting industry at in the area where the building is located, government incentives and the cost of electricity, the payback period of retrofit measures can differ considerably. Depending on these same factors, simple measures such as installing more efficient lighting can pay for themselves in operational energy cost savings periods ranging from less than a year to a period that exceeds the average tenancy length.

Building the case for an energy retrofit in many cases means proving the value of investing in energy savings beyond the simple "energy cost savings" story. To do so, it is helpful to tap into what really motivates key decision-makers and show them how energy efficiency can contribute to those goals. For example, in many countries we see a rapidly growing demand for green office buildings, driven in part by the success of green building rating and certification schemes such as LEED (USA) and BREEAM (UK), and inefficient buildings considered to be less attractive by prospective tenants.

In some countries pro-active government regulations and incentives are sending a clear signal to stakeholders that building energy efficiency is material and worthy of their attention. An example of the government leading by example is the "One City: Built to Last" plan in New York City,¹⁰ launched in September 2014.

¹⁰ City of New York (September 2014). One City Build to Last. Transforming New York City's Buildings for a Low-Carbon Future

The rise of better financing and contracting models that mitigate or even eliminate the risk and burden of high upfront cost and uncertain operational cost savings, as well as schemes that incentivize utilities to help their customers save rather than consume more energy is also increasingly driving greater uptake of building energy efficiency retrofitting.

Obstacles to Building Retrofitting

In order to accelerate the uptake of building retrofitting, some of the most common hurdles which need to be addressed include:

- Low cost of electricity, particularly compared to property rents and land prices, with energy costs accounting for only a small percentage of overall business costs or household expenditure;
- Insufficient government policies and regulations, resulting in market inefficiencies along with energy consumption not being considered a key issue by the private sector;
- Real or perceived high upfront costs for more energy efficient buildings;
- Split benefits between landlords and tenants where landlords have little incentive to reduce the building's energy use since tenants pay a major portion of the building's overall energy costs and will thus reap most of the benefits of the upgrade;
- Lack of awareness of the hidden costs of high energy consumption and of how to best approach a building retrofit from a technical and financial perspective;
- Limited access to capital where lenders have limited exposure to retrofit programs and financing models and consider the risks of lending to be fairly high;
- Legal or structural challenges, such as mortgage covenants which prevent accumulation of further debt or changes to the structure of a building without explicit consent of the lender;
- Insufficient demand for buildings with green credentials.

Building Life-Cycle Triggers that Benefit Retrofitting

Beyond the actions and incentives by a variety of stakeholders who are pushing to overcome obstacles and raise the bar in the retrofit market, energy retrofits can be made more feasible, valuable and financially cost-neutral if timed in accordance with certain events in a building's life cycle. Some of the key triggers include the following.^{11, 14}

Adaptive reuse, market repositioning, or modernization

Repositioning an existing building often requires significant capital whereas the cost of an energy retrofit is incremental and likely to be quite small by comparison. In commercial buildings for example, interior fit-outs can change frequently resulting in new lighting layouts and newly installed or modified communication and data lines. These provide important opportunities for technology upgrades, such as changing lighting to electrical ballasts and upgrading control systems. Controlling waste heat from IT data and communication systems can also be simultaneously addressed.¹¹

Roof, window or other major envelope replacement

Planned roof, window and other major envelope replacements provide opportunities for significant improvements in efficiency at minor incremental cost, providing the leverage for a retrofit that reduces cooling loads and potentially the cost of replacing major equipment, such

¹¹ Rocky Mountain Institute (2012). Guide to Building the Case for Deep Energy Retrofits

as HVAC. Refurbishments of the building envelope, for example, offer a major opportunity to reduce the heat load on the interior premises through measures such as improved glazing, external shading methods, and solar films¹².

HVAC, lighting or other major equipment replacement

Major building service equipment replacements can also provide opportunities to address the building envelope, such as the façade (e.g. shading devices, solar films) and other building components to reduce thermal and electrical loads. The result of such a load reduction could allow for fewer replacements of central building services equipment, leading to marginal or no incremental aggregated costs to retrofit.

A service refurbishment of a commercial building's sub-system, for example, likely takes place every five to ten years, providing an opportunity for upgrading the overall systems control if not already included under a tenant's interior fit-out. Providing more sensors and meters, as well as building information management and building automatic control functions, significantly facilitates performance monitoring and auditing along with an increase in energy performance, such as through automatic dimming or turning on/off of lights.¹²

Upgrades to meet code

Building energy efficiency codes become increasingly stringent, often mandating a certain minimum level of compliance for major building retrofits. Such retrofits may be accompanied by substantial disruptions and costs, enough that an effort to pursue more ambitious energy improvements beyond the code becomes feasible or even profitable.

Fixing an 'energy hog'

Some buildings have such high energy use that an energy retrofit will have compelling economics even without leveraging any of the factors above. Many buildings in European and American cities are at least several decades old, with older buildings, if not upgraded, usually having single pane glazing, resulting in considerable heat transfer from outside.

Major occupancy change

A company or tenant moving a significant number of people or products into or out of a building presents a prime opportunity for a retrofit. First, the changeover provides an opportunity for generating an interior layout that improves energy and space efficiency, and can potentially even create more leasable space through downsizing mechanical equipment. Further, the commencement of a new tenant lease provides the building owner or manager with an option to overcome the competing financial-return issue through a green lease contract, leveraging tenant investment in a more energy efficient building.

Energy management planning

As part of an ongoing energy management plan for a group of buildings, the owner may desire a set of replicable efficiency measures. These measures can be developed from retrofits of an archetypical building and applied to a larger set of similar buildings.

¹² City University of Hong Kong on behalf of Climate Change Business Forum (2010). Every Building a Powerhouse

A number of global trends are likely to drive interest in building retrofitting. In recent years, for example, new risks have emerged, such as increased volatility of fuel prices for electricity generation and energy insecurity in terms of dependencies on certain scarce fossil resources and the locations from which these have to be sourced. The so called ‘negawatt’ - every unit of energy which not used - is not subject to these risks and comes at a much lower cost than nearly any other electricity resource option as shown in Figure 5. We can therefore expect these developments to accelerate the uptake of energy efficiency.

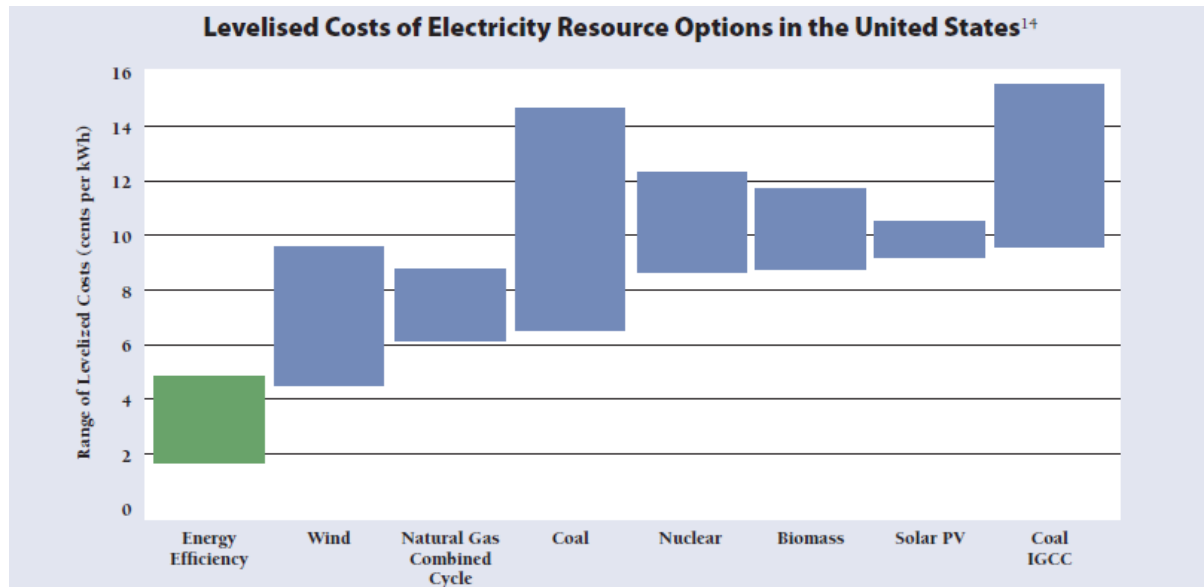


Figure 5 Levelized cost of electricity resources indicating that energy efficiency is a highly cost effective resource¹³

In lower income communities we see the rise of ‘energy poverty’, a condition where households are unable to pay for the cost of electricity and/or gas to power, heat or cool their homes. More and more municipal governments are beginning to address this issue by incentivizing building retrofits through programs with often no upfront costs to the residential owners or tenants and with the capital costs being paid back in small increments out of the savings on the electricity bill.

1.3 ADVANTAGES AND DISADVANTAGES

An argument could be made that energy efficiency should be focused new buildings rather than dealing with the challenges of retrofitting existing buildings. In countries such as China where significant volumes of new-built buildings are still being added to the total building stock such an approach could make sense. However, in most countries the majority of total building stock for the next few decades already exists today.

The continuation of high energy consumption by existing building stock is therefore costly to owners, tenants and society in many ways. Further, an energy efficiency upgrade can make a building more desirable in the property sales or rental market, leading to higher occupancy rates and potentially higher sales value or rents.

¹³ RAP, David Crossley (2014). Energy Efficiency as a Resource for the Power Sector in China

Efficient buildings are also believed to be healthier buildings, resulting in lower health-related absenteeism or productivity losses. Energy efficient buildings are increasingly used for public relations and brand management, contributing to a company's 'social license to operate', while green credentials can often also be used to satisfy reporting, procurement or investment requirements. A retrofitted building is therefore less likely to lose value and be subject to functional obsolescence.¹⁴ Therefore, there are many compelling reasons to pursue building retrofits for the world's existing commercial, industrial and residential buildings.

¹⁴ National Resource Defense Council. High Performance Demonstration Project webpage, retrieved from <http://www.nrdc.org/business/cgi/>

2 METHODOLOGY

2.1 ADOPTION SCENARIOS AND APPROACH

Because retrofitting encompasses several solutions in the buildings sector that have been modeled by Project Drawdown, we have not undertaken modeling of retrofitting in order to avoid double counting. Instead, we use retrofitting as a benchmark of what is possible if building sector solutions are adopted in aggregate. Drawdown solutions that are encompassed within retrofitting include insulation, LED lighting, energy efficient roofs, HVAC efficiencies and solar hot water.

Here we provide a recapitulation of the methodology and results of modeling and analysis produced by the Global Buildings Performance Network (GBPN) and the Central European University (CEU). For the climate effects of retrofitting, we have reviewed the methodology and results set forth in Urge-Vorsatz, et.al.'s *Best practice policies for low carbon & energy buildings: based on scenario analysis* (2012) and the Centre for Climate Change and Sustainable Energy Policy (3CSEP), Central European University's online *Tool for Building Energy Performance Scenarios* (2014), which analyze the total thermal energy use and associated CO₂ emissions under Frozen, Moderate and Deep Efficiency uptake scenarios for the world's building stock in a number of key regions (EU, USA, China and India) up to the year 2050. For financial cost analysis of retrofitting, we have reviewed Urge-Vorsatz, et. al.'s *Monetary Benefits of Ambitious Building Energy Policies* (2015), which quantifies the cumulative additional costs versus the cumulative energy cost savings for the Moderate and the Deep Efficiency uptake scenario until 2050.

Model applied

The GBPN and CEU research reports we have reviewed are based on the Center for Climate Change and Sustainable Energy Policy - High Efficiency Buildings Model (3CSEP HEB model), which is a sophisticated global building energy model developed by the Center for Climate Change and Sustainable Energy Policy of the Central European University in Budapest, Hungary. The Center has also played a key role in authoring the Buildings chapter for the Fourth and Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

The 3CSEP HEB model distinguishes:

- Buildings located in urban, rural areas or slums (where applicable);
- 3 building types (single family houses, multi-family buildings, commercial and public buildings,
- 6 subcategories of building types: hotels and restaurants, educational buildings, hospitals, offices, retail buildings, and others);
- 5 building vintages (standard, new, retrofit, advanced new and advanced retrofit buildings);
- 17 climate zones; and
- 11 world regions.

The 3CSEP HEB model studies the performance of whole buildings rather than the sum of individual components. The model's focus is on space heating and cooling, since over half of global final energy use in buildings can be attributed to space heating and cooling, as well as water heating which is responsible for another 10-20% of energy use. Approximately two-thirds of a building's total final energy use is

covered through the analysis of thermal energy performance. The model could not fully address some key factors such as how energy consumption in buildings is influenced by the behavior of its occupants.

Due to the major challenge of collecting a set of accurate and representative cost data, the model derives a zero order estimate of financial costs and benefits, providing a preliminary indication of the overall cost-effectiveness of each scenario. The investment costs were calculated as additional to the baseline cost, which would take place if the current policy and technological trends continue without energy efficiency gains until 2050 (Frozen Efficiency scenario).

Scenarios considered

The three main scenarios included in the 3CSEP HEB model are considered policy-relevant techno-economic scenarios, which aim to present potential trends of building energy use under different conditions.

The three scenarios differ according to the level of ambition in building performance policy and technological developments:

- A scenario with very ambitious actions (Deep Efficiency);
- A scenario with moderately ambitious actions (Moderate Efficiency); and
- A scenario without further actions (Frozen).

Key assumptions for each of the three scenarios are described in Table 2:

Parameter	Deep	Moderate	Frozen
Main features of final energy use for SH&C	Wide proliferation of building best-practices in construction and renovation	Compliance with national building codes and current enforced energy efficiency policies (e.g in EU – EPBD)	Energy performance of new and retrofit buildings do not improve as compared to their 2005 levels
Main feature for water heating energy use	Solar systems and/or advanced heat pumps gain large significance	Water heating efficiency measures are not more ambitious than currently existing programs	The fuel mix and efficiency of water heaters do not change
Share of advanced buildings	By 2022 advanced will replace most of conventional new and retrofit buildings on the market	In most of the regions no advanced buildings are assumed, except for (EU, Western Europe and North America)	Advanced buildings assumed only in Germany as 5% and in Austria as 10% of their new building stock; no advanced retrofit buildings
Energy performance of advanced buildings	Passive house level (15-30 kwh/m2/yr)	Passive house level (15-30 kwh/m2/yr)	Passive house level (15-30 kwh/m2/yr)
Energy performance of conventional buildings	New buildings correspond to regional building codes or averages; retrofit consume 30% less than standard buildings	New buildings correspond to regional building codes or averages; retrofit consume 30% less than standard buildings	New buildings consume 10-20% more than the national building codes or averages; retrofit consume 10% less than standard buildings
Renovation rate	Till 2019 – 1.4%, from 2020 – 3% for all regions	Till 2019 – 1.4%, from 2020 – higher level (1.5 - 2.1%, depending on the region)	Fixed at 1.4% for all regions
Policies considered	Strong political efforts are need to encourage such an ambitious market transformation	Current policy trends (e.g. EPBD recast in EU-27 and local building codes in other regions)	No policy interventions

Table 2 Assumptions as applied to the Deep, Moderate and Frozen Efficiency scenarios applied in the 3CSEP HEP model^{Error!}
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Geographical coverage

The 3CSEB HEB model provides projections on a global level as well for 11 key regions - North America (NAM); Western Europe (WEU); Eastern Europe (EEU); Former Soviet Union (FSU); Latin America (LAC); Pacific OECD/Oceania (PAO); Centrally Planned Asia (CPA); Pacific Asia (PAS); South Asia (SAS); Middle East (MEA); and Africa (AFR).

The GBPN and CEU research, in particular the report on Monetary Benefits, focus on four key zones - the European Union, United States, China and India - which align with the regional focus areas identified by Project Drawdown. In 2005, these four regions accounted for more than 60% of global building energy end-use.

Climate classifications

Within each identified region one or more climate zones have been considered in the 3CSEB HEB model in order to capture the differences in building energy use caused by climate variations. The

differentiation between climate zones – 17 in total - is based on these climate factors and their influence on building energy demand for space heating, cooling and dehumidification:

- Heating Degree Days (HDD);
- Cooling Degree Days (CDD);
- Relative Humidity of the warmest month (RH);
- Average Temperature of the warmest month (T);

The climate zones as applied and their characteristics are presented in Figure 6 and Table 3.

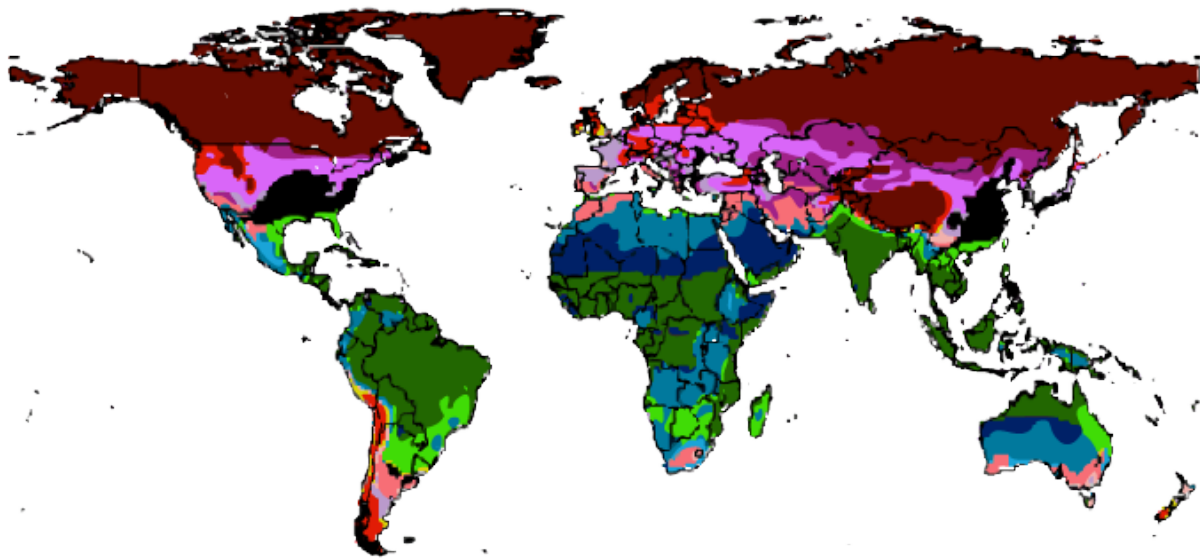


Figure 6 Climate zones overlaid on the world map as applied in the ECSEB HEB mode|Error! Bookmark not defined.

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

Table 3 Definition of the 17 climate zones as applied in the ECSEB HEB mode[Error! Bookmark not defined.

Building types classifications

The research by GBPN and CEU distinguished building categories by their location (urban, rural, areas of informal housing), building type (single-family, multifamily, commercial and public buildings with subcategories) and building vintage (existing, new, advanced new, retrofit, advanced retrofit).

Area type

The GBPN and CEU research distinguishes between urban and rural building areas for residential buildings on the basis of projections of urbanization rates in each region and country. For commercial and public buildings a small share (5-10%) of floor area was assumed to be rural, based on expert judgments. In addition, informal settlements in developing regions were taken into account on the basis of the share of urban population living in informal housing, according to UN-HABITAT statistics. (GBPN 2014)

Building type

The GBPN and CEU research divided residential urban buildings into single-family (detached or attached) and multifamily, according to the population living in each building type. Rural residential buildings are assumed to be single-family ones only. Commercial and public buildings both in urban and rural areas were divided into six sub-categories: hotels & restaurants, educational, hospitals, offices, retail buildings, and others, according to the share of the floor area for each commercial and public building type in the total commercial and public floor area.

Building vintage

In the energy use scenarios, five building vintages are distinguished: standard, new, retrofit, advanced new and advanced retrofit buildings representing different levels of energy performance. Standard buildings are those buildings, which had been built in the country or region prior to the analyzed period, including old buildings which are usually the least efficient ones. Advanced buildings are assumed to consume much less energy than default buildings.

Building stock calculations

The GBPN and CEU research based building floor area calculations on annual dynamics, including fluctuations in the existing building stock as a result of demolition and renovation. The demolition rates vary from one region to another in the range of 0.3 to 1%, a rate of 0.5% being applied in most regions.

Retrofit rates have been assumed to range from 0.7% to 3% of existing building stock per annum, with 3% applied to the Deep Efficiency scenario from 2020 onwards with a ramp-up period from 2015 to 2020 starting at a current rate of 1.4%; 1.5 to 2.1% depending on region from 2020 onwards for the Moderate Efficiency scenario; and a steady 1.4% for the Frozen Efficiency scenario.

Region	RETROFIT RATE					
	Deep scenario		Moderate scenario		Frozen scenario	
	2005-2019	from 2020	2005-2019	from 2020	2005-2019	from 2020
AFR	1.4%	3.0%	1.4%	1.5%	1.4%	1.4%
CPA	1.4%	3.0%	1.4%	1.6%	1.4%	1.4%
EEU	1.4%	3.0%	1.4%	2.1%	1.4%	1.4%
FSU	1.4%	3.0%	1.4%	1.9%	1.4%	1.4%
LAC	1.4%	3.0%	1.4%	1.6%	1.4%	1.4%
MEA	1.4%	3.0%	1.4%	1.5%	1.4%	1.4%
NAM	1.4%	3.0%	1.4%	2.1%	1.4%	1.4%
PAO	1.4%	3.0%	1.4%	2.1%	1.4%	1.4%
PAS	1.4%	3.0%	1.4%	1.5%	1.4%	1.4%
SAS	1.4%	3.0%	1.4%	1.5%	1.4%	1.4%
WEU	1.4%	3.0%	1.4%	2.1%	1.4%	1.4%

Table 4 Retrofit uptake scenarios as percentage of existing building stock by region as applied in the ECES HEB model^{Error! Bookmark not defined.}

Residential Buildings

Residential floor area growth was based on floor area per capita estimates and population projections for each region with the assumptions that the developing world will have approximately the same standard of living in terms of living space per capita as OECD countries by 2050. This is then coupled with the urbanization rate to produce a total floor area for rural and urban buildings. Building floor area has also been calculated for each climate zone by applying the share of population for each climate zone within a region/country.

Commercial and Public Buildings

The main driver for commercial floor area calculation has been GDP projections for each region, yielding “commercial and public floor area elasticity”. This constant, when multiplied by GDP for a given year provides the estimated commercial and public floor area demanded by the economy. Since developing countries have a higher ratio of commercial and public floor area to GDP than OECD countries, the ratio has been assumed to decrease over time and eventually achieve an average OECD level of floor area elasticity, representing a shift to higher GDP output per unit floor area synonymous with greater economic development.

Thermal energy use calculations

Thermal comfort

Thermal comfort combines space heating and cooling needs to maintain an acceptable indoor air temperature, with demand varying by region. Advanced buildings, according to the 3CES HEB model’s logic, have a state-of-the-art design which allows for a significant reduction of thermal energy demand in most climate zones (up to 90%).

Energy use for space heating and cooling was calculated by multiplying the estimated floor area values for each region, climate zone, building type and building vintage in each year by specific energy consumption figures of exemplary buildings for each category, with the results summed to obtain aggregate numbers for the region and globally.

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

Table 5 Estimated energy end use (EJ) for space heating & cooling per each scenario in 2050 and % change from 2005 levels^{Error!}
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Key assumptions for data input into the 3CES HEB model were the following:

1. Energy consumption for space heating and cooling of residential buildings in rural versus urban areas is assumed to be similar in developed regions and 30% lower in developing regions;
2. Retrofit buildings consume 30% less than standard buildings in Moderate and Deep Efficiency Scenarios and 10% less in Frozen Efficiency Scenario for all regions in general;
3. Energy performance of advanced buildings is determined by best practices which can be achieved in a particular climate zone, according to a number of case studies. Most data are in the order of 15-30 kWh/m² (1 square meter equals 10.76 square feet) depending on the region;
4. Informal buildings consume 70% less than single-family buildings in climate zones which require heating and 95% less energy for those climate zones where only cooling is needed.

Water heating

Assumptions on regional technology mix and the efficiencies of the technologies were made to determine regional average efficiency levels for water heating and their improvement potentials. In addition, the changing volume of hot water consumption in some regions was taken into account.

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

Table 6 Estimated energy end use (EJ) for water heating per each scenario in 2050 and % change from 2005 levels

Accounting for the Lock-In effect

The Lock-In effect refers to the risk of locking in a reduced energy saving potential through the adoption of relatively inferior technologies. There is often a considerable gap between the most energy efficient and cost-effective technologies available at some point in time and those that are most commonly used. This can be due to a multitude of reasons, including risk aversion, market failures, low electricity prices, the use of short payback periods, lack of awareness and more.

The delay in adoption and slow diffusion of new and more efficient technologies can result in a reduced potential for energy savings in the long term. If, for example, moderate energy efficiency performance levels become the norm in retrofit buildings, it can be either impossible or extremely uneconomical to further reduce energy consumption in those buildings for decades to come and in some cases, for the entire remaining lifetime of the building.

Table 7 shows the potential for a lock-in effect of a region's energy savings potential by 2050, as a percentage of 2005 energy end-use needs in the event present standards were to prevail for new construction and existing building retrofits combined.

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

Table 7 Percentage of 2005 energy end use needs which could be locked-in by 2050

CO2 emissions calculations

For the calculation of energy-related CO2 emissions, energy end-use has been converted to primary energy using primary energy factors, and subsequently applying CO2 emission factors for the different key types of fuels used in the generation of energy. To obtain regional emission factors, country level emission factors were aggregated.

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

Table 8 CO2 emission factors by region as applied in the 3CES HEB model^{Error! Bookmark not defined.}

Cost calculations¹⁵

For the cost analysis module of the 3CES HEB model, cost-effective best practices of building energy performance which can be replicated for similar climatic conditions and building types were identified. The costs associated with the implementation of a Deep Efficiency scenario were estimated based on the current costs of developing exemplary new and retrofit buildings. The cost data from exemplary projects were included only if upscaling the best-practice across similar building types, climate zones and vintages was considered possible.

¹⁵ Ürge-Vorsatz, D. Reith, A., Korytárová, K., Egyed, M. and Dollenstein, J. (2015). Monetary Benefits of Ambitious Building Energy Policies

With consistent and reliable cost data lacking for some of the regions, climate zones, building types or building vintages, costs were assumed using a cost transfer from another similar category elsewhere in the world with better data, taking into account regional differences in cost levels and economic conditions.

The cost analysis performed by GBPN and CEU focused on two main indicators - total cumulative additional investment cost and total cumulative energy cost savings. Total cumulative additional investment costs show how much more (compounded) investment is needed by 2050 in order to accomplish the transition towards Moderate or Deep Efficiency buildings. This is compared to the pathway in the Frozen efficiency scenario, where building investments (new construction or renovation) are not primarily focused on energy savings and, therefore, the energy saving potential cannot be realized to its full extent. Total cumulative energy cost savings show the benefits in terms of lowered energy bills this investment brings relative to development under the Frozen Efficiency scenario.

To the extent possible, the study team identified genuine cost data for the given region, its climate zone and building types, with priority given to original regional data over cost transfer. If costs of available case studies proved extremely low or high, these cases were examined in greater detail, and if they proved non-reliable, a cost transfer was applied from a different climate zone or even region.

The cost calculations account for technology learning, i.e. a decrease in costs due to a technology's diffusion in the market, such that the investment costs per unit of floor area gradually decrease over time.

Methodology applied

The methodology applied for cost analysis consisted of several steps:

1. Data collection;
2. Development of algorithms;
3. Comparison with results of relevant studies; and
4. Sensitivity analysis

For the calculation of *total cumulative additional investment costs* the following approach was applied:

- Additional specific investment costs per unit of floor area were calculated as a difference between the full cost of a specific building vintage in the Moderate or Deep Efficiency scenario and cost of the corresponding vintage in the Frozen Efficiency scenario;
- Additional investment costs are calculated by a multiplication of calculated annually added floor area and the corresponding investment cost per floor area for the given region, climate zone, vintage and building type. A technology learning factor is applied to the costs of advanced buildings in the Moderate and Deep Efficiency scenarios;
- Calculated additional investment costs are cumulative for the period until 2050;

For calculation of the *total cumulative energy cost savings* the following steps have been taken:

- Total energy savings are calculated as a difference between total energy consumption in the Frozen Efficiency and total energy consumption in a Deep/Moderate Efficiency scenario (EJ) for each region, building type and year. Energy savings of retrofitted buildings represent the savings

stemming from renovating standard buildings to the level of conventional retrofit as well as to the level of advanced retrofit (Moderate/Deep Efficiency scenario);

- The resulting energy savings (EJ) per region and building type were converted into TWh and multiplied by the corresponding region-specific energy prices for different fuels;
- Calculated annual energy cost savings are cumulative until 2050, for each region, building type and scenario.

2.2 CLIMATE INDICATORS

The 3CES HEB model discussed in section 2.1 was used by GBPN and CEU to calculate the CO₂ emissions and the CO₂ emissions reduction up to the year 2050 from thermal energy use in new and retrofitted buildings, with the Input – Output parameters shown in Figure 7.^{16,17}

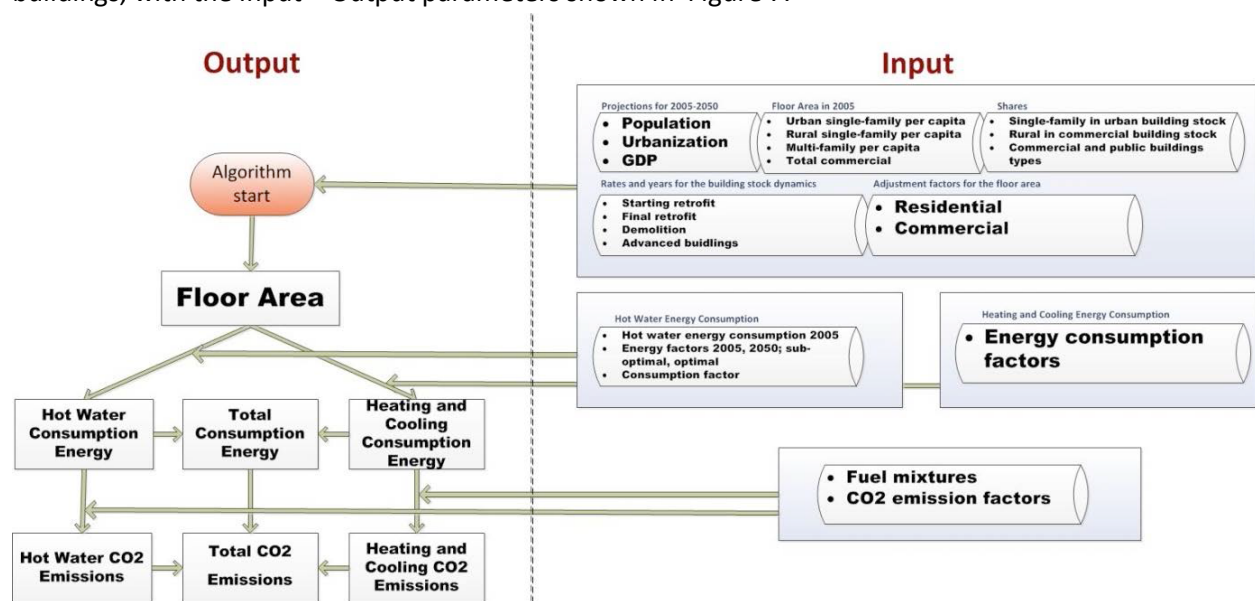


Figure 7 Flowchart with input and output parameters and linkages for calculation of CO₂ emissions from thermal energy use¹⁷

For Project Drawdown purposes we have assumed that the Frozen Scenario (GBPN and CEU) equals our Reference Case (REF) adoption scenario and that the Deep Efficiency Scenario equals our Optimistically Plausible (OPT) adoption scenario. The results presented here represent the results from 2005 up to the year 2050 for new and retrofit buildings combined.

It should be noted that the 2030 Challenge scenario proposed by Architecture 2030 is an alternative optimistic case that exceeds the GBPN Deep Efficiency Scenario. The 2030 Challenge proposes a fossil fuel reduction standard for all new buildings and major renovations of 80% in 2020, 90% in 2025 and carbon-neutral in 2030. The 2030 Challenge proposes that “major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 70% below the regional (or country) average/median for that building type” and defines a “major renovation” as “any

¹⁶ Global Buildings Performance Network, Central European University (2012). Best practice policies for low carbon & energy buildings: based on scenario analysis

¹⁷ Ürge-Vorsatz, D. Reith, A., Korytářová, K., Egyed, M. and Dollenstein, J. (2015). Monetary Benefits of Ambitious Building Energy Policies

renovation of a building where (a) the total cost of the renovation related to the building envelope or the technical building systems is higher than 25 % of the value of the building, excluding the value of the land upon which the building is situated, or (b) more than 25 % of the surface of the building envelope undergoes renovation.”¹⁸

Space heating and cooling

The United States and the European Union showed CO₂ emission reductions in the year 2050 from space heating and cooling energy in both the Moderate Efficiency (-15% and -61%) and the Deep Efficiency (-65% and -69%) scenarios. The reason for the significant mitigation potential in the EU is the ambitious energy use reduction targets set in the European Performance of Buildings Directive (EPBD). China presents a modest emissions reduction potential under the Deep scenario (-19%), while the Moderate and the Frozen Efficiency scenarios displayed a significant increase in CO₂ emissions. In most developing regions, like India, CO₂ emissions will increase in all three scenarios, with the smallest increase under Deep Efficiency.

Globally, CO₂ emissions by 2050 would be reduced compared to the 2005 level only in the Deep Efficiency/OPT scenario where we see a 47% (3Gt) reduction. In the Frozen Efficiency/REF and Moderate Efficiency scenarios global emissions would increase by 62% (4.3 Gt) and 19% (1.3Gt), respectively.¹⁹

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

Table 9 CO₂ emissions from space heating and cooling in 2050 compared to 2005 under 3 efficiency scenarios¹⁹

Water heating

Under the Frozen Efficiency/REF scenario CO₂ emissions from water heating would grow in all regions to different extents, with the highest growth in China and India. In the Moderate Efficiency scenario, however, the study shows a CO₂ emission reduction by 2050 of 32% in the USA and 56% in the EU, while China and India under this scenario are still growing significantly.

In the Deep Efficiency/OPT scenario the USA and EU demonstrate that almost half of CO₂ emissions from water heating in these regions can be avoided by 2050, while in China and India CO₂ emissions from water heating energy use still continue to grow albeit at a slower rate.

¹⁸ The 2030 Challenge, Architecture 2030, http://architecture2030.org/2030_challenges/2030-challenge/

¹⁹ Global Buildings Performance Network, Central European University (2012). Best practice policies for low carbon & energy buildings: based on scenario analysis

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

Table 10 CO₂ emission from water heating in 2050 compared to 2005 under 3 efficiency scenarios¹⁹

Space heating, cooling and water heating combined

The GBPN and CEU research concluded that about 40% of global CO₂ emissions from thermal energy use attributable to buildings can be avoided by 2050, compared to a 2005 baseline, in the case of an ambitious uptake of state-of-the-art building technologies, which corresponds to almost 3 Gt in CO₂ emission reductions.

As for key regions, a significant potential for CO₂ savings can be seen in the USA and EU, with a potential reduction of 63% (1.8 GT) and 66% (1.3 Gt) by 2050, respectively, under the Deep Efficiency/OPT scenario. In China, CO₂ emissions grow in all scenarios, although at a much more modest level in comparison to India, where the growth in CO₂ emissions by 2050 could be as high as 700% under the Frozen Efficiency/REF scenario. Space heating and cooling is responsible for the majority of the related CO₂ emissions in all regions considered under all three scenarios.

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

Table 11 Combined CO₂ emissions from space heating, cooling and water heating in 2050 compared to 2005 under 3 efficiency scenarios¹⁹

The following table and charts were derived from *Tool for Building Energy Performance Scenarios* and represent total thermal energy use (in PJ) for the period 2015 to 2045 under a Deep Efficiency (OPT) and Frozen Efficiency (REF) scenario for existing buildings only, for the countries/regions of the USA,

Western and Eastern Europe, China and India, and clearly show the major reduction potential under an OPT versus a REF scenario.²⁰

Regions and Climate Zones	Scenarios	2015	2020	2025	2030	2035	2040	2045
USA	Deep efficiency	14020	12180	9765	7313	4917	4385	4387
USA	Moderate efficiency	14280	13310	12320	11320	10330	9579	9052
USA	Frozen efficiency	14990	14450	13930	13390	12870	12330	11820
Western Europe	Deep efficiency	11650	10130	8100	6044	4117	3659	3612
Western Europe	Moderate efficiency	11840	10930	9770	8257	6842	5650	4806
Western Europe	Frozen efficiency	12380	11930	11460	10980	10520	10050	9604
Eastern Europe	Deep efficiency	1851	1606	1273	932.92	601.88	529.31	535.34
Eastern Europe	Moderate efficiency	1887	1767	1636	1491	1346	1208	1129
Eastern Europe	Frozen efficiency	1969	1902	1833	1758	1681	1599	1525
China	Deep efficiency	6950	5628	4140	3101	3243	3520	3760
China	Moderate efficiency	7114	6263	5354	4557	4359	4496	5170
China	Frozen efficiency	7556	6971	6357	5685	5290	5236	5652
India	Deep efficiency	2094	1735	1280	988.26	1111	1236	1341
India	Moderate efficiency	2088	1831	1569	1383	1421	1685	2316
India	Frozen efficiency	2258	2099	1939	1780	1620	1807	2476

Table 12 Total thermal energy use (PJ) in existing buildings for the period 2015 to 2045 under 3 scenarios²⁰

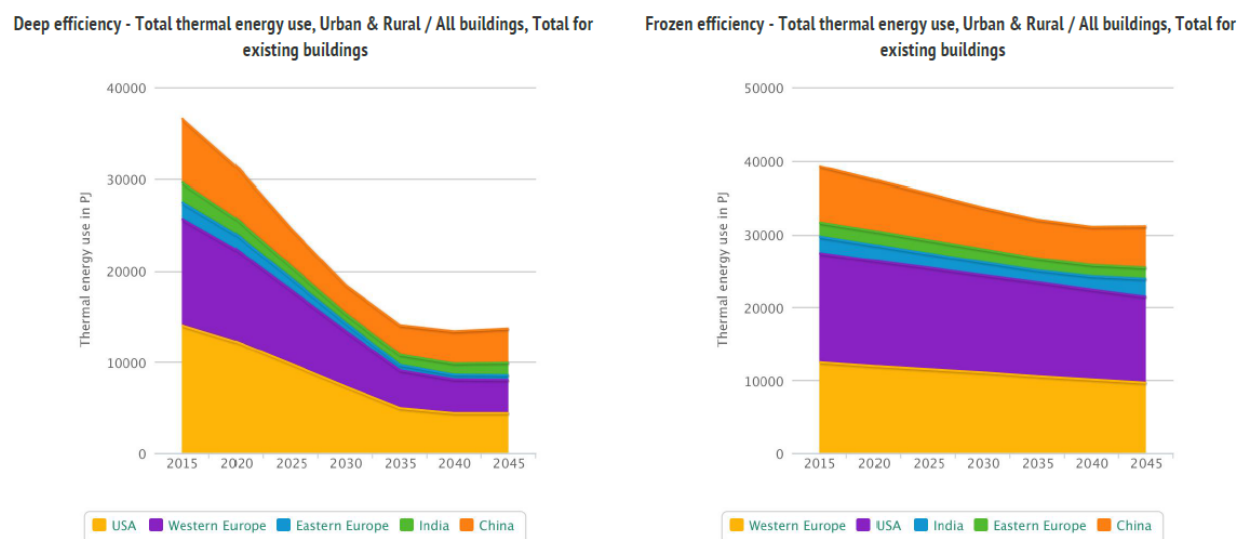


Figure 8 Thermal energy use 2015 to 2045 in existing buildings under a Deep Efficiency and Frozen Efficiency scenario for the USA, Western and Eastern Europe, China and India²⁰

At an average 2.13 Gigaton of carbon per 1 PPM by volume²¹ the Deep Efficiency/OPT scenario would prevent an additional 8.9 Gigaton (14 – 5.1) of CO₂ emissions to the atmosphere over the 2005 to 2050

²⁰ Global Buildings Performance Network (2014). Tool for Building Energy Performance Scenarios

²¹ Retrieved from <http://cdiac.ornl.gov/pns/convert.html> (US DOE)

period compared to the Frozen Efficiency/REF scenario, equating an approximate drop in atmospheric carbon levels of 4.2 PPM.

2.3 FINANCIAL INDICATORS

For cost calculations, we extended the 3CES HEB model as developed and applied by GBPN and CEU with a Cost Analysis module. The Cost Analysis model uses input on floor area and energy end-use for space heating and cooling for the 11 world regions, 17 climate zones, 5 building vintages and several building types in order to calculate investment costs and energy savings under the Frozen, Moderate and Deep Efficiency Scenarios as shown in Figure 10.²²

Figure 9 provides an example of collected investment cost data per unit of floor area collected for the European Union – at 2005 rates - for Single Family (SF), Multi-Family (MF) and Commercial & Public (C&P) buildings under Frozen, Moderate and Deep Efficiency scenarios for various building types (new or retrofit – conventional and advanced) and climate zones. Green cells indicate genuine data from the region and climate zone concerned, while white cells represent a cost transfer from another sufficiently suitable region and/or climate zone.

EU-27				SF											
				Frozen efficiency scenario				Moderate efficiency scenario				Deep efficiency scenario			
				New		Retrofit		New		Retrofit		New		Retrofit	
				New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit
RID	CID	% CID	Climate	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}	N ^{ret}	AN ^{ret}	R ^{new}	AR ^{new}	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}
4-14	2	24%	HHD	1112	1571	561	935	1390	1571	748	935	1390	1571	748	935
4-14	6	30%	HHD + LCD	576	1198	613	1021	827	1198	817	1021	827	1198	817	1021
4-14	8	26%	MHD + LCD	831	887	545	909	855	887	727	909	855	887	727	909
				MF											
				Frozen efficiency scenario				Moderate efficiency scenario				Deep efficiency scenario			
				New		Retrofit		New		Retrofit		New		Retrofit	
				New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit
RID	CID	% CID	Climate	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}	N ^{ret}	AN ^{ret}	R ^{new}	AR ^{new}	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}
4-14	2	24%	HHD	1223	1342	361	601	1223	1342	481	601	1223	1342	481	601
4-14	6	30%	HHD + LCD	465	995	206	344	888	995	275	344	888	995	275	344
4-14	8	26%	MHD + LCD	769	1643	206	344	1467	1643	275	344	1467	1643	275	344
				C&P											
				Frozen efficiency scenario				Moderate efficiency scenario				Deep efficiency scenario			
				New		Retrofit		New		Retrofit		New		Retrofit	
				New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit	New	Advanced new	Retrofit	Advanced retrofit
RID	CID	% CID	Climate	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}	N ^{ret}	AN ^{ret}	R ^{new}	AR ^{new}	N ^{new}	AN ^{new}	R ^{ret}	AR ^{ret}
4-14	2	24%	HHD	1711	1391	332	553	1711	1391	443	553	1711	1391	443	553
4-14	6	30%	HHD + LCD	1082	1939	493	821	1711	1939	657	821	1711	1939	657	821
4-14	8	26%	MHD + LCD	1248	2073	493	821	1974	2073	657	821	1974	2073	657	821

Figure 9 Investment costs per unit of floor area for the EU under 3 efficiency scenarios²²

²² Ürge-Vorsatz, D. Reith, A., Korytárová, K., Egyed, M. and Dollenstein, J. (2015). Monetary Benefits of Ambitious Building Energy Policies

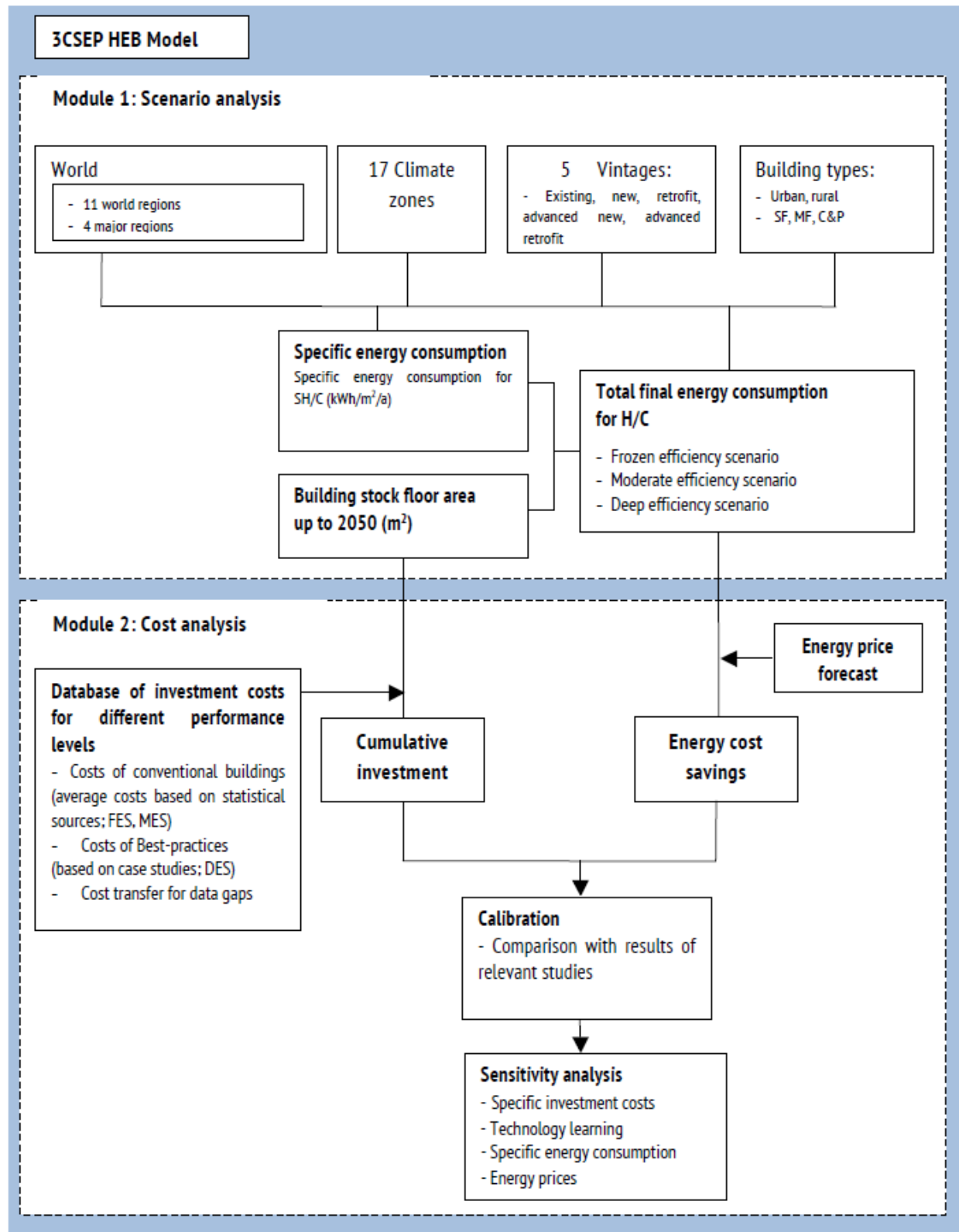


Figure 10 Flowchart displaying the calculation of investment costs and cost savings for 3 efficiency scenarios²²

The calculations showed that much lower cost-effectiveness (i.e. the difference between energy cost savings and additional investment costs) would be achieved under the Moderate Efficiency scenario as compared to the Deep Efficiency scenario in all 11 world regions. In some regions such as the USA the cumulative additional investment costs up to 2050 could even be higher in the Moderate scenario than in the Deep scenario as a result of a lower share of advanced buildings in the Moderate Efficiency and the costs related to technological learning (Urge-Vorsatz, et al (2015).

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	21.2	45.9
Commercial & public buildings (C&P)	17.1	28.1
Multi-family buildings (MF)	6.1	25.3
Total	44.3	99.2

Table 13 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 at world level under a Deep Efficiency scenario²²

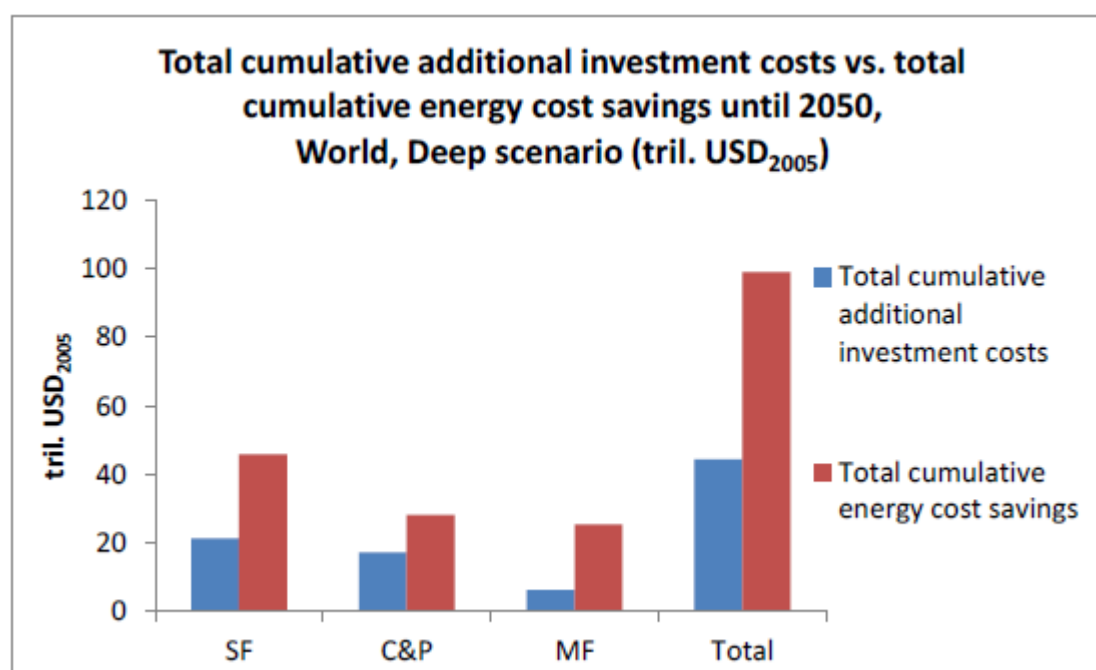


Figure 11 Total cumulative additional investment costs versus total cumulative energy cost savings until 2050 for the world as a whole under a Deep Efficiency scenario²²

When compared to findings from other relevant studies, such as the Global Energy Assessment (2012) and energy efficiency studies by McKinsey (2007, 2009) on cost analysis of low energy transition in the building sector, the results of the cost analysis by the 3CSEP HEB Model came in at the same level of magnitude in most cases. The differences observed were mainly due to more conservative investment costs used in the 3CSEP HEB Model as a result of a significantly more thorough and detailed process of data collection as well as extensive expert reviews where data were not available. Nonetheless, further

future data collection and verification would be beneficial, particularly for India, China and other developing regions.

Sensitivity analysis showed that if energy prices were to fall significantly, the Deep Efficiency scenario may no longer be cost-effective for the EU, China, USA and globally. In addition, if investment costs do not decrease sufficiently, i.e. when the learning factor is not high enough, the Deep Efficiency scenario would no longer be cost-effective for the USA.

On the other hand, results showed that cost-effectiveness could be reached under certain circumstances, even under the Moderate Efficiency scenario in some regions. For example, cost-effectiveness could be reached in China and India if energy prices increase by at least 30% of their currently projected level by 2050, or if investment costs decrease by at least 25% below currently forecasted levels in China or at least 50% in the USA.

European Union

In the EU all building types considered showed cumulative energy cost savings exceeding the total cumulative additional investment costs until 2050 for the Deep efficiency scenario. The Single Family category showed the highest total cumulative additional investment costs, as well as the highest total cumulative energy costs savings potential as a result of its large share in the advanced retrofit floor area by 2050. In general, total cumulative additional investment costs would grow steadily until about 2035, when most of the existing buildings would be renovated under that scenario.

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	2.0	5.3
Commercial & public buildings (C&P)	1.9	2.4
Multi-family buildings (MF)	1.2	2.1
Total	5.1	9.8

Table 14 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the EU under a Deep Efficiency scenario²²

United States

In the United States, all building types would be cost-effective under the Deep Efficiency scenario by 2050. Single Family buildings had the highest cost-effectiveness due to their large share of floor area in the advanced building category up to 2050 in comparison to other building types in the USA's total building stock, followed by Commercial & Public buildings.

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	2.1	4.8
Commercial & public buildings (C&P)	1.6	2.6
Multi-family buildings (MF)	0.5	0.9
Total	4.3	8.3

Table 15 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in the USA under a Deep Efficiency scenario²²

China

In China, investments for all building types except for Single Family were shown to be cost-effective under the Deep Efficiency scenario, with Multi-Family buildings showing the highest cost-effectiveness. Commercial & Public buildings show the highest total cumulative energy cost savings as well as the highest total cumulative investment cost due to this building category accounting for the largest share of total floor area among all building types in China.

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	1.5	1.2
Commercial & public buildings (C&P)	4.1	6.6
Multi-family buildings (MF)	1.1	4.2
Total	6.8	11.9

Table 16 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in China under a Deep efficiency scenario²²

India

In India, the total cumulative energy cost savings exceeded the total cumulative additional investment costs by 2050 for all building types. Single Family buildings showed the highest total cumulative energy cost savings, constituting the largest share of advanced buildings in India in 2050 (57% of advanced new floor area and 76% of advanced retrofitted floor area). This was followed by Commercial & Public buildings, which can secure relatively high energy cost savings.

Building type	Total cumulative additional investment costs until 2050	Total cumulative energy cost savings until 2050
	tril. USD ₂₀₀₅	tril. USD ₂₀₀₅
Single-family buildings (SF)	3.3	6.2
Commercial & public buildings (C&P)	0.8	2.9
Multi-family buildings (MF)	0.8	2.7
Total	5.0	11.8

Table 17 Total cumulative additional investment costs and total cumulative energy cost savings until 2050 in India under a Deep Efficiency scenario²²

2.4 RESULTS

The GBPN and CEU research concluded that about 40% of global CO₂ emissions from thermal energy use attributable to buildings can be avoided by 2050, compared to a 2005 baseline, in case of an ambitious uptake of state-of-the-art building technologies, which corresponds to almost 3 Gt in CO₂ emission reductions.

As for key regions, a significant potential for CO₂ savings can be seen in the USA and EU, with a potential reduction of 63% (1.8 GT) and 66% (1.3 Gt) by 2050, respectively, under the Deep Efficiency/OPT scenario. In China, CO₂ emissions grow in all scenarios, although at a much more modest level in comparison to India, where the growth in CO₂ emissions by 2050 could be as high as 700% under the Frozen Efficiency/REF scenario. Space heating and cooling is responsible for the majority of the related CO₂ emissions in all regions considered under all three scenarios.

Deep Efficiency/OPT building retrofits are also anticipated to be cost-effective on a global level and for the four major regions considered (EU, USA, China and India) with total cumulative energy cost savings exceeding total cumulative additional investment costs, providing an accumulated ROI of 124% by 2050.

Much lower cost-effectiveness would be achieved under the Moderate Efficiency scenario, while in some regions such as the USA, the cumulative additional investment costs up to 2050 could even exceed the savings. As such it is clear that pursuing a Deep Efficiency/OPT scenario would not only provide the greatest carbon reduction benefits but also financially result in the highest return on investment.

2.5 DISCUSSION

In the United States and the European Union, buildings account for about 40% of total energy consumption, while in China, buildings currently consume 28% of total energy demand with total consumption growing dramatically. Cooling, heating, lighting and other operational services, as well as appliances, are responsible for a large portion of the energy being used in the existing buildings sector.

Improving building energy efficiency is one of the most cost-effective and fastest ways to reduce electricity demand and associated fuel imports, while indirectly slashing carbon emissions, as well as improving local air quality and public health. While many initiatives focus on new buildings, in most countries the majority of the buildings that will make up the urban environment by the year 2030 already exist today.

Building retrofits can be undertaken and financed in a myriad different ways, while the most suitable measures can also vary considerably depending on the climate and the building location, shape and form. In general, ambitious deep efficiency building retrofits are anticipated to be cost-effective on a global level and for the four major regions considered (EU, USA, China and India) with total cumulative energy cost savings exceeding total cumulative additional investment costs by 124% for the period up to 2050.

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