Building energy use scenarios at the global and regional level

CENTER FOR CLIMATE CHANGE AND SUSTAINABLE ENERGY POLICY
CENTRAL EUROPEAN UNIVERSITY

Global Buildings Performance Network

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With much contribution from Ksenia Pterichenko

IEA Webinar
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A novel approach to global building energy modeling

- **Considers** buildings as complete systems rather than sums of components -> performance-based approach

- **Recognizes** that
  - State-of-the-art building energy performance can be achieved through a broad variety of designs and component combinations
  - Systemic gains are important

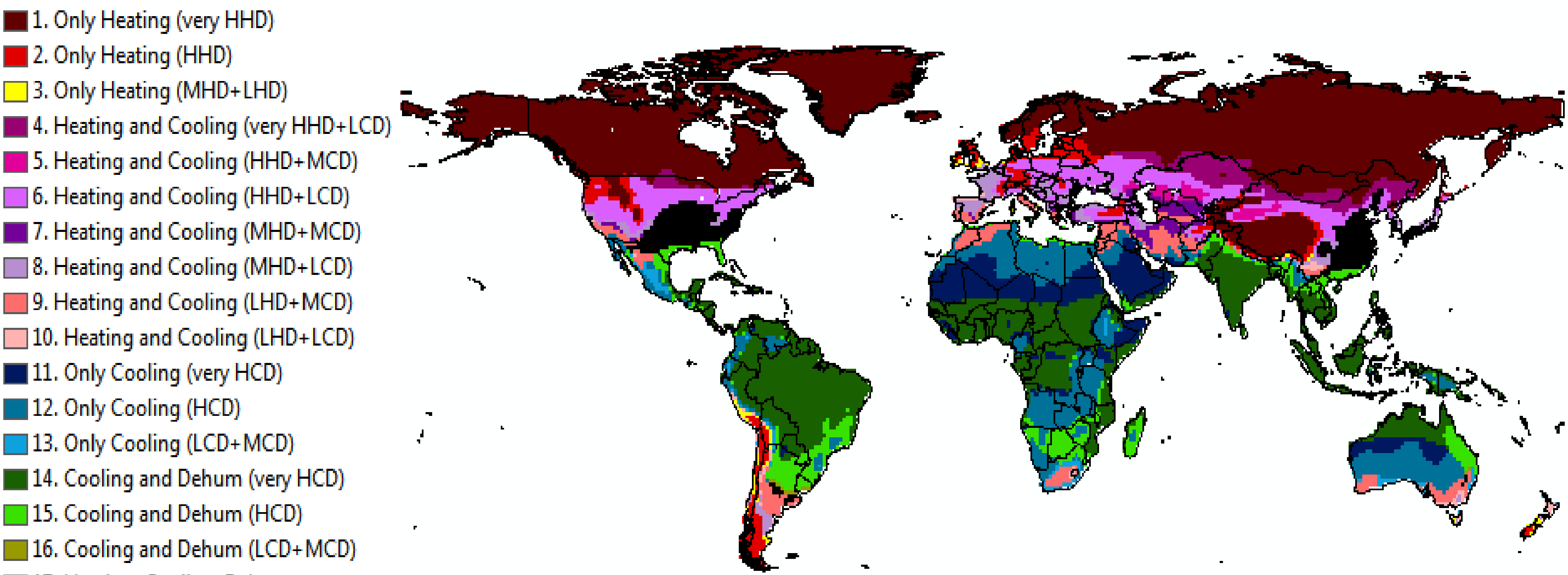
- **Assumes** that existing best practices become the standard (both in new construction AND renovation) after a certain transition time

Main Philosophy and Assumptions

- Assumes that the world's building stock will transform over to today's known (and built) cutting edge in architecture
  - At the most affordable cost
  - At the natural rate of building construction and retrofit; increased in some scenarios
- The main pillars of the model are existing best practices
  - Best practice from and energy and investment costs perspective
- The world's building stock is broken down by regions, climate zones, building types and building vintages

Climate Types

NASA climatic data + GIS spatial analysis



Main parameters: HDD, CDD, Relative Humidity, Average Temperature of the Warmest Month

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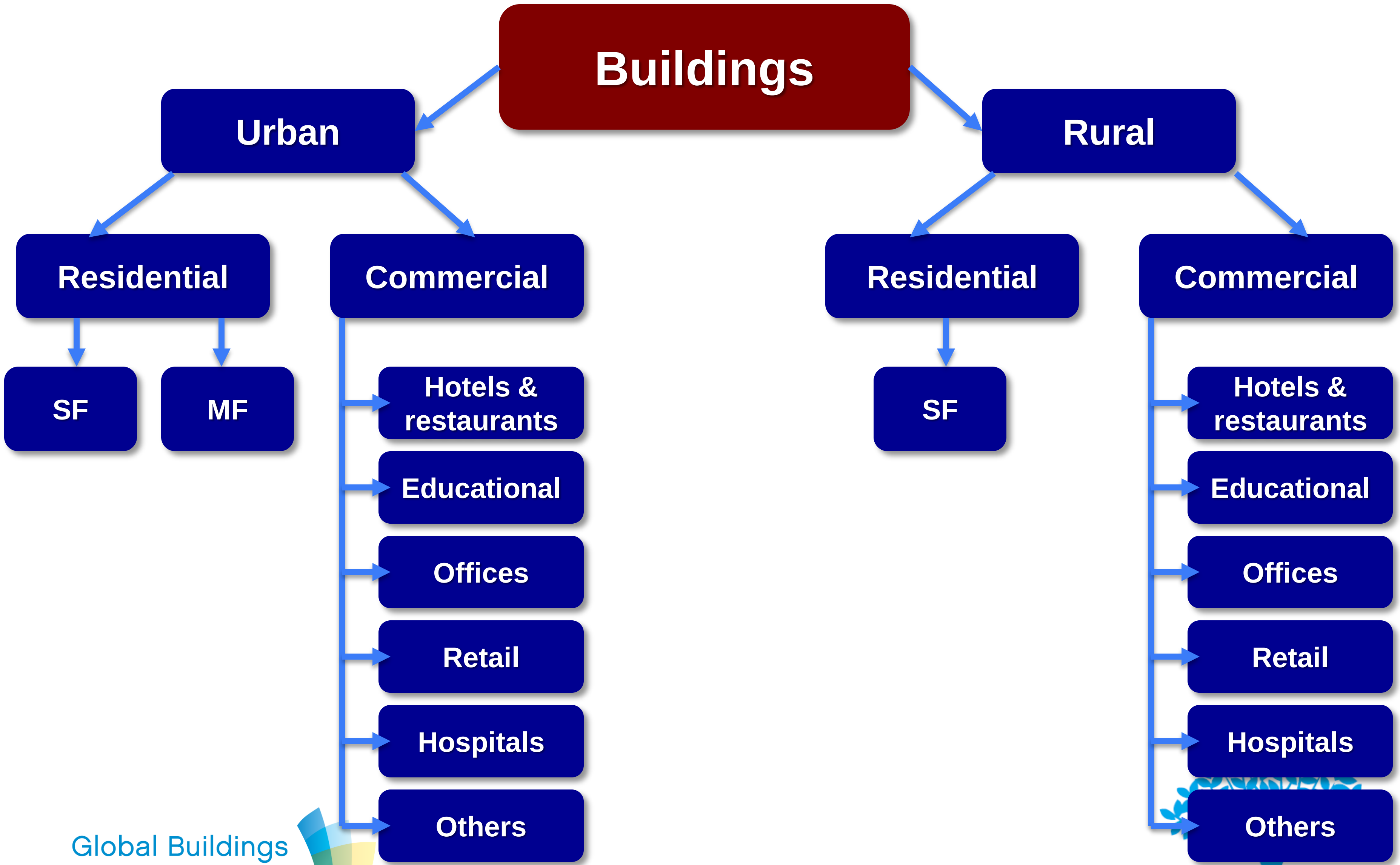
Key Assumptions on Building Types



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Final Thermal Comfort Energy Use Calculation

$$\text{Final Energy} = \sum_{i=1}^{41}\sum_{j=1}^{12}\sum_{k=1}^{17}\sum_{l=1}^{5} \text{Floor Area}_{i,j,k} \times \text{Energy Intensity}_{i,j,k} \left(m^2 \times \frac{kWh}{m^2 \times year}\right)$$

- **Energy Use Calculation:**
  - *i = 1 to 41 (14 Regions + 27 Countries in EU-27)*
  - *j = 1 to 16 Building Types*
  - *k = 1 to 17 Climate Zones*
  - *l = 1 to 5 Different Building Vintages*

- Energy use is calculated for each region and each climate zone with the split to building types and building vintages

Key global findings: potentials for climate change mitigation

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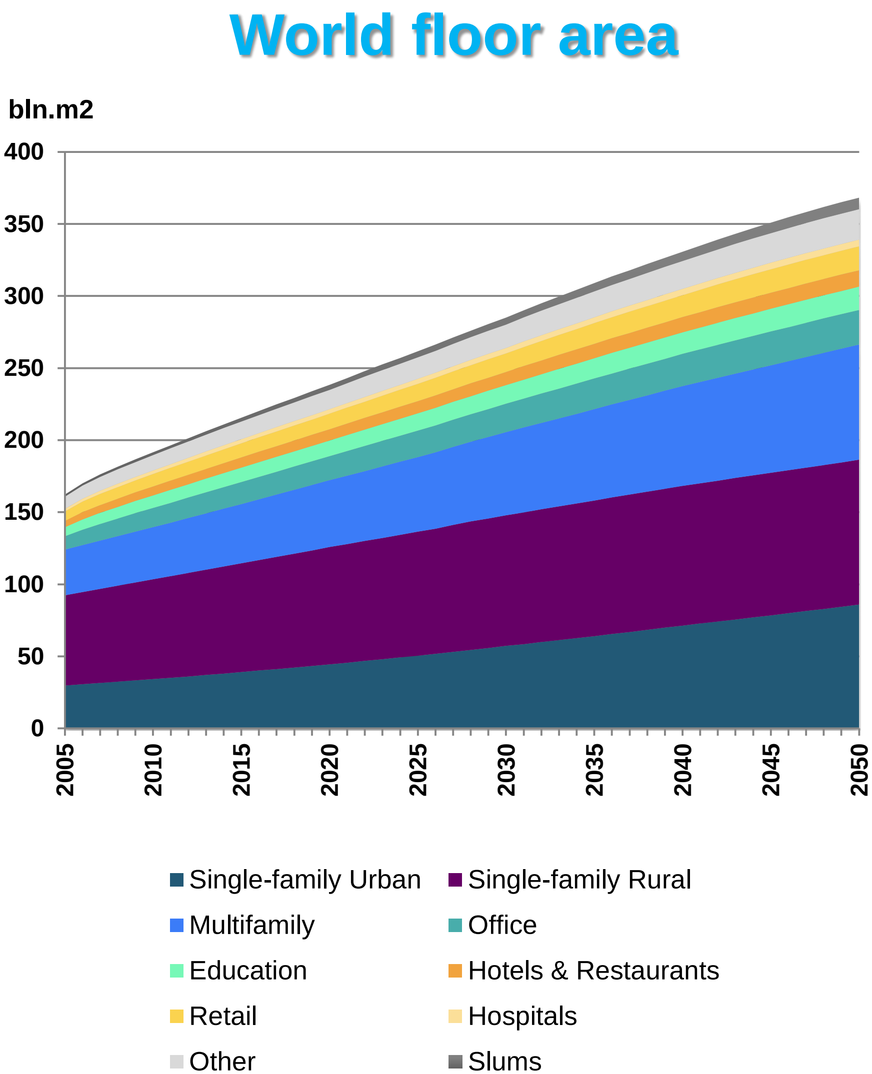
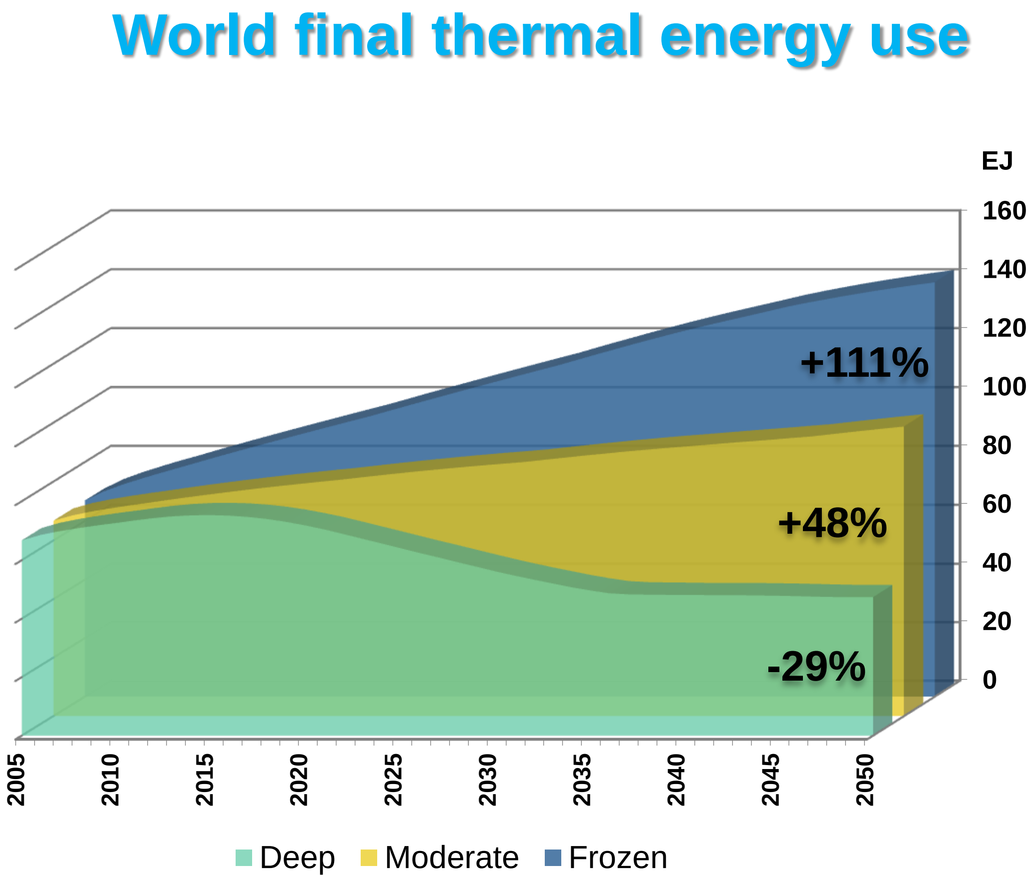
This is in stark contrast with a hypothetical no-action scenario in which energy use increases by 111% (frozen efficiency scenario). However, even i



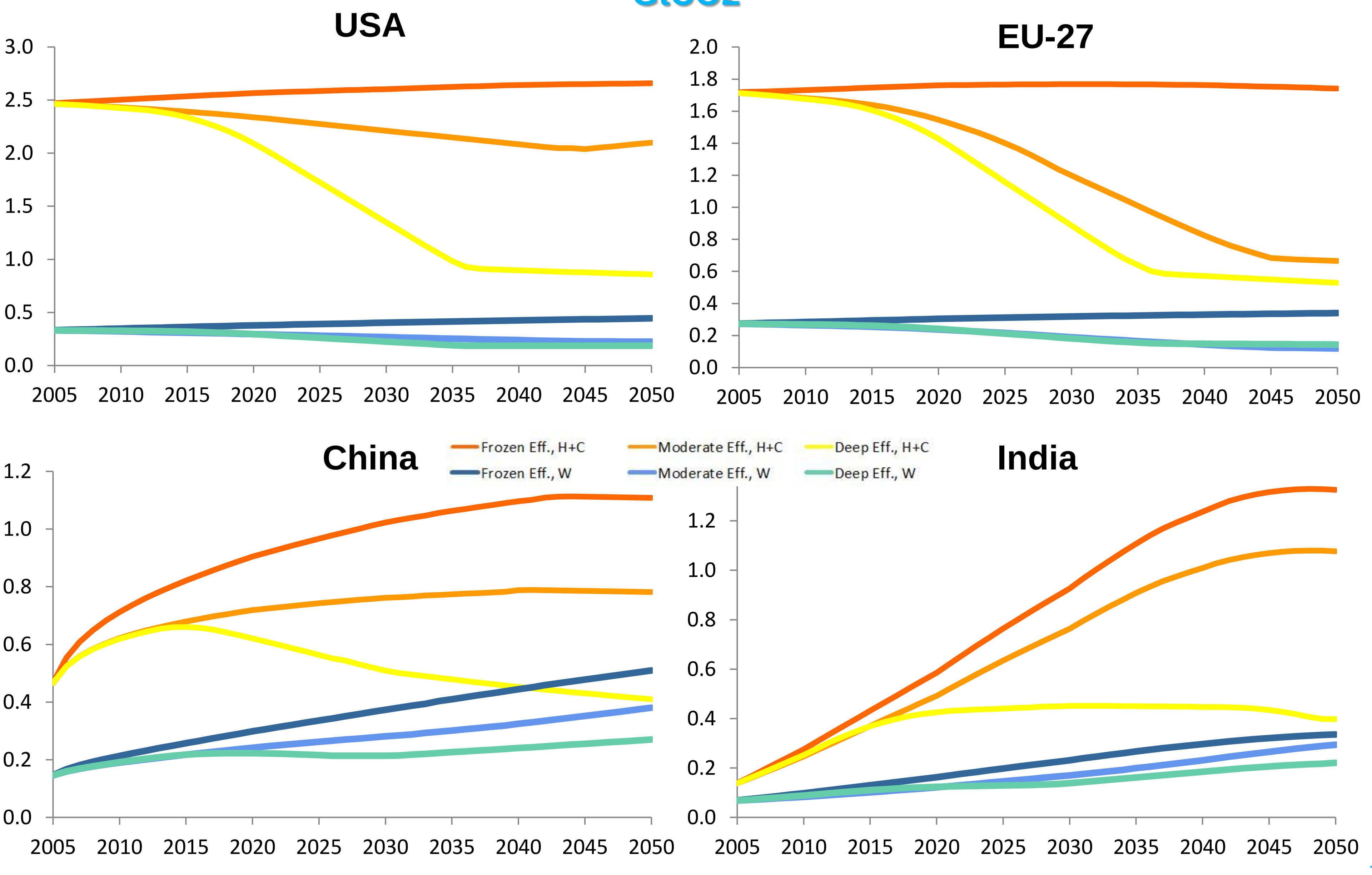


WORLD total final building thermal energy for three scenarios, contrasted by floor area development during the same period. For the final energy, percentage figures show the change of the scenario in 2050 as compared to 2005. Floor area is by main building type

The potentials are very different

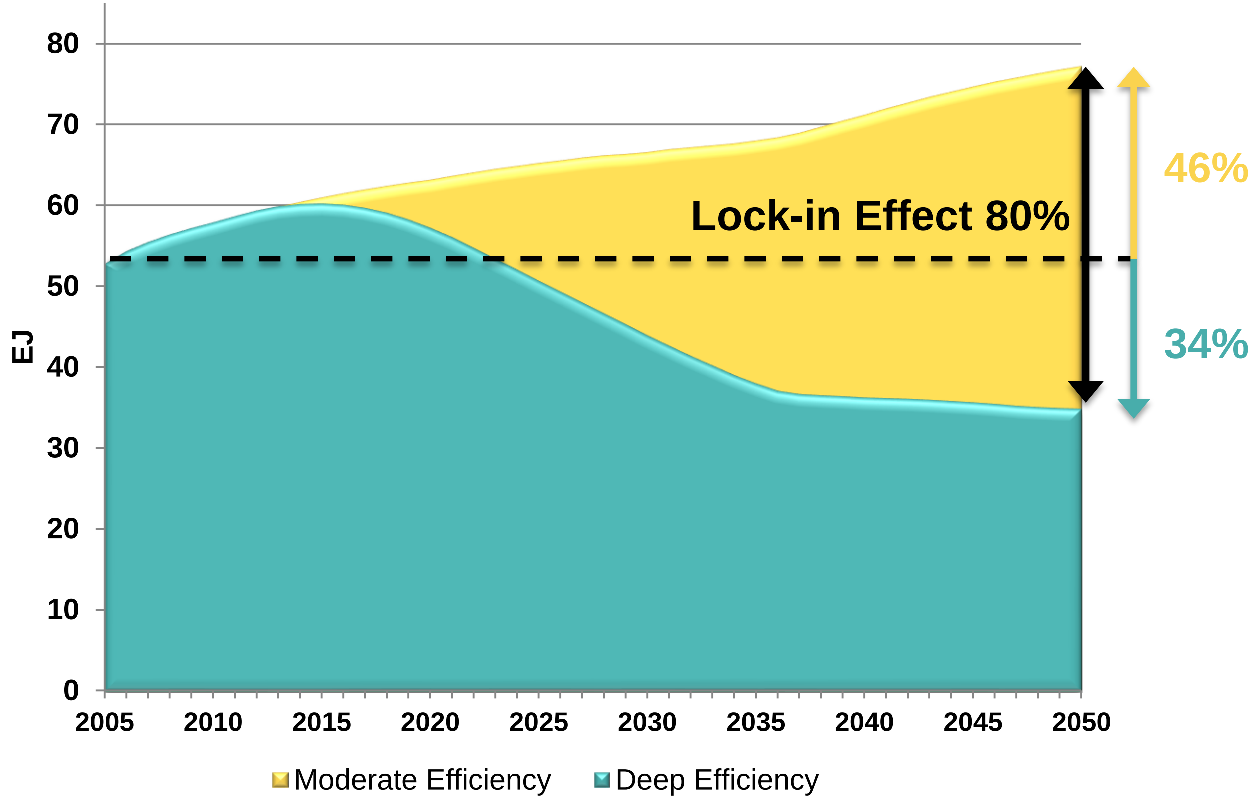
(CO2 emissions from SH&C&HW)

GtCO2



KF4: there is a significant lock-in risk

Unlocking this energy savings potential in the future will either be extremely expensive, or technologically unfeasible for several more decades



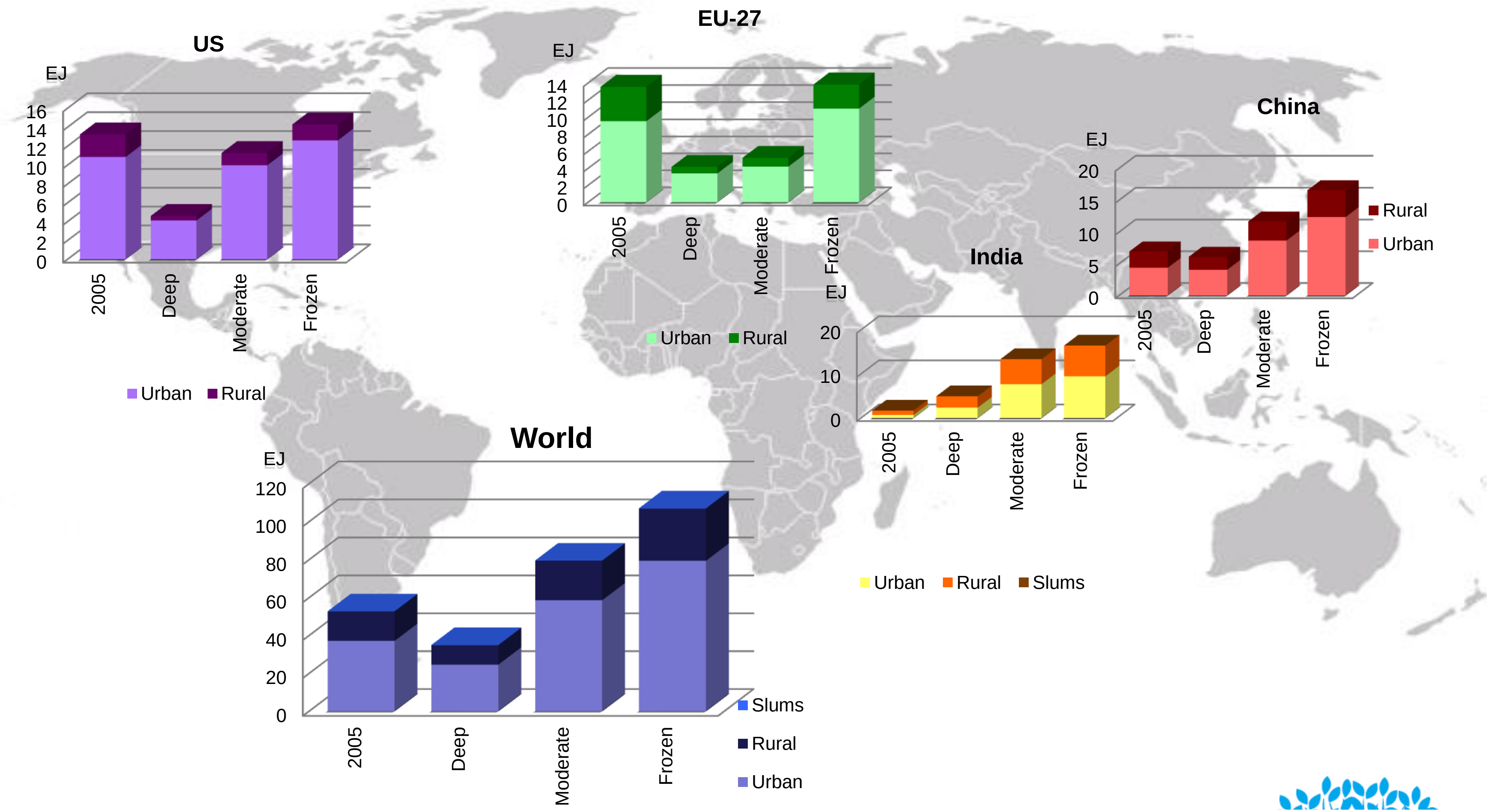
Early action, strategic policy planning, ambitious energy performance levels in building codes for new construction and retrofits are crucial

KF5: urban-level policies gain unique importance, esp. in developing countries

- **Despite still lower population, urban buildings use 70% of the sector’s final energy.**
- **With the largest growth in developing countries, 85% of growth in building energy use during the projection period comes from urban areas, 70% of this entire growth from developing country cities.**

Dominant share of urban building energy use

despite the fact that the rural population is still larger

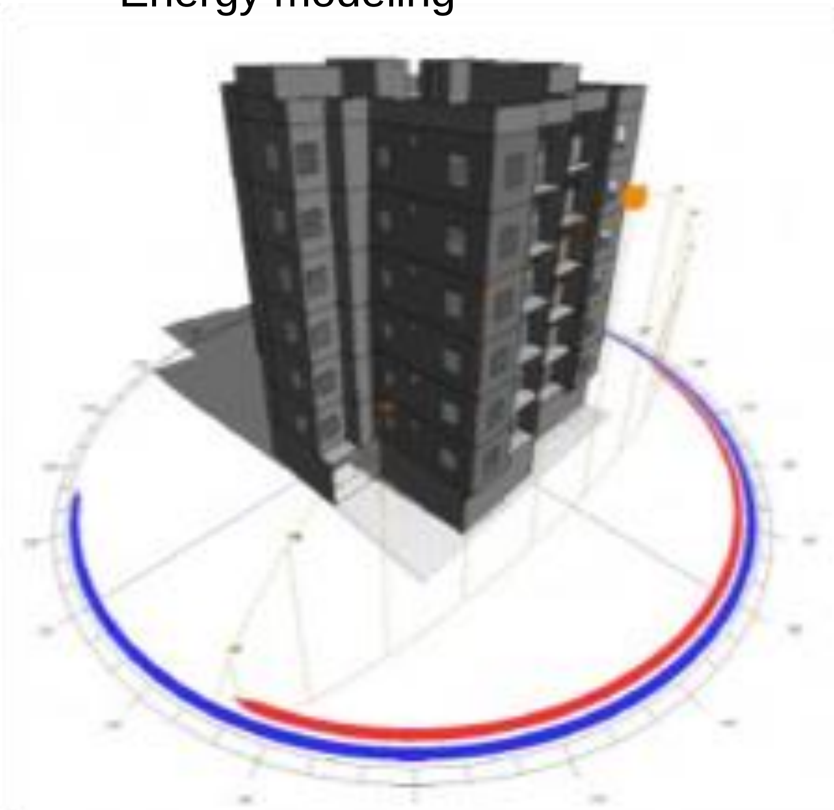


Albeit a significant share (up to 60%) of urban population lives in slums in several regions, they do not contribute significantly to world thermal building energy use with a 0,06 % of total heating/cooling building energy use, and thus to reduction opportunities.

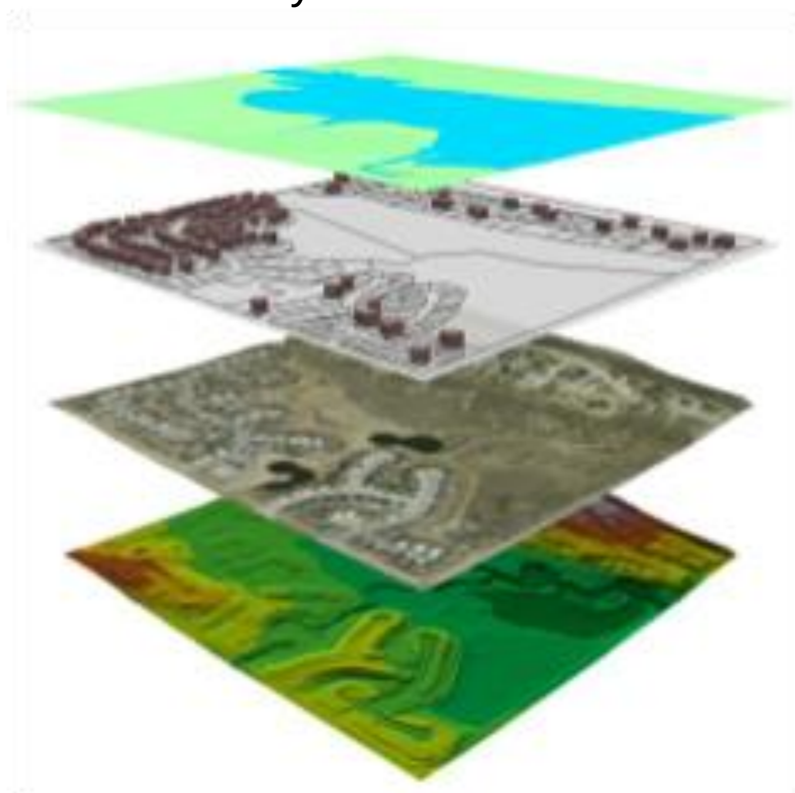
Ksenia Petrichenko, PhD dissertation, 2014

Theoretical framework

Energy modeling



GIS analysis



Building Integrated Solar Energy (BISE) Model

for assessing technical building-integrated solar energy potential

Ksenia Petrichenko, PhD dissertation, 2014

Methodology

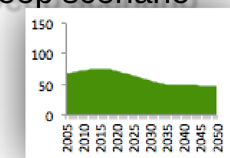
BISE

3CSEP-HEB

BUENAS

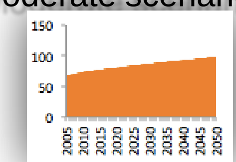
BAU scenario

Deep scenario

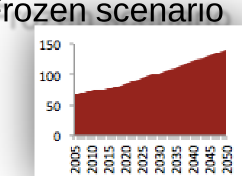


Best-practice scenario

Moderate scenario



Frozen scenario



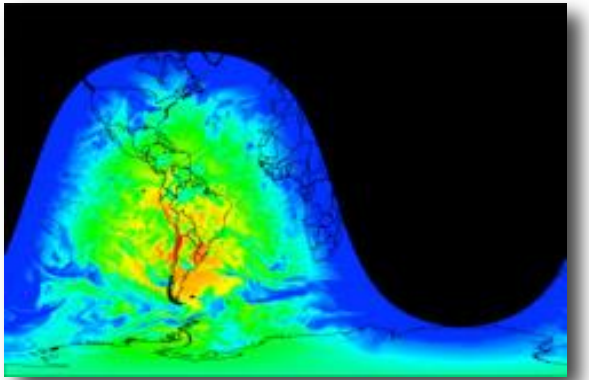
[solar] energy supply

energy demand

Combination of the results from three models gives the opportunity to analyze how much building energy use can be covered by solar energy produced on site

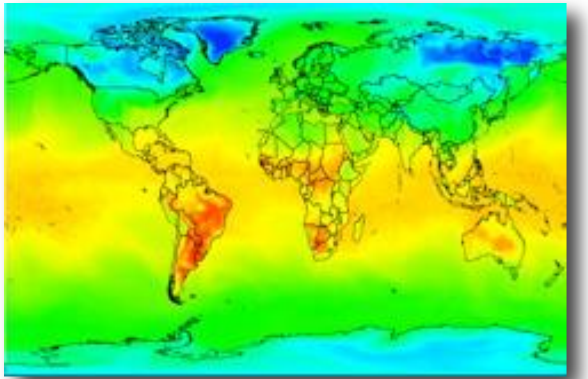
Ksenia Petrichenko, PhD dissertation, 2014

Input data



global solar radiation

data for:
- every hour,
- every day,
- every month,
- every year (2001-2005)

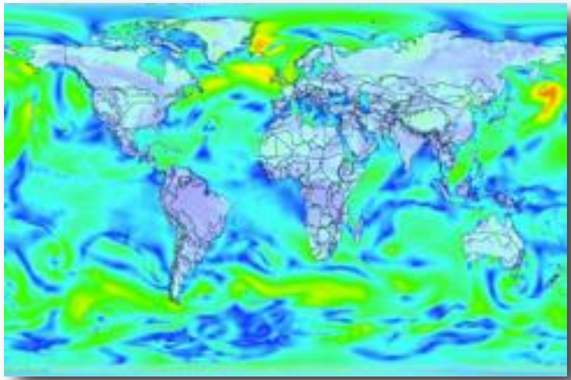


ambient air T

24 hours x 365 days x 5 years = 43,800 observations

'averaged' year across 2001-2005

'typical' day for every month

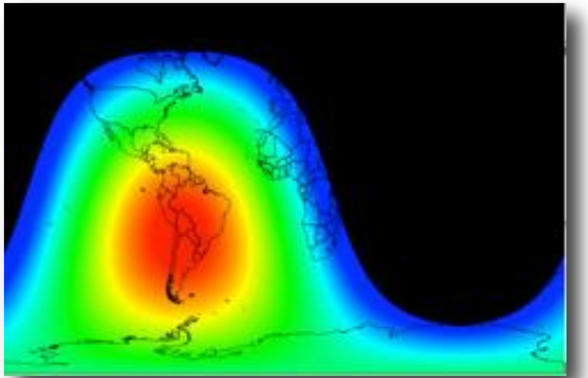


wind speed

Northward wind

Eastward wind

Data and results are visualised with a custom-made application using Windows Presentation Foundation technology



TOA radiation

Source: NASA's Science Mission Directorate's web-site

Ksenia Petrichenko, PhD dissertation, 2014

Key equations

Solar system area

Roof area for each region and climate zone

$$RA = FA \times RF_{ratio}$$

Roof area available for solar systems installation for each region and climate zone

$$RA_{available} = RA \times AvF_f \times AvF_s$$

Solar system area

$$A_S = RA_{available} \times F_{aperture}$$

Hourly radiation

Hourly total solar radiation on the (tilted) plane of the solar array

$$I_T = I_B R_b + I_D \left(\frac{1 + \cos\beta}{2}\right) + I_{glob}\, \rho \left(\frac{1 - \cos\beta}{2}\right)$$

Solar electric output

Electric efficiency of the solar system

$$\eta_{elec} = \eta_r \times (1 - \beta_p \times (T_c - T_r))$$

Electric energy output generated by one square meter of a solar system per hour

$$E_{EL\ output} = I_T \times \eta_{elec}$$

Solar thermal output

Thermal energy output generated by one square meter of a solar system per hour

$$E_{TH\ output} = F_R \times (I_T \times (\tau a - \tau \times \eta_{elec}) - U_L \times (T_{in} - T_a))$$

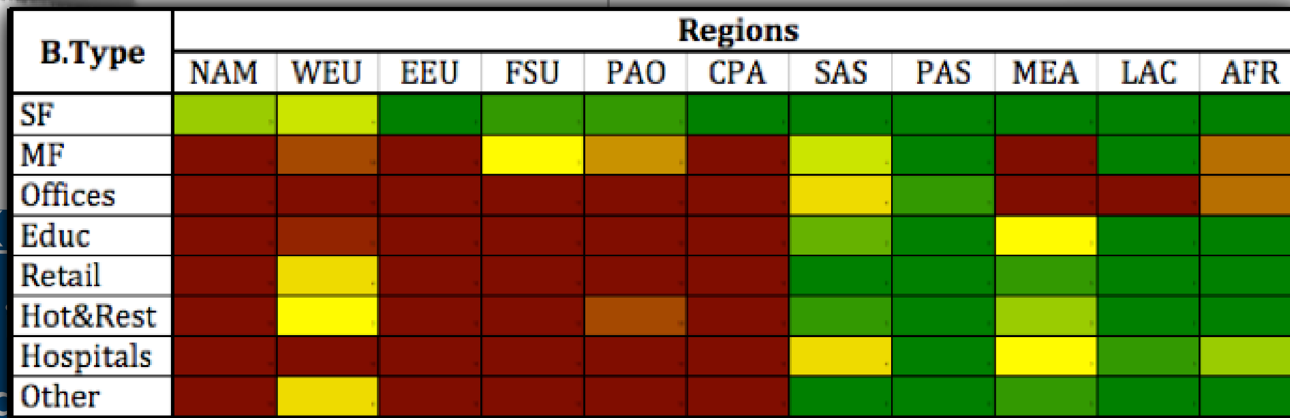
Evolution of the model

Ksenia Petrichenko, PhD dissertation, 2014

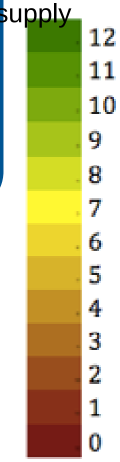
DEEP scenario

Ksenia Petrichenko, PhD dissertation, 2014

-50% energy intensities for lighting & appliances



Number of months during the year 2050, in which energy use is covered by solar energy supply



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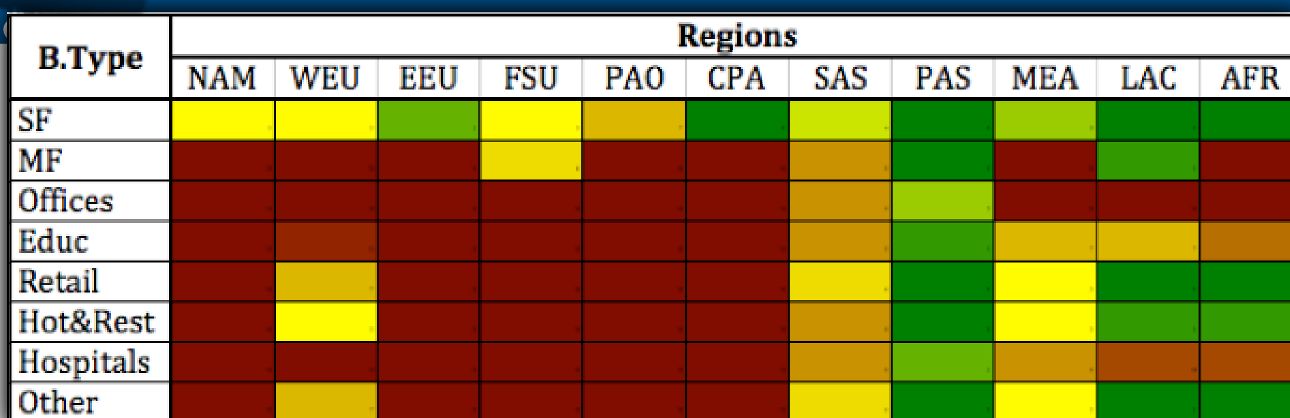
MODERATE scenario

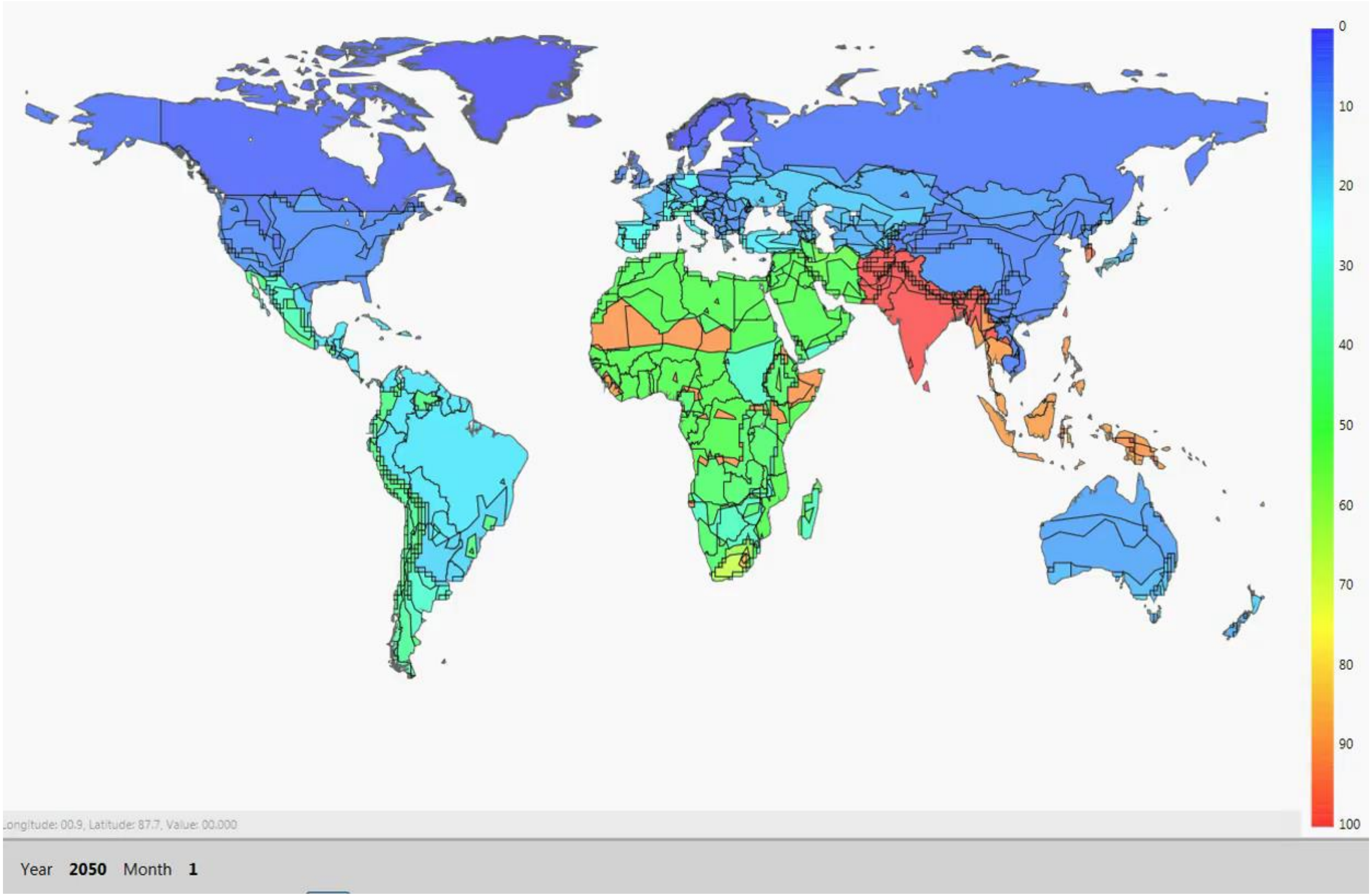
ent for any NZEB in order to avoid oversizing of the

le energy systems and overexploitation of energy

res



3. Energy efficiency plays a crucial role in NZEBs: electric



10. Office buildings, electric, 2050 *Ksenia Petrichenko, PhD dissertation, 2014*

Substantial further research needs

- Costs – ALMOST done
- Software and platform improvements
- Potential through behavior
- RES:
  - assuming availability of different types of storage
  - Other types of solar technology
  - Other types of RES
- Moving from building level to community level

Acknowledgement to funders and key researchers

- Evolved over 6 years of work
- Major Funders:
  - Global Energy Assessment
  - Global Best Practice network for Buildings
  - UNEP SBCI
  - CEU
- Lead researchers:
- KSENIA PETRICHENKO
  - Maja Staniec
  - Miklos Antal
  - Michael Labelle

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Thank you for your attention

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Supplementary Slides

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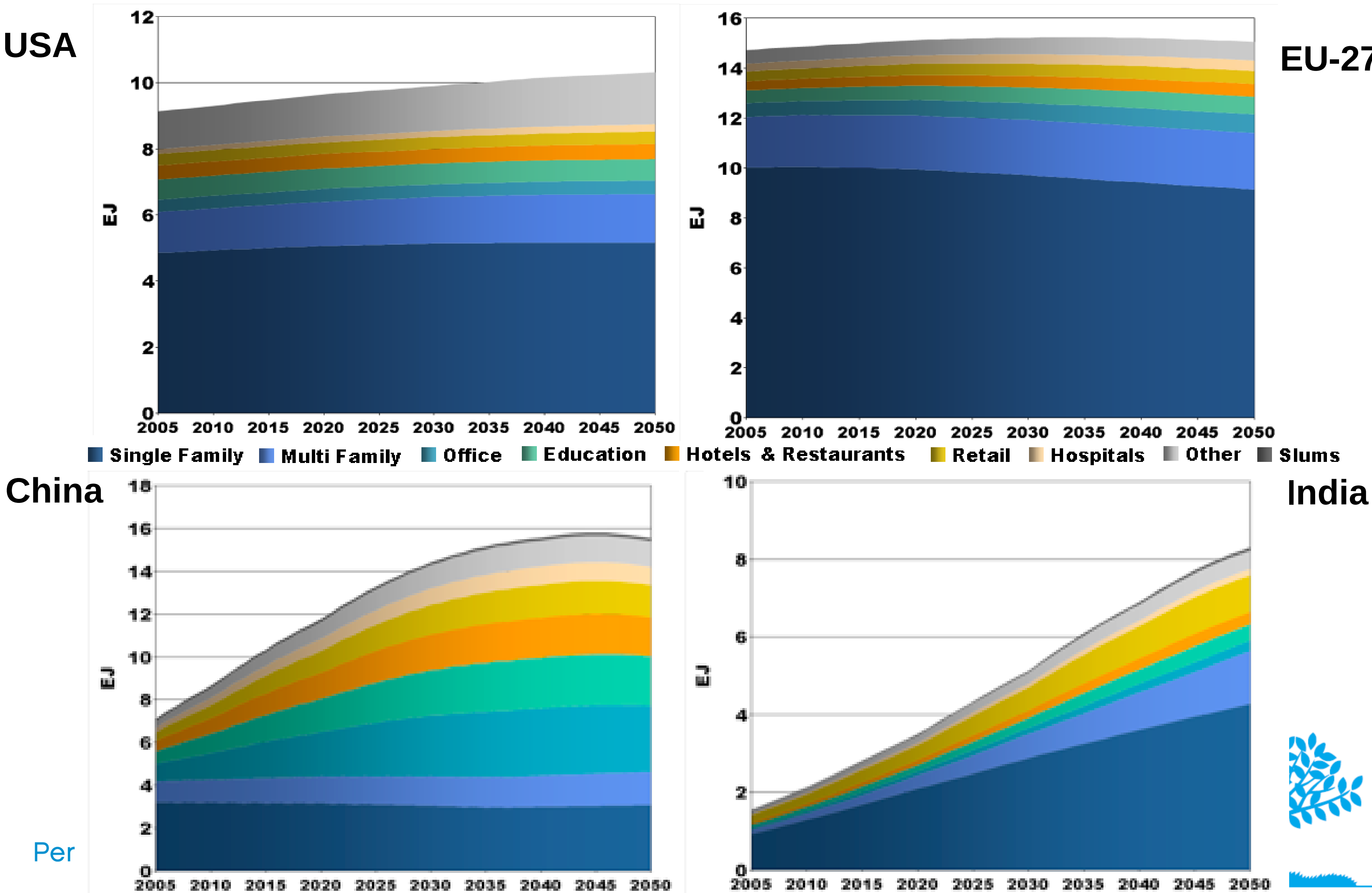
Key finding 1:
by 2050, global building final thermal energy use can be reduced by about one-third, (-34% for space heating and cooling) as compared to 2005 values

- despite an app. 127% increase in floor area + a significant increase in thermal comfort levels

Different building types dominate (FE sce)



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Key finding 2:
however, even the most ambitious present policy trends will not take us anywhere near this level

- even **if today's policy trends and ambitions are implemented, global building energy use will still increase by about a half (~48%) of 2005 levels**

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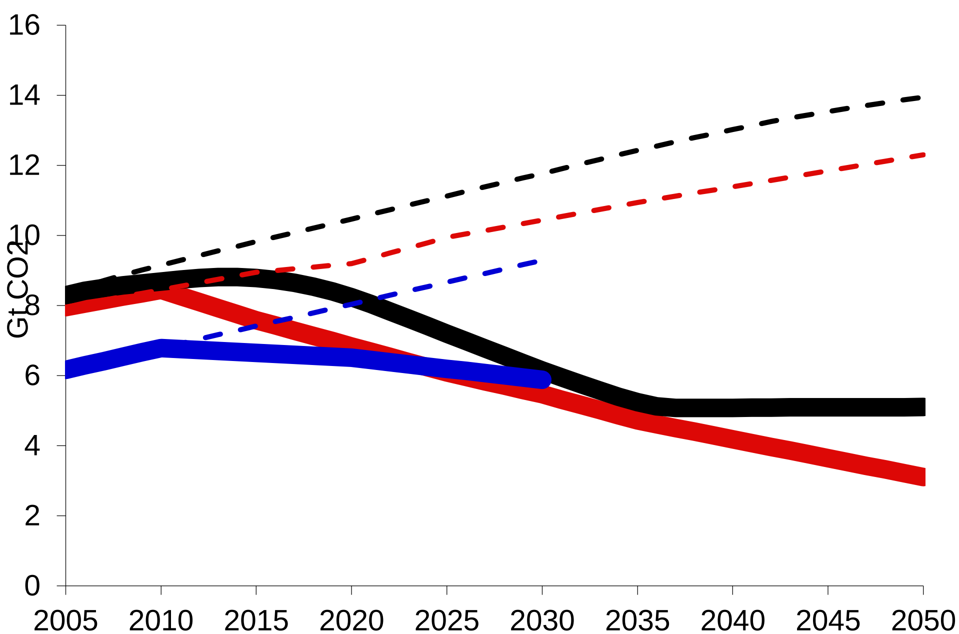
Key finding 3: improved efficiency will not be enough

- Based on 18 studies reviewed
- total sector final energy cannot go down with efficiency alone
- RES + behavioural change + supply decarbonisation will also be needed
- However, heating+cooling is able to bring much higher reductions than plug loads

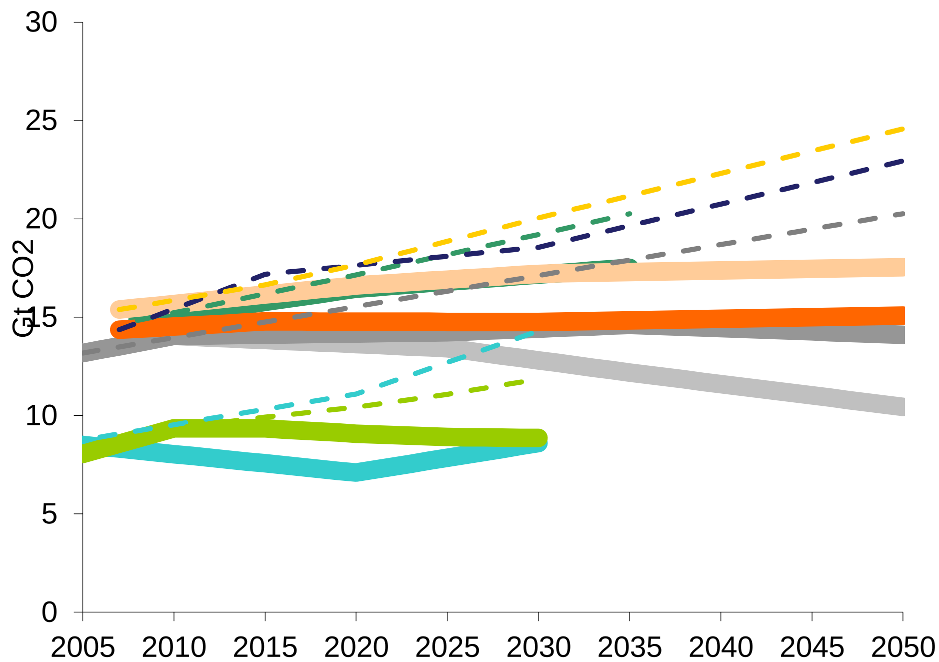
KF3: Energy efficiency is not enough



BUENAS

3CSEP HEB

LAUSTSEN



Greenpeace

ETP'10

HARVEY "HighGDP, FastEI"

HARVEY "LowGDP, FastEI"

McKinsey

IPCC AR4

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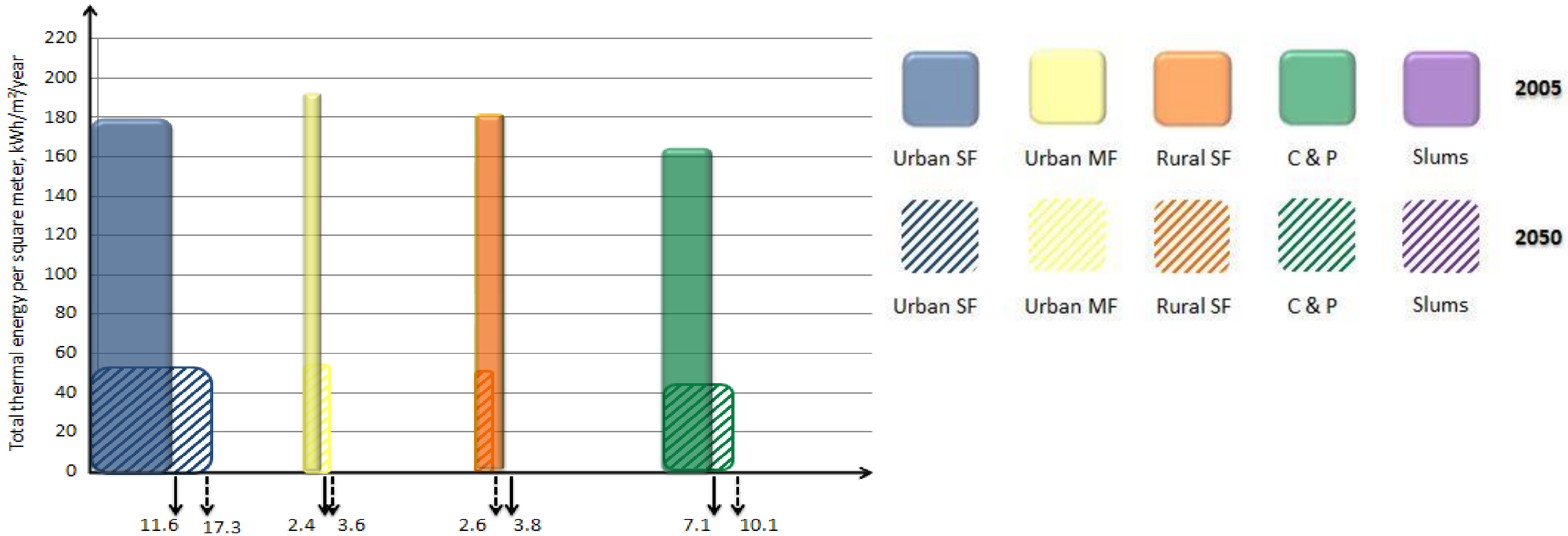
The size of the opportunity is very different by region

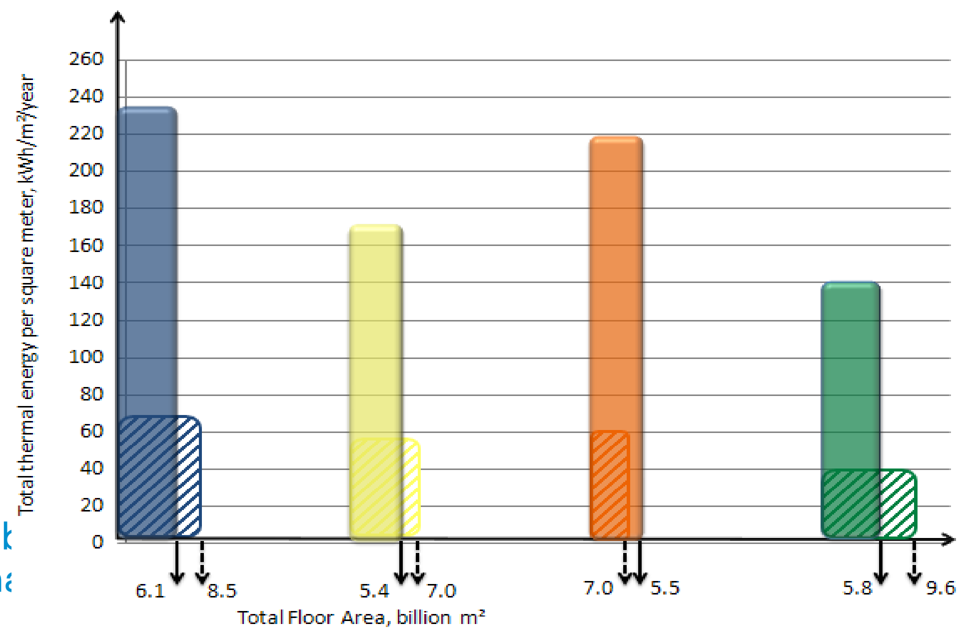
- **Reduction potentials in the EU and the US are above 60%**, CO_2 savings can be measured in gigatons (1.8 and 1.3Gt, respectively).
- In **China**, the explosive **growth of floor space can be offset by energy efficiency improvements**.
- In **India**, it is already a **success if thermal energy use just doubles**.
- In EU and US retrofits; while India and China new construction dominates the opportunities.
- in India, but also in China, policies to encourage limitations in residential per capita floorspace are a crucial

Final energy mitigation potential for Deep Efficiency scenario between 2005 and 2050

USA



EU-27



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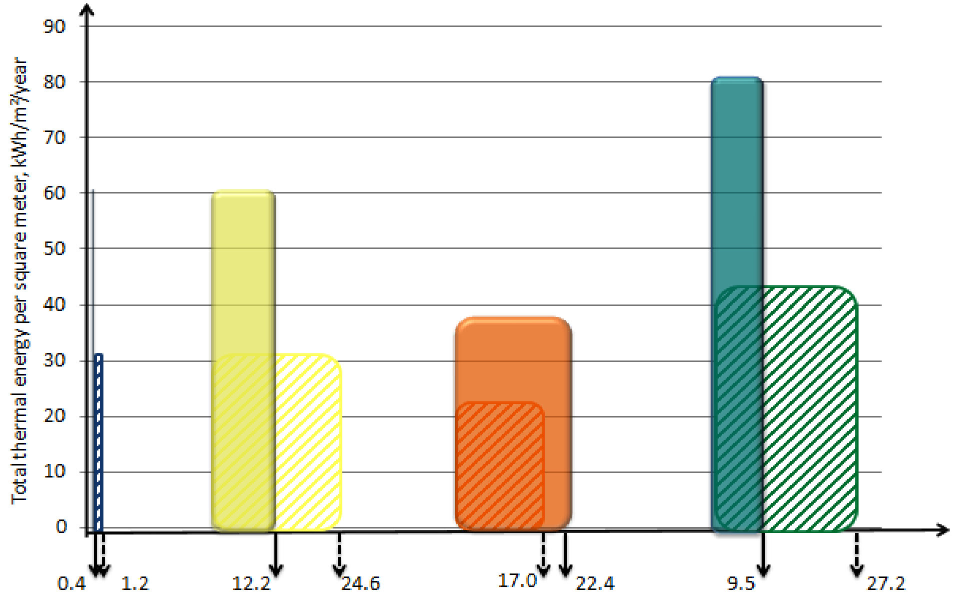
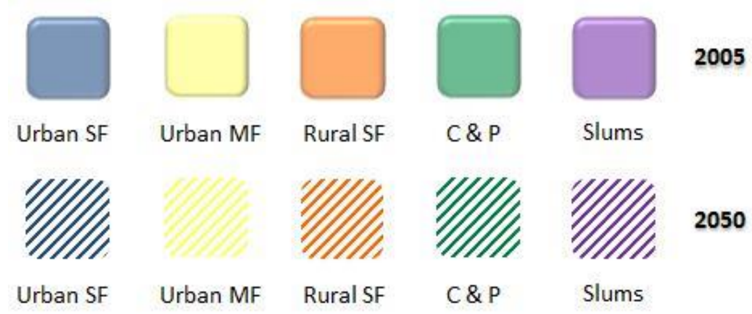
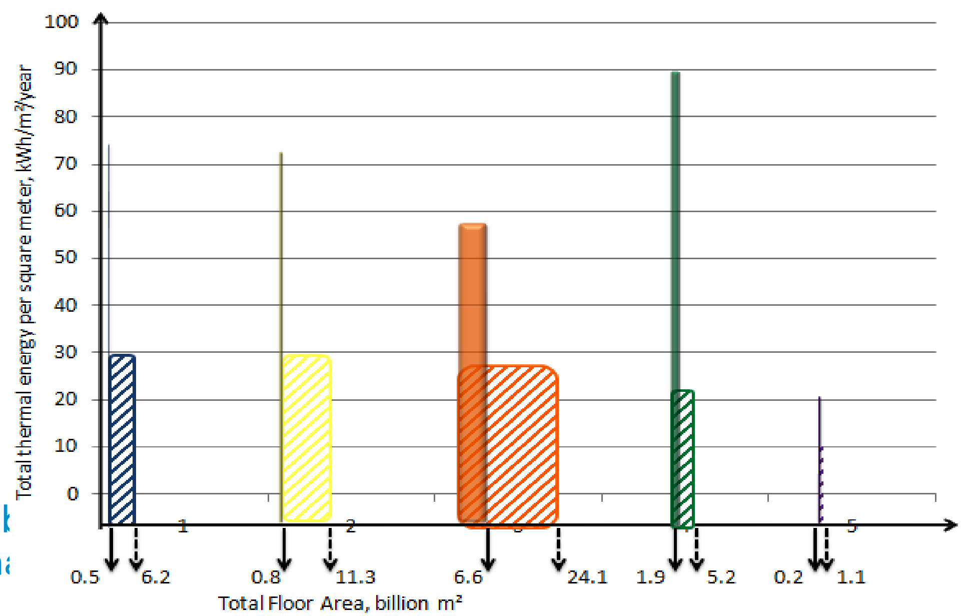
Final energy mitigation potential for Deep Efficiency scenario between 2005 and 2050

China





India



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Conclusions

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Key findings

There is a significant potential: by 2050 building final energy use can be cut by 1/3rd as compared to 2005 through very high performance buildings

Significant lock-in risk: 80% of 2005 H&C energy use by 2050

Even today's most ambitious policy trends will leave us far from this potential – policy gap

Immediate action, strategic planning and ambitious performance levels in codes and retrofits can only avoid the lock-in

Heating & cooling energy use offers the greatest saving potential

Reduction potentials in the EU and the US are above 60%. In China, floorspace growth can be offset by efficiency. In India, success is if thermal energy use just doubles

Energy efficiency improvements alone are not enough for large reductions: RES, behavioural change and low C supply

Acceleration of retrofit rates brings climate benefits only with very ambitious performance levels; and only to a limit

Policies using holistic/systemic approaches achieve larger savings than those focusing on components

Urban policies, esp. In developing country cities are key: 85% of growth is from urban areas. Limiting floorspace increase esp. in India?

The main policy focus in US & EU on retrofitted buildings, in China & India on new construction

Policy-relevant techno-economic scenarios

Deep Efficiency

State-of-the-art technologies

Full thermal comfort

Accelerated retrofit rate – from 1.4 to 3% by 2020

New buildings are built to regional standards

Renovations achieve app. 30% energy savings

After 2022 today's building best-practices will become the standard

The energy efficiency of WH increases rapidly

Moderate Efficiency

Recent policy trends (e.g. EPBD in the EU)

Global retrofit rate = 1.4%

Accelerated retrofit rate – from 1.4 to 2.1% in EU and US, 1.6 in China, 1.5 in India by 2020

New buildings are built to regional standards

Renovations achieve app. 30% energy savings

WH efficiency measures are not more ambitious than current

Frozen Efficiency

Hypothetical future - without policy and market developments

Fixed retrofit rate = 1.4%

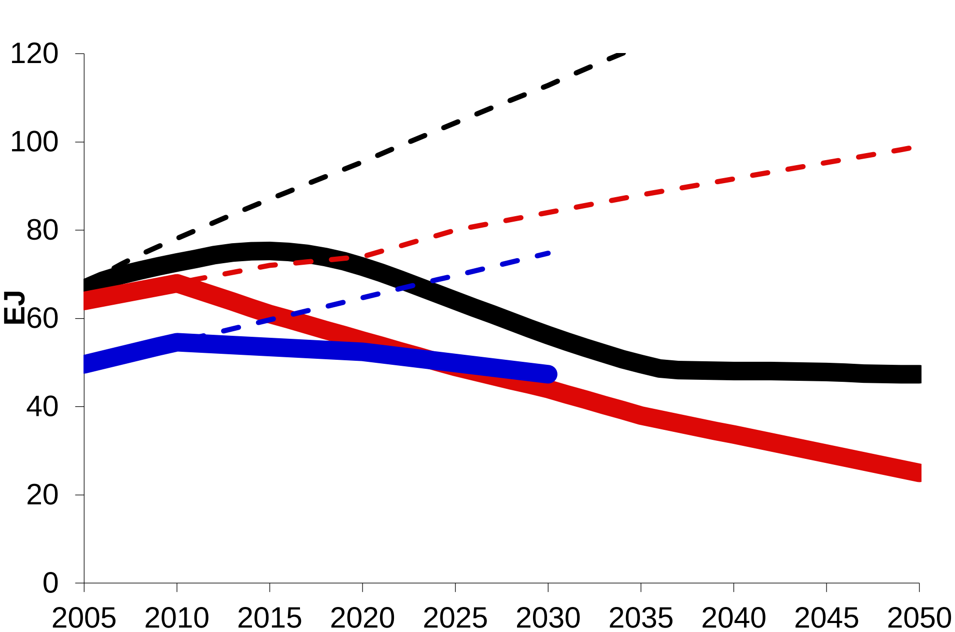
Energy performance of new and retrofit buildings does not improve as compared to their 2005 levels

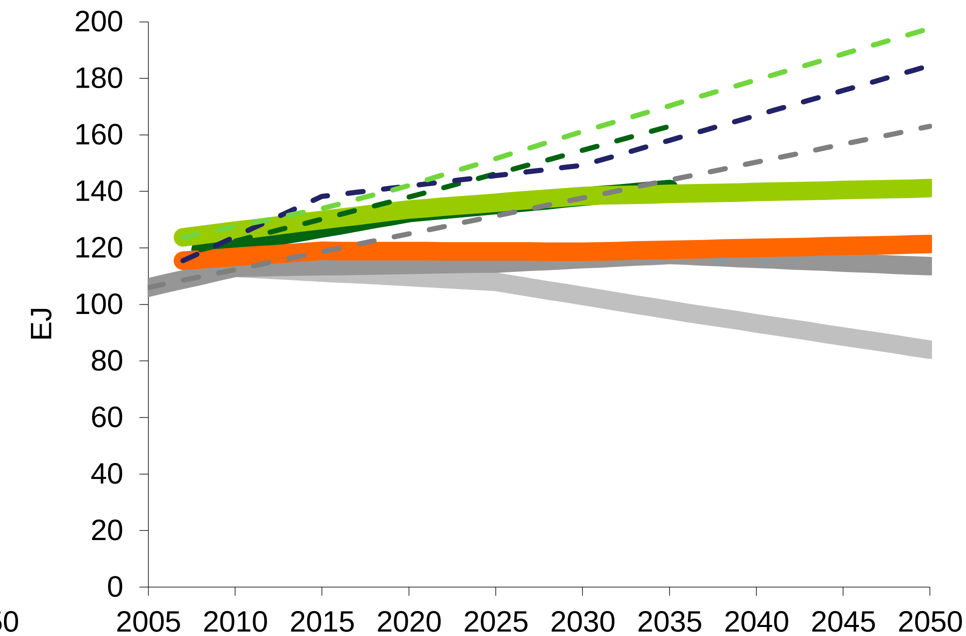
Renovations achieve app. 10% energy savings

Advanced buildings introduced only in Western Europe (1% of New BS)

Energy use growth is projected

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





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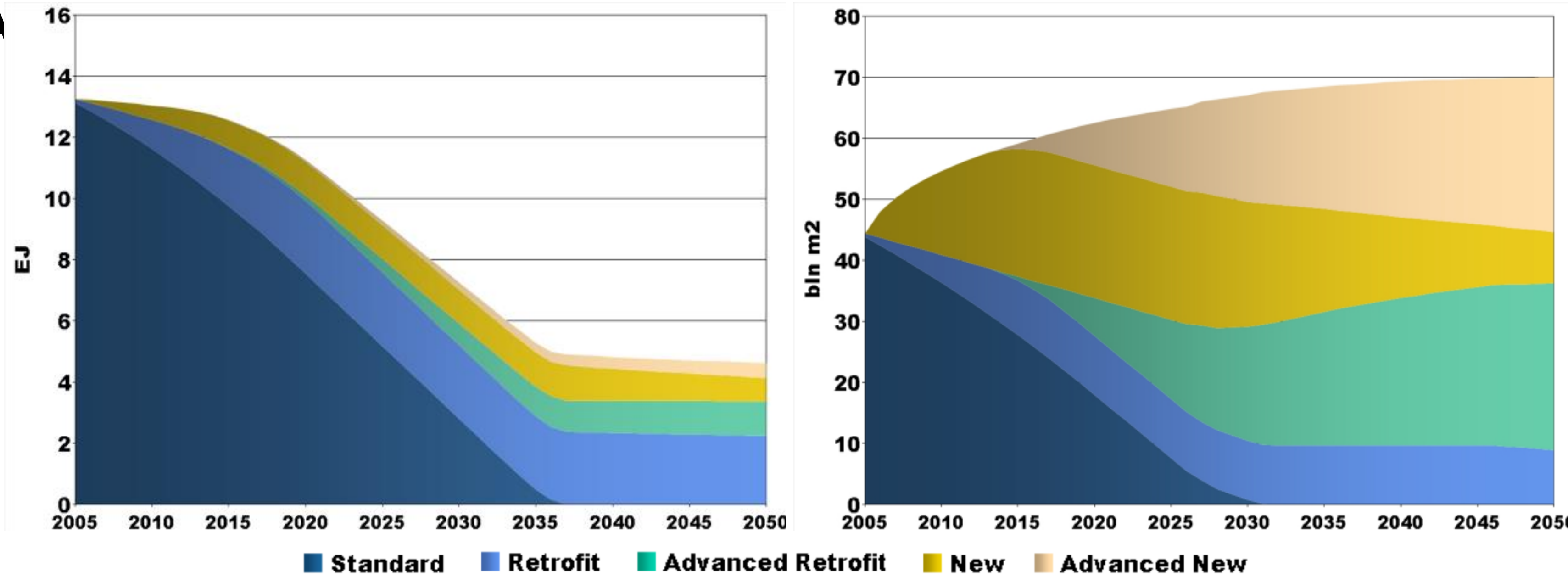
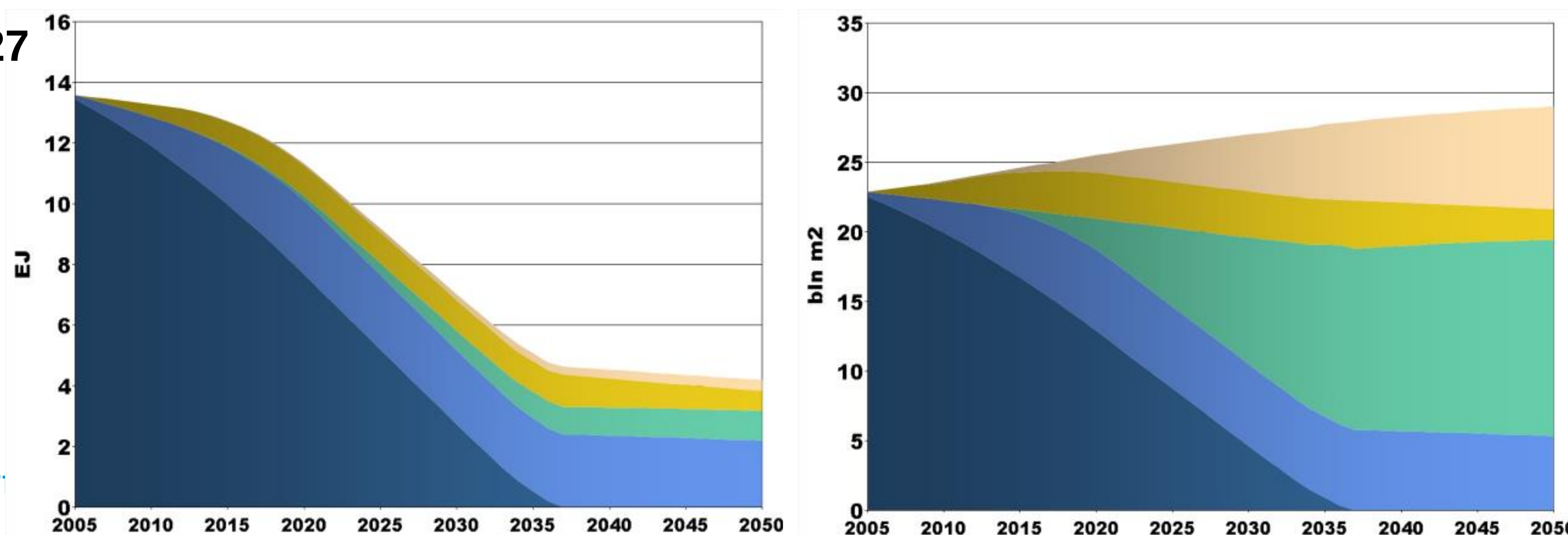
Final Energy for SH&C and floor area by building vintage. Deep Efficiency Scenario

USA

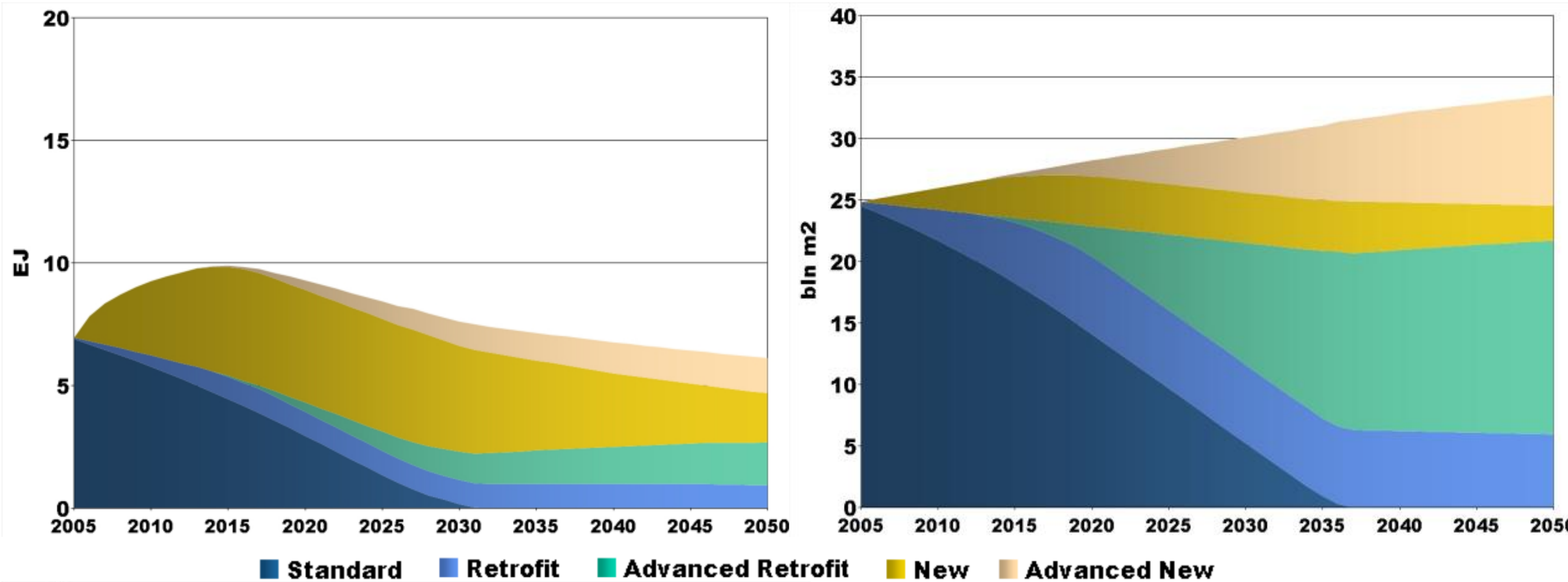


EU-27

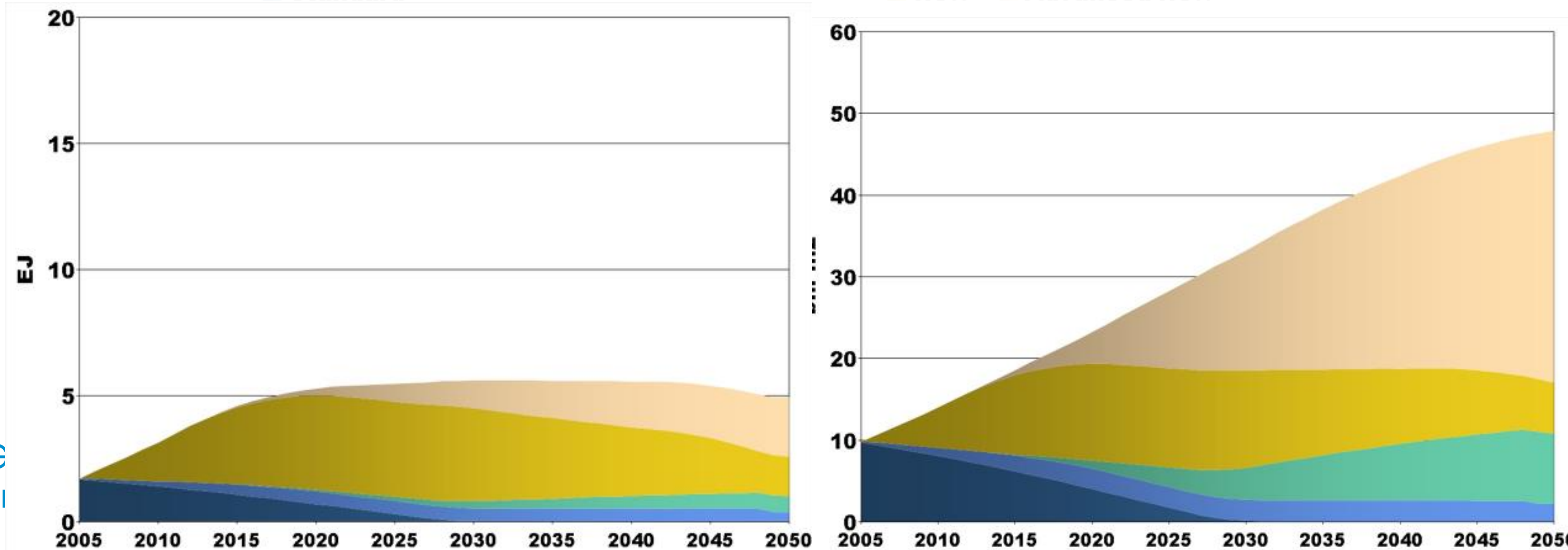


Final Energy for SH&C and floor area by building vintage. Deep Efficiency Scenario

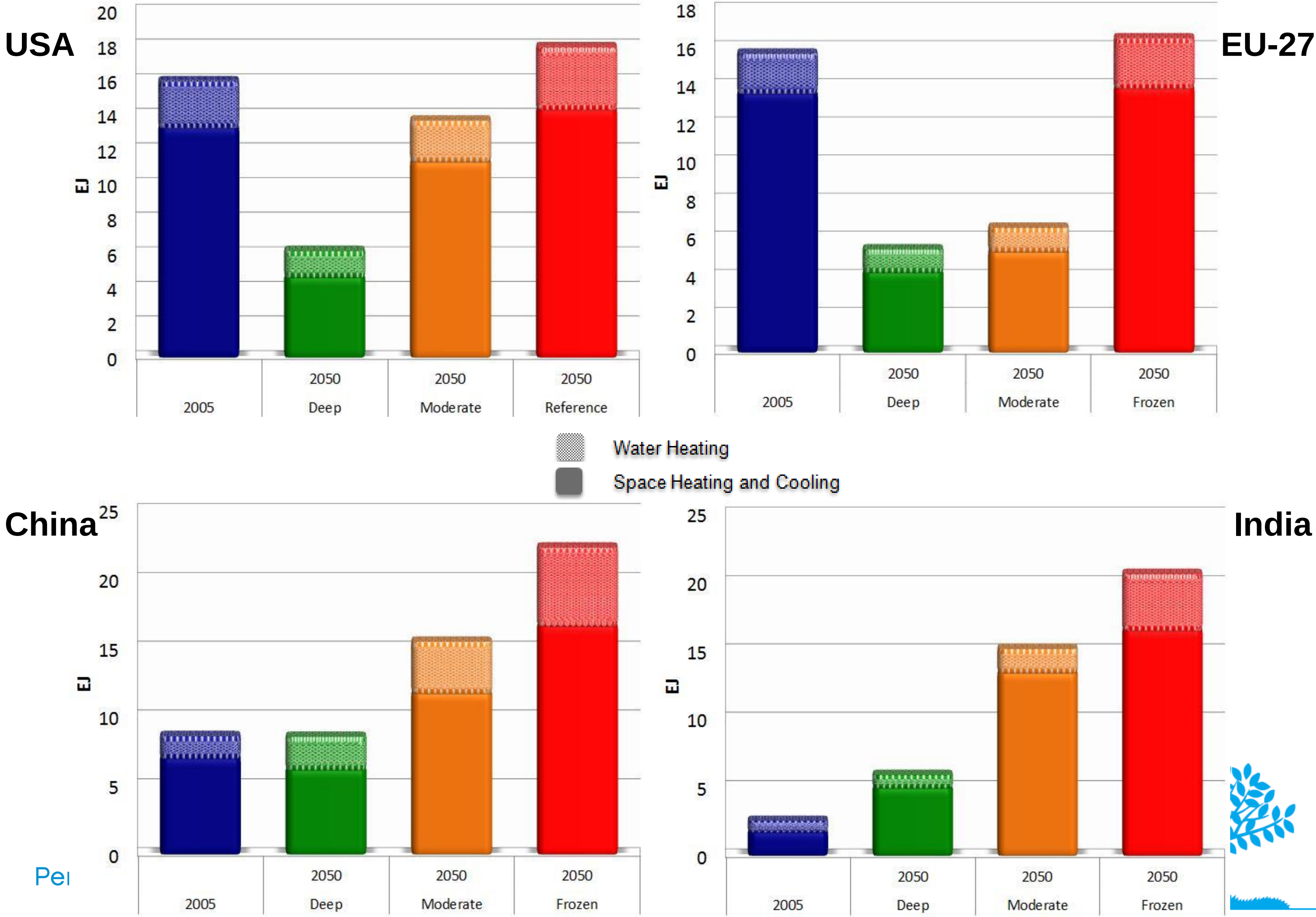
China



India

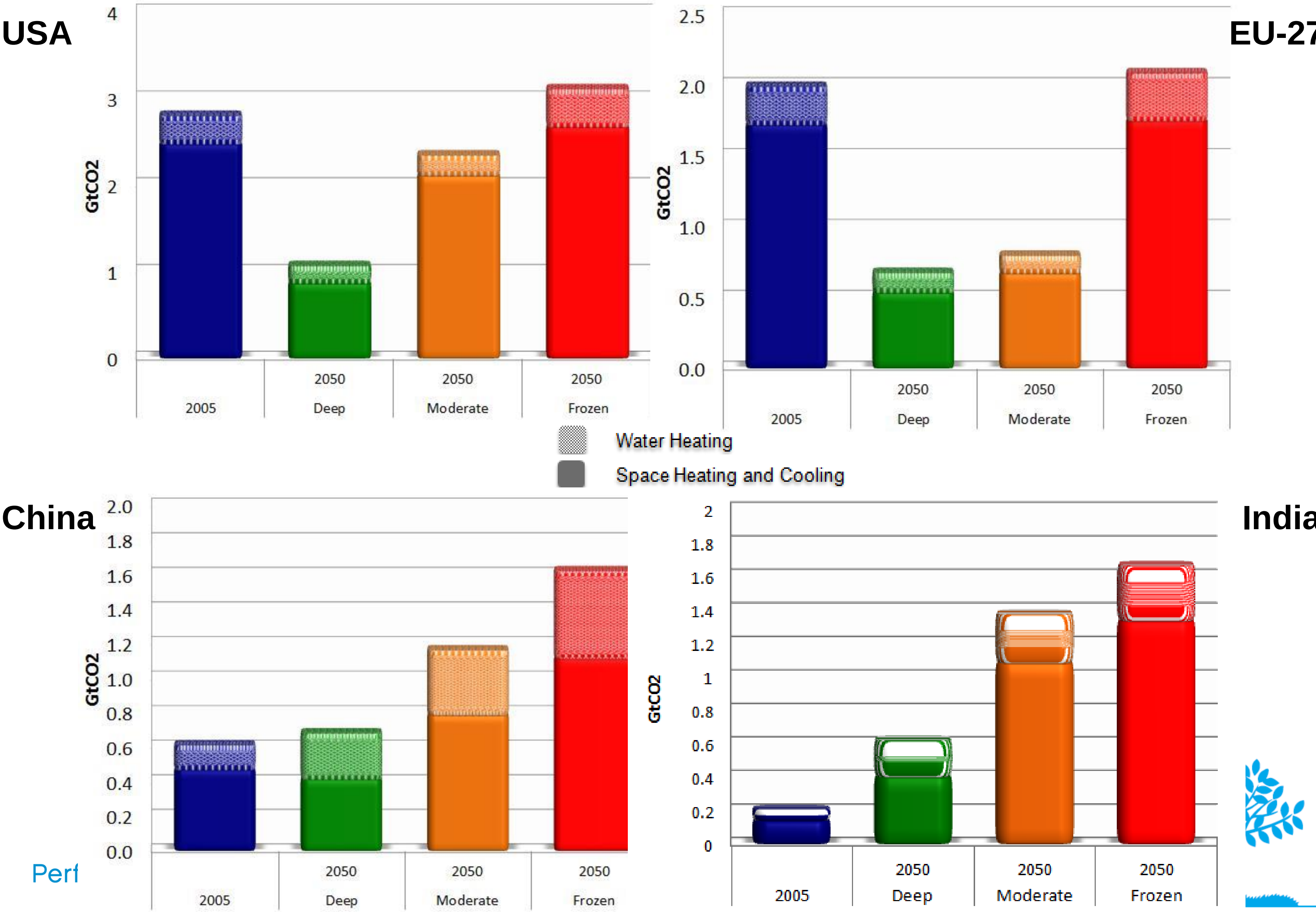


Final energy by end-use & by scenario



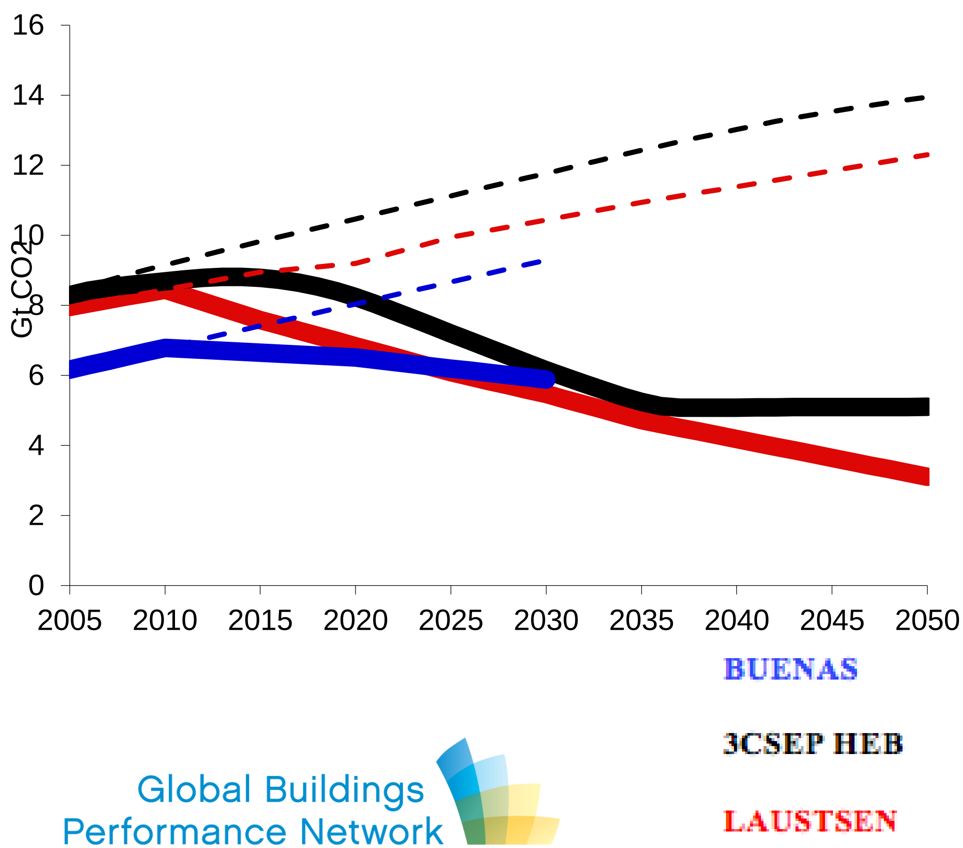
Pe

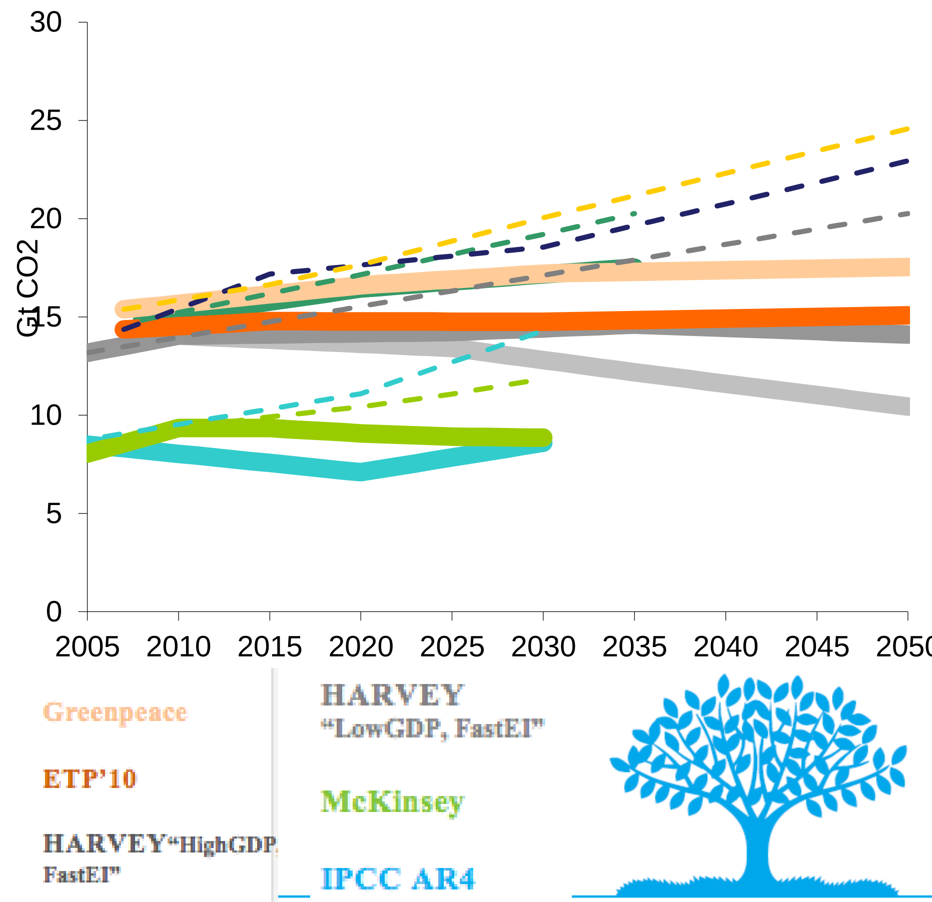
CO2 emissions by end-use & by scenario



KF3: Energy efficiency is not enough

- Improved efficiency alone will not bring the sector's emissions anywhere near what is needed for reaching ambitious climate targets. Even the most ambitious scenarios are only able to compensate for the increase in service demand, i.e. total final energy use at best stays constant until 2050 for the entire sector. This means that in order to reach stringent climate goals, policies pushing for energy-efficiency need to go hand-in-hand with the other levers such as switching to low-carbon fuels (renewables) and encouraging behavioral and lifestyle change.





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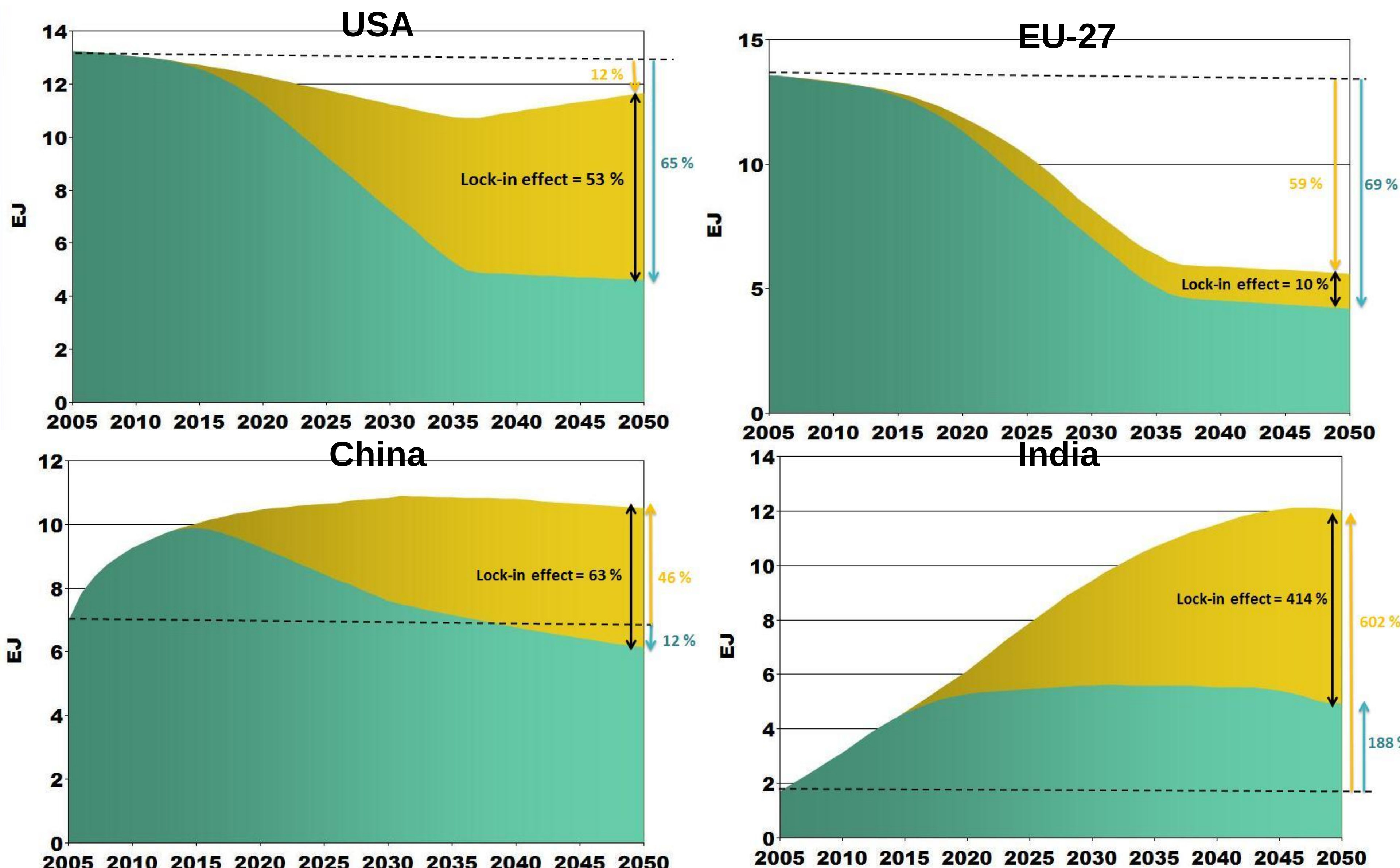
Lock-in Effect

from space heating & cooling for Moderate Efficiency and Deep Efficiency scenarios for key regions



Main limitations

Short time period for the study

Poor data availability

Constant fuel mix for CO2 emissions calculations

Indirect emission from bio-fuels are not considered in the analysis

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Main Philosophy and Assumptions

- Assumes that the world's building stock will transform over to today's known (and built) cutting edge in architecture
  - At the most affordable cost
  - At the natural rate of building construction and retrofit
  - Taking into account capacity and other limitations, but assuming ambitious and supportive (not financially but legally) policy environment
- The main pillars of the model are existing best practices
  - Best practice from and energy and investment costs perspective
- The world's building stock is broken down by regions, climate zones, building types and building vintages
- Model eradicates energy poverty during analyzed period (2005-2050)
- Model includes several scenarios:
  - Frozen Efficiency
  - Moderate Efficiency
  - Deep Efficiency

Key Assumptions on Building Vintages

There are different energy intensities used in the model for different regions, building vintages, building types and climate zones

Base Year Floor Area and Projections Residential

- Floor Area per building type per capita and population are the main indicators for residential floor area dynamics
- GEA Population Projection Database
- Assumed that developing regions will increase their floor area to the OECD level by 2050 or some fraction of OECD levels
- A fraction of existing building stock for both Residential and C&P is considered “Historical” and cannot be demolished or retrofitted to advanced level

Base Year Floor Area and Projections Commercial

- Floor area for first year (McKinsey, LBNL, regional reports, etc.)
- GEA GDP 2005USD projections
- C&P Floor Area projection based on Floor Area per unit GDP (USD2005) in 2005
- Developing regions are assumed to reach OECD levels (or fraction) of this “floor area elasticity” by 2050
- Tempers otherwise exponential floor area increase if C&P floor area tied directly to GDP

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GBPN – 3CSEP Energy Use Modeling

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Final Thermal Comfort Energy Use Calculation

$$\text{Final Energy} = \sum_{i=1}^{41} \sum_{j=1}^{12} \sum_{k=1}^{17} \sum_{l=1}^{5} \text{Floor Area}_{i,j,k} \times \text{Energy Intensity}_{i,j,k} \quad (m^2 \times \frac{kWh}{m^2 \times year})$$

- **Energy Use Calculation:**
  - *i = 1 to 41* *(14 Regions + 27 Countries in EU-27)*
  - *j = 1 to 16 Building Types*
  - *k = 1 to 17 Climate Zones*
  - *l = 1 to 5 Different Building Vintages*

- Energy use is calculated for each region and each climate zone with the split to building types and building vintages

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Water Heating Energy Use Calculation

$$\text{WH Energy} = \sum_{i=1}^{41}\sum_{j=1}^{12}\sum_{k=1}^{5} \text{Floor Area}_{i,j,k} \times \text{WH Energy Intensity}_{i,j,k} \ \left(m^2 \times \frac{kWh}{m^2 \cdot year}\right)$$

- **WH Energy Use Calculation:**
  - *i = 1 to 41 (14 Regions + 27 Countries in EU-27)*
  - *j = 1 to 16 Building Types*
  - *k = 1 to 3 Building Vintages (standard / retrofitted / advanced)*
- 2005 WH Energy values: literature data or calculated (residential: population based, C&P: floorspace based)
- WH Energy Intensity is calculated on the basis of regional average energy factor assumptions for 2005 and 2050 (climate considered in these averages)
- If no EF calculation can be performed (no data), existing energy intensity assumptions are used

Water Heating Main Concepts

- Energy sources: fuels, electricity, renewables
- Comparison of performance: energy factor (EF)
  - definition: $$\mathrm{EF} = \frac{useful\ hot\ water\ energy}{input\ non-renewable\ energy}$$
  - → the same as efficiency for conventional sources
    e.g. EF~0,9 for an efficient gas heater
  - → EF > 1 for renewable sources
    e.g. solar system in Sweden: EF~2 (~50% backup)*
    solar system in Cyprus: EF~5 (~20% backup)*
  - EF > 1 for heat pumps (cheap air source: 2,2-2,5)

*illustrative numbers (without losses)

Key messages

Buildings are a key lever in mitigating climate change

The potential to reduce building thermal energy use and CO2 emissions is significant

Policy actions have to be more ambitious than current efforts

Policy actions have to be taken immediately; the delay is too costly

Heating & cooling energy use offers the greatest saving potential

Energy efficiency improvements in buildings are not enough

Heating & cooling energy use offers the greatest saving potential

Policies have to focus on holistic opportunities in buildings

Ambitious energy performance levels have to be reflected in the building codes

The main policy focus in US & EU on retrofitted buildings, in China & India on new construction

Actions in urban areas & on region-specific building types are crucial

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Main lessons learned

A significant potential for energy use and CO_2 emissions reduction can be achieved in the building sector through state-of-the-art technological measures implemented worldwide

Realisation of this potential requires strong political support. If the efforts are moderate, almost 80% of global final thermal energy savings can be locked-in by 2050

Even a very ambitious proliferation of energy efficient best practices is insufficient to achieve vital global greenhouse gas reduction targets. The decarbonisation of energy supply and significant behavioural and lifestyle changes are needed

The major increase in energy use and related CO_2 emissions will come from the developing world due to rapid economic development

Developed regions: promote "deep" renovation through ambitious building codes and standards. Developing regions: new building stock has the dominant role - enforcement of stringent building codes

Reduction potentials in the EU and the US are above 60%. In China, the explosive growth of floor space can be off set by energy efficiency improvements. In India, it is a great success if thermal energy use just doubles

Objective

Determine the global and regional potential for building energy-related mitigation:

- **Dwelling on holistic approaches that consider buildings as complex systems rather than sums of components**
- **in the most robust and credible manner that is allowed by data**

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“everyone knows the potential is big…”

- Buildings are a key contributor to climate change
- They hold the largest and most cost-effective mitigation potential
- However, there are few studies that rigorously quantify this potential
- …and compare the different pieces of work out there on the issue

- **This report presents a unique attempt to assess the importance of the buildings sector in mitigating climate change using scenario analysis, and to offer policy insights on how the savings potentials can be best captured**

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Project Team and Roles

Diana Ürge-Vorsatz	Project Leader
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Miklos Antal	Researcher, WH, technologies
Maja Staniec	Researcher, model comparison, CO_2
Michael Labelle	Project Manager
Eren Ozden	Data collection
Elena Labzina	Software development

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Further key credit to:

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Scenario analysis: what it is NOT

- The purpose of scenarios is NOT to predict the future
- But to give “what…. If….” insights into consequences of certain decisions

Policy-relevant techno-economic scenarios

Deep Efficiency

How far can buildings contribute to mitigation goals if we push the efficiency lever as far as we can, based on today's demonstrated (cost-effective) best practices?

Moderate Efficiency

Where could we be if today's policy ambitions were all implemented fully?

Frozen Efficiency

What would happen if it went on as what we do today in construction and retrofit?

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Key finding 1: by 2050, global building final thermal energy use can be reduced by about one-third, (-34% for space heating and cooling) as compared to 2005 values

- despite an app. 127% increase in floor area + a significant increase in thermal comfort levels
- in stark contrast with the frozen eff scenario: 111% increase
- This finding is very robust against even large uncertainties (app. 24% change for 50% difference in assumed performance level increases; reduction is still possible)

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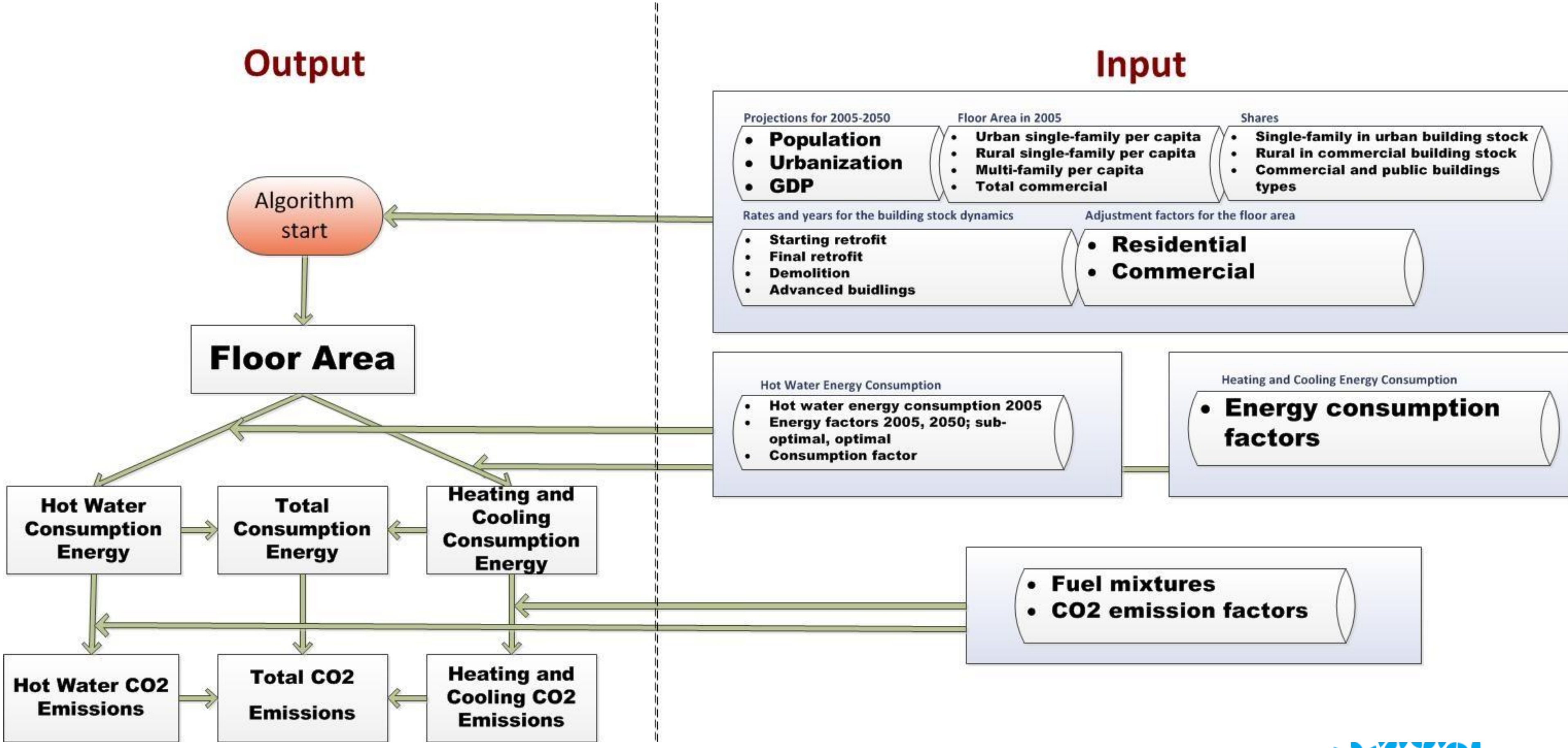
Further key findings

- Policies focusing on holistic/systemic opportunities in buildings are likely to achieve much more significant reductions than those focusing on individual building components
- studies optimizing mitigation over a longer period achieved higher and more dynamic reductions as opposed to studies focusing on the shorter-term. This points to the crucial importance of strategic, long-term policy-making and the stability of policy structures
- the crucial importance of immediate action and the high cost of delay. Therefore fast action, as well as an accelerated transformation of the construction industry/markets is of paramount importance
- a too large acceleration in retrofit rates is not desirable, partially due to an increased lock-in effect. As a policy implication, in an ideal case, the retrofit dynamic is accelerated only by the time when the market is ready for advanced retrofits.
- if performance levels in building codes and retrofits remain far from their state-of-the-art levels, accelerating building retrofits will not bring major climate benefits.

Modeling logic for 3CSEP-HEB model



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