Chapter 7
Decarbonisation Pathways for Buildings

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Abstract This section documents the development of four different energy demand pathways on the basis of the high-efficiency buildings (HEB) model of the Central European University. The assumptions and the scenario narratives are derived and the results provided in numerous graphs and tables. Of the four derived scenarios, two are selected for the OECM and the selection criteria are justified. The results in terms of the global energy demand and energy-related CO_2 emissions are provided in tables.

Keywords Decarbonisation pathways · Buildings · Residential · Commercial · High-efficiency buildings (HEB) model · Energy intensities · Floor area · Bottom-up demand projections

The developments of the regional and global energy demand for the building sector are described in this chapter. Sections 7.1 and 7.2 document the development of the bottom-up energy demand projections for buildings with the methodology described in Sect. 3.2 and are authored by Prof. Dr. Diana Ürge-Vorsatz, Dr. Souran Chatterjee, and Benigna Boza-Kiss of the Central European University Budapest, Hungary. The last section describes the implementation of this research in the wider OneEarth Climate Model (OECM) to generate a single 1.5 °C energy pathway for buildings and construction.

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7.1 Buildings

The building sector is responsible for 39% of process-related greenhouse gas (GHG) emissions globally and accounts for almost 32% of the global final energy demand, making the building sector pivotal in reducing the global energy demand and climate change (Ürge-Vorsatz et al., 2015a, 2020). The building sector is often suggested to have the largest low-cost climate change mitigation potential, achievable by reducing the energy demand (Ürge-Vorsatz & Tirado Herrero, 2012a; Güneralp et al., 2017a). However, with the increasing rates of population growth and urbanisation, the building stock is projected to double in developing regions by 2050, so reducing the global energy demand will become challenging (EIA, 2015a). Along with these challenges, new building stocks in developing regions will simultaneously provide opportunities for energy-efficient construction, which could substantially reduce the global energy demand. In developed regions, opportunities to reduce the energy demand will predominantly involve renovating the existing building stock (Prieto et al., 2019a; Chatterjee & Ürge-Vorsatz, 2020).

The IPCC's fifth assessment report makes clear that the energy demand must be reduced substantially by 2050 to limit the global temperature rise to 1.5 °C (Rogelj et al., 2018a). However, today, most mitigation pathways still rely on supply-side solutions, and little effort has been made to understand the demand-side potential (Creutzig et al., 2018a). More precisely, understanding the global energy demand for the building sector by assessing the future growth in floor area and the corresponding energy demand is crucial in the context of the 1.5 °C target. Therefore, different models of the building energy demand are used to understand the future energy consumption and emission potential of the building sector under different policy scenarios.

7.2 The High-Efficiency Buildings (HEB) Model: Energy Demand Projections for the Building Sector

To develop detailed energy demand projections for the regional and global building sectors, the *high-efficiency buildings* (HEB) *model* was used. The HEB methodology is documented in Sect. 3.2 and is among the most detailed models for this sector. The key output of the HEB model consists of floor area projections for different types of residential and tertiary buildings in different regions and countries, the total energy consumption of residential and tertiary buildings, the energy consumption for heating and cooling, the energy consumption for hot water energy, the total CO_2 emissions, the CO_2 emissions for heating and cooling, and the CO_2 emissions for hot water energy. The HEB is based on a bottom-up approach, and it includes rather detailed technological information for one sector of the economy. However, it also uses certain macroeconomic and socio-demographic data, including population growth rates, urbanisation rates, and floor areas per capita. The HEB model uses four different scenarios to understand the dynamics of energy use and to explore the potential of the building sector to mitigate climate change by exploiting various opportunities. The four scenarios are:

1. *Deep efficiency scenario*: The *deep efficiency* scenario demonstrates the potential utility of state-of-the-art construction and retrofitting technologies, which can substantially reduce the energy consumption of the building sector and therefore CO_2 emissions while also providing full thermal comfort in buildings. In this scenario, exemplary building practices are implemented worldwide for both new and renovated buildings.
2. *Moderate efficiency scenario*: The *moderate efficiency* scenario incorporates present policy initiatives, particularly the implementation of the Energy Performance of Building Directive (EPBD) in the EU and building codes for new buildings in other regions.
3. *Frozen efficiency scenario*: This scenario assumes that the energy performance of new and retrofitted buildings does not improve relative to the baseline. Retrofitted buildings will consume around 10% less energy for space heating and cooling than standard existing buildings, whereas most new buildings have a lower level of energy performance than that in the *moderate efficiency* scenario due to their lower compliance with building codes.
4. *Nearly net-zero scenario*: The last scenario models the potential of deploying 'nearly net-zero energy buildings' (buildings that can produce as much energy locally through the utilisation of renewables as they consume, on annual balance) around the world. It differs from other three scenarios in that it not only calculates the energy consumption but already incorporates the local energy supply to arrive at the final energy demand. In other aspects, it uses the same parameters as the *deep efficiency* scenario.

The aim of the scenario analysis is to determine the importance of different policies for building energy-efficiency measures and to show how much the final energy consumption of the building sector can be reduced across the world. Table 7.1 summarises the actual parameters of the four scenarios.

7.2.1 Regional Breakdown of the High-Efficiency Buildings (HEB) Model

The end-use demand and its corresponding emissions are produced until 2060 at yearly resolution for 11 key regions, which include 28 member states of the European Union and 3 key countries (India, China, and the USA), and cover the world. Those 11 regions shown in Fig. 7.1 differ from the 10 IEA regions used for the regional transport demand analysis. The main differences are as follows: OECD Europe (IEA) is broken down into Western and Eastern Europe (HEB); Africa (IEA) and the Middle East (IEA) are grouped into Middle East and Northern Africa (HEB)

Table 7.1 Parameters of the four scenarios

Parameter	Deep efficiency scenario	Moderate efficiency scenario	Frozen efficiency scenario	Nearly net-zero scenario
Initial retrofit rate	1.4%	1.4%	1.4%	1.4%
Accelerated retrofitting rate	3% in developed countries and 1.5–1.6% in developing countries after 2027	3% in developed countries and 1.5–1.6% in developing countries after 2027	No accelerated retrofitting rate is assumed	3% in developed countries and 1.5–1.6% in developing countries after 2027
Energy-efficiency measures for new buildings	New buildings are built to regional standards	New buildings are built to regional standards	New buildings do not improve relative to the existing stock	New buildings are built to regional standards
Energy-efficiency measures for renovated buildings	Renovations reduce the energy demand by approximately 30%	Renovations reduce the energy demand by approximately 30%	Renovations reduce the energy demand by approximately 10%	Renovations reduce the energy demand by approximately 30%
Share of advanced buildings within the new and retrofitted stock	All new and retrofitted buildings have a very low energy demand after 2030 in EU, NAM, and PAO and after 2037 in other parts of the world	Advanced buildings (new buildings) are only introduced in Western Europe after 2035, and after 2045, all retrofitted buildings have a very low-energy design	Advanced buildings are only introduced in Western Europe after (1% of the new and retrofitted building stock)	All new and retrofitted buildings have a net-zero energy demand after 2030 in EU, NAM, and PAO and after 2037 in other parts of the world

Fig. 7.1 Global coverage of HEB model

and sub-Saharan Africa (HEB); India (IEA) is part of the South Asia (HEB) region, which includes the neighbouring countries Bangladesh, Bhutan, Sri Lanka, Nepal, and Pakistan—countries that are part of the IEA region non-OECD Asia; China (IEA) is part of the group Centrally Planned Asia, which includes Cambodia, Lao, Mongolia, North Korea, and Vietnam, all of which are part of the IEA region non-OECD Asia; Pacific Asia (HEB) is the remaining part of the non-OECD Asia (IEA) region and all Pacific Island states.

7.2.2 HEB: Data and Assumptions

Similar to any bottom-up energy demand model, the HEB model is very data-intensive. Therefore, it relies on a broad variety of input sources, including statistical databases and the scientific peer-reviewed and grey literature, to incorporate the most up-to-date data. The HEB model largely depends on four sources for its basic input data:

World Bank Databases Both present and historical data on population and real gross domestic product (GDP) figures are obtained from the World Bank databases. The GDP forecast data play a particularly crucial role because they determine the growth in floor area of non-residential buildings. The HEB model calculates future GDP values based on historic and present GDP growth rate data obtained from the World Bank database. The future real GDP is predominantly calculated for non-OECD countries for which future forecasts of real GDP are not available. However, for the OECD member states, this model uses the OECD database of real GDP projections. In addition to the forecast GDP and real GDP databases, the HEB model uses the population forecast database of the World Bank to calculate the future population growth for different countries and regions.

United Nations Development Programme (UNDP), UN-Habitat, and United Nations Conference on Trade and Development (UNCTAD) Population Databases To calculate the growth in floor area and therefore the final energy consumption for heating and cooling, population projection data are required. Together with the World Bank database, the HEB model uses the UNDP population projection database to calculate future populations. Furthermore, because the HEB uses rural and urban classifications, urbanisation rate data are obtained from the UNCTAD database. However, none of these databases contains data on slums or the informal settlement of different regions. Therefore, urban populations living in slums are calculated based on UN-Habitat projections.

In addition to population and GDP data, other important data points used in HEB, such as building stock data and energy intensity data, have been collected from several project reports and datasets of the European Commission, as well as the Eurostat database in the case of the EU, the US Energy Information Administration (EIA) database, and various literature sources. Further information on the data collection can be found in the previous report of HEB in Urge-Vorsatz et al. (2012a). In some cases, data for some of the parameters are unavailable, and in those cases, the HEB model relies on expert judgement. For instance, the energy intensity (specific energy consumption) of advanced buildings mainly utilises the 'passive house' principle, meaning that the useful energy demand may not exceed 15 kWh/m^2/year for heating. This concept has been shown to be applicable throughout the world, and various other measures are used to reduce the cooling and dehumidification demands. The total useful demand can be supplied by increasingly efficient heat pumps, which results in very low final energy demands in such advanced buildings. In the *nearly net-zero* scenario, the energy consumption of advanced buildings is even more reduced by potential local energy production, which is calculated with the Better Integration for Sustainable Energy (BISE) model at the building level. The basic input data used in the HEB model are presented, together with their sources, in Table 7.2.

The key assumptions of the model are presented in Table 7.1, and the sources of the key input data are documented in Table 7.2. Assumptions, such as the retrofitting rate, the share of advanced buildings within the new and retrofitted stock, and the energy performance of buildings of different vintages, are based on expert judgements and the authors' experience in the field of modelling building energy. Because data for these parameters are not available, the authors have made several assumptions related to their magnitudes (Table 7.1). Moreover, because the HEB model provides a realistic evaluation of the building energy demands under different policy scenarios, different scenario-specific assumptions are also used to define the scenarios.

The findings are presented in Sects. 7.2.3 and 7.2.4. First, the findings of the study show the future floor area projections under different scenarios, and then it presents future space-heating and space-cooling demand of the different regions. Space-heating and space-cooling demand largely depends on the floor area growth,

Table 7.2 Key input data used in the HEB model and their sources

Description	Sources
GDP forecast	World Bank (2020) and OECD (2021a)
Population forecast	World Bank (2021a, b) and UN DESA (2019)
Urbanisation rate forecast	Our World in Data (2021a), United Nations Conference on Trade and Development (2021), and UN DESA (2018)
Urban populations living in slums (forecast)	Our World in Data (2021a) and UN-Habitat (2021a)
Shares of building types (residential and commercial) within a region	Eurostat (2021a), Hong et al. (2014a), EIA (2015a), and European Commission (2021a)
Demolition rate, retrofitting rate, floor area per capita/GDP	European Commission (2021b), EIA (2012, 2015a), and ENTRANZE (2014a), and literature (Chatterjee & Ürge-Vorsatz, 2020)
Specific energy use for heating	Schnieders et al. (2015a), Mantzos et al. (2015), Hotmaps (2021a), and Heat Roadmap and experts' judgement

and hence, the results of floor area are presented first. To calculate floor area and final energy demand, HEB model first calculates region-specific population and GDP with the help of Eqs. 3.1–3.9 (Sect. 3.2). Based on the region-specific populations and GDP growth rates, then region-specific floor area and final energy consumption for space heating and cooling are calculated.

7.2.3 *Floor Area*

The floor area for each of the regions is calculated with Eqs. 3.10 and 3.11 (Sect. 3.2). In accordance with the HEB modelling assumptions, the growth in floor area in the residential sector depends predominantly on the population growth, whereas the growth in non-residential or commercial floor area depends on the GDP growth of the region. Based on these equations and assumptions, the findings of the HEB model show that the global floor area will increase by 77% from 2022 to 2060 and the global floor area growth will be dominated by the growth in the Asian, Middle Eastern, and African regions. Precisely, substantial growth in floor area will be observed in the Middle East and Africa (180%), followed by Pacific Asia (174%), Africa (131%), and Latin America (130%) (refer to Fig. 7.2).

Significant population and GDP growth is projected for regions such as the Middle East and Africa, Africa, and Pacific Asia in the future, so the floor area growth in these regions will be substantial. If the global growth in floor area is further analysed according to different building categories and classifications, it can be seen that the substantial increase in floor area will be dominated by urban floor area (99% growth is projected by 2060 relative to 2022), which will mainly be caused by an increasing rate of urbanisation. As a result of the increasing urbanisation rate, urban slums are projected to increase significantly to 176% by 2060. However, the floor area of slums constitutes only a small proportion of the global floor area (2.4%

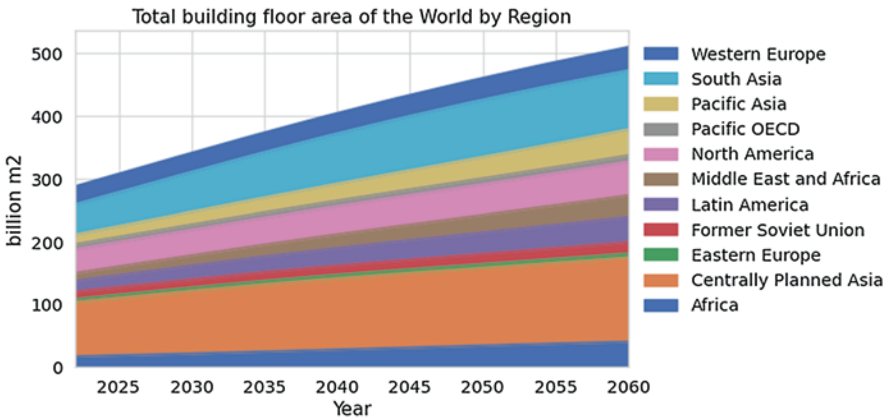

Fig. 7.2 Growth of the total floor area and its distribution among the regions of the world

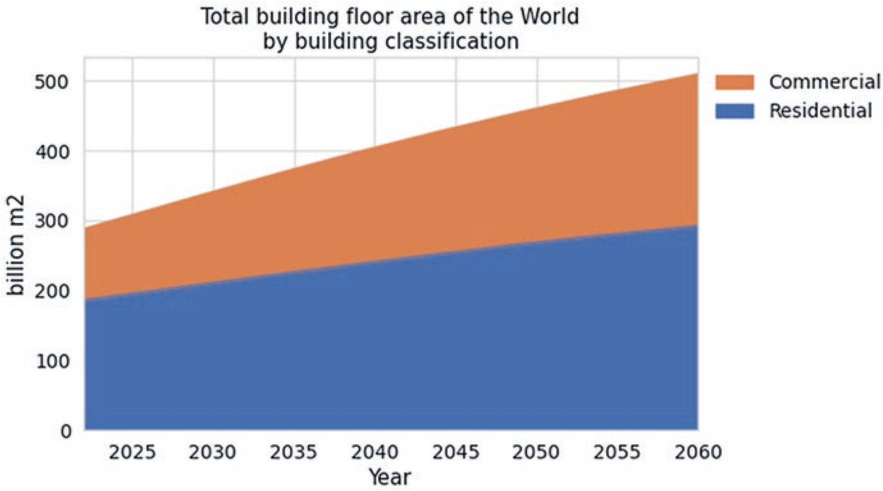

Fig. 7.3 Total building floor area in the world by building classification

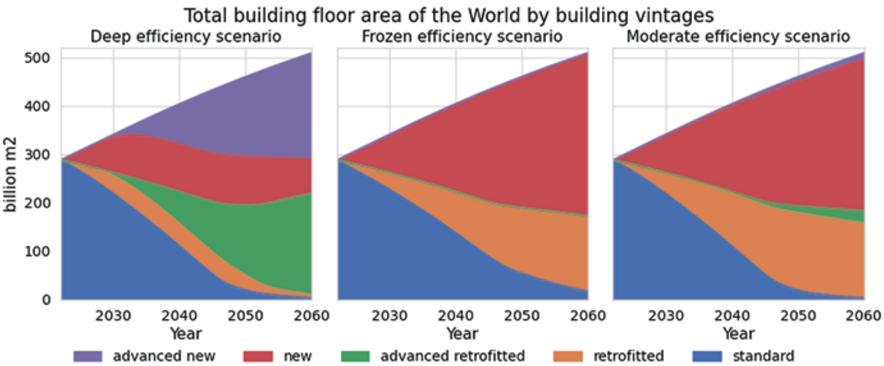

Fig. 7.4 Distribution of the total floor area throughout the world by building vintage across the modelling period

of the global floor area, which is projected to increase to 3.7%), so the growth of slum areas will have little impact on the global floor area growth. Moreover, if floor area growth is analysed per building classification, substantial growth can be projected for both residential and commercial buildings. More precisely, the global residential building sector is projected to grow from 186 billion m^2 in 2022 to 292 billion m^2 by 2060, and the global commercial building sector is projected to grow from 102 billion m^2 in 2022 to 217 billion m^2 by 2060 (refer to Fig. 7.3).

The findings of the HEB model are summarised in Figs. 7.4 and 7.5. However, it is important to understand the future proportions of buildings of different vintages, because they have different levels of energy performance and therefore different energy consumption patterns. The floor area growth for buildings of different

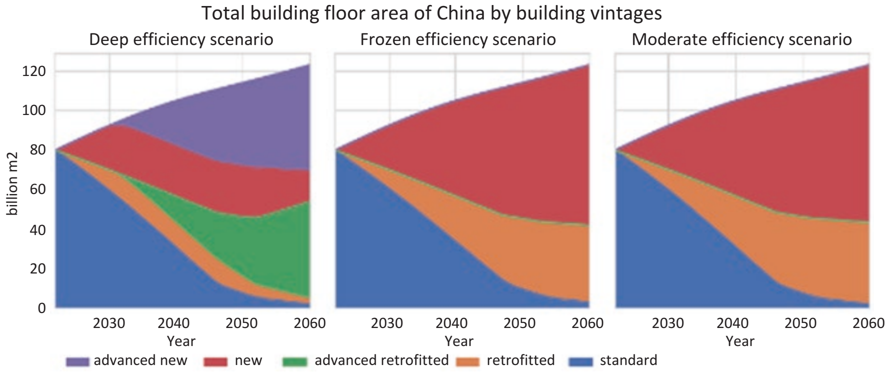

Fig. 7.5 Distribution of the total floor area in China by building vintages across the modelling period

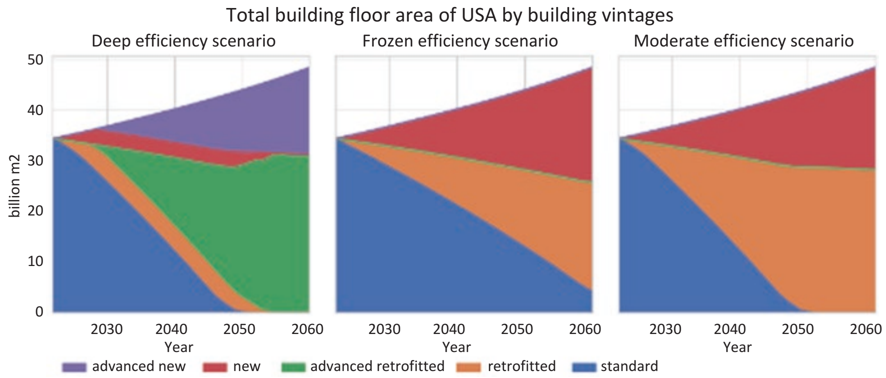

Fig. 7.6 Distribution of the total floor area in the USA by building vintages across the modelling period

vintages is presented in Figs. 7.4, 7.5, 7.6, 7.7, 7.8 and 7.9, which shows the share of each vintage and its change over the modelling period across the different scenarios in each of the regions. It is important to note that the total floor area remains the same in all scenarios.

The findings show that the growth in total floor area is mainly dominated by growth in China and India. More precisely, China's share of the global total floor area in 2022 will be around 28%, and by 2060, it will increase by 54%, whereas India's share in 2022 will be 14% and will increase by 96% by 2060. Furthermore, significant growth in floor area can be observed by 2060 in key regions, such as the USA (41%), Pacific OECD (25%), and EU-28 (22%).

The results of the HEB model also show that a very small amount of today's building stock will remain as it is until 2060. Therefore, to reduce the energy demand and the impact of the energy demand of the building sector on climate change, it

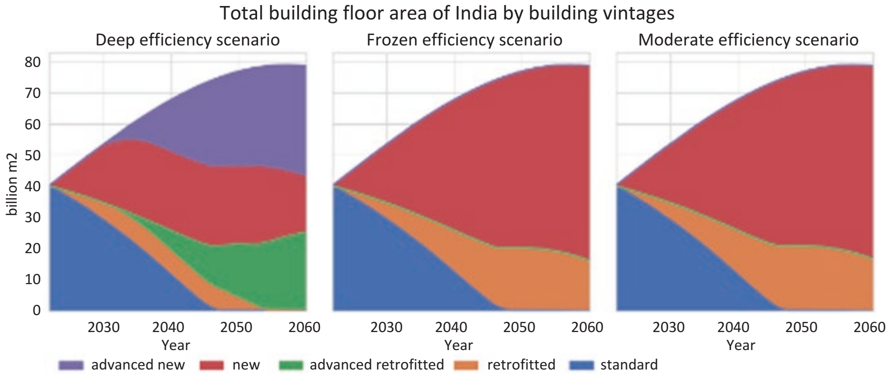

Fig. 7.7 Distribution of the total floor area in India by building vintages across the modelling period

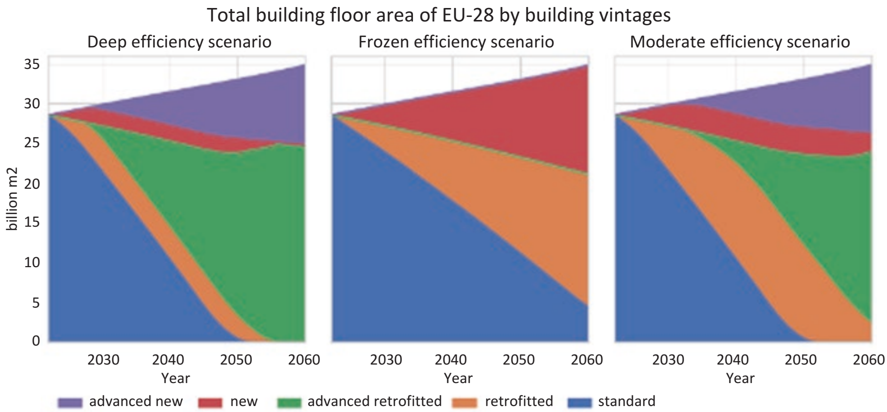

Fig. 7.8 Distribution of the total floor area in EU-27 countries by building vintages across the modelling period

will be crucial to implement advanced efficiency measures for retrofitted and new buildings that will be constructed in 2022–2060. If today's best practices of energy efficiency are applied to all new and retrofitted buildings globally (*deep efficiency* scenario), 43% of the building stock will be classifiable as 'advanced new' buildings and 41% of the building stock as 'advanced retrofitted' buildings in 2060. However, a significant amount of stock will remain less energy-efficient based on the assumption that the construction market cannot adjust immediately to the new practices required to build highly efficient buildings. On the contrary, if the current practice is '*frozen*' and no advanced measures are introduced, 99% of the stock will remain less efficient while having the rest unchanged in 2022 values. It is noteworthy that according to the findings of the HEB model, 66% of the building stock in 2060 does not yet exist in 2022. The *moderate efficiency* scenario assumes that only

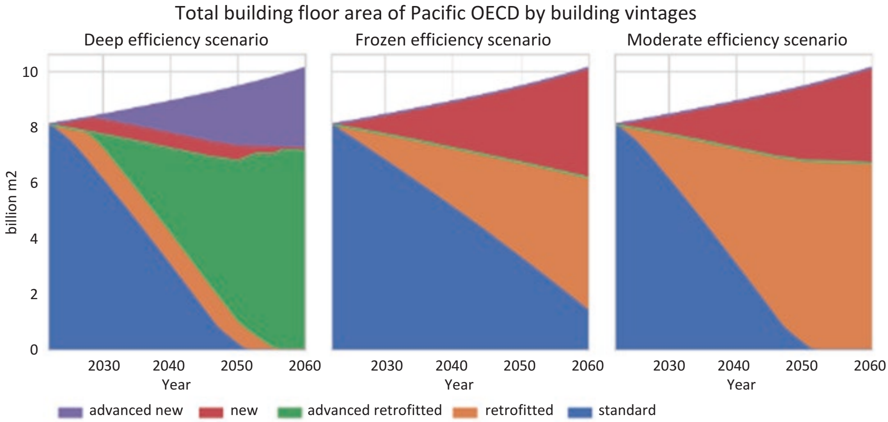

Fig. 7.9 Distribution of the total floor area in Pacific OECD countries by building vintages across the modelling period

present policies will be enforced and there will no further more ambitious goals set throughout the world. Under this scenario, only a minor share (7%) of the floor area will be classifiable as 'advanced' (2% new and 5% retrofitted). This is because most countries with strong policies for energy-efficient buildings (especially the EU) will only play a minor role in constructing a share of new buildings around the globe.

7.2.4 Final Energy Use for Space Heating and Cooling Under the HEB Scenarios

The final energy use for space heating and cooling will largely depend upon the calculated floor areas. After the floor area is calculated for each region, the thermal energy use is calculated. Like the floor area calculations, thermal energy use is also calculated for the four different scenarios.

Among the four scenarios, the final energy use for space heating and cooling under two scenarios clearly shows immense potential for reducing the energy demand of the building sector by 2060. At the global level, if best practices in building construction and retrofitting become standard, the final energy for heating and cooling will decrease from 24 PWh in 2022 to 10 PWh in 2060, which corresponds to a 56% drop, as shown in Table 7.3. However, if existing policies continue in place until 2060, the final energy use will increase by 34% by 2060 relative to the 2022 level. In other words, under the *moderate efficiency* scenario, the global final energy required for space heating and cooling will increase by 34% by 2060 relative to that in 2022. Under the *deep efficiency* scenario, the global final energy demand in 2060 will be 67% less than under the *moderate efficiency* scenario, whereas under the *frozen efficiency* scenario, it will be 37% higher, which corresponds to an 83% increase relative to the 2022 level.

Table 7.3 Results for final energy use for heating and cooling in the key regions and the world

Scenario	Baseline	*Moderate efficiency*		*Deep efficiency*			*Nearly net zero*			*Frozen*		
	2022 PWh	2060 PWh	Δ% to 2022	2060 PWh	Δ% to 2022	Δ% to Moderate	2060 PWh	Δ% to 2022	Δ% to Moderate	2060 PWh	Δ% to 2022	Δ% to Moderate
China	4.10	6.86	+67%	2.86	−30%	−58%	1.03	−75%	−85%	9.65	+135%	+41%
EU-28	2.82	0.66	−77%	0.37	−87%	−44%	0.00	−100%	−100%	2.97	+5%	+353%
India	2.33	7.50	+222%	2.60	+12%	−65%	1.70	−27%	−77%	8.82	+279%	+18%
Pacific OECD	0.99	0.77	−22%	0.15	−85%	−81%	0.00	−100%	−100%	0.99	+1%	+29%
USA	5.16	4.61	−10%	0.76	−85%	−84%	0.00	−100%	−100%	5.87	+14%	+27%
World	23.59	31.49	+34%	10.49	−56%	−67%	4.42	−81%	−86%	43.05	+83%	+37%

There are two key reasons behind the significant energy savings in the *deep efficiency* and *nearly net-zero* scenario compared with the *frozen efficiency* and *moderate efficiency* scenarios:

1. Low retrofitting rates
2. Higher proportions of advanced new and retrofitted buildings

More precisely, in the *deep efficiency* and *nearly net-zero* scenarios, the retrofitting rate is assumed to be 3% in developed countries and 1.5–1.6% in developing countries after 2027. The same retrofitting rates are assumed in the *moderate efficiency* scenario. However, in the *frozen efficiency* scenario, the retrofitting rate is assumed to be no higher than 1.4% across all regions. Similar to the retrofitting rate, under the *deep efficiency* scenario, it is assumed that all new and retrofitted buildings will have a very low energy demand in the EU, NAM, and PAO after 2030 and in the other parts of the world after 2037. Under the *nearly net-zero* scenario, it is assumed that all new and retrofitted buildings will have a net-zero energy demand in EU, NAM, and PAO after 2030 and in other parts of the world after 2037 because the local onsite solar electric production is included in the definition of the *nearly net-zero* scenario. In the *moderate efficiency* scenario, advanced buildings are only introduced in Western Europe after 2035 for all new buildings, and after 2045, all retrofitted buildings will have a low-energy design. Based on these assumptions, the findings of HEB highlight the importance of ambitious in-act policies.

Key regions, such as China, EU-27, and India, consume most of the global energy, so it is important to know how the building sectors in these regions will perform under different scenarios. Regions such as the USA and EU-27 have much greater potential to reduce space-heating- and space-cooling-related energy use with the help of best practices. Precisely, 73% and 75% of energy consumption related to thermal comfort can be reduced by 2060 in the USA and EU-27, respectively, if best practices are followed. The *nearly net-zero* scenario goes one step further than the *deep efficiency* scenario. The results show that the energy consumption of buildings for heating and cooling can reach almost zero in the EU, the USA, and Pacific OECD countries by 2055–2057. Although heating- and cooling-related energy consumption in China and India will not reach zero in the modelled period, significant reductions in China and India (85% and 27%, respectively) can be achieved relative to 2022 values. Figures 7.10 and 7.11 show the final energy demands for space heating and cooling in different parts of the world under the different scenarios (Fig. 7.12).

Globally, commercial and public buildings in urban areas are the largest consumers of space-heating- and space-cooling-related energy. Therefore, best practices should especially focus on commercial and public buildings in urban areas. Commercial and public buildings in urban areas will reduce their consumption by up to 33% by 2060 under the *deep efficiency* scenario. Similarly, urban residential buildings will reduce their consumption by up to 57% globally by 2060 under the *deep efficiency* scenario. Under the *nearly net-zero* scenario, commercial and public buildings still have a significant share of energy consumption in 2060, but the total energy demand is extremely reduced. It is noteworthy that reducing the energy intensity of commercial and public buildings even further will require further

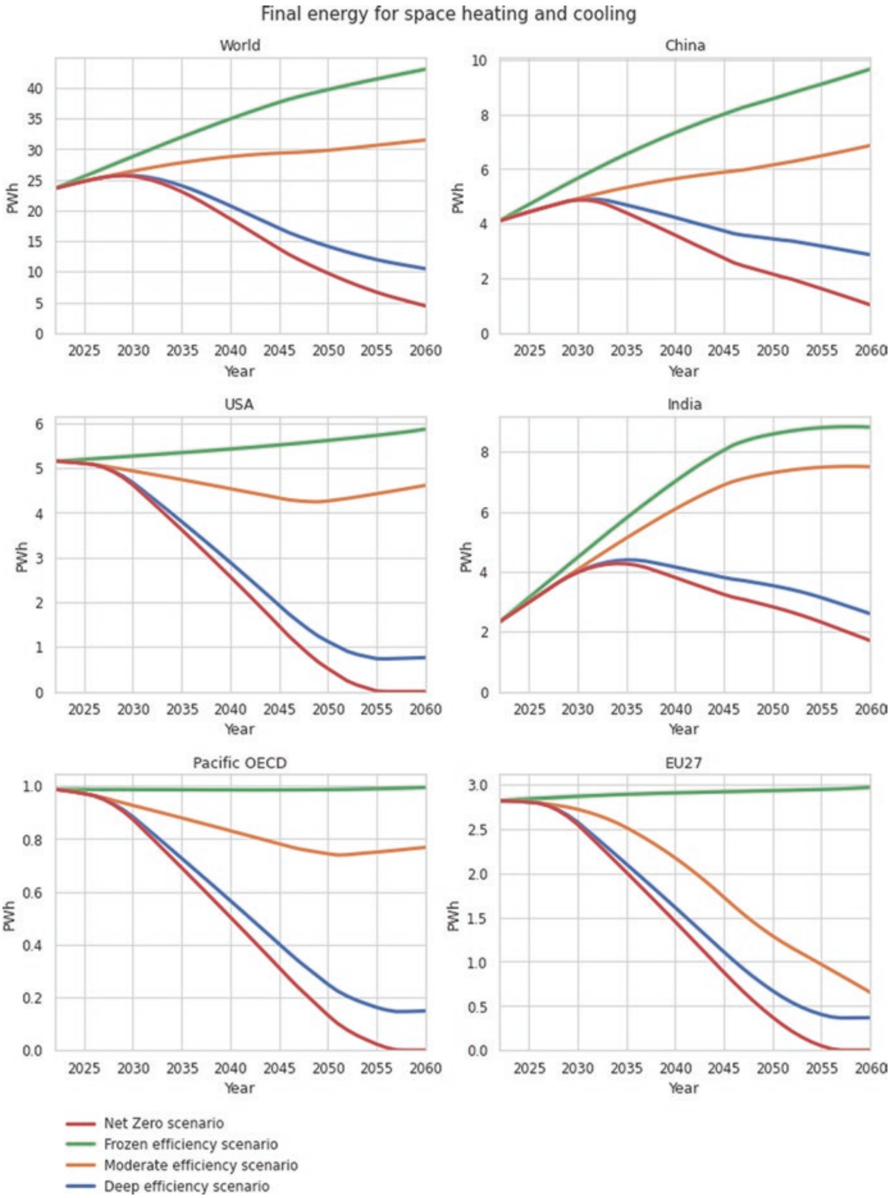

Fig. 7.10 Final energy consumption for space heating and cooling in the world and key regions (in PWh)

investigation of the usage characteristics of different building types. Therefore, even more effort will be required than merely servicing these building with renewable energy. Similar findings are obtained from the analysis of the region-specific final energy demands for the USA, the European Community, India, China, and the OECD Pacific.

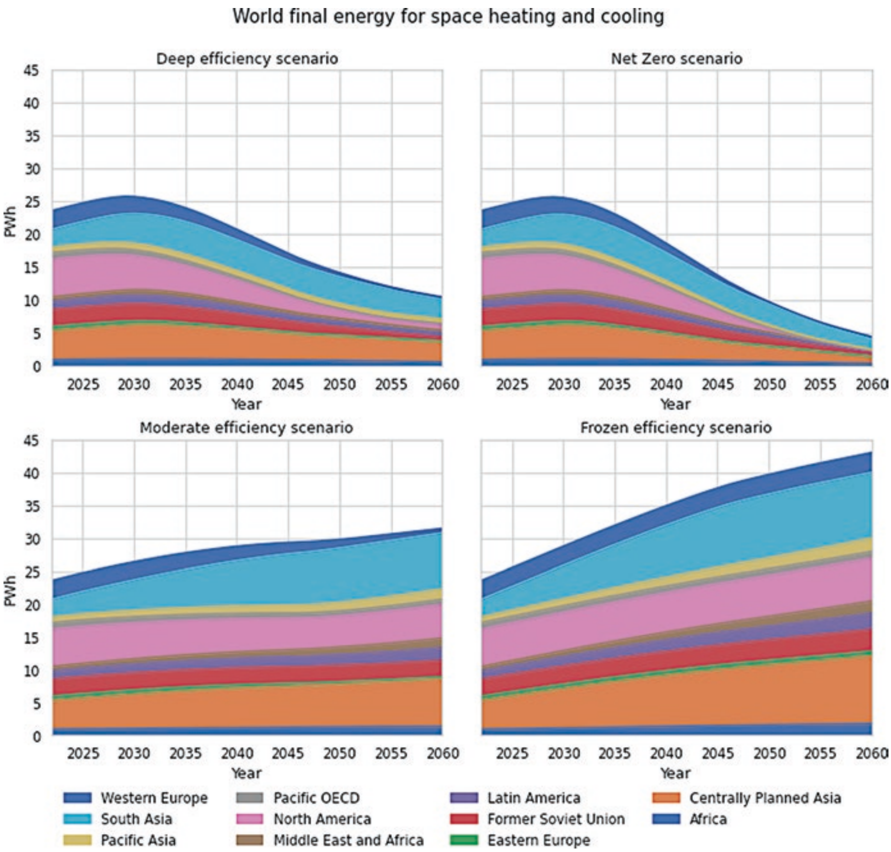

Fig. 7.11 Shares of the total heating and cooling energy consumption attributable to different regions of the world

Commercial buildings are the largest consumer of space-heating- and space-cooling-related final energy in low- to middle-income regions, such as India and China. However, in developed regions, such as the Pacific OECD, EU-28, and the USA, the residential building sector is the largest consumer. The HEB results show that these developed high-income regions can substantially reduce their energy demands in both residential and commercial building sectors if advanced high-efficiency energy measures are standardised over the years. In fact, in these regions, if local energy production is included (i.e. *nearly net-zero* scenario), then the building sector can achieve a net-zero status by 2060. In contrast, the low- to middle-income regions will not be able to achieve a net-zero status by 2060, even if the local production of solar electric energy is added into the calculation. However, regardless of the local energy production, these regions can still achieve a substantial reduction in China, and in India, the rate of increase will be slowed by the introduction of advanced efficiency energy measures, such as new energy-efficient

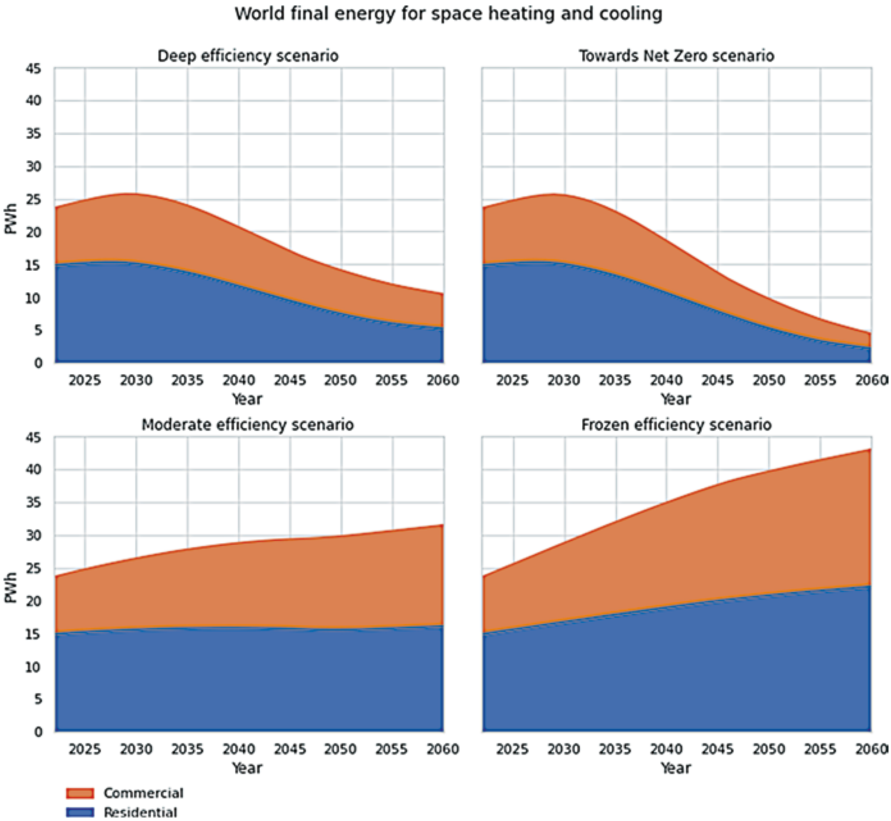

Fig. 7.12 Shares of final energy consumption for space heating and cooling for the world by building category (in PWh)

building codes and the rigorous renovation of existing buildings. More precisely, in India, even with advanced energy-efficiency measures, the final energy demand for heating and cooling will increase by 12% in 2060 relative to that in 2022, which is 65% lower than the final energy demand for 2060 if the existing efficiency measures are followed until 2060.

7.2.5 *Key Findings for the HEB Scenarios*

The HEB model analysis demonstrates the potential for reducing the energy demand in the building sector if state-of-the-art high-efficiency buildings are implemented worldwide. The findings of the study show that with a higher share of high-efficiency renovations and construction (as assumed in the *deep efficiency* and *nearly net-zero* scenarios), it will be possible to reduce the final thermal energy used globally in the building sector by more than half by 2060. In some regions, such as the EU and Pacific OECD, it will even be possible to achieve net-zero status for the thermal energy demand. However, this pathway towards high-efficiency or net-zero emissions is ambitious in its assumptions and requires strong policy support. On the contrary, if policy support to implement more high-efficiency buildings is not in place (*frozen efficiency* scenario) or even if the present policy scenarios are continued (*moderate efficiency* scenario), the total thermal energy demand of the building sector could increase by 34–83% by 2060 relative to the 2022 level. Furthermore, if the present rate of energy-efficiency measures is continued, 67–80% of the global final thermal energy savings will be locked in by 2060 in the world building infrastructure. The lock-in effect of the building sector also indicates that if the present moderate energy performance levels become the standard in new and/or retrofitted buildings, it will be almost impossible to further reduce the thermal energy consumption in such buildings for many decades to come.

7.3 1.5 °C OECM Pathway for Buildings

Based on the results of the detailed HEB model analysis, the *deep efficiency* scenario was chosen for commercial buildings and the *moderate efficiency* scenario for residential buildings. These scenarios were chosen after stakeholder consultation with representatives of the respective industries, members of the Carbon Risk Real Estate Monitor (CRREM), the Net-Zero Asset Owner Alliance, and academia. To integrate the building sector into the 1.5 °C pathway as part of the OECM, consistent with all other industry and service sectors and the transport sector, the selection of one specific pathway for the building sector as a whole was necessary. The energy demand for the construction sector was also required to calculate the emissions for the Global Industry Classification Standard (GICS) (see Chap. 2). This section documents the calculation process and the results for the residential and commercial building sector and construction.

Table 7.4 shows the assumed development of floor space for residential and commercial buildings, which was taken from the HEB analysis and the projected economic development of the construction sector. The increase in the construction industry is based on the overall global GDP, developed as documented in Chap. 2, and is therefore not directly related to the HEB floor space projections. The direct link between both parameters was beyond the scope of this analysis and is therefore highlighted as a potential source of error.

The global energy intensities for residential and commercial buildings (in kilowatt-hours per square metre (kWh/m^2)) are the second main input for the OECM 1.5 °C building pathway and are taken from the documented HEB analysis. The global values were calculated on the basis of the total HEB results for the global energy demand per year divided by the floor space. The global values are the sum of the values for all 11 regions analysed with HEB. Table 7.5 also shows the reductions

Table 7.4 OECM—global buildings: projected floor space and economic value of construction

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
			Projection					
Residential buildings	[Billion m²]	184	196	211	226	241	255	269
Residential buildings—variation compared with 2019	[%]	0	6%	15%	23%	31%	38%	46%
Commercial buildings	[Billion m²]	101	112	130	146	163	177	192
Commercial buildings—variation compared with 2019	[%]	0	12%	29%	46%	62%	76%	91%
Construction: residential and commercial building—economic value	[bn $GDP]	2149	2699	3186	3753	4321	5607	2149
Variation compared with 2019	[%]	0	26%	48%	75%	101%	131%	161%

Table 7.5 OECM—global buildings: assumed energy intensities

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
			Projections					
Residential buildings: energy intensity	[kWh/m²]	81	78	74	70	66	62	58
Variation compared with 2019	[%]	0%	−4%	−9%	−14%	−19%	−23%	−28%
Commercial buildings: energy intensity	[kWh/m²]	87	81	77	65	53	43	33
Variation compared with 2019	[%]	0%	−7%	−11%	−25%	−39%	−51%	−62%
Construction								
Construction: residential and commercial buildings—energy intensity	[MJ/$GDP]	0.70	0.57	0.56	0.56	0.56	0.55	0.54
Variation compared with 2019	[%]	0%	−19%	−19%	−20%	−20%	−22%	−23%
Energy demand: mining and quarry—sand, stones, clay, gravel	[PJ/yr]	510	526	618	724	829	934	1034
Variation compared with 2019	[%]	0	3%	21%	42%	63%	83%	103%

in the energy intensity for residential and commercial buildings relative to the values in the base year 2019.

The energy intensity of the construction industry was calculated with the total energy demand (in petajoules (PJ)) in 2019, as provided in the IEA World Energy Balances 2019 for Construction and the projected economic values (in $US) for the same year. The energy demand value for construction in the IEA statistics includes the construction of roads and railways, as well as other civil engineering and utility projects, as defined in IEA (2020). Therefore, the shares of the energy demand for residential and commercial buildings must be estimated. The calculated energy intensity for construction work was compared with published values.

Based on the assumptions and input parameters documented in Tables 7.4 and 7.5, the energy demand for all sub-sectors was calculated. Table 7.6 shows the calculated annual energy demand for residential and commercial buildings and for the construction industry. The energy demand consists of the energy required for space heating and cooling ('heating energy') and the electricity demand, which includes all electrical applications in the buildings but excludes electricity for heating and cooling. This separation is necessary to harmonise the input data from the HEB, which do not include electricity for household applications such as washing machines, etc., with the OECM.

The electricity demand for residential buildings is based on the bottom-up analysis of households documented in Sect. 3.1.2. The electricity demand for the service sector is based on a breakdown of electricity and heating in 2019 across all service

Table 7.6 OECM—global buildings: calculated annual energy demand for residential and commercial buildings and construction

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
			Projections					
Residential buildings: total energy demand	[PJ/yr]	82,565	77,724	77,039	75,274	75,199	66,944	63,147
Variation compared with 2019	[%]	0%	−6%	−7%	−9%	−9%	−19%	−24%
Residential buildings: heat energy demand	[PJ/yr]	60,417	54,746	56,056	56,739	56,983	56,677	55,989
Variation compared with 2019	[%]	0%	−9%	−7%	−6%	−6%	−6%	−7%
Residential buildings: electricity demand	[PJ/yr]	22,148	22,979	20,983	18,536	18,216	10,268	7158
Variation compared with 2019	[%]	0%	4%	−5%	−16%	−18%	−54%	−68%
Commercial buildings: total energy demand	[PJ/yr]	34,567	40,609	44,311	42,549	39,315	35,991	31,676
Variation compared with 2019	[%]	0%	17%	28%	23%	14%	4%	−8%
Commercial buildings: heat energy demand	[PJ/yr]	28,432	34,736	38,346	36,482	33,137	29,690	25,243
Variation compared with 2019	[%]	0%	22%	35%	28%	17%	4%	−11%
Commercial buildings: electricity demand	[PJ/yr]	2921	2686	2619	2554	2490	2428	2367
Variation compared with 2019	[%]	0%	−8%	−10%	−13%	−15%	−17%	−19%
Construction of residential and commercial building: energy demand	[PJ/yr]	1505	1531	1798	2108	2415	2719	3010
Variation compared with 2019	[%]	0%	2%	20%	40%	60%	81%	100%

Table 7.7 OECM−global buildings: energy supply

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
			Projections					
Residential buildings—heating: fossil fuels	[PJ/yr]	38,274	25,484	15,547	10,781	6450	1912	0
Residential buildings—heating: renewable, electric, and synthetic fuels	[PJ/yr]	22,144	29,262	40,509	45,958	50,533	54,765	55,989
Residential buildings—heating: renewable share	[%]	36.7%	53.5%	72.3%	81.0%	88.7%	96.6%	100.0%
Residential buildings—electricity: fossil fuels	[PJ/yr]	16,712	11,017	5412	2117	930	187	0
Residential buildings—electricity: renewables	[PJ/yr]	5436	11,962	15,571	16,418	17,286	10,081	7158
Residential buildings—electricity for heating share	[%]	6.6%	18.2%	20.4%	37.7%	42.0%	48.4%	54.0%
Commercial buildings—heating: fossil fuels	[PJ/yr]	18,011	16,170	10,635	6932	3751	1002	0
Commercial buildings—heating: renewable, electric, and synthetic fuels	[PJ/yr]	10,421	18,567	27,711	29,550	29,386	28,688	25,243
Commercial buildings—heating: renewable share	[%]	36.7%	53.5%	72.3%	81.0%	88.7%	96.6%	100.0%
Commercial buildings—electricity: fossil fuels	[PJ/yr]	2204	1288	676	292	127	44	0
Commercial buildings—electricity: renewables	[PJ/yr]	717	0	−1	−1	2363	−1	−1
Commercial buildings—electricity for heating share	[%]	6.2%	17.0%	19.0%	35.2%	39.2%	45.2%	50.4%
Construction of residential and commercial buildings: fossil fuels	[PJ/yr]	1356	1037	854	809	675	512	273
Residential buildings—heating: renewable, electric, and synthetic fuels	[PJ/yr]	149	494	944	1300	1740	2207	2737
Residential buildings—heating: renewables share	[%]	9.9%	32.3%	52.5%	61.6%	72.0%	81.2%	90.9%

sectors, published in the IEA World Energy Balances. The future values until 2050 are based on the projections for the analysed service and industry sectors documented in Chaps. 5 and 6.

The supply side for the building and construction sectors is based on the 1.5 °C pathway for energy utilities, as documented in Chap. 12 . In contrast to the demand side, the supply values for electricity are provided both for room climatisation (heating and cooling) and for appliances (Table 7.7). The total energy-related CO_2 emissions were calculated based on the energy supply mix for heating and electricity generation (Table 7.8).

Table 7.8 OECM—global buildings: energy-related CO_2 emissions

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
			Projection					
Residential buildings: total emission intensity (heating and electricity)	[kgCO_2/kWh]	0.61	0.35	0.17	0.07	0.04	0.01	0.00
Residential buildings: emission intensity—heating per square metre	[kgCO_2/m2]	7.8	5.0	2.6	1.5	0.8	0.2	0.0
Residential buildings: emission intensity—heat	[kgCO_2/kWh]	0.097	0.064	0.036	0.021	0.013	0.003	0.000
Residential buildings: emission intensity—electricity	[kgCO_2/kWh]	0.509	0.291	0.135	0.052	0.024	0.007	0.000
Residential buildings: total emission intensity—compared with 2019	[%]	0%	−36%	−67%	−81%	−89%	−97%	−100%
Residential buildings: total emissions	[MtCO_2/yr]	4578	2830	1343	605	320	74	0
Residential buildings: emissions—heat	[MtCO_2/yr]	1446	975	553	336	201	54	0
Residential buildings: emissions—electricity	[MtCO_2/yr]	3132	1855	789	269	119	21	0
Residential buildings: total emissions—compared with 2019	[%]	0%	−38%	−71%	−87%	−93%	−98%	−100%
Commercial buildings: total emission intensity (heating and electricity)	[kgCO_2/kWh]	19.88	12.64	7.07	3.75	1.91	0.45	0.00
Commercial buildings: emission intensity—heat per square metre	[kgCO_2/m^2]	19.6	12.5	7.0	3.7	1.9	0.4	0.0
Commercial buildings: emission intensity—heat	[kgCO_2/kWh]	0.227	0.154	0.090	0.057	0.036	0.010	0.000
Commercial buildings: emission intensity—electricity	[kgCO_2/kWh]	0.509	0.291	0.135	0.052	0.024	0.007	0.000
Commercial buildings: total emission intensity—compared with 2019	[%]	0%	−36%	−67%	−81%	−89%	−97%	−100%
Commercial buildings: total emissions	[MtCO_2/yr]	5107	3255	1696	810	425	98	0
Commercial buildings: emissions—heat	[MtCO_2/yr]	1975	1400	907	541	306	78	0
Commercial buildings: emissions—electricity	[MtCO_2/yr]	3132	1855	789	269	119	21	0

(continued)

Table 7.8 (continued)

Parameter	Units	2019	2025	2030	2035	2040	2045	2050
Commercial buildings: total emissions—compared with 2019	[%]	0%	−38%	−71%	−87%	−93%	−98%	−100%
Construction: total emissions	[MtCO_2/yr]	128	81	54	38	23	12	0
Construction: emissions—fuels	[MtCO_2/yr]	65	45	34	29	18	11	0
Construction: emissions—electricity	[MtCO_2/yr]	63.1	36.1	19.8	8.9	4.6	1.6	0.0

The specific energy-related CO_2 emissions are also provided for power and heat generation, as well as per square meter of floor area, for residential and commercial buildings. The specific energy demand and the CO_2 emissions per square meter are key performance indicators for the finance industry for real estate. Moreover, these parameters are used for regulatory frameworks, such as the EU energy performance for building directive (EU, 2010).

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