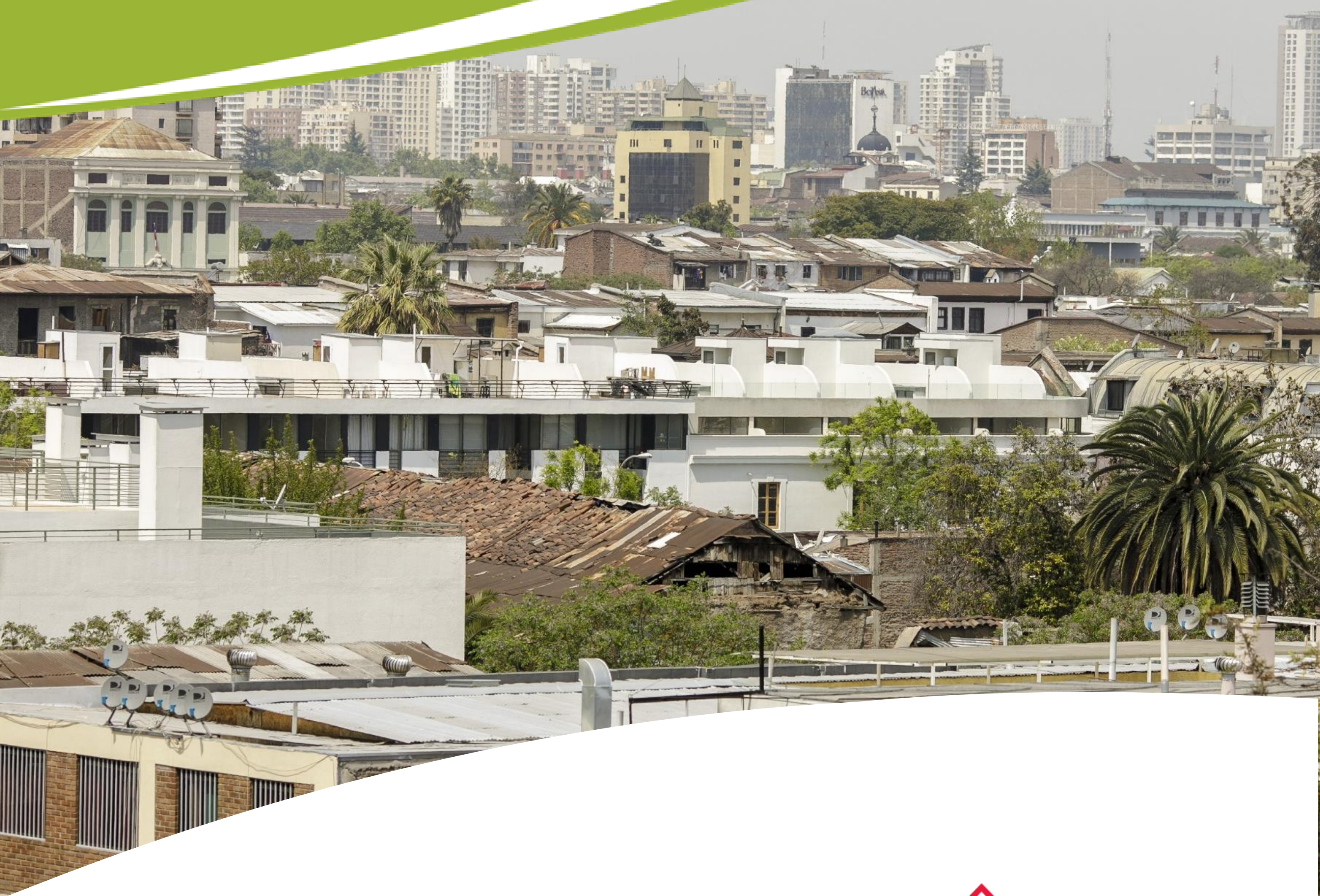
BUILDING SECTOR EMISSIONS IN HOT CLIMATE ZONES

APPROACHES FOR THE MOST EFFECTIVE EMISSION MITIGATION IMPACTS

Working Paper
October 2021



EEDUS
Energy Efficiency for Sustainable Urban Development

PEEB
PROGRAMME FOR ENERGY EFFICIENCY IN BUILDINGS

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CONTENT

1. INTRODUCTION AND SCOPE

1.1. Building decarbonization – a systematic approach for hot climates

The buildings and construction sector combined accounted for 38% of global energy-related CO_2 emissions in 2019[1]. Energy demand and emissions from buildings are expected to continue to grow strongly, mainly in countries in hot climates, where strong population growth and increasing prosperity will lead to higher energy needs, especially for air conditioning of interior spaces in hot climates.

To drive the **decarbonisation of the building sector**, policy makers face the challenge of aligning their climate policies for the building sector to achieve the most cost-effective CO_2 reductions for new construction and retrofits of existing buildings. But which measures will have the greatest impact, and which building types need to be addressed first?

Modeling the building energy demand for different building design measures shows where the greatest CO_2 reductions can be achieved and helps to direct efforts where they will be most effective. It also helps analyze the potential and reasonableness of net-zero buildings in different climate zones to meet the climate goals of the Paris Agreement.

This **working paper** shows which **building types** in which **hot climate zones** have the highest energy reduction and emissions mitigation potentials. It provides guidance on where medium- or high-ambition decarbonisation measures for new buildings or retrofits make the most sense for developing effective national mitigation strategies for buildings in a targeted country. It is based on a **technical expert study** by the global Programme for Energy Efficiency in Buildings (PEEB) and the Energy Efficiency for Sustainable Urban Development (EEDUS) project in Brazil.

1.2. Building types and climate assumptions

The technical expert study made some basic assumptions, which are summarised below. The main building types and climate classifications are briefly described in this section, while the more detailed assumptions and methodology are presented in the third chapter.

Building types

Different building types, such as residential, office, administrative or commercial buildings, have different energy needs due to the purpose, respective use and user behaviour patterns. To simplify the approach, the variety of different residential and non-residential building types was grouped into five main building types.

	Building type	Building characteristics
1	**Bungalow**	Residential single-family house, 1 storey, housing units with 60 m^2 area
2	**Town House**	Residential multi-family row house, 2 storeys, units with 80 m^2 area
3	**Apartment**	Residential multi-family apartment building, units between 40m^2 an 80m^2
4	**Hotel**	Multi-storey hotel building or student dormitory, average single rooms 22 m^2
5	**Office**	Multi-storey office or administrative building, average floor area of 450 m^2

[1] Global Alliance for Buildings and Construction (GlobalABC). 2020 Global Status Report.

Figure 1: Main building types (Source: Österreicher, Seerig (2020), Building Climate Study)

Climate zones

Energy demands in buildings vary due to the specific climatic conditions, such as average daily and nightly temperatures, temperature amplitudes between day and night, different air humidity levels, solar radiation intensities and prevailing air currents. Despite many general similarities, there are often significant climatic differences from one hot climate zones to the other that require fundamentally different construction methods and building designs.

The various hot climates and sub-climate zones have been grouped into five main climate zones, according to the Köppen climate classification[2].

Figure 2: Main hot climate zones and representative cities (Source: Elaboration by PEEB based on Österreicher, Seerig (2020), Building Climate Study)

Climate data and climate change

To consider the effects of anthropogenic climate change, two different climate data sets were used as a basis for the simulations. On one hand, climate data with typical meteorological average values for the period from 2006 to 2015 was used to reflect the current climate conditions in hot climates. In addition, data for the projected climate in 2050 was used, which considers the increase in average temperatures as well as changes in other climate values for the five main climate zones.

[2] Köppen, W. (1884). The thermal zones of the Earth according to the duration of hot, moderate and cold periods and of the impact of heat on the organic world, Meteorol. Z. Retrieved from http://koeppen-geiger.vu-wien.ac.at/pdf/Koppen_1884_2.pdf

Baseline and scenarios

The following baseline and three improvement scenarios were analysed for each of the five different building types and five main climate zones.

Baseline: For each of the five main building types reference models have been defined, reflecting typical building structures, construction methods and building components, as well as standard building materials, technologies, equipment and appliances.

Retrofit scenario: The " retrofit scenario" (S1) focuses on the renovation of an existing building typology with a low energy performance. In this scenario, only measures that are technically feasible and economically viable for retrofitting are considered, such as moderate improvement of the building shell and of the building energy system. It is assumed that only buildings in good structural condition that have the potential for energy improvements (as an alternative to their demolition) are included in this scenario.

Basic new build scenario: The "basic new building scenario" (S2) defines a new building scenario that is built with a slightly higher energy efficiency standard than in the "basic retrofit scenario" (S1). The building envelope has significantly improved values compared to the baseline and the S1 scenario and includes additional measures such as flexible solar shading and reflective coatings in the surfaces. The technical building equipment is the same as in the S1 scenario but supplemented with a mechanical instead of a natural ventilation system.

Ambitious new build scenario: The "Ambitious New Construction Scenario" (S3) considers the same architectural improvements as the "basic new build scenario" (S2), but with a significantly improved quality in terms of technical building equipment and the integration of renewable energies. In this scenario, both solar thermal and photovoltaic (PV) systems are included. This scenario is considered challenging but feasible within the selected climate zones.

	Baseline and scenarios	**Scenario characteristics**
	Baseline	Baseline building with conventional energy performance standard
1	**Retrofit scenario**	Retrofitted building with basic energy efficiency standard compared to baseline
2	**Basic new build scenario**	New building with basic energy efficiency standard compared to baseline
3	**Ambitious new build scenario**	New building with a high energy efficiency standard (nearly zero carbon building) compared to baseline

Table 1: Baseline and scenarios (Source: Österreicher, Seerig. 2020: Building Climate Study)

2. MOST EFFECTIVE APPROACHES FROM DIFFERENT PERSPECTIVES

This chapter presents the most effective energy saving and CO_2 reduction potentials in the main building types in hot climates from different perspectives under these guiding questions:

- Which **climate zones** offer the highest mitigation potentials?
- Which **building types** have the highest mitigation potentials?
- Which of the three **improvement scenarios** can achieve the highest impacts?
- What are the most effective **building improvement measures**?
- Where are the greatest **impacts of climate change** by 2050?
- Which building types achieve **zero carbon** easily?

2.1. Climate zones: Which climate zones offer the highest mitigation potentials?

As to be expected, the absolute highest energy saving and CO_2 reduction potentials for all building types exist in the hottest climate zones, the **hot arid and tropical climate zones**.

	Climate zone	Energy demand	CO_2 reduction potential
1	Hot arid climate (semi-arid)	**Very high cooling demand**	**Very high**
2	Tropical wet and dry climate (savannah)	Medium cooling demand	Medium
3	Tropical wet climate (rainforest)	**Very high cooling demand**	**Very high**
4	Humid subtropical climate	Low cooling demand	Low
5	Mediterranean climate (hot summer)	Low cooling demand	Low

Table 2: Energy demand and CO_2 reduction potential of hot climate zones (Source: Österreicher, Seerig. 2020: Building Climate Study)

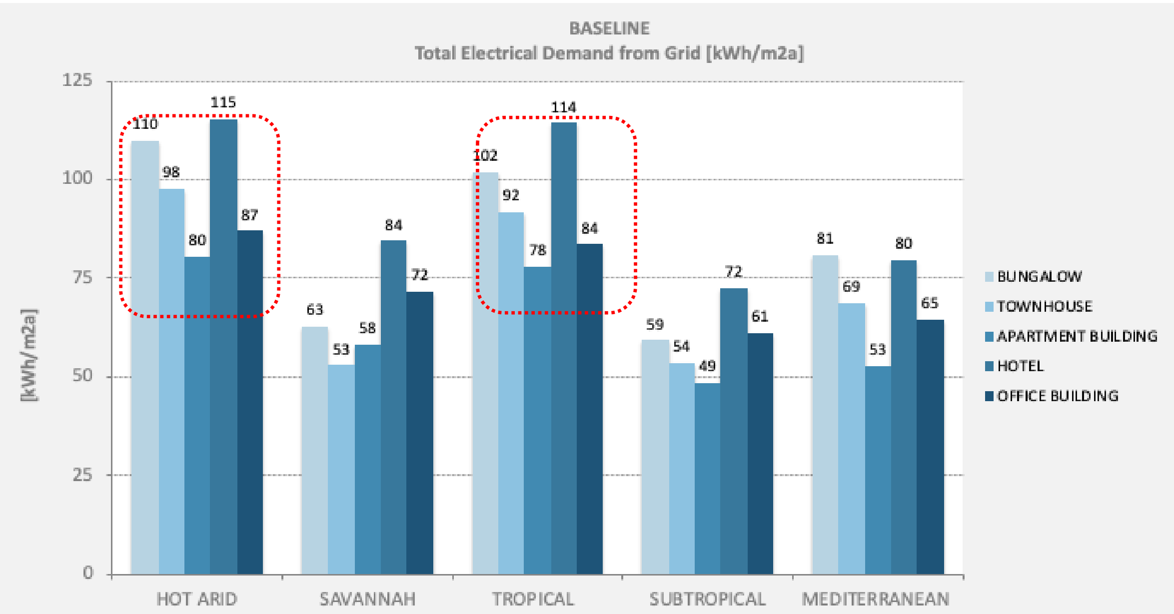

Figure 3: CO_2 reduction potential per climate zone, highlighting hot arid and tropical climate zones (Source: Österreicher, Seerig (2020): Building Climate Study)

The example of the bungalow shows that the cooling demand and thus the total energy demand is highest in the hot arid and tropical climate zones.

2.2. Building types: Which building types have the highest mitigation potentials?

In absolute terms, the greatest energy and emission savings can be achieved in the **bungalow, townhouse and hotel** building types. In the case of **bungalow**, this is due to the relatively high and unfavourable surface-to-volume ratio; resulting in higher temperature losses through the building envelope and thus high energy consumption for space cooling. There is also a high consumption of domestic water, comparable to the water consumption in hotels.

The **office building** has high internal loads (equipment and lighting). Domestic hot water plays only a minor role. Increasing energy efficiency in this type of building can be achieved – in addition to passive building design measures – primarily through more efficient space cooling (night cooling and controlled ventilation with heat recovery) and the use of energy-efficient lighting. The use renewable energies for water heating has a smaller impact on the total energy demand of office buildings due to the less use of water.

	Building type	Energy-saving and CO_2 reduction potentials
1	**Bungalow**	**High due to high surface-to-volume ratio**
2	**Townhouse**	**Medium**
3	**Apartment building**	Low
4	**Hotel**	**High due to high cooling and hot water demand**
5	**Office**	Low

Table 3: Energy-saving potential of building types (Source: Österreicher, Seerig 2020: Building Climate Study)

In residential building types, the savings between the scenarios are significant, similarly in hotels. In offices, due to the use-related internal loads and low hot water demand, the savings potentials are significantly lower.

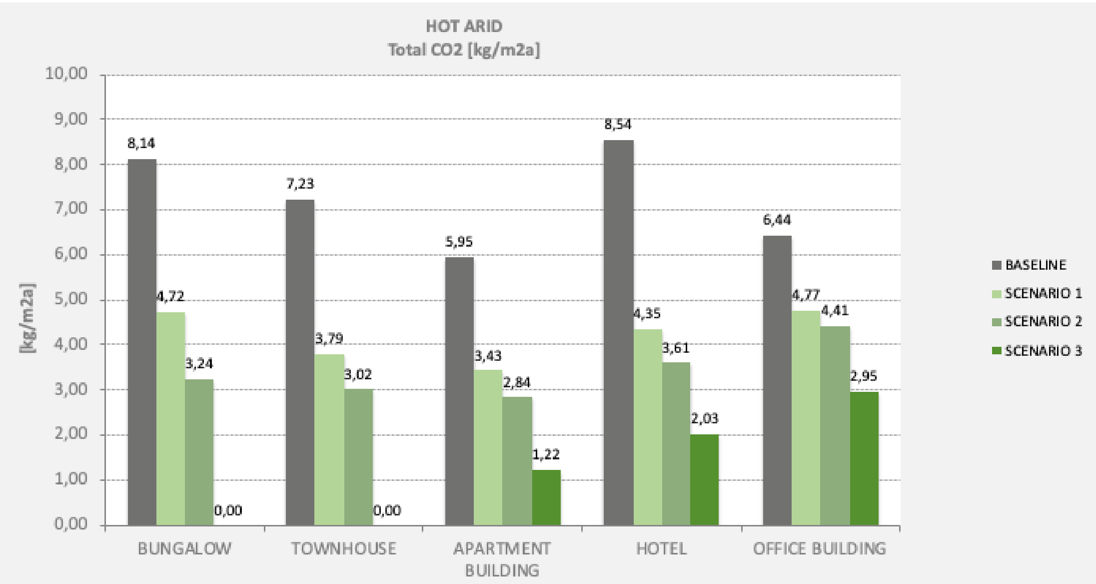

Figure 4: CO_2 reduction potential per building type, highlighting bungalow and hotel types (Source: Österreicher, Seerig (2020): Building Climate Study)

2.3. Scenarios: Which improvement scenarios have the highest mitigation effects?

In *absolute* terms, the highest energy saving and CO_2 reduction potentials for all building types can be achieved by the **"ambitious new build scenario" S3**, followed by the basic new build and retrofit scenarios.

In *relative* terms, the "retrofit scenario" S1 and the "basic new build scenario" S2 offer the highest energy saving and CO_2 reduction potentials **compared to the baseline**.

	Scenario	Energy-saving and CO_2 reduction potentials
1	**Retrofit scenario S1**	Highest energy-saving potential compared to baseline. Good option for a cost-effective retrofit.
2	**Basic new build scenario S2**	Highest energy-saving potential compared to baseline. Good option for a cost-effective new building.
3	**Ambitious new build scenario S3**	**Highest energy-saving potential in absolute terms**, Suitable for higher ambition in new buildings.

Table 4: Energy-saving potential of scenarios (Source: Österreicher, Seerig. 2020: Building Climate Study)

It can further be stated that as the **ambition levels of the scenarios increase**, the differences in energy saving and CO_2 reduction potentials gradually decrease (the differences between the bars in the diagramme below flatten out). As a conclusion can be said, the ´simpler´ and less ambitious a scenario and its measures are, the more important and effective the **climate-specific building improvement** approach is.

In addition, while the effect of increased ambition 'flattens' the differences in impact due to the climate zone, the importance of **internal heating and cooling loads** (through building use and user behaviour) increases and matters. Especially for the **"ambitious new building scenario"**, it is of great importance many people are in the building at what time of day and week and what are their specific user requirements.

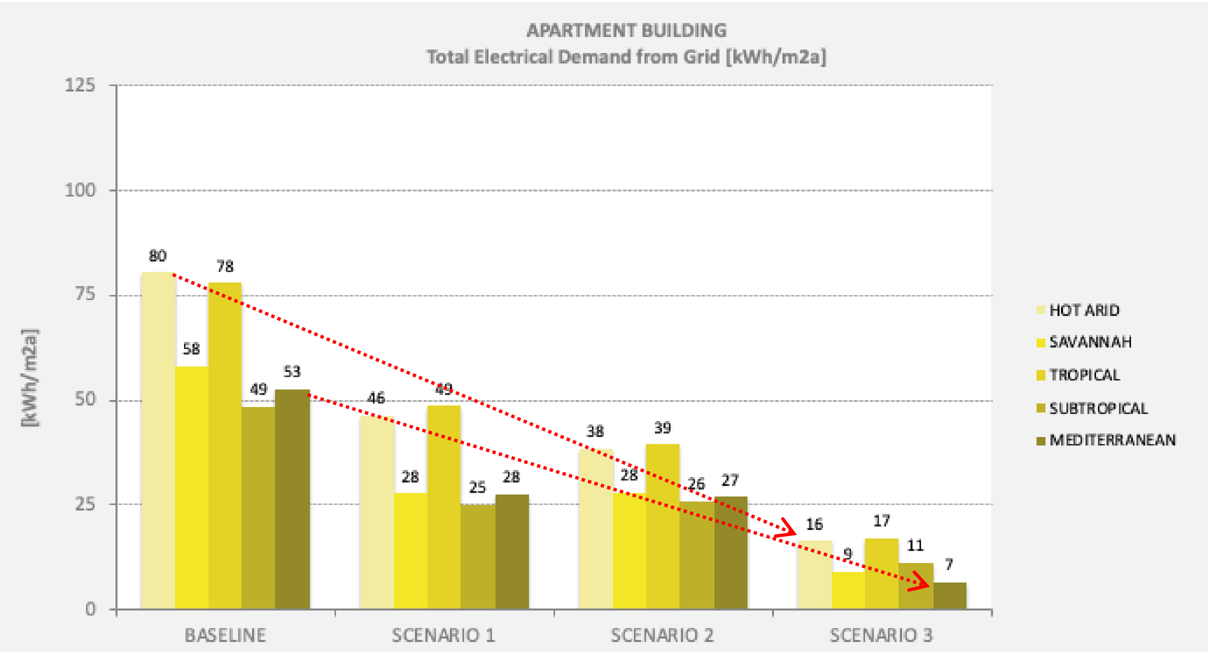

Figure 5: Electrical energy reduction potential per improvement scenario, example apartment building (Source: Österreicher, Seerig (2020), Building Climate Study)

2.4. Building measures: What are the most effective building improvement measures?

The building improvement measures for the five building types can be catagorized into: **building design**, **building systems** and **renewable energy systems**. For each scenario, a combination of measures from these three categories is applied, which increases in complexity and ambition depending on the scenario.

Building design measures (mainly scenario 1)

Passive building design measures focus mainly on reducing cooling and heating energy demand and include: Improved building envelope, improved windows, fixed and adaptive external solar shading, and light-coloured reflective surfaces on roofs and facades.

The greatest impact can be achieved through **improved windows**, with high-performance glazing showing good effects as a first step. The use of **external solar shading** is of similar importance in all regions. Both measures reduce cooling loads without any operating energy.

In regions with high sun elevation angles (in all climate zones except the mediterranean climate), a fixed external sunshade or manually controlled shading is sufficient. In regions with a mediterranean climate with lower sun elevation angles, a flexible external sunshade is required. For good performance of this type of shading, automated control is recommended.

Building system measures (mainly scenario 2)

Based on passive measures, the focus of these measures is on efficient energy supply with technical building systems. These measures include: Decentralised split units, central compression systems, ceiling fans, night cooling and controlled ventilation with heat recovery.

The greatest effect can be achieved through **improved split units** (or their replacement by a central compression system) in connection with **night cooling**.

On the one hand, night cooling reduces the cooling load in the building and on the other hand, the improvement of the cooling units reduces the operating energy (electrical energy). The use of ceiling fans has an additional but minor impact on thermal comfort.

Renewable energy system measures (exclusively scenario 3)

The renewable energy system measures focus on integrating sustainable energy sources into the building to meet all or part of its electricity and heating energy demand. These measures include water heating through solar thermal, photovoltaic, solar heating and cooling, and the use of heat pumps. The use of **domestic hot water by solar thermal** has the greatest effect, especially in buildings where domestic hot water plays an important role, such as residential buildings and hotels. Another important measure is the use of **photovoltaics** for the improved scenarios in connection with **heat pumps**.

To fully exploit these applications an appropriate alignment of the modules is essential: The orientation and tilt should be chosen so that their energy production remains sufficiently high throughout the whole year without producing extensive peaks or gaps during summer or winter respectively. To achieve the highest possible performance in each climate zone, the tilt angle of PV systems and solar collectors should be 0° in the hot dry climate, savannah climate, tropical climate and subtropical cimate, while it should be set to 30° and the azimuth angle to 0° (south orientation) in the mediterranean climate.

The following table shows an overview of all simulated improvement measures and highlights the most effective ones for each scenario – always in combination with the other measures.

	Building measures	Baseline	Scenario S1	Scenario S2	Scenario S3
Building design	Standard building shell	▪			
	Improved building shell		▪		
	High performance building shell			▪	▪
	Standard windows	▪			
	Improved windows		Most effective		
	High performance windows			▪	▪
	No external shading	▪			
	Fixed external shading		Most effective		
	Flexible external shading - manual		Most effective	▪	
	Flexible external shading - automatic				▪
	Light coloured reflective coatings		▪	▪	▪
Energy systems	Decentralized split units	▪			
	Improved decentralized split units		▪	Most effective	
	Central compression system				▪
	Ceiling fan		▪	▪	
	Night cooling - natural		▪	Most effective	
	Night cooling - mechanical			Most effective	
	Controlled ventilation with heat recovery				▪
Renewables	Domestic hot water by solar thermal		▪	▪	Most effective
	Photovoltaics				Most effective
	Solar heating				▪
	Solar cooling				▪
	Heat pump (heating & cooling)				Most effective

Table 5: Most effective building measures in combination with the other measures (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

Additional potential measures without essential effect

There are several measures, which have been tested out in the simulations but not considered suitable due to the non-effectivity in the presented climates:

- **Evaporative Cooling:** With evaporative cooling the room air is cooled by means of increasing the air humidity ratio to 70 %. The simulated climates are already humid: the effect of additional evaporation is subsequently negligible.
- **Earth-Ducts for Pre-Conditioning:** Earth ducts provide that fresh air flows through a channel in the ground, where it is pre-cooled or pre-heated and is then transported into the heat exchanger. Since the simulated climates have a small annual amplitude variation of air and ground temperature, this results in a poor efficiency of the earth ducts. The use of the heat exchanger makes the effect of the earth ducts negligible.
- **Concrete Core Activation:** Through concrete core activation, the cooled water is supplied from a water-to-ground heat exchanger to a building construction with integrated pipes (e.g. a concrete ceiling). To cool down the interior space with a

temperature of 26°C, the temperature of the water loop should vary between 18°C and 22°C. This means that the soil temperature should be at a level of 13°C -15°C. However, the simulated climates have significantly higher soil temperatures in summer. This results in a negligible efficiency of the system.

2.5. Climate change: Where are the greatest impacts of climate change by 2050?

Due to **global warming** with increasing average temperatures, the cooling demand for all building types in all hot climates will generally increase. The building energy modeling shows that the **highest increase** in energy demand and CO_2 emissions will occur in the **hottest climates**.

In contrast, in **subtropical and mediterranean climates**, the decrease in **heating demand** due to global warming will be **negligible**.

	Climate zone	Increase in energy demand by 2050
1	**Hot arid climate (semi-arid)**	**Highest increase in energy demand**
2	**Tropical wet and dry climate (savannah)**	Moderate increase in energy demand
3	**Tropical wet climate (rainforest)**	**Highest increase in energy demand**
4	**Humid subtropical climate**	Moderate increase in energy demand
5	**Mediterranean climate (hot summer)**	Moderate increase in energy demand

Table 6: Climate change impacts on energy demand by 2050 (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

The modeling also shows that the **relative differences** in energy demand and CO_2 reduction potentials between the different scenarios and building types are **similar** for the current and projected 2050 climate states.

The more ambitious the improvement scenario, the lower will be the impact of climate change.

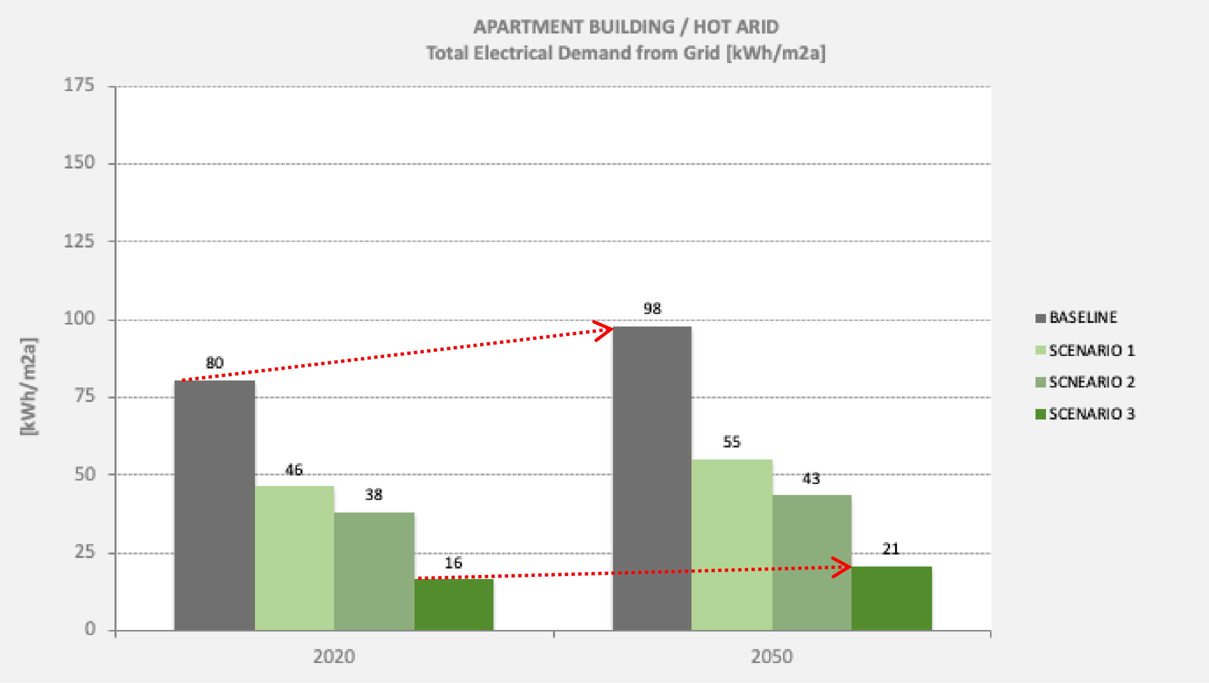

Figure 6: Impacts of climate change by 2050 on electrical energy demand, example apartment building in hot arid climate zone (Source: Österreicher, Seerig (2020): Building Climate Study)

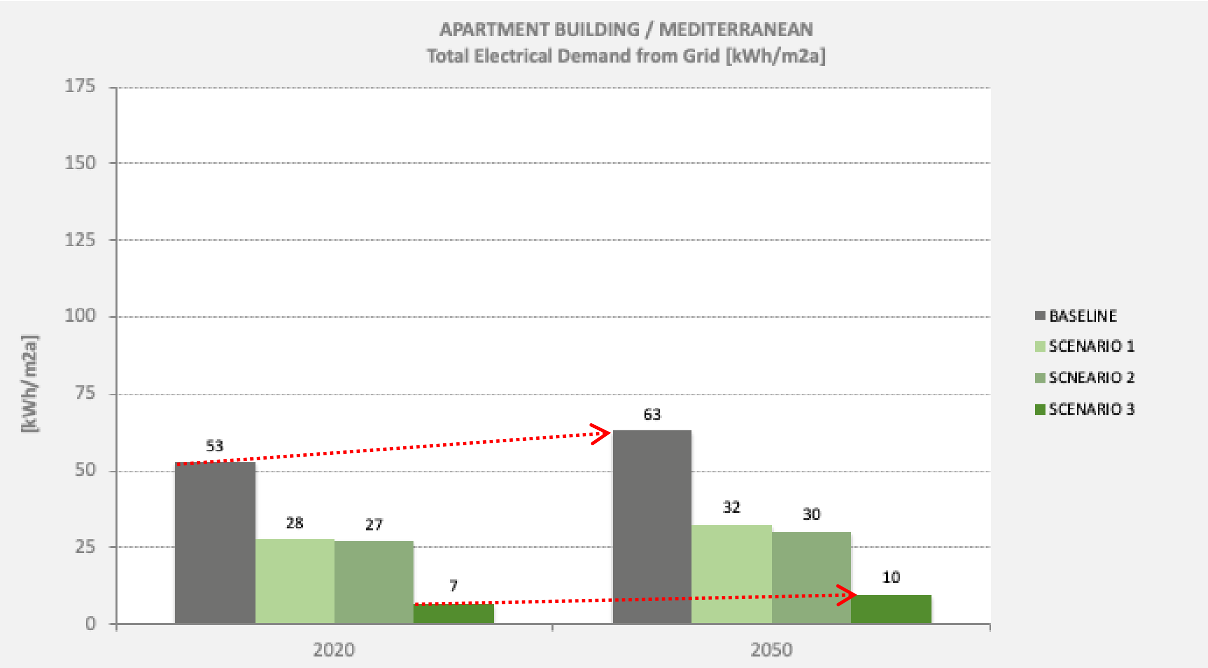

Figure 7: Impacts of climate change by 2050 on electrical energy demand, example apartment building in mediterranean climate zone (Source: Österreicher, Seerig (2020), Building Climate Study)

2.6. Zero-carbon: Which building types achieve zero carbon easily?

In the **bungalow and townhouse** building types, the ambitious improvement scenario 3 can achieve zero-carbon buildings in all climate zones without additional measures or high effort. This is directly related to the relatively large available surface area for photovoltaic (PV) systems on facades and roofs.

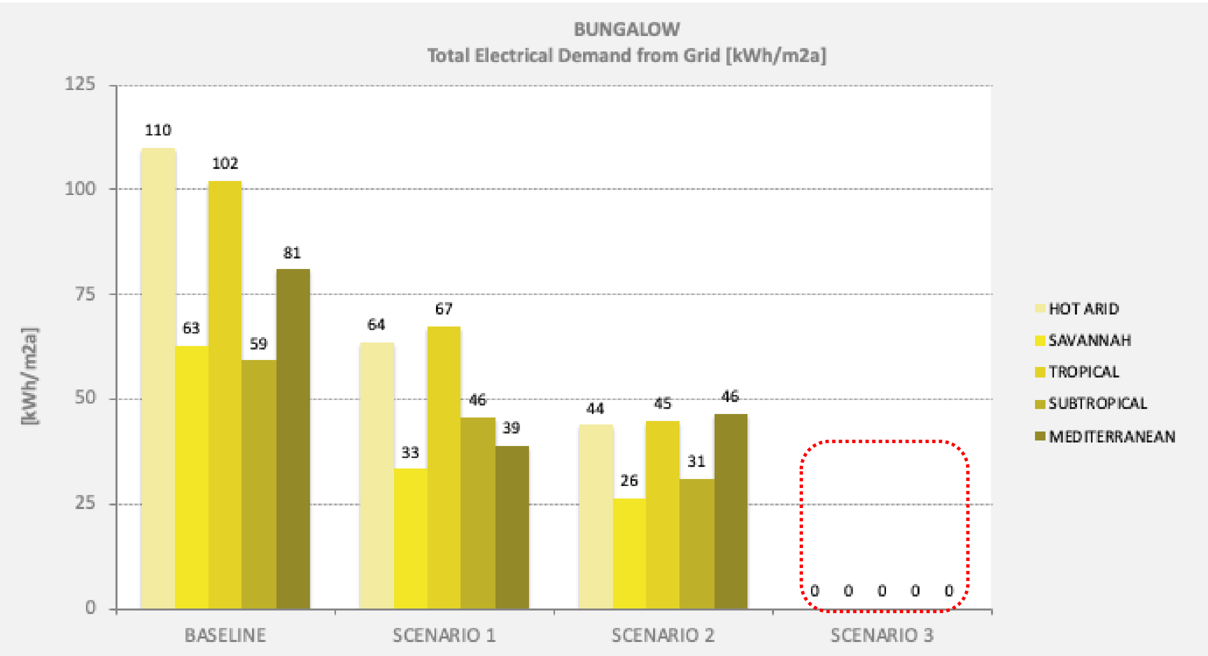

Figure 8: Zero carbon building possible in scenario 3, example bungalow (Source: Österreicher, Seerig (2020): Building Climate Study)

The **apartment building type** can almost achieve near-zero carbon building with Scenario 3, but some additional measures would be needed to achieve full carbon neutrality.

The most difficult building type to achieve carbon neutrality is the **office building**, followed by the **hotel**, as the energy loads are generally higher and the potential area to incorporate renewable energy systems is smaller compared to buildings with a high *floor area to volume ratio* (such as the bungalow type). To achieve zero carbon requires the use of additional areas or district solutions for PV systems, which are feasible but represent a greater effort.

For office buildings and hotels, the mediterranean, subtropical, and savanna climate zones are best suited for achieving a zero-carbon building.

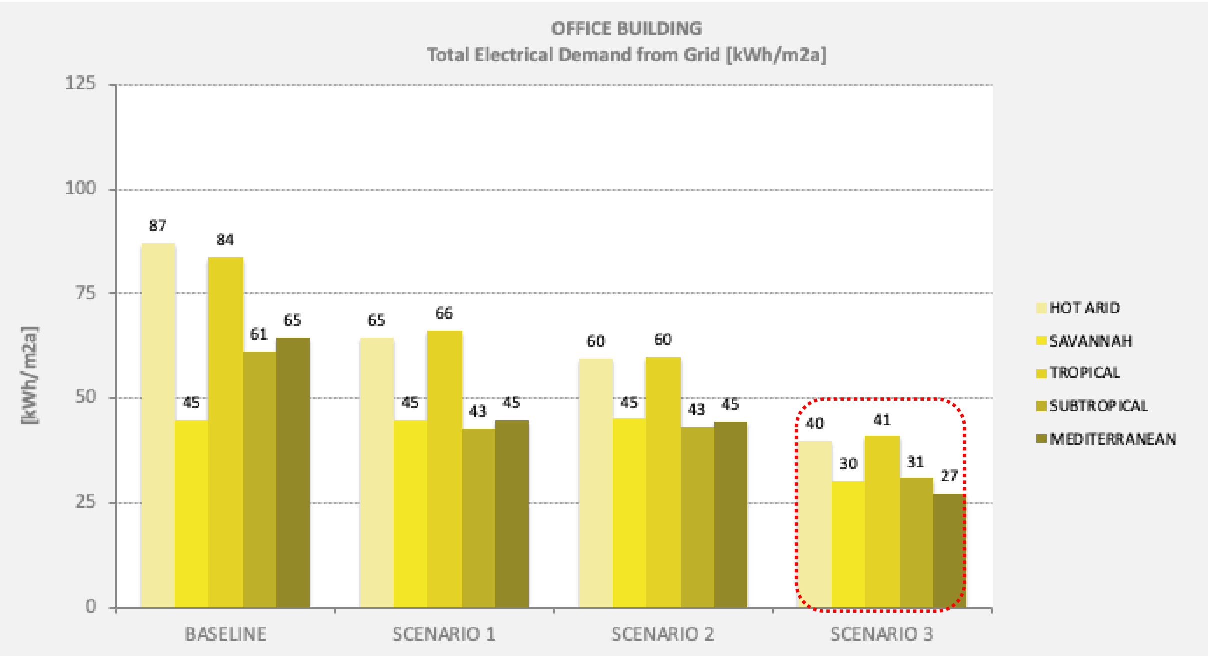

Figure 9: Zero carbon building hardly possible in scenario 3, example office building (Source: Österreicher, Seerig (2020): Building Climate Study)

In summary, zero carbon is easier to achieve in building types with predominantly **low internal electrical loads** and where the available **area for renewable energy installation** is high compared to the floor area. Therefore, zero carbon can be most easily achieved in the bungalow and the townhouse building types in all climate zones.

	Building type	**Zero carbon achievability**
1	**Bungalow**	**Zero carbon can be achieved with scenario 3 in all climate zones**
2	**Townhouse**	**Zero carbon can be achieved with scenario 3 in all climate zones**
3	**Apartment building**	Zero carbon can **almost** be reached with few additional measures
4	**Hotel**	**Difficult** building type to achieve carbon neutrality, Easier reachable in the mediterranean, subtropical and savannah climates
5	**Office**	**Most difficult** building type to achieve carbon neutrality, Easier reachable in the mediterranean, subtropical and savannah climates

Table 7: Zero carbon achievability (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

3. METHODOLOGY, ASSUMPTIONS AND COST EFFECTIVENESS

This section introduces the methodology used, the building technology assumptions and the results of the technical expert study that simulated the energy demand and CO_2 emission reduction potentials of the main building types in the main hot climate zones for the three energy optimisation scenarios.

3.1. Methodology and assumptions

The methodology consists of five steps:

1. **Baseline Model Definition**
2. **Baseline Model Simulation** for the 5 building types and 5 climate zones
3. **Definition of Scenarios**
4. **Simulation of Scenarios** and
5. **Presentation of Results** of the simulation of the optimization scenarios.

The methodology focusses on simplifying the individual models, the sound definition, elaboration and assessment of the base-line models and associated scenarios, and the clear and functional presentation of the results.

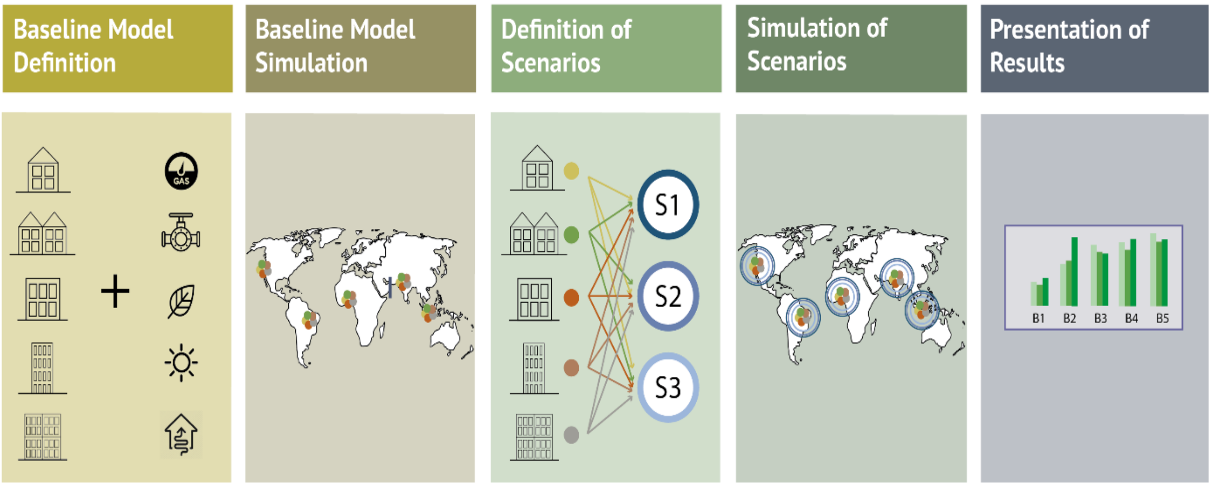

Figure 10: Methodology of improvement scenarios (Source: Österreicher, Seerig (2020), Building Climate Study)

Step 1: Definition of baseline model

In the first step, the five building types were defined in detail regarding their architecture, orientation, building systems and user requirements. The basic models are provided as 3d architectural models, which serve as visualisation and data set for the simulation. The buildings were placed in a theoretical urban context with no additional obstructions or shadows from other structures.

The building designs were developed for a variety of architecturally and climatically different regions. Therefore, the designs are free from specific styles that are prevalent in the different countries. The theoretical approach allows conclusions to be drawn about the most suitable solutions for specific climate zones, building types and quality improvement.

The internal gains are based on international standards[3] and are defined as follows:

Building Type No.	Bungalow	Townhouse	Apartment	Hotel	Office
Building Type	Residential Building			Hotel / Student dormitory	Office Building
Activity [W/Person]	70			70	70
Presence [m^2/Person]	30			Hotel room: 15 Office: 14 Restaurant: 5 Other area: 0	Office: 10 Other areas: 0
Lighting [W/m^2]	2.7			Hotel room: 2.7 Office: 15.9 Restaurant: 5 Other areas: 2.7	Office: 12.5 Other areas: 2.7
Equipment [W/m^2]	8			Hotel room: 8 Office: 15.9 Restaurant: 2 Other areas: 0	Office room: 10 Other areas: 0

Table 8: Assumptions for internal gains of five building types (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

For the description of the architectural measures and technical systems, refer to section 3.2.

Step 2: Simulation of baseline model

In the second step, the basic models comprising the five different building typologies were simulated with the thermal-dynamic simulation application *EnergyPlus*[4] for the five investigated climate zones. Each model is based on one of the five previously developed building types with specific frameworks for materials, building services, attendance schedules, lighting schedules and equipment schedules.

Two different climate datasets have been applied to the simulations. The **first dataset is based on current climate data** with average climate data of the last 10 years (2006 to 2015), Based on the cities of Brasilia, Casablanca, Petrolina, Recife and Sao Paulo.

The typical meteorological years (TMY) were compiled by the "TMY Generator" web server by the "EU Science Hub", the European Commission's science and knowledge service[5]:

This dataset is therefore showing results based on the assumption that the climate does not significantly change over the coming years.

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[3] SIA 2024 - Space utilization data for energy and building technology

[4]***EnergyPlus*** is a dynamic building energy simulation program (with hourly calculation) used by engineers, architects and researchers to model both energy consumption (for e.g. heating, cooling, ventilation, lighting and plug and process loads) and water consumption in buildings.

[5] https://re.jrc.ec.europa.eu/pvg_tools/en/#TMY and https://ec.europa.eu/jrc/en/PVGIS/tools/tmy

The second dataset is a future projection for the year 2050, which takes changing climate scenarios into account. This dataset is showing results based on the assumption that the climate does change over the coming years.

For the compilation of the second dataset, the dataset 1 was adjusted using the climate file generator "CCWorldWeatherGen", developed by the University of Southampton, United Kingdom.[6] A comparative study of climate file generators is available.[7]

Step 3: Definition of scenarios

In the third step 3, the three scenarios are defined using challenging but achievable measures for the areas in the investigated climate zones. The measures include material properties and technical building systems that are suitable for a wide range of applications and building types. Furthermore, the selected measures should be suitable for the respective countries in the different climate zones. To allow for a broad development approach, three different scenarios were defined following the baseline. The measures are divided into measures related to architecture and measures related to technical building equipment and renewable energies. The aim was to propose realistic and accessible scenarios with high replication potential.

Step 4: Simulation of scenarios

In the fourth step, the simulations of the three scenarios were carried out. Each of the baseline models was modified for each climate zone and modelled in *EnergyPlus*. Based on the respective climate data, the building model and other framework conditions (such as lighting and equipment schedules), hourly energy performance data is generated over the period of one year, providing detailed results on the behaviour of the building under different framework conditions.

Step 5: Elaboration of results

As a result, there are 200 different models covering 5 building types in 5 climate zones and four scenarios (baseline and 3 scenarios).

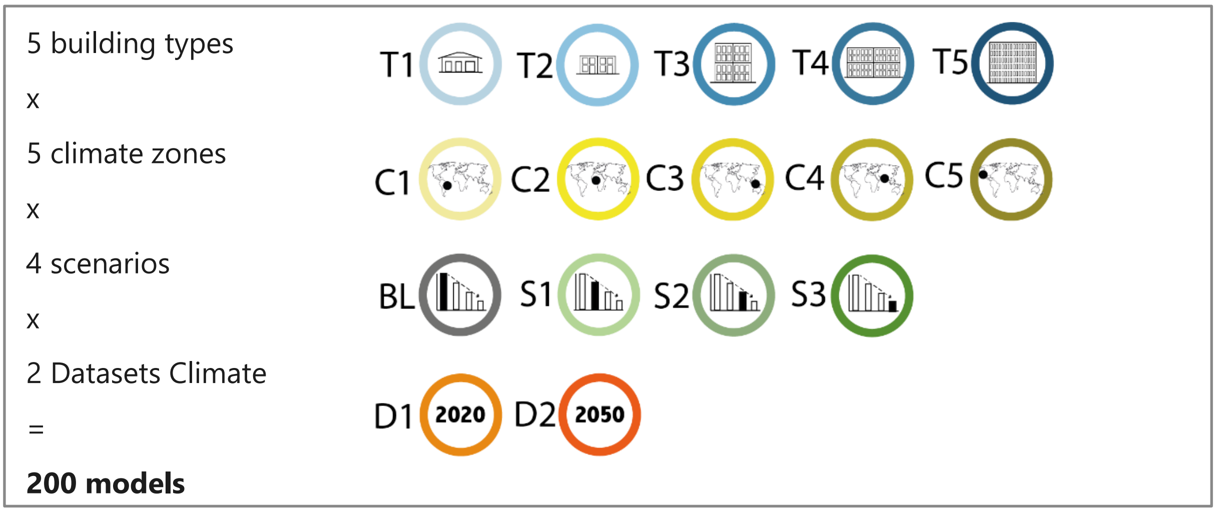

Figure 11: Methodology: Models (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

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[6] https://energy.soton.ac.uk/climate-change-world-weather-file-generator-for-world-wide-weather-data-ccworldweathergen/

[7] https://www.sciencedirect.com/science/article/pii/S187661021734849X

Each simulation was conducted for the following outcomes and relates to the three objectives.

Cooling Demand [kWh/m²a]

ENERGY DEMAND

Heating Demand [kWh/m²a]

ENERGY DEMAND HEATING

Energy Demand Electrical [kWh/m²a]
Cooling Energy Demand Electrical
Room Heating Energy Demand Electrical
DHW Energy Demand Electrical
Lighting and Equipment Energy Demand Electrical

ENERGY DEMAND ELECTRICAL

Total Electrical Demand from Grid [kWh/m²a]
(Total Electrical Demand minus Total Generation Renewables)

TOTAL ELECTRICAL ENERGY DEMAND FROM GRID

Total CO_2 [kg/m²a]

TOTAL CO_2

Figure 12: Objectives (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

3.2. Assumptions for baseline and scenarios

Building design measures

The following assumptions for the architectural, technical building systems and renewable energy systems have been defined for all five building types.

S1

Retrofit scenario: The measures of the **retrofit scenario (S1)** are mainly **architectural measures** focussing on **passive building design measures** with the goal of reducing the energy demand of the buildings, mainly for cooling and, in some climate zones, for heating.

S2

Basic new build scenario: The measures of the **basic new build scenario (S2)** are mainly **architectural measures plus energy efficiency measures** focussing on reducing the energy demand plus increasing the efficiency of the energy supply with highly efficient technical building systems.

S3

Ambitious new build scenario: The measures of the **ambitious new building scenario (S3)** are architectural and energy efficiency measures plus the integration of renewable energy systems to reduce the energy demand to a minimum and increase the energy efficiency to the highest aspiration level towards **near-zero energy buildings**.

	Building measures	Baseline	Scenario S1	Scenario S3	Scenario S3
Building design	Standard building shell	▪			
	Improved building shell		▪		
	High performance building shell			▪	▪
	Standard windows	▪			
	Improved windows		▪		
	High performance windows			▪	▪
	No external shading	▪			
	Fixed external shading		▪		
	Flexible external shading - manual			▪	
	Flexible external shading - automatic				▪
	Light coloured reflective coatings		▪	▪	▪
Energy systems	Decentralized split units	▪			
	Improved decentralized split units		▪	▪	
	Central compression system				▪
	Ceiling fan		▪	▪	
	Night cooling - natural		▪		
	Night cooling - mechanical			▪	
	Controlled ventilation with heat recovery				▪
Renewables	Domestic hot water (DHW) by solar thermal		▪	▪	▪
	Photovoltaics				▪
	Solar heating				▪
	Solar cooling				▪
	Heat pump (heating & cooling)				▪

Table 9: Building standard of baseline and building measures for three scenarios (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

Building material properties

The material properties for the baseline and scenarios have been defined with the following values for all 5 building types.

		Unit	Baseline	Scenario S1	Scenario S3	Scenario S3
U-Values	External Walls	W/m^2K	1,70	0,40	0,31	0,31
	Windows Glass	W/m^2K	4,00	2,00	1,40	1,40
	Windows Frame	W/m^2K	1,80	1,80	1,00	1,00
	Internal Walls to Staircase	W/m^2K	2,40	2,40	2,40	2,40
	Floor Slab	W/m^2K	1,48	0,32	0,20	0,20
	Roof Flat	W/m^2K	0,99	0,43	0,19	0,19
	Roof Slanted	W/m^2K	1,19	0,39	0,20	0,20
G-Value	Windows Glass	%	80,00	75,00	70,00	70,00
Infiltration	Air Change Rate	1/h	0,50	0,50	0,50	0,50

Table 10: Material properties for baseline and the scenarios (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

3.3. Cost effectiveness of scenarios

The costs of the individual measures are highly dependent on the location of the building which influences not only the actual cost of the material or systems, but also the availability of the materials and systems, the skills of the construction workers, and adequate maintenance. In addition, costs also vary depending on the current and specific economic and market situation.

The following table provides an overview of the different measures for architecture, building systems and renewable energy systems and a rough estimate of the additional costs. It can be seen that except for the measure "improved high-performance windows", all measures related to potential architectural changes are either in the "cost neutral" or "low additional cost" range.

	Building measures	**Baseline**	**Scenario S1**	**Scenario S3**	**Scenario S3**
Building design	Standard building shell	▪			
	Improved building shell		▪		
	High performance building shell			▪	▪
	Standard windows	▪			
	Improved windows		▪		
	High performance windows			▪	▪
	No external shading	▪			
	Fixed external shading		▪		
	Flexible external shading - manual			▪	
	Flexible external shading - automatic				▪
	Light coloured reflective coatings		▪	▪	▪
Energy systems	Decentralized split units	▪			
	Improved decentralized split units		▪	▪	
	Central compression system				▪
	Ceiling fan		▪	▪	
	Night cooling - natural		▪		
	Night cooling - mechanical			▪	
	Controlled ventilation with heat recovery				▪
Renewables	Domestic hot water by solar thermal		▪	▪	▪
	Photovoltaics				▪
	Solar heating				▪
	Solar cooling				▪
	Heat pump (heating & cooling)				▪

	Cost neutral
	Low additonal cost of maximum +20 %
	Medium additional cost slightly higher than +20%

Table 11: Cost estimate for all measures for Baseline, Scenario 1, 2 and 3 (Source: PEEB based on Österreicher, Seerig. 2020: Building Climate Study)

4. CONCLUSION

The working paper shows which **building types** in which **hot climates** have the highest energy and CO_2 reduction potential. It identifies where medium- or high-ambition decarbonization measures for new buildings and retrofits make the most sense to develop the most effective national mitigation strategies for buildings in a target country.

Both cooling demand and the largest increase in energy demand and CO_2 emissions due to climate change are highest in **hot arid and tropical climates**.

Passive measures such as an improved building envelope, improved windows, and adaptable external solar shading, as well as light-colored reflective surfaces on roofs and facades, are effective ways to reduce the carbon footprint in all hot climates.

To further increase thermal comfort and reduce carbon emissions, sustainable **active thermal building systems** such as central compression systems, ceiling fans, automatic night cooling, and controlled ventilation with heat recovery are essential, especially in non-residential buildings.

All building measures must be supported by **renewable energy measures** to meet all or part of the electricity and heating energy needs. These measures include water heating through solar thermal, photovoltaic, solar heating and cooling, and the use of heat pumps. The use of hot water by solar thermal has the greatest effect, especially in residential buildings and hotels.

Regarding the **additional costs** of the above-mentioned measures, improved windows and heat pumps cause medium costs, which, however, are quickly amortised during the building's operation. External shading, improved decentralised split units and photovoltaics represent low additional investment costs, while reflective coating, night cooling and solar thermal are cost-neutral. However, costs can vary greatly due to local condition and economy.

As a general conclusion, the "simpler" and less ambitious the building improvement measures, the more important and effective is a **climate-adaptive** approach to building improvement. To achieve zero carbon, building types with predominantly **low internal electrical loads** and buildings with available space for **renewable energy installation** are recommended.

ABBREVIATIONS

BIM	Building Information Modelling
BMS	Building Management System
BIPV	Building Integrated Photovoltaic
CAD	Computer Aided Design
CHP	Combined Heat and Power
DHW	Domestic Hot Water
GWP	Global Warming Potential
HP	Heat Pump
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communication Technology
NZEB	Nearly Zero Energy Building
PV	Photovoltaic
RES	Renewable Energy Systems
TAB	Thermally activated slab (Concrete core activation)

FIGURES AND TABLES

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Weather Data, current climate data

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Weather Data, future climate data
CCWorldWeatherGen, University of Southampton, United Kingdom:
https://energy.soton.ac.uk/climate-change-world-weather-file-generator-for-world-wide-weather-data-ccworldweathergen/

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