D4.3. Recommendations for enhanced and integrated strategies, policies and schemes relevant for space cooling

Cool LIFE

Co-funded by the European Union

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor CINEA can be held responsible for them.

Deliverable Information Sheet

Version	Final
Grant Agreement Number	101075405
Project Acronym	LIFE21-CET-COOLING-CoolLIFE
Project Title	Open Source Tools to Face the Increase in Buildings' Space Cooling Demand
Project Call	LIFE-2021-CET
Project Duration	36 months
Deliverable Number	D4.3
Deliverable Title	Recommendations for enhanced and integrated strategies, policies and schemes relevant for space cooling
Deliverable Type	Report
Deliverable Dissemination Level	Public
Work Package	WP4
Lead Partner	IEECP
Authors	Jean-Sébastien Broc, Dario Bottino Leone, Giulia Conforto, Anne-Sofie Nejsum, Evangelos Kyrou, Adrienn Gelesz, Bruno Duplessis, Aadit Malla, Indriany Lionggo, Petra Pomper, Konstantina Karalaiou, Nives Della Valle, Dimitris Athanasiou, Jérémy Clero, Marco Peretto, Simon Pezzutto
Contributing Partners	EURAC, e-think, ABUD, MinesParis-ARMINES, TU Wien
Reviewer	Vlasis Oikonomou
Official Due Date	30/04/2025
Delivery Date	First version published on 05/08/2025 Final version 30/10/2025

List of Acronyms

CAs	Comprehensive Assessments
CBA	Cost-Benefit Analysis
EBC	Energy in Buildings and Communities Programme
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
ESPR	Ecodesign for Sustainable Products Regulation
EU SILC	EU Statistics on Income and Living Conditions
GWP	Global Warming Potential
HVAC	Heating Ventilation and Air Conditioning
IEA	International Energy Agency
LTRS	Long-Term Renovation Strategies
MS	Member State
NAS	National Adaptation Strategies
NAP	National Adaptation Plans
NECP	National Energy and Climate Plans
RED	Renewable Energy Directive
UBEM	Urban Building Energy Modelling

List of Tables

List of Figures

Keywords list

- Space cooling policies
- Comprehensive assessment on heating and cooling
- Building regulations
- Building renovation
- Ecodesign Directive
- Policy recommendations

Disclaimer

Table of Contents

Executive summary

This report aims at summarizing the main lessons learned along the CoolLIFE project about the context and policies relevant to space cooling, and at suggesting recommendations for further developments to promote sustainable solutions in an integrated way. These recommendations build on all the previous work in the project, including literature reviews, syntheses and assessments about space cooling technologies and measures, thermal comfort, behavioural interventions, energy demand for space cooling, effectiveness and impacts of measures, EU policy framework, Member States' policies and financing schemes relevant to space cooling. They are also based on discussions with experts during the national workshops done in Italy (April 2025), Greece (April 2025) and France (July 2025), lessons learnt from analysing a selection of national schemes and experiences, and conclusions and recommendations from other European or international projects.

For each category of recommendations, their presentation starts with summarizing key issues identified and lessons gathered during the project, before describing the suggested recommendations to further disseminate or complement good practices. Overall structure of the suggested recommendations:

Main category	Axis
Starting from the needs, anticipating changes	Starting from the building occupants – citizen
	What solutions for what conditions: considering operating limits and risks
	Linking mitigation and adaptation
	Planning to avoid ineffective and expensive actions in a hurry
	Sustainable space cooling for all: addressing summer energy poverty
A multilevel approach to provide whole-year comfort in a sustainable way	Towards efficient and climate-resilient buildings
	Promoting broader markets of sustainable space cooling solutions linked to adaptation and resilience strategies
	Ensuring an effective enforcement of regulations applicable to cooling systems, from design to disposal
Considering space cooling in the overall energy and climate framework	Assessing the main issues raised by space cooling in the country
	Coordinating the way space cooling is addressed in national planning
	Providing support for local authorities to develop solutions relevant to their territories

Improving the way space cooling is addressed in the comprehensive assessments	Overcoming the data issue
	Using sensitivity analysis to anticipate upcoming challenges
	What the Energy Efficiency First principle means for comprehensive assessments: considering a broader scope of options
	Discussing the coordination between the national and local level

1. Introduction

1.1. Increasing importance of space cooling while still hidden in the heating and cooling policy framework

The European Environment Agency (Quefelec 2023) stressed that final energy consumption for space cooling in residential buildings tripled between 2010 and 2019 in the 19 euro-area countries (based Eurostat data), while households' equipment rate in air conditioning in Europe rose from 14% in 2010 to about 20% in 2019 (based on ODYSSEE data). This shows a **strong increasing trend**.

Cooling was previously estimated to account for around 4% of EU final energy consumption in 2016, with 106 TWh/year for space cooling (i.e. 1.9% of EU final energy consumption) and about 110 TWh/year for process cooling complemented by 0.6 TWh/year for district cooling (Gerard et al. 2021). As space cooling is mostly generated from electricity, its share is primary energy consumption is larger. But it remains **much less than space heating** in most Member States. This explains the focus on space heating in most policies dealing with energy consumption in buildings.

Giussani et al. (2024) provides a complementary assessment of the *useful energy demand*[1] for space cooling in buildings as of 2021, showing that (1) **tertiary buildings** would represent **about 78% of the useful energy demand** for space cooling in EU27. And (2) that **four countries** alone would represent **79% of the useful energy demand** for space cooling in EU27 (Spain: 33.4%; Italy: 24.1%; France: 15.8%; Greece: 5.7%). Moreover, some countries may represent a small share of energy demand in EU27 due to their size, whereas space cooling represents a significant share of their useful energy demand and final energy consumption (e.g. Cyprus and Malta). This explains why space cooling is addressed to **various extents among Member States**. This not only reflects differences in needs for space cooling (e.g. in terms of cooling degree days), but also in terms of equipment rates. Giussani et al. also highlights difficulties encountered when assessing energy demand for space cooling, especially in terms of **data availability**. Complementary assessments at national level are thus useful to improve the evidence base for policymaking.

More frequent and intense heat waves accelerate the trend towards increasing energy demand for space cooling, and contribute to **peak loads** in summertime, and even power cuts such as in Italy in summer 2023. Several National Energy and Climate Plans (e.g. France, Greece, Italy and Spain) stressed that an uncontrolled growth in the cooling demand could be a **concern for energy security**. Likewise, warmer summers and heat waves represent a **major risk for health**, with over 70,000 excess deaths in Europe in 2003, and more than 60,000 in 2022 (Ballester et al. 2023). Heatwaves would cause about 90% of fatalities related to climate-related extreme events (Quefelec 2023). Summer comfort is thus a **major challenge for both mitigation and adaptation policies**.

---

[1] *Useful energy demand* for space cooling represents the net heat extracted from the space area that is cooled. This is different from the *final energy consumption* that represents the energy input to the cooling generators. The conversion factor between useful energy demand and final energy consumption depends on the cooling technology. Most space cooling is delivered by electrically driven cooling equipment that have an energy efficiency ratio greater than 1. Therefore, final energy consumption for space cooling is significantly lower than its useful energy demand.

1.2. CoolLIFE objectives and scope

The CoolLIFE project (November 2022-October 2025) aims to address the need for sustainable solutions to the EU's rising demand for space cooling in buildings. The main objectives of the project are to:

- Develop an open-source tool for mapping and simulating space cooling demand at multiple spatial scales and time horizons.
- Create a publicly accessible knowledge repository on space cooling technologies, user practices, policies, and financing mechanisms.
- Promote passive and nature-based space cooling solutions through scenario modelling and policy recommendations.
- Engage stakeholders involved in the planning, design and implementation of sustainable solutions for space cooling, and related policies.

This report aims at summarizing the main lessons learned about the context and policies relevant to space cooling, and at suggesting recommendations for further developments to promote sustainable solutions in an integrated way.

It is primarily meant for policy makers, officers and analysts, as well as experts and researchers dealing with space cooling and related policies and regulations. Especially these involved in the preparation of National Energy and Climate Plans, comprehensive assessments on heating and cooling, building regulations and national building renovation plans (formerly long-term renovation strategies). But more generally, it can of interest for any stakeholder involved or interested in the field of sustainable solutions for space cooling.

1.3. Main conclusions from the policy review

Two previous reports reviewed the current EU policy framework and national policies relevant to sustainable space cooling (Broc et al. 2024), and available financing schemes (Conforto 2024). This section summarises the main conclusions from both reports.

The EU framework covers the **dominant space cooling technologies** (vapour compression systems) with regulations to remove the least efficient devices from the market, inform consumers about the efficiency and consumption of the devices, and plan the phase out from fluorinated gases (due to their very high GWP – Global Warming Potential). Updates of these regulations should soon be adopted to strengthen the requirements and stimulate the developments of more efficient and climate-friendly alternatives. However, the review of space cooling technologies done in CoolLIFE (Duplessis et al. 2024) showed that these alternatives are rarely ready to be massively deployed. A mix of policy measures to complement the regulations may therefore be needed to support innovation, demonstration and market release.

At **building level**, while space cooling is assumed to be included in the energy performance calculations and requirements due to the EPBD (Energy Performance of Buildings Directive), the way it is addressed in national building regulations may vary among countries. The EPBD recast adopted in 2024 emphasises the need to consider summer comfort. Its transposition could be an opportunity to enhance the requirements to minimise cooling needs in new buildings, and to ensure that major renovations do not worsen the conditions for summer comfort. The development of climate-resilient building regulations could help to address these issues.

At **urban level**, the EED (Energy Efficiency Directive) promotes the development of district cooling which remains rare so far. Going beyond the building level is also relevant to address urban heat islands, and more generally to adapt urban planning and make use of nature-based and passive solutions. Ensuring summer comfort and other cooling needs in a sustainable way indeed implies the consideration of current and future changes in local climate conditions, and therefore an integrated approach from both the mitigation and adaptation sides. This should start with minimising cooling needs through urban planning and building design or renovation, and enabling occupants to meet their comfort needs in simple and efficient ways.

Relevant **financing schemes** include various types of incentives for building refurbishment, promotion of renewable energy technologies, and assistance for vulnerable households. The mapping of financing schemes identified the following issues or needs in this field:

- Clarifying the scope of solutions and approaches for sustainable space cooling.
- Analysing how financing schemes can be designed or adapted, considering the differences in needs according to the segments of the building stock and the profiles of building owners or occupants.
- Defining criteria or requirements to ensure that renovation schemes are also relevant to space cooling/summer comfort.
- Making the co-benefits (e.g. health, reduced peak load, productivity) salient, in addition to energy and cost savings alone, can better motivate decisions to invests in sustainable space cooling
- Analysing the interactions and possible linkages between mitigation and adaptation measures, and how integrated approaches can be developed.

In the EU framework, the main requirements applicable to space cooling have mostly been focused on cooling devices, district cooling and developing the share of RES in heating and cooling. This **technical focus** did not favour the development of integrated approaches. The changes from the Fit-for-55 package may improve this, for example with the EPBD recast emphasising more the importance of summer comfort, and the EED recast introducing an official EU definition of energy poverty, clarifying that adequate cooling is part of the basic levels and decent standards of living and health.

The shift in the governance at EU level to an integrated reporting of all the dimensions of the Energy Union means that the main national energy and climate planning document reported in the EU context (NECP – National Energy and Climate Plans) does not enter into the details of each dimension of the Energy Union, and particularly of topics such as space cooling. Indeed, despite the related fast-growing demand, space cooling still represents a small share of most Member States' final energy consumption, and is already almost fully electrified: this is therefore not a major direct challenge for decarbonisation, apart from that of electricity production itself. Nevertheless, space cooling is already an important issue for security of electricity supply in a few countries (e.g. Greece, Italy and Spain) already facing significant increases in summer peak loads. National adaptation strategies and plans also often present increasing summer temperatures and heat waves as major changes to anticipate, emphasising the impacts on health as well as economic activity (e.g. tourism). The analysis of the EU framework showed that space cooling is a topic that illustrates well the need to consider **more integrated approaches**, beyond siloed technical solutions, and addressing jointly mitigation and adaptation.

1.4. Methodology for preparing the recommendations

The recommendations are one of the final results of the CoolLIFE project. They build on all the previous project work, including:

- The literature review and taxonomy of space cooling technologies and measures (Duplessis et al. 2023)
- The literature review and survey about thermal comfort and occupant-centric space cooling (Hurtado-Verazaín et al. 2023)
- The literature review and analysis of behavioural interventions (Gelesz et al. 2023)
- The assessment of energy demand for space cooling in European countries (Giussani et al. 2024)
- The assessment of the effectiveness of measures to reduce energy consumption and GHG-emissions for meeting cooling needs (Malla et al. 2024)
- The assessment of multiple, socioeconomic impacts of sustainable space cooling (Gelesz et al. 2024)
- The review of the EU policy framework and Member States' policies relevant to space cooling (Broc et al. 2024)
- The review of financing schemes relevant to space cooling, at the EU and national levels (Conforto 2024)

The recommendations are also based on:

- discussions with experts during the national workshops done in Italy (April 2025), Greece (April 2025) and France (July 2025) (see minutes in the Annexes)
- lessons learnt from analysing a selection of national schemes and experiences (see below about the good practices factsheets)
- conclusions and recommendations from sister LIFE projects also dealing with space cooling, notably CoolToRise (about summer energy poverty) and CoolingDown (about RES for cooling).

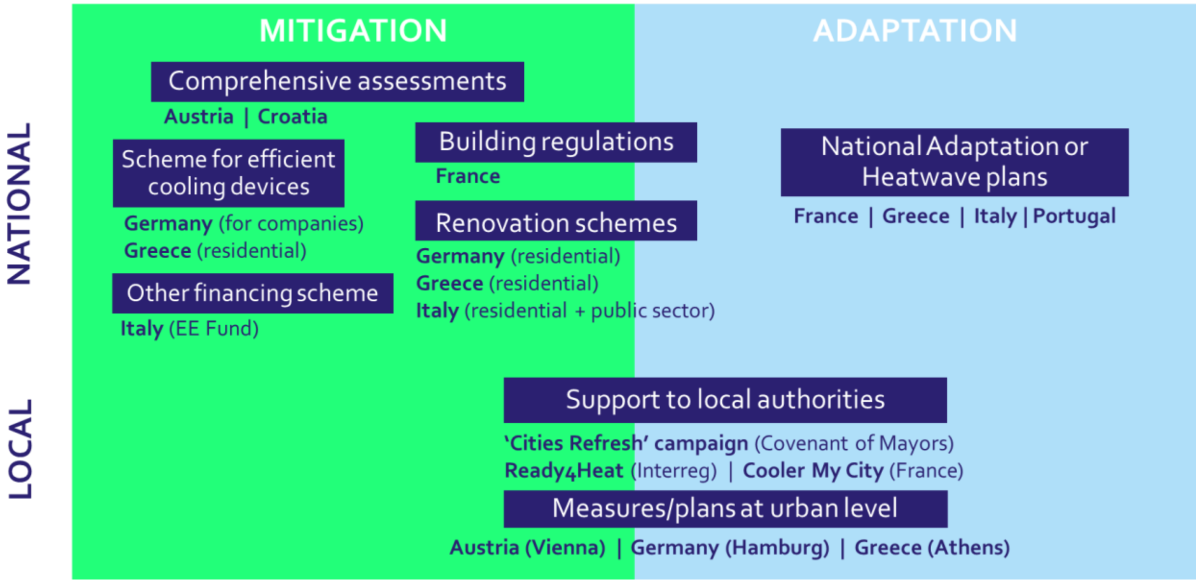

Figure 1. Overview of the 19 good practices factsheets identified in CoolLIFE.

The examples analysed in these factsheets were selected to illustrate the diversity of policies and measures implemented by Member States or local authorities.

The good practices factsheets can be found separately (stand-alone files) on the CoolLIFE website. They are also available altogether in the annexes of this report.

The presentation of the recommendations in the following sections reflects the process starting from the knowledge gained along the project:

1. **The issue(s)**: based on the literature and exchanges with stakeholders and experts, we identify key problems, questions or challenges that should be address when developing a strategy and policies for sustainable space cooling.
2. **Lessons learned / knowledge available**: based on the literature, and experience with existing policies or schemes (e.g. from the good practices factsheets), a short summary about key points highlighted by experts and that can guide stakeholders' practices and policy design.
3. **Possible ways forward / recommendations**: our suggestions about how the experience and knowledge available could be used to improve practices and policies.

2. Starting from the needs, anticipating changes

Space cooling or maintaining the indoor temperature within predefined boundaries is not an objective in itself. It is a means to meet human needs, for example to safeguard health and labour productivity of building occupants. Strategies for sustainable space cooling and related standards should be based on a **detailed analysis of those needs**, considering the multiple factors that can influence thermal comfort and differences among individuals.

This should also consider **how the needs can be affected by future changes**, notably climate changes. Investments made today in technical systems (e.g. air conditioning systems) have a lifetime until 2040 or beyond. Investments in new buildings or retrofitting of existing building envelopes set the features of these buildings until 2050, and very likely beyond. Anticipating upcoming climate conditions is thus essential.

This chapter deals with the **upstream part of policies and strategies**, looking at how recent developments in research and experience from stakeholders could inform policymaking at design and planning stages.

The suggested recommendations are therefore focused on **transferring these inputs to the policymaking process**, as well as **fostering knowledge sharing** between researchers, policymakers, building professionals and citizen.

We structured these recommendations according to key issues identified from the literature and stakeholders' experience:

- The need to switch from a techno/building-centric approach to an **occupant-centric** approach (section 2.1)
- The concepts of **operating limits and risks** to guide the selection of the most suitable solutions in the context of climate change (section 2.2)
- The **strong interactions between mitigation and adaptation** when dealing with space cooling and resilience to extreme heat events (section 2.3)
- The need for planning and **considering different timescales**, despite cooling needs surging only on short periods, compared to heating season (section 2.4)
- The need of **specific support for the most vulnerable groups** who are usually the most impacted by summer discomfort and heat-related health risks (section 2.5)

2.1. Starting from the building occupants – citizens

The issue(s):

Key points raised in (Lizana et al. 2022):

- Until the invention of vapour-compression refrigeration in the early 20th century, human beings have developed various solutions and practices (behaviours, architectural design, choice of materials, etc.) to adapt to hot weather conditions.

- The development of air-conditioning systems went together with an increasing tendency to consider buildings a purely technical system, to be optimised according to technical criteria (i.e. setpoint temperature), independently of the differences in the needs of building occupants or users. This resulted in the dominance of building-centric instead of occupant-centric approach to meeting cooling needs.
- This is one of the reasons why policies and strategies for space cooling tend to be too focused on cooling technologies, overlooking solutions to avoid, or at least minimize, cooling needs while ensuring summer comfort.
- More generally, energy efficiency policies have been focused on energy performance requirements mostly related to technical features of buildings (see e.g. building codes or Energy Performance Certificates) or to their technical systems and equipment, including air conditioning systems (see e.g. energy labelling or ecodesign regulations, or mandatory inspections of large air conditioning systems).

Lessons learned / knowledge available:

Findings from the **literature review done in CoolLIFE** (Hurtado-Verazaín et al. 2023):

- The standardized approach towards thermal comfort has been first developed based on the psychrometry chart, that was meant for determining the physical states of the air within air-conditioned areas. The current standard indices for determining satisfaction with the indoor thermal environments are similar all around the globe and have been developed based on Fanger's model from the 1970's.
- This standard methodology meant for air-conditioned areas considers the following factors: air temperature, mean radiant temperature, humidity, air velocity, clothing insulation, and metabolic rate. The standards also incorporate methods for assessing the effect of increased air velocity, notably related to the use of fans.
- In practice, air-conditioning might still be designed and operated considering mostly temperature rather than other thermal comfort parameters. Reciprocally, the development in the use of air conditioning systems reinforces temperature as the main comfort criteria.
- For space without air conditioning, standards include adaptive thermal comfort calculation methods based on the outdoor running mean temperatures. However, the adaptation of comfort criteria to different groups or locations is missing.
- Information on space cooling preferred setpoints for residential buildings is very limited as opposed to literature regarding heating setpoints or space cooling in commercial buildings.
- Occupant's behaviour in using active space cooling is different than what is seen for heating: preferred summer temperatures cannot be taken as realistic setpoints, and are heterogenous.
- Likewise, limited information is available on to what extend and how active space cooling devices are used to reach this targeted value.
- A number of simplifications in the standard methodologies cannot address the complexity of the thermal sensation of each individual, and can have limitations regarding space types in their application.
- Thermal comfort is indeed first and foremost a socially constructed phenomenon, with a dynamically evolving nature as a function of time, space, and context.

- Dynamic feedback loop between space cooling expectations and space cooling infrastructure: the higher the equipment rate of air conditioning systems, the more expectation of lower optimal indoor temperature during summer, which in turn feeds back into the deployment and availability of space cooling technologies.
- At the opposite, persons living in warmer regions tend to feel comfortable in warmer indoor environments.
- A failure to properly specify the parameters of the feedback loop between thermal comfort and air conditioning availability might severely mislead predictions of future space cooling demand.
- People's perception of thermal comfort depends on both internal and external factors.
- Internal factors include inherent physiological variables (such as gender, age, metabolism, among others), psychological experiences (personal relations, perception of control), behavioural variables (level of activity, clothing), or personal preferences.
- External factors include the surrounding physical environment (design, materials, colors, textures) and the influence of society and culture on behaviours and choices (e.g. social norms, perceptions of which clothing choices are appropriate). Contextual determinants of thermal comfort for example include the financial incentives and the social environment when one decides on their clothing choices, activity levels, and social behaviours.
- Accounting for these factors is fundamental to the effective design and operation of buildings and their technical systems. For example, a perfectly calibrated building model designed for Scandinavian citizens might have limited applicability for a Mediterranean market.
- The current meaning of summer thermal comfort is strongly associated with the use of air conditioning from building occupants' perspective. But this is not set in stone: it has evolved throughout time and could keep evolving, in order to support the adaptation capacities of individuals. Therefore, the design of solutions to reduce space cooling demand should be greatly informed by the social, physiological, spatial, and cultural dimensions of thermal comfort.
- Studies have highlighted the lack of adaptive environments with operable windows, movable shadings, integrated fans or personalised cooling alternatives, partially because of cultural and building-centric frameworks focused on centralised indoor temperature control.
- Taking a socially constructed view of human behaviour in the context of space cooling opens up a lot of possibilities for meetings occupants' needs in a sustainable way. For example, on how energy demand can be reduced given the right changes in the social environment where individuals are embedded.

This last point was also emphasised by Lizana et al. (2022): "*Cooling design combining all comfort parameters through centralised and individualised systems can harness a larger comfort range in which people feel comfortable, downsizing the cooling system capacity and decreasing operating and environmental costs*". They illustrated this with the example of introducing air velocity to increase the upper threshold at which people start feeling discomfort.

Complementary **lessons learned from the examples** of Italy's National Adaptation Plan (PNACC) and Greece's National Heatwave Plan & Athens' Chief Heat Officer (see more details in the annexes):

- Technical measures should go together with practical information or training of occupants. For example, night-time ventilation protocols are as important as physical upgrades. Occupant practices (shading use, night ventilation) are essential.

- Participatory processes involving citizen, stakeholders and experts, are useful to raise awareness, discuss the implications of extreme heat events and solutions to mitigate them, as well as to identify traditional knowledge relevant to local specificities. This can increase the legitimacy of the strategies adopted, and the involvement of citizen and stakeholders.
- More generally, two-way communication is essential, to inform citizen and stakeholders about why action is needed, what can be done, and to collect feedback and suggestions from citizen and stakeholders, so that strategies can be tailored to local specificities.

Suggested recommendations:

- **Promoting studies to improve knowledge and data availability about space cooling-related behaviours**

Surveys or field studies about space cooling-related behaviours can bring detailed knowledge and data (see e.g. Hurtado-Verazaín et al. 2023; Durand-Daubin et al. 2024). These results are valuable inputs to identify trends, gaps in the information of building occupants and owners, enabling conditions for efficient behaviours, or to test and validate assumptions made in standards and models.

They grow the evidence base for specifying standards and designing policies taking into account occupants' needs and practices.

The literature review showed that the number of studies and related data about space cooling-related behaviours in European countries remains limited compared to other similar topics (e.g. space heating-related behaviours). A meta-review could identify knowledge and data gaps more in detail, as a basis to prioritize a European programme that could coordinate surveys and studies to fill these gaps.

This programme could either be specific to space cooling & summer comfort, or could look at thermal comfort for the whole year, which could inform more integrated approaches.

- **Facilitating multi- and inter-disciplinary exchanges and knowledge gathering**

The literature reviews done in CoolLIFE show the diversity of knowledge and experience on space cooling, from various fields and perspectives. Researchers, experts, policymakers and other stakeholders could benefit from opportunities for cross-cutting exchanges and initiatives to gather knowledge and experience, such as the Annex 80 of IEA EBC (Energy in Buildings and Communities) programme.

Such initiatives may already be organised per type of stakeholder (e.g. association of HVAC engineers, network of energy agencies). This could be complemented with opportunities for cross-cutting exchanges among various types of stakeholders (e.g. ad-hoc working groups, dedicated seminars). This would help align research, policymaking, professional experience and feedback from building owners and occupants.

- **Revising standards in line with current knowledge and allowing flexibility (cf. national/local specificities)**

International and national standards (e.g. ASHRAE Standard 55, EN 16798) play a major in the specifications of regulations, reference manuals, and for the professional practices. The process and working groups defining these standards may however be dominated by a limited number of fields of expertise or stakeholder types. A cross-cutting approach could help align the revisions of standards with multidisciplinary knowledge, and experience from technical experts and practitioners, researchers, policy officers and representatives from organisations of owners and tenants.

Ahead of major revision cycles, public bodies could commission studies to update independent state of the art.

More detailed considerations for revising standards related to thermal comfort include:

  - investigating how more factors proven to be important for defining or assessing thermal comfort (e.g. physiological variables, behavioural variables, cultural differences) could be integrated in standards related to thermal comfort
  - allowing flexibility in international standards for adaptations to national specificities, while having shared sets of indicators to allow cross-country monitoring
  - considering adaptative comfort for air-conditioned areas (not only for areas without air conditioning)
  - considering a broader range of activity type.

- **Specifying enabling conditions for efficient and adaptative behaviours**

Building occupants and operators can have a major influence on the effectiveness of the space cooling solutions, and ultimately on the indoor comfort. However, they can adopt efficient and adaptative behaviours only if enabling conditions are met. These conditions are not limited to technical conditions (e.g. possibility to open windows). They may include social norms (e.g. about clothing at work), information and awareness, among others.

Specifying enabling conditions per type of solution could make related information more systematically available to professionals, and thereby to building occupants and owners. Such documentation could be updated regularly, considering the development in space cooling solutions and feedback from their use. This documentation should be presented in an accessible format.

- **Involving citizen and building occupants in the process to define strategies for sustainable space cooling**

Citizen and building occupants know best their needs. When discussing decisions that will impact their living or working conditions, their experience with the building, urban environment, etc. should be considered, for example:

  - by architects and building engineers when preparing a construction or renovation project
  - by local governments and agencies when preparing a local adaptation plan or projects to improve neighbourhoods
  - by national governments and agencies when preparing the national adaptation or heatwave plan, or when revising building regulations or renovation schemes.

While obvious, this is not yet a systematic practice. For example, various studies reported cases where building automation and control systems have been designed and implemented according to a theoretical use of the building diverging significantly from the actual practices and needs of building occupants.

2.2. What solutions for what conditions: considering operating limits and risks

The issue(s):

Key points raised in (Alessandrini et al. 2019) and (Zhang et al. 2021):

- There is a broad range of solutions to improve / maintain summer comfort in buildings. They can be evaluated in many ways, for example considering energy performance, thermal comfort, air quality, capital expenditure and applicability in different climate zones.
- In practice, each solution has operating limits: when certain conditions are exceeded (e.g. max outdoor temperature, humidity rate), they can no longer maintain comfort (or even minimum health requirements). This can be illustrated by ceiling fans and night ventilation, which are very effective cooling solutions up to certain temperatures and humidity rates, but become insufficient (or are no longer possible) when these limits are exceeded.
- The risk of operating limits to be exceeded is strongly related to the extreme heat risks (cf. long-duration heatwaves and prevailing warm annual conditions) that are increasing due to climate change.
- This results in higher heat-related health risks (e.g. fatigue, hyperthermia, heat stroke and heart failure), with a situation worsen by ageing populations and increasing share of the population living in dense urban areas.
- Heat-related health risks depend on various factors that can be described with five main categories: environmental factors (e.g., lack of vegetation, urban heat island, building construction quality), socio-demographic factors (e.g., age, gender), health factors (e.g., obesity, pre-existing diseases), social factors (e.g., poverty and social isolation), and behavioural factors (e.g., inadequate clothing, reduced mobility)
- Cooling strategies that work well today might not remain effective under long-term climate change, or in extreme events such as a heatwave or power failure.

Lessons learned / knowledge available:

From the literature:

- The efficiency of passive measures to refresh dwellings depends strongly on the local climate, building characteristics (e.g. dynamic thermal response to indoor and outdoor stresses) and occupant behaviour. This means that there cannot be a generic answer about the ability of a system to avoid heat-related health risks (Alessandrini et al. 2019).
- A gap is observed in temperature ranges between the legitimate domain of thermal comfort ("moderate thermal environment") set in the ISO 7730 standard, and the thresholds about "heat stress" proposed in the ISO 7243 standard. This gap can be explained by the discrepancies in the standard experimental conditions

used for the assessments. Further investigation is required to better identify the threshold values between thermal comfort and heat-related health risks (Alessandrini et al. 2019).

- Using typical weather or historical weather files for the assessment of cooling demand and effectiveness of cooling strategies can create a bias for building design, or selection of options for building retrofits or technical systems of buildings. While future typical weather files are widespread, methodologies to reproduce future extreme conditions and consider climate uncertainties are scarce, partly due to the lack of data accessibility. (Machard et al. 2020). The IEA EBC Annex 80 "Resilient Cooling for Buildings" developed datasets of current and future projected weather files for building simulations in 15 major cities distributed across 10 climate zones worldwide (Machard et al. 2024).
- Combining weather files about typical weather years ad heatwave events enable to assess in a more comprehensive way the resilience of buildings to overheating in future climate conditions. Similarly, sensitivity analysis considering multiple types of future weather files, climate models or scenarios help addressing uncertainties in climate projections (Machard et al. 2020).
- The assessment of the potential of passive measures is also strongly depending on the assumptions about the occupant scenarios and the hot periods to cope with. Building designers, owners and occupants should therefore be engaged in these choices to consider realistic occupant behaviours, and to discuss how occupants can adapt their behaviours during heatwaves (Alessandrini et al. 2019).
- More generally, resilience capacities[2] of cooling strategies at building level depend on various parameters: the function of cooling strategies (reducing heat gains, removing sensible/latent heat, or enhancing personal comfort), the driven forces (passive or active), design feature, and control and operation of the cooling system. This implies that no single solution can provide all resilience capacities, and that a combination of cooling strategies is likely to be more effective (Zhang et al. 2021).
- Studies already raise the issue that even ambitious adaptation strategies might not be enough to entirely avoid air conditioning during extreme heat events, with different time horizons according to the countries (e.g. by the end of the century in France, according to Viguié et al. 2020). Nevertheless, implementing passive measures and adaptation actions can significantly reduce energy consumption of air conditioning (by 60% in the French case study of Viguié et al.). This also points out that usage efficiency can be the most effective measure, ahead of policies on insulation, reflective materials and urban greening.
- Methods can already be used to assess the resilience of buildings to both, current heat waves and their recurrence in the future under the impact of climate change. Such studies can provide building owners and asset managers with reliable information to assess heat-related health risks for occupants and what actions can mitigate these risks. Assessing the probability of risk occurrence provides a documented basis for a cost-benefit balance and to decide about adaptation pathways (Roccamena et al. 2024).

[2] Zhang et al. (2021) considers four main criteria to characterize resilience capacities of cooling solutions:
"***Absorptive capacity*** *can be calculated as the ratio of the absorbed heat load (or heat storage) to the change in heat load during a certain disruption.*
Adaptive capacity *can be calculated as the ratio of the heat load reduction to the change in heat load during a certain disruption.*
Restorative capacity *can be calculated as the ratio of the heat removed from the building to the heat stored after a certain disruption.*
Recovery speed *can be calculated as the time required to remove the stored heat from a building until reaching a designed thermal condition.*"

- Such methods can help classify buildings into categories, considering the extent to which faultless performance criteria or operating limits are exceeded. This can help prioritize interventions and select relevant solutions. Such assessment should also consider variations according to building occupants, according to their acclimatisation level and their sensitivity to heat (Roccamena et al. 2024).
- These issues are no longer limited to Southern Europe. Research showed that while new buildings in Finland should cope with future climate conditions, this is already no longer the case for part of the existing buildings. Passive solutions could effectively reduce their indoor temperatures during typical summers, but active cooling systems would likely be needed during hot summers (Velashjerdi Farahani et al. 2024).

Complementary **lessons learned from the examples** of Italy's National Adaptation Plan (PNACC) and Hambourg green roof strategy (see more details in the annexes):

- Italy's National Adaptation Plan (PNACC) encourages municipalities to contribute to monitoring campaigns of indoor temperature (with low-cost dataloggers in a sample of dwellings to build an evidence base) and report to the National Adaptation Observatory.
- Italian pilots part of the PNACC reported 2–4 °C drop during 2023 heat-wave events in retrofitted flats, that passive cooling measures can lower annual cooling electricity by up to 50 % when insulation and shading are combined, and that 84 % of surveyed households reported "notable improvement" in summer comfort after installing shutters and practicing night ventilation.
- Design responses differ according to local climate and building types. Guidance must be both archetype-based and location-specific. Harmonised taxonomies and open archetype libraries can help streamline modelling and evaluation.
- In the meantime, "rule-of-thumbs" communication as a first layer of advice for households (e.g., external shade before noon, night ventilation after 22:00, fans to extend comfort by about 2–3 °C operative temperature) can be co-designed with behavioural experts and help for short-term impacts.
- Downscaling future climate projections to building-level metrics (e.g., hours above comfort thresholds) is non-trivial. Staged pilots across climate archetypes with randomised inspections can help calibrate thresholds, costs, and user guidance before national roll-out
- Acoustic and security requirements may limit night-time ventilation in urban areas.
- Local programmes can be opportunities for experimenting innovative solutions and design in real conditions, as part of scientific research, then providing science-based evidence to improve and promote these solutions.
- Monitoring real buildings through low-cost temperature loggers and short post-occupancy surveys can be key to iterative improvements.
- Evidence-based standardisation is pivotal: pattern books with replicable details (e.g. over-window awnings, shutters) and minimum performance descriptors (e.g. solar-factor ranges, ventilation rates) reduce design and permitting frictions.

Suggested recommendations:

- **Linking implementation, monitoring and research to grow science-based evidence**

Actual impacts of space cooling solutions are still a field of investigation. Programmes promoting these solutions can provide samples of real cases for monitoring their impacts as part of scientific research. The resulting science-based evidence can guide further revisions of the programme, and provide sound information to professionals, building occupants and owners.

Monitored data (e.g. measurements, surveys) can be used to test and validate the relevance of underlying assumptions used in model-based assessments (e.g. assumed range of operating conditions).

- **Maintaining future weather files including typical weather years ad heatwave events**

Anticipating the impacts of climate change on cooling needs is essential. The knowledge in this field is evolving rapidly. Maintaining official and publicly available future-scenario weather files at national level can help disseminate and harmonize the practices, taking into account the different climate zones in the country.

These weather files should consider both, future typical weather years and expected heatwave events, to provide key input data for heat-resilience assessments.

- **Providing methodologies to streamline sensitivity analysis**

Climate projections include significant uncertainties, especially when considering long-term horizon in line with the expected lifetime of buildings. This calls for sensitivity analysis that can help assess the risks related to these uncertainties, and these risks are mitigated depending on the mix of solutions implemented.

However, sensitivity analysis might be complex to implement and to interpret. Providing methodologies and guidelines could help a more systematic and comparable practice.

- **Promoting heat-resilience assessments to anticipate overheating risks and prioritize asset managers' actions**

Heat-resilience assessments can help asset managers anticipate overheating risks in their building stock, categorize the buildings according to their level of risks, and prioritize their actions and investments accordingly.

Such assessment can be specific, or part of a broader resilience or adaptation assessment, in line with the approach promoted by national or local adaptation plans.

- **Categorizing typical situations, operating limits and mix of solutions**

A simplified approach can be developed to assess the national, regional or local building stock. This can be useful to inform individual building owners or to guide the design of policies to promote packages of solutions per type of building, for example. This can also provide a benchmark for more detailed assessments.

Identifying relevant mix of solutions per type of situation can then help verify that these solutions are well covered by regulatory models (e.g. models used to implement building regulations or to prepare Energy Performance Certificates), to avoid bias in the models that would make that these solutions would be disregarded in practice.

A categorization of typical situations can also be used to assess where and when air conditioning systems may become necessary to mitigate overheating risks.

- **Involving building designers, owners and occupants in the definition of scenarios and analysis of results**

Assessments at building level can be tailored to consider the building’s specificities, and should also consider realistic occupant behaviours. This implies encouraging discussions between building designers, owners and occupants, when defining the scenarios to be assessed and when analysing the results.

Guidelines and case studies could help disseminate and harmonize participatory practices.

2.3. Linking mitigation and adaptation

The issue(s):

- Thermal comfort in summer, space cooling and the use of air-conditioning systems are closely related to both, mitigation and adaptation to climate change. Increasing temperatures and heat waves is the main driver for increases in the equipment rate and use of cooling systems, resulting in increases in electricity consumption and in GHG emissions (indirectly from electricity generation, and directly from the leakages of refrigerants). Moreover, an uncontrolled development of air conditioning in urban areas could worsen urban heat islands, which in turn increases the cooling needs (Quefelec 2023).
- Another link is that the fast-growing use of air-conditioning systems combined with more frequent, intense and longer heatwaves increases the pressure on the electricity system (cf. summer peak loads). Which may result in power outages, thereby stopping air-conditioning systems (if no backup supply) at critical times, with possible serious implications up to increased morbidity and mortality. (Baniassadi and Sailor 2018)
- Strategies for energy efficiency in buildings are not always consistent with cooling strategies, notably about improving resilience to extreme heat: there can be a trade-off between both objectives. Notably because energy efficiency strategies might be focused on reducing space heating consumption during winter. Whereas high insulation, air-tightness and radiation loads (e.g. due to large south facing windows) can have adverse effects for summer comfort (Baniassadi and Sailor 2018).
- Energy efficiency measures and strategies for housing and services rarely consider actions beyond the building level, apart from district heating and cooling. Adaptation strategies usually cover better the local / urban level (e.g. to address urban heat island effects), with a major role devolved to local authorities.

- Different administrations or agencies, or different units with the same institution, may be in charge of energy efficiency measures and adaptation measures respectively. This can be seen in the planning, implementation and reporting of both groups of policies, and may result in inconsistencies or lost opportunities of synergies.

Lessons learned / knowledge available:

- At building level, the implication of energy efficiency strategies on building resiliency to heat depends strongly on building characteristics and underlying climate. For example, increasing the insulation and airtightness were found to be beneficial to passive survivability in warmer climate, unlike similar studies in colder climate. (Baniassadi and Sailor 2018).
- Definitions of thermal resiliency metrics can have a major influence on the interpretation of the results of simulations (Baniassadi and Sailor 2018).
- At urban level, recent developments in Urban Building Energy Modelling (UBEM) can contribute to assess indoor overheating risks in urban settings (e.g. due to urban heat islands). UBEM was primarily focused on energy simulation rather than indoor thermal comfort, and was often using a generic approach, modelling a limited set of archetype buildings. These simplifications can result in suboptimal climate adaptation and mitigation strategies. However, UBEM is increasingly incorporating microclimate data and climate change scenarios, also considering new thermal comfort metrics in line with addressing climate change, among other developments. Still, further endeavours are needed so that enhanced assessments of urban-level indoor overheating can support better-informed urban planning and building design strategies, to provide resilience against overheating (Morales et al. 2025).
- At national level, while most National Energy and Climate Plans and comprehensive assessments on heating and cooling include limited information about adaptation measures, the National Adaptation Plans or Strategies increasingly make the link between mitigation and adaptation measures, when dealing with buildings or addressing extreme heat events.
- National Adaptation Plans and Strategies and National Heatwave Plans (e.g. in France and Greece) may then be the drivers for more integrated strategies for sustainable space cooling.

Suggested recommendations:

- **Mapping possible synergies and adverse effects of mitigation and adaptation measures**

Research and experience gains from pilots or local schemes document risks of adverse effects (e.g. maladaptation) and benefits that mitigation measures can have for adaptation purposes, and reciprocally.

A systematic mapping could help update guidelines for integrated approaches, that can be prepared for building design, building renovation and urban planning.

- **Ensuring consistency among mitigation and adaptation policies**

The preparation and validation process of new policies or revisions of policies should include a consistency check to avoid inconsistencies in the purposes or provisions of mitigation and adaptation policies dealing with the same object (e.g. buildings, urban environment).

This consistency check could build on the mapping of synergies and adverse effects and include coordination between relevant administrations or departments (see also section 4.2).

For example, renovation schemes should be aligned with plans about heat-related health risks. Reciprocally, national adaptation plans should consider passive measures among the actions for climate-resilient buildings (see also section 3.1).

- **Valuing co-benefits through co-funding**

When solutions have well-documented co-benefits, their promotion may be supported from several policies. This could help address funding issues through co-funding or increase outreach through multiple communication channels and messaging.

For example, green roofs and façades can be incentivised through the reduction in wastewater fee splits, as they retain rainwater (see Hambourg Green Roof Strategy in the annexes).

2.4. Planning to avoid ineffective and expensive actions in a hurry

The issue(s):

- When not anticipated, heatwaves can generate severe impacts (e.g., excess deaths, blackouts).
- Many Member States have prepared national heatwave plans or alike to mitigate these impacts, inform citizens and empower their capacity to adapt, and organize the adaptation of public services and economic activities when needed.
- However, not all plans include a more structural approach with actions on medium and long term.
- In the meantime, heatwaves often trigger peaks in sales of air-conditioning devices (Dolques and Dépoues 2024), that might have low efficiency, be installed or used in bad conditions, etc.
- More generally, market trends show significant increases in sales of air-conditioning systems over the years. Whereas passive measures might be disregarded (e.g. due to lack of information about their availability and benefits).

Lessons learned / knowledge available:

Key results from the assessment done in the CoolLIFE project (Malla et al. 2024):

- Integrating high-efficiency passive measures alongside technological advancements could significantly reduce cooling energy demands in the EU27 by up to 55% by 2030 and almost 80% by 2050 compared to a baseline scenario.
- These strategies are particularly effective in non-residential sectors due to higher baseline energy demands. Moreover, the study highlights the importance of sector-specific approaches, given the varying characteristics and requirements across different regions.
- GDP of the EU27 region could be increased by close to 6 billion euros annually until 2050 in the scenario reducing cooling energy demands compared to the baseline scenario. This can be translated to an additional employment of an average 124 000 to 300 000 full-time employment years in each year at the EU27 level, together with avoiding 36 600 lost working days.
- The environmental implications of unmitigated increases in cooling demand could significantly worsen energy consumption and associated greenhouse gas emissions. Our environmental impact scenarios projected that without substantial efficiency improvements and widespread adoption of passive measures, CO_2 and NO_x emissions would rise steeply. However, these emissions could be considerably mitigated through the combined application of advanced technological deployments and passive cooling measures. To align with the EU's ambitious net-zero emissions target by 2050, it is imperative to actively enhance the performance and adoption rates of low-emission cooling technologies

Suggested recommendations:

- **Setting clear and measurable targets with regular monitoring**

National and local plans should define clear directions for action and regularly monitor progress. This could avoid episodic policy debates raised by extreme heat events, and decisions based on reactions to emergency situations.

- **Structuring action plans from short-term to long-term**

Policy interventions need to address emergency situations (e.g. in case of extreme heat events) up to long-term impacts of climate change. Action plans should be structured accordingly, considering priorities, time and budget needed for implementation.

- **Providing stability and visibility about funding**

Feedback from almost all renovation schemes or adaptation plans raises the major issue of stability and visibility about funding. This is essential to engage stakeholders in the development of the products and services needed to implement the expected mitigation and adaptation measures. This is also needed for the confidence of building owners and other investors.

2.5. Sustainable space cooling for all: addressing summer energy poverty

Summer energy poverty was not directly in the scope of CoolLIFE. However, this is an important and growing issue (Thomson at al. 2019; Cornelis 2025). Therefore, we summarize here some of the main conclusions and recommendations from the sister project CoolToRise that was specifically focused on summer energy poverty. More details can be found in (Gayoso Heredia et al., 2023).

The issue(s):

- Energy poverty was officially defined at the European level for the first time in the EED recast (EU)2023/1791 adopted in September 2023, in Article 2(52):

  > “*a household’s lack of access to essential energy services, where such services provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing national social policy and other relevant national policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes*”.
- Energy poverty has a multidimensional nature, driven by factors such as low income, low energy efficiency of dwellings, limited availability of energy sources, skyrocketing energy prices, etc.
- While winter energy poverty is well-documented, obtaining a comprehensive picture for the summer is more challenging.
- The EU SILC (EU Statistics on Income and Living Conditions) survey done in 2012 found that 19% of Europeans were unable to keep their homes adequately cool in summer (Eurostat data). This figure provides an initial glimpse into the extent of summer energy poverty across the EU. For comparison, the SILC survey done in 2013 found that 11% of the population declared an inability to keep their homes adequately warm.
- These statistics support the hypothesis that more households struggle to maintain comfort in summer compared to winter (Sanz Fernndez et al., 2024).
- While in winter people can use clothes and blankets to reduce their heating needs, passive options are limited during hot summer days, when the occupants cannot invest in or install solutions such as sun shading or ceiling fans, or when the dwelling does not enable efficient practices (e.g., no shutters, or limited possibility for night ventilation). Without air conditioning, people might then be left with either relying on mobile fans or leaving their houses looking for a climate shelter (Sanz Fernandez et al., 2024).
- With growing inequities and more frequent extreme heat events, the current situation is likely to be even more severe.
- Data for 2022 is available for a few countries only, and some of them indeed show a worsening trend. For example, in Portugal, 38.3% of the population reported living in dwellings that are not adequately cool in the summer, compared to 35.7% in 2012.
- The summer of 2022, marked by record-breaking heat, witnessed over 61,000 deaths across Europe (Ballester et al., 2023). Women were more affected than men, and southern countries such as Italy, Greece, Spain, and Portugal experienced higher heat-related mortality rates.

- Additionally, heat can adversely impact pregnant women, potentially leading to premature births. Vulnerable groups include not only the elderly and individuals with preexisting medical conditions, but also children and outdoor workers (Tobìas et al., 2014).

Lessons learned / knowledge available:

- Given that a portion of summer mortality can be linked to the urban heat island (Iungman et al., 2023), addressing this phenomenon should be prioritized as part of adaptation and heat mitigation strategies (i.e. targeting areas vulnerable to urban heat island effects).
- Five key actions were found when it comes to improving neighbourhoods' adaptation to heat and thus alleviating summer energy poverty (Pérez Rodrìguez et al., 2024):
  - incorporation of vegetation and green spaces,
  - humidification and presence of water,
  - shading and ventilation improvements,
  - enhanced routes and walkaways, and
  - community activities in spaces that serve as climate shelters.
- Public spaces can be essential for the vulnerable groups. It is thus vital to increase and protect existing trees near the neighbourhood; install pergolas with deciduous vegetation around the neighbourhood to create cool areas and corridors in summer that also allow sunlight in winter; promote native and drought-resistant species in public and private spaces; increase the presence of trees and green areas in playgrounds and schoolyards to promote safe and stimulating outdoor activities for children; and replace impermeable pavements with vegetated areas, natural soils, and permeable surfaces (Pérez Rodrìguez et al., 2024).
- Proper water management needs to be promoted; permeable pavements are to be used to facilitate water infiltration and retention in the ground or be captured and stored in subsurface layers for later reuse or drainage. The presence and evaporation of water in the neighbourhood contributes to surface cooling (Pérez Rodrìguez et al., 2024).
- Critical areas most exposed to solar radiation that require more shading need to be identified. Additionally, pergolas, awnings, and shading structures need to be incorporated in places such as courtyards, squares, and parks within or near the neighbourhood, inviting social interaction and permanence along with urban furniture (Pérez Rodrìguez et al., 2024).
- Awareness programs indicating at what time it is appropriate to leave home should be delivered, in addition to promoting good habits that enhance well-being when going out (Pérez Rodrìguez et al., 2024).
- Spaces such as libraries, museums, senior centers, cultural centers, health centers, and social centers have to be designated and adapted to become free-access climate shelters, adjusting their hours to promote their use by the public. Sitting areas in shopping centers, not linked to consumption, need to be equipped to relieve visitors from the heat (Pérez Rodrìguez et al., 2024).

Suggested recommendations:

- **Prioritizing decent living conditions over energy savings**

Actions tackling summer energy poverty may not generate energy savings on short term, as vulnerable households are rarely equipped with air conditioning systems. These actions are however essential to help vulnerable households cope with deteriorating living conditions due to warmer summers and heatwaves. They can also deliver collective benefits (e.g. reduced health expenses).

Energy efficiency or energy savings might not be a relevant primary objective for measures tackling summer energy poverty.

- **Identifying priority target groups**

Data is often missing at national or local level to assess the extent of summer energy poverty and identify who is affected the most. Better knowledge on summer energy poverty should be part of the objectives of surveys on living conditions (e.g. EU SILC) and of research on heat resilience.

- **Using targeted and dedicated policy measures**

Including provisions to prioritize vulnerable households within general schemes has shown limited results (see for example Greece's renovation programme in the annexes). Dedicated measures including specific communication and outreach prove to be more effective.

- **Promoting holistic and adaptive cooling measures**

Tackling summer energy poverty should go beyond individual air-conditioning units. Holistic solutions – such as passive cooling (insulation, shading, reflective materials, night ventilation), urban green spaces, and neighbourhood cooling refuges – can reduce overheating and dependence on mechanical cooling. Where air conditioning is essential to safeguard health, tailored support for vulnerable households (e.g. subsidies, help with operating costs) should be based on a register or mapping of at-risk populations.

3. A multilevel approach to provide whole-year comfort in a sustainable way

The current EU policy framework relevant to space cooling is primarily focused on technical systems (see Figure 2), i.e. equipment (cooling devices and fans) and buildings, and on cooling supply, through efficiency and RES (see Figure 3). This chapter looks at issues and policies related to the technical systems, and how they could be enhanced or complemented. Overall planning and cooling supply are addressed in the following chapters 4 and 5.

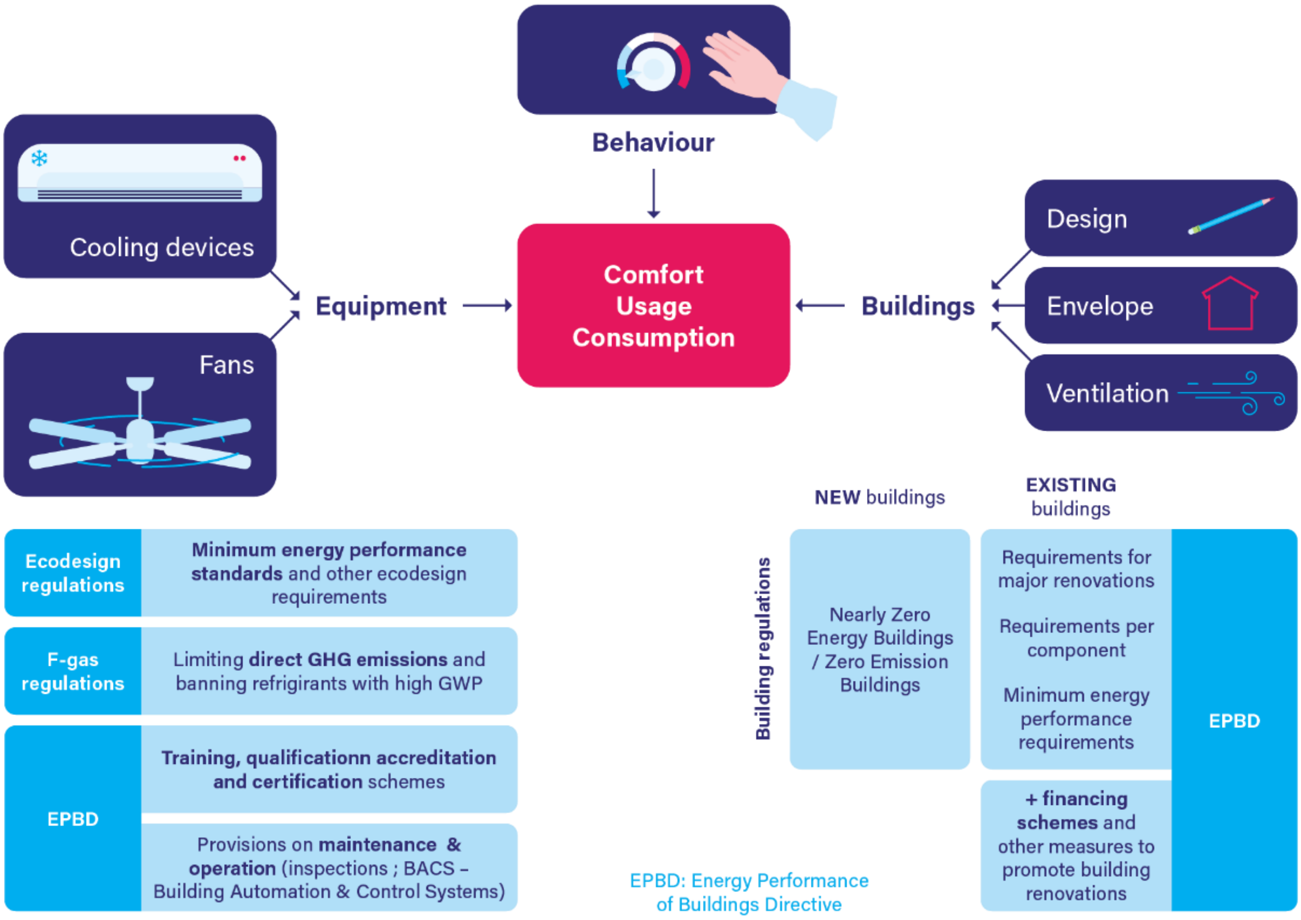

Figure 2. Coverage of the equipment and building level in the EU policy framework.

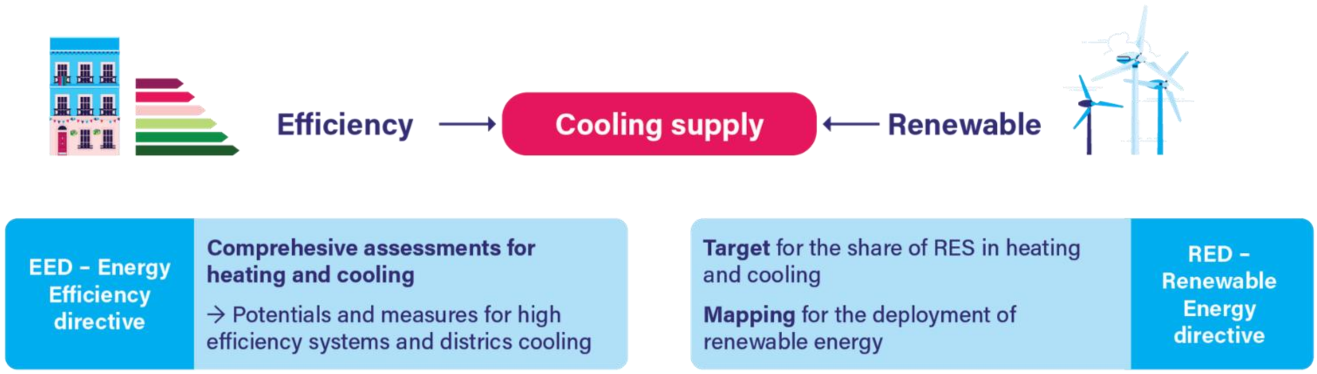

Figure 3. Coverage of cooling supply in the EU policy framework.

The previous analysis of the policy framework (Broc et al. 2024) has shown that provisions on space cooling are often secondary or hidden by the provisions on space heating, as space heating represents by far the largest share of energy consumption in buildings in most cases. Moreover, as highlighted in chapter 2, adverse effects can occur when space heating - comfort in winter and space cooling - comfort in summer are addressed separately. Providing the conditions for whole-year comfort therefore comes out as the umbrella objective.

Building on the literature, stakeholders' experience and the recommendations from the previous chapter, we structure our suggestions of recommendations to meet this objective according to three main topics:

- Integrated approaches for buildings, reconciling energy performance and climate-resilience (Section 3.1)
- Promoting the diversity of solutions to avoid that addressing space cooling be limited to air conditioning systems (Section 3.2)
- Considering the enforcement of current regulations for cooling systems (Section 3.3).

3.1. Towards efficient and climate-resilient buildings

The issue(s):

- In Europe, the priority challenge is to improve existing buildings, due to the low renewal rate with new buildings and that most existing buildings have not been designed to cope with current and future risks of overheating (and other risks due to climate change).
- Energy performance of buildings is mostly focused on reducing space heating consumption (as main share of buildings' energy consumption). Whereas some of the solutions to reduce space heating consumption might create adverse effects for comfort in summer (see also section 2.3).
- Building regulations may use a restrictive definition of comfort, with energy performance requirements mostly focused on meeting average indoor temperature (see also section 2.1)
- More generally, the growing risks due to extreme weather events related to climate change, especially about health impacts and property losses, raise the need to revise building codes and standards, in line with climate

adaptation policies (Hinge 2023). Among various aspects, this includes considering future weather data to better address changes in cooling needs (see also section 2.2).

Lessons learned / knowledge available:

- The main approaches to make a building resilient against overheating can be grouped in four categories (when considering the building level): (1) Reducing heat loads to people and indoor environments, (2) Removing heat from indoor environments (production, emission and combined), (3) Increasing personal comfort apart from space cooling, and (4) Removing latent heat from indoor environments (Stern et al. 2024).
- The IEA EBC Annex 80 about ''Resilient Cooling of Buildings" developed a structured approach to evaluate Key Performance Indicators for assessing the resilience of buildings across various technologies, grouping KPIs in four main categories: thermal comfort, heat stress, energy performance, HVAC ad grid (Holzer et al. 2024). Overall, this initiative provides a comprehensive overview of recent technical research about building cooling under extreme events, particularly with regard to the adaptability and resilience of cooling systems under extreme climatic conditions.
- Improving energy efficiency in buildings can support climate resilience and bring multiple resilience benefits (Ribiero et al. 2015, Hinge 2023).
- The role of ventilation is essential to avoid that increased insulation and airtightness create risks of overheating as less heat could be dissipated. Likewise, when buildings and their systems are improved focusing on temperature control only, further adverse effects may occur such as increased indoor air pollution, due to inadequate air renewal (e.g. when air conditioning systems do not include any fresh air supply) (Lizana et al. 2022).
- Sun shading and related solutions are essential to reduce heat inputs due to solar radiation and are often a no-regret option (easy to implement, clear gains and limited costs).
- Renovation schemes increasingly include passive measures for summer comfort (e.g. sun shading) as part of the action types eligible to financial incentives (see the examples of Greece's Residential Energy Renovation Programme and Italy's ecobonus in the annexes of this report).
- Recent revisions of building regulations tend to address more explicitly the conditions for comfort in summer and overheating risks: more comprehensive definitions of thermal comfort, definition of specific indicators (e.g. number of hours of discomfort in summer without air conditioning systems, maximum allowed cooling demand), specific requirements to avoid overheating (e.g. mandatory solar protection according to the share of glazing surface), revised weather files considering extreme heat events (Broc et al. 2024). Most of these requirements promote passive measures in priority, to improve passive survivability (i.e. considering the risk of power outage or air conditioning failure during heatwaves).
- In 2022, UK formally issued a new component (document O) of its building regulations to minimize building overheating, following a study that quantified the overheating risk in the UK domestic housing stock and the potential costs and benefits of policy measures to decrease the risk (Arup 2022; see also Hoggett et al. 2024). The new requirements can be met either through a simplified (but prescriptive) method or using dynamic thermal modelling (more flexibility in the solutions). The requirements give a clear preference to passive design measures (Hinge 2023).
- Similar national studies have been done in other countries (e.g. in France, see Peuportier et al. 2023). This provides a growing knowledge base to adapt building regulations and provide guidelines to professionals.
- The EU policy framework does not include yet a clear vision for a climate-resilient built environment. An EU strategy for climate-resilient built environment could help increase consistency between adaptation and buildings policies, building on the experience of pioneer regions and cities (BPIE, 2024). As first steps, the Renovation Wave communication includes a definition for climate-resilient buildings, DG CLIMA published

EU-level technical guidance for adapting buildings to climate change (Ramboll and CE Delft 2023) and the new EPBD adopted in 2024 mentions policies and measures to increase the climate resilience of buildings as part of the optional information to be included in National Building Renovation Plans.

- Building regulations can address thermal comfort and some aspects of passive survivability, but need to be complemented with other policies (Hinge 2023), notably to address urban heat island effects (see section 4.3).
- The implementation of provisions addressing overheating risks and resilience is still recent. Research is needed to assess what measures may be most impactful and the various uncertainties due to climate change (Hinge 2023).

Suggested recommendations:

- **Ensuring renovation programmes are 'fit for cooling'**

Heat resilience assessment can be required for large renovation projects. Simplified checklists could be used for smaller projects, for example emphasising the importance of ventilation.

Eligible action types should include passive measures, and at least no-regret options (e.g. sun shading).

Measures for energy advice should provide building owners with information about whole-year comfort (not only about the heating season).

- **Favouring deep renovations and synergetic actions**

Studies show that single actions achieve limited impacts compared to renovation packages or deep renovations. This is true for both, winter and summer comfort, reducing space heating and space cooling consumption. Deep renovations should therefore be favoured, for example with higher grant rates.

The support to certain action types could also include conditions to favour synergies and avoid missed opportunities. For example:

  - an assessment of the feasibility of sun shading options could be required for projects of façade renovation.
  - the installation of solar PV panels could be required in case of installation or replacement of air conditioning systems (except when not technically possible)

- **Ensuring that building regulations address summer comfort and overheating risks**

Provisions in the building regulations should for example:

- Include definition and assessment of comfort that is not limited to average indoor temperature
- Include definition and assessment of criteria specific to the summer period (e.g. hours of discomfort without air conditioning)
- Require the use of weather files that reflect future climate conditions in terms of typical year and extreme heat events

More generally, building regulations could consider integrating climate-resilient standards (covering other aspects than overheating risks).

- **Revising Energy Performance Certificates to include information about summer comfort**

Energy Performance Certificates are a key source of information for building owners and tenants. As they mostly deal with energy consumption and GHG emissions, the information they include on summer comfort is usually limited.

A revision of the Energy Performance Certificates could enhance the information about summer comfort, for example by identifying overheating risks and including more systematically actions about summer comfort in the recommendations.

3.2. Promoting broader markets of sustainable space cooling solutions linked to adaptation and resilience strategies

The issue(s):

- From a market perspective, space cooling might be perceived in a restricted view, considering mostly standard air-conditioning devices, with a focus on growing product sales. Moreover, the market has been dominated by product-based business models, where producers and retailers manage only a small part of the lifecycle of the cooling appliances (Lizana et al. 2022).
- In this product-based model, final customers may first look for the lowest initial investment cost, and then face defaults in installations, while maintenance might be inadequate. This can result in higher operating costs, refrigerant leaks and other failures (Lizana et al. 2022).
- The product-based model also favours obsolescence, as manufacturers may favour sales volumes over durability (Jensen et al. 2021).
- Considering a mix of solutions, instead of air-conditioning as a silver bullet, might imply to change the way the markets and offers are structured. Coordination is needed, between the various trades that may be involved (e.g. building insulation, ventilation, cooling products, nature-based solutions).

- Information on passive measures and other alternatives to space cooling- as well as on risk factors of overheating in buildings – is often less widely disseminated and less accessible than information on space heating and air conditioning systems.
- The relevance of solutions is highly dependent on the local conditions (e.g. local climate) and the type(s) of building use or segment of the building stock (e.g. housing, offices, healthcare). Information should therefore be available in a tailored way.

Lessons learned / knowledge available:

- Recent research provides updated review and taxonomy of space cooling measures (passive and active), showing a broad set of solutions (e.g. Zhang et al. 2021, Duplessis et al. 2024)
- Lizana et al. (2022) suggested an order to consider solutions for sustainable space cooling, to increase heat resilience of buildings, downsize cooling needs and systems, as shown in the figure below.

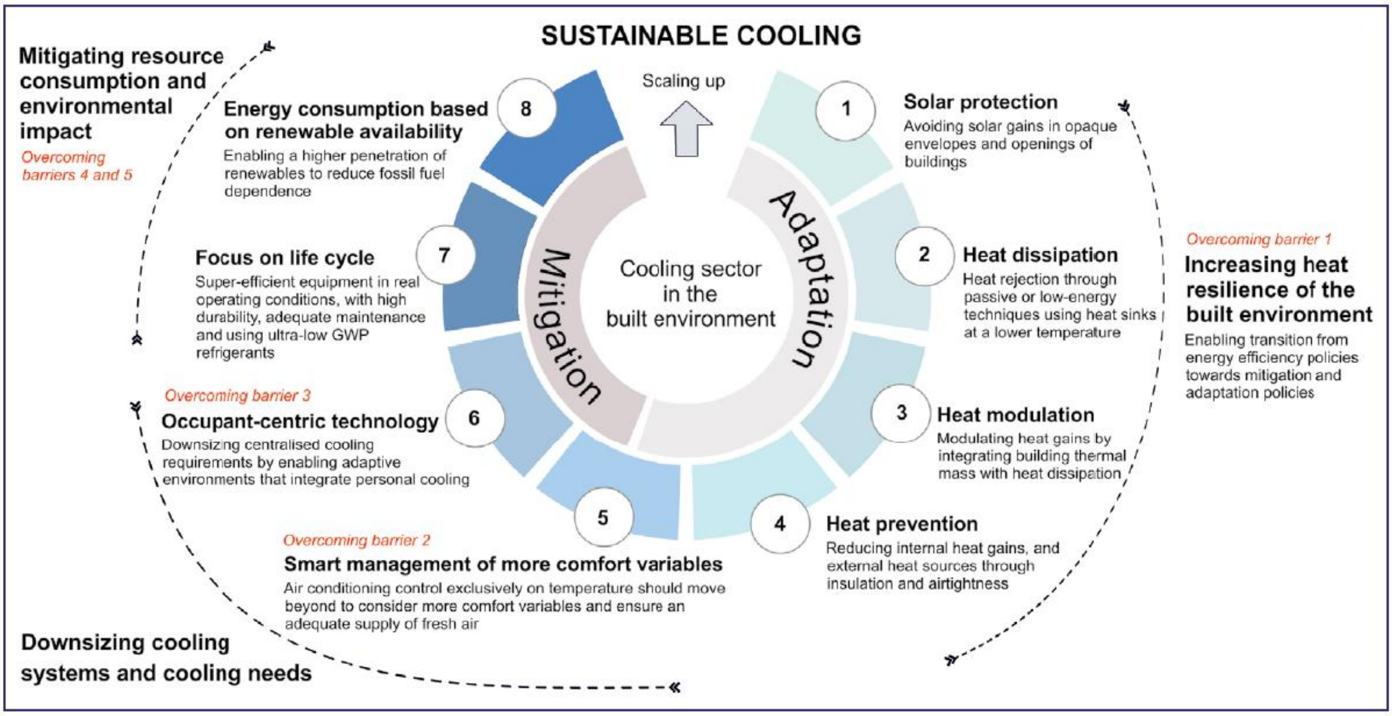

Figure 4. Recommended steps towards sustainable cooling in the built environment (figure 6 of Lizana et al. 2022)

- Overall, publicly available resources providing information and recommendations about sustainable solutions for space cooling (and beyond, for adapting buildings to climate change) are growing, for example:
    - The IEA EBC (Energy in Buildings and Communities Programme) Annex 80 about ‘‘Resilient Cooling of Buildings” produced detailed recommendations per technical solutions (Levinson et al. 2024), and results from a sample of field studies (Qi et al. 2024).
    - The European Commission (DG CLIMA) published technical guidance on adapting buildings to climate change (Ramboll and CE Delft 2023), with a focus on existing buildings, and covering

heatwaves (in chapter 1) among other climate hazards. This includes a short description of typical solutions, and a discussion about stakeholder roles to promote and implement them.
    - OID (2024) provides a guide for the adaptation of tertiary buildings, with practical factsheets per action type, covering, among others, solutions relevant to sustainable space cooling.
- A few references have discussed the possibility to develop service-centric models or hybrid models (combining product sales and service options), with the long-term objective of cooling as a service (Lizana et al. 2022). Such models put an emphasis on the operating and end-of-life phases, creating an incentive for market players to promote higher system efficiency, avoid oversizing, ensure good quality installation and maintenance. However, further research is needed to overcome the barriers to this transformation.

Suggested recommendations:

- **Raising awareness about alternatives to air conditioning systems**

Various resources are available about alternatives to air conditioning systems. However, general awareness about their availability may still be limited.

A well-identified national public online resource about solutions for summer comfort could become the go-to source for information designed for a general audience. Communication campaigns could then promote this resource and key messages to raise awareness about alternatives to air conditioning systems, as well as about efficient use of air conditioning systems.

- **Providing professionals with set of technical recommendations**

Various resources also exist about technical information and guidance. However, professionals may have limited time to go beyond their initial field of expertise and consider other technics and solutions.

Technical recommendations officially promoted by well-established public agencies could help promote good practices, and enlarge the scope of solutions considered by professionals.

- **Including space cooling solutions in the plans about skills and supply chain for the buildings sector**

Shortage in trained installers and in the supply chain is a common challenge faced by renovation programmes. This is addressed with plans about skills and supply chain for the buildings sector. However, these plans do not necessarily cover the needs of the markets for sustainable space cooling solutions.

Including space cooling solutions in these plans could support the development of these markets. This covers for example educational and vocational/training programmes, as well as regular monitoring of markets to assess trends and identify bottlenecks.

- **Supporting innovation, demonstration and performance-based approaches**

The uptake of alternative or innovative solutions requires robust, well-documented evidence of their effectiveness and delivered outcomes, enabling professionals to make informed choices. Real estate stakeholders, architects, planners and building professionals might be reluctant to opt for alternatives to technical solutions they are familiar with, unless they can be sure that they are at least as reliable. Supporting innovation and demonstration is therefore essential to their development. This is also needed to demonstrate compliance with relevant regulations (e.g. fire safety) and how operational the solutions are (e.g. about maintenance).

Innovation is also needed in terms of services (e.g. to experiment the approach of cooling as a service).

3.3. Ensuring an effective enforcement of regulations applicable to cooling systems, from design to disposal

The issue(s):

- The dominant cooling technologies are already covered by the ecodesign, energy labelling and F-gas regulations, but the adoption of these regulations may not deliver the expected impacts if not effectively enforced. For example, this was evidenced by the Effect project in the Nordic countries (Dragovic and Broc 2018), though not specifically about cooling products.
- Disposal of air-conditioning products will increase, due to the growth in sales observed since the early 2000's in certain countries. This might raise concerns about the collection of refrigerants that represent a high risk for climate change, due to their high GWP (Global Warming Potential).

Lessons learned / knowledge available:

- Market surveillance is essential and supported through the Concerted Action on Market Surveillance, including a work package dealing with cooling products[3].
- Member States may pool resources (e.g. for lab testing) and share information (e.g. about results of controls, products/retailers with higher risks), as demonstrated by the Nordsyn cooperation in the Nordic countries (Dragovic and Broc 2018).

[3] https://eepliant.eu/index.php/new-products/air-conditioners/60-new-products/204-eepliant4-wp8-air-heating-and-cooling-products

Suggested recommendations:

- **Strengthening cooperation in market surveillance**

Importance and effectiveness of market surveillance have been documented. However, the means dedicated to it rarely meet the needs. Strengthening cooperation among Member States could help address this. For example through shared laboratories, joint inspections, and exchange of non-compliance findings

- **Accompanying the transition to natural refrigerants**

The F-gas regulation set the roadmap to phase out refrigerants with high GWP. Achieving these targets may require further public interventions.

- **Strengthening the measures dealing with AC systems' end of life**

The growth in the disposal of air-conditioning systems should be anticipated. For example, with measures:

    - To favour products with long-lifetime
    - To raise awareness of product owners about the risks and consequences of improper disposal
    - To increase capacities to collect old AC systems
    - To increase recycling capacities

4. Considering space cooling in the overall energy and climate framework

Space cooling is often hidden in the overall energy and climate framework, at EU or national level, due to its low share in the total energy balance. However, it is related to major issues, including risks for health, electricity system and economic activity (see section 4.1). Moreover, space cooling is related to various policy fields and stakeholders, calling for integrated approaches and coordination (see section 4.2). Multi-level coordination, notably between national and local levels, is also essential to the success of strategies for sustainable space cooling (see section 4.3).

4.1. Assessing the main issues raised by space cooling in the country

The issue(s):

- Space cooling and maintaining a minimum indoor comfort during summer period can be related to various impacts and risks (e.g. health, pressure on the electricity system or power outage, limitations in economic or social activities).
- Related assessments might be spread, possibly creating risks of adverse effects (e.g. maladaptation), and making it difficult to get a comprehensive picture when comparing or prioritizing strategies.

Lessons learned / knowledge available:

- National adaptation strategies and plans can be the focal point where various impacts and risks are considered together.
- National adaptation strategies and plans are also increasingly related to mitigation policies. This can for example be illustrated for the topic of space cooling through the linkage between the concepts and measures for climate-resilient buildings and building regulations, renovation programmes and other measures for energy efficiency in buildings.
- At the opposite, the link with adaptation in the National Energy and Climate Plans remains limited, even if recent or upcoming revisions of building regulations to address overheating risks or similar provisions are sometimes mentioned (Broc et al. 2024).

Suggested recommendations:

- **Mapping and quantifying the expected impacts of warmer summers and extreme heat events**

The preparation of National Adaptation Strategies and Plans can be the opportunity to assess the expected consequences of warmer summers and extreme heat events, identify the most critical ones and put figures on them. This is essential to get the issues recognised in the policy agenda and prioritize communication and action.

This is also an opportunity to put together studies and data from various stakeholders (health administration, environment administration, electricity network operators, insurance companies, civil society organisations, etc.)

- **Ensuring up-to-date information of stakeholders**

Information from the assessments of expected impacts should be made easily available (and in an accessible format), so that stakeholders can take this into account in their own planning. This may require different types of summaries, according to target groups (in terms of formats and language).

4.2. Coordinating the way space cooling is addressed in national and local planning

The issue(s):

- In theory, the national planning and reporting processes related to energy and climate are now integrated through the Governance Regulation of the Energy Union and Climate Action: the various assessments or plans required by the Energy Efficiency Directive (EED), Energy Performance of Buildings Directive (EPBD), the Climate Law and the Renewable Energy Directive shall all come together with the National Energy Climate Plans prepared for 10-year periods with mid-term updates (i.e. revision every 5 years), as shown in the figure below.

Figure 5. Integration of national planning and assessments relevant to space cooling (in the EU policy framework).

- In practice, these national planning and reporting processes include limited cross-references for the moment, and their integration is not obvious yet. This can be partly because their timing has been affected by the revisions of legislation due to the fit-for-55 package. For example, the National Building Renovation Plans, replacing the former Long-Term Renovation Strategies, have delayed to the end of 2025 (due to the late adoption of the EPBD recast), whereas the other assessments were due by June 2024.

- Beyond the timing issue and the streamlining of the reporting processes, integration implies cross-cutting communication and coordination between various administrations or units. This is not straightforward and may take iterations before going from simple juxtaposition to real integration.
- Internal silos, bureaucratic inertia, and competing priorities may slow progress.

Lessons learned / knowledge available:

- Defining a clear mandate for a cross-cutting position in charge of heat resilience can give visibility to the topic and facilitate communication with multiple departments. This also helps mobilise support across departments and attract media attention (see e.g. Athen's Chief Heat Officer).
- A dedicated budget can help secure funding for implementing cross-cutting measures.
- Collaboration across levels of government is also essential to streamline policy implementation and financing.
- Integrating space cooling measures in overarching strategies such as energy and climate plans, adaptation plans or urban planning can support coordination among administrations and ensure that these measures remain on the agenda (see e.g. Hambourg Green Roof Strategy)
- For building-related measures, various regulations and requirements need to be considered (e.g. fire safety, acoustics, indoor air quality, protection of historical buildings or neighbourhoods) and may limit the options that can be implemented, notably for improving building envelope.

Suggested recommendations:

- ❖ **Strengthening the links between National Building Renovation Plans and Comprehensive Assessments on heating and cooling**
- ❖ **Ensuring visibility of space cooling or heat resilience in umbrella plans and strategies**
- ❖ **Defining a coordinator in charge of cross-cutting communication and cooperation**
- ❖ **Considering the needs of dedicated budget for cross-cutting measures**

4.3. Providing support for local authorities to develop solutions relevant to their territories

The issue(s):

- The role of local authorities is further highlighted by the EED recast adopted in 2023 that requires local heating and cooling plans in municipalities of more than 45,000 inhabitants. These plans shall be aligned with other local climate, energy and environment planning requirements in order to avoid administrative burden for local and regional authorities and to encourage the effective implementation of the plans.

- An integrated approach could thus be derived from the one described in the previous section about the national level, as shown in the figure below. Further dimensions may be considered at the local level, notably urban planning.

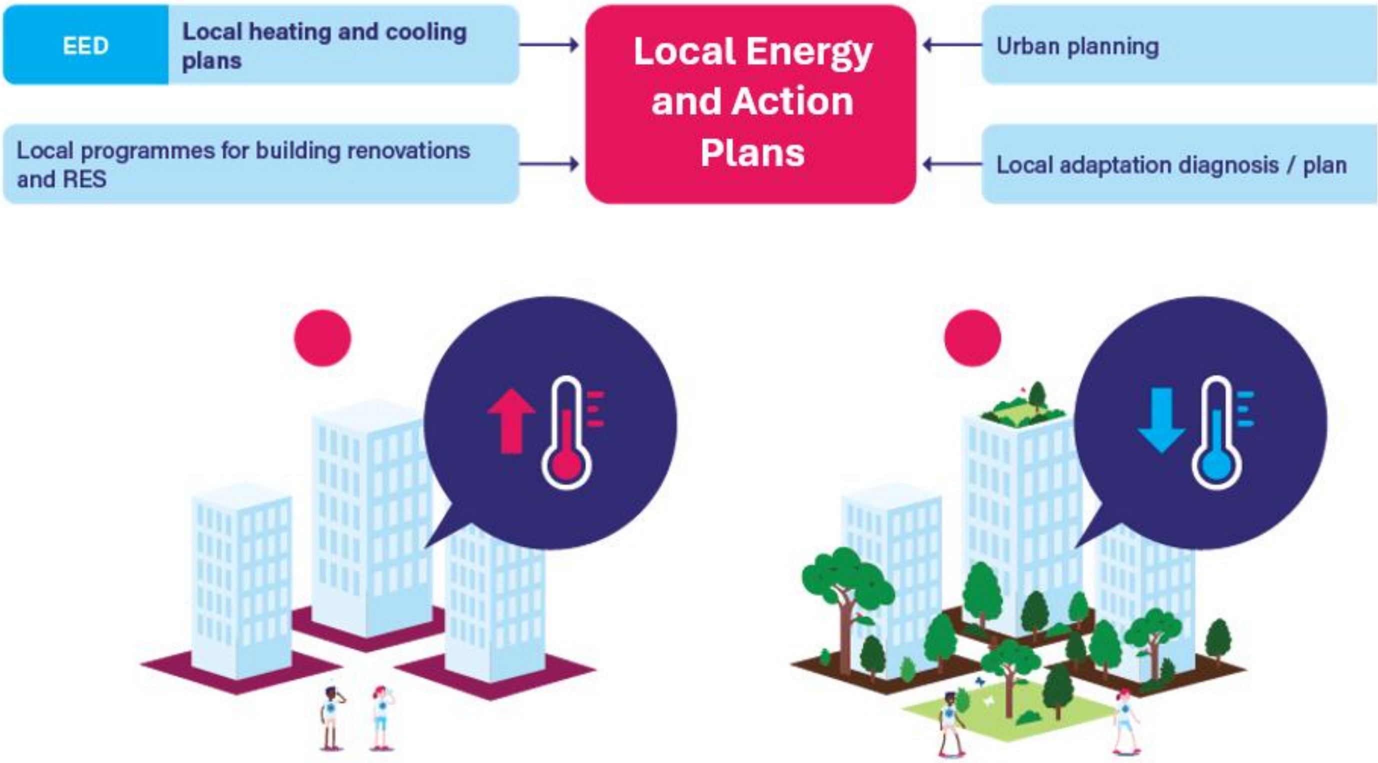

Figure 6. Integrated planning at local level.

- Similar challenges as at the national level apply at the local level (e.g. different timing in the planning processes, difficulties to coordinate various administrations or services). However, the local level may offer a more operational perspective and a field to experiment new approaches.
- Large discrepancies can be observed in the capacities and experience of local authorities. Some front-runners may experiment innovative approaches that pave the way for improvements in national regulations, guidelines or recommendations. Whereas other local authorities may struggle to comply with minimum requirements or disregard some aspects.
- About the provisions on local heating and cooling plans, the EED thus stipulates that "*Member States shall support regional and local authorities to the utmost extent possible by any means, including financial support and technical support schemes*". The local plans can for example start from the information available in the national comprehensive assessment on heating and cooling.
- Support to local authorities is even more important for a topic as complex as space cooling, for which information and experience might be less available (e.g. compared to space heating).
- Local authorities play a major role in the field of space cooling also because measures at building level cannot address all aspects (see also section 3.1): the urban environment can have a major impact on cooling needs and overheating risks, notably through urban heat island effects.

Lessons learned / knowledge available:

- Acknowledging the importance to consider measures beyond the building level, the former IEA EBC Annex 80 on resilient cooling (see section 3.1) is now continued with Annex 97 about "Sustainable Cooling of Cities"
- Several on-going European projects or initiatives develop support and experience sharing among local authorities, specifically for local heating and cooling plans (see e.g., ESCALATE, Plan4Cold, CHAMP) or for addressing heatwaves and improving heat resilience in cities (READY4HEAT, Cities Refresh campaign of the Covenant of Mayors).
- National resources and online platforms are also developed at national level, providing support in national language, which might be more effective to reach all municipalities. See for example the 'My Cooler City' platform in France.

Suggested recommendations:

- **Supporting cross-country experience sharing through European programmes**
- **Developing national platforms to provide support in national language and based on local examples**
- **Providing local authorities with funding proportional to their responsibilities**
- **Enabling local authorities to design and implement holistic cooling strategies**

5. Improving the way space cooling is addressed in the comprehensive assessments

Article 25(1) of the EED recast requires Member States to prepare comprehensive assessments on heating and cooling, that is now part of to their National Energy and Climate Plan (NECP). The first assessment was due by 2015, then with a first update in 2020 and the latest due by June 2024. The next update follows the same timeline as the NECP (draft due by January 2028, and final version by January 2029, in view of the 2031-2040 period).

The contents of these assessments are specified in Annex X of the EED recast. As regards cooling, this includes the assessment of the current cooling demand per sector and of the cooling supply by technology, cooling map to identify potentials for district cooling, a forecast of trends in the cooling demand for the next 10 years and perspective in the next 30 years, an overview of the existing policies and measures relevant to cooling, an analysis of economic potential for efficiency in cooling (using a cost-benefit analysis to compare cooling solutions), and an overview of the strategy and planned policies and measures to achieve the economic potential identified.

In theory, the comprehensive assessments should therefore provide a solid basis for a sound national heating and cooling plan, anticipating upcoming needs and coordinating actions to meet these needs in a cost-effective way.

As this chapter is focused on comprehensive assessments only, the structure is slightly different. We summarize first the issues and lessons learned related to comprehensive assessments (through the lens of space cooling), and then present the key suggested recommendations to improve the way space cooling is addressed in comprehensive assessments. These recommendations also build on the previous chapters.

The issue(s):

(based on the review of 2020 comprehensive assessments, see Broc et al. 2024)

- Comprehensive assessments progressively include more data about cooling. However, the focus is still on heating, especially when describing policies and measures, and even for the five countries with the largest cooling demand.
- This may be explained (1) by the prominent weight of space heating compared to space cooling in the final energy consumption, (2) because cooling is not a direct challenge for decarbonisation (as mostly supplied from electricity), whereas heating remains a major source of direct CO_2 emissions, and (3) because data scarcity about cooling remains an issue.
- The approach and processes related to heating and cooling plans or assessments are often focused on the supply of heat and cooling (e.g. promoting district heating and cooling). This might be because the improvement of the building stock was addressed in the national LTRS – long-term renovation strategies (becoming national building renovation plans with the EPBD recast of 2024). However, the reviews of LTRS

found that they were most often focused on reducing energy consumption due to space heating, similarly to the conclusions from the review of the comprehensive assessments.

- There is therefore a lack of data for scenarios to assess the impacts of changes in the building stock (e.g. due to renovation) on future cooling needs.
- Likewise, cooling is rarely addressed in the part about cost-benefit analysis, when comparing solutions. And when it is the case, this is mostly done by comparing active cooling systems with different efficiency levels, and possibly district heating.
- The EED recast clarifies in its Article 25(3) that the cost-benefit analysis part of the comprehensive assessments shall take into account the Energy Efficiency First (EE1st) principle. As regards space cooling, this should call for example to include passive measures in the comparison. Which has very rarely been done so far (see the example of Austria’s 2024 comprehensive assessment in the annexes of this report).
- About policies and measures, most of the comprehensive assessments cover a broad scope, for example including measures for energy efficiency in buildings (building codes and schemes for building renovation), promotion of RES (mostly for heating) and development of district heating (sometimes also district cooling). However, the link with space cooling is rarely explicit, except for some references to energy labelling and regulations for air conditioners or cooling products, measures to promote district heating and cooling (when district cooling is clearly mentioned), and measures for RES for cooling (mostly about geothermal).
- When discussing measures for building renovation, the focus is usually on reducing the heating demand, the possible impact on the cooling demand being rarely mentioned (the same for shading for example). The description of the renovation schemes mentions that actions related to space cooling are eligible only for one Spanish programme (National Housing Plan 2018-2021), where efficient air conditioners and connection to district cooling can be eligible. Nevertheless, some schemes in other countries also include actions related to space cooling in their scope (e.g. France’s white certificates, Italy’s Ecobonus), despite not being mentioned in the comprehensive assessment.
- Most of the 2020 comprehensive assessments did not include an explicit reference or link to adaptation strategy, plan or measures. Likewise, issues related to heat waves or urban heat islands are rarely mentioned. These points were not included in the Commission’s Recommendation (EU) 2019/1659 on comprehensive assessments, which may explain this gap.

Lessons learned / knowledge available:

Lessons learned from the review of the 2020 comprehensive assessments[4]:

- The assessment of cooling needs per sector confirmed the negligible share of space cooling in energy consumption of residential buildings in most countries. Whereas this share was often around 15% or above (e.g. close to 30% in Spain) in the service sector. Likewise, despite the service sector representing a smaller share of the building stock, its cooling demand is higher than the one of the residential sector.
- The current lower equipment rate in the residential sector (compared to service sector) explains why a stronger growth in cooling demand is expected in the residential sector in the coming years.
- Overall, the assessments identified limited economic potential for district cooling. A few existing district cooling networks were reported, mostly used to supply large office buildings or neighbourhoods with high density of commercial buildings. District cooling seems to be more developed in Nordic countries (e.g.

[4] 2024 comprehensive assessments were not available at the time of this review.

Finland) than in Southern countries (e.g. Spain and Greece), except for Italy (where district cooling was reported to grow). This might occur because district cooling has mostly developed in those areas together with district heating (including in Italy), supplying a large share of the buildings (in Nordic countries).
- When space cooling is covered in the cost-benefit analysis, the most cost-effective option is often found to be heat pumps (sometimes combined with photovoltaic systems, like in Cyprus' assessment).
- The number of new or planned measures with explicit link with space cooling was limited, including: an update of the national regulation for thermal energy systems for buildings (Spain), measures to develop district cooling (France, Greece and Italy), specific consideration about the possible introduction of new limits on the use of cooling systems to be evaluated by defining restrictions related to the climate zones (Italy).

Croatia's 2020 Comprehensive Assessment was one of the assessments including the most details and analysis about space cooling (see the annexes of this report for more details):

- Data specific to energy delivered and useful energy for space cooling, per main sector (residential, services and industry), and with further disaggregated data (e.g. individual houses / multifamily buildings; sub-sector in services; data and map per county) were included.
- It included a comparison of a Baseline-As-Usual (BAU) scenario with a scenario with integrated measures showing that these measures would compensate most of the increase in cooling demand found in the BAU scenario.
- The main action type considered to reduce energy consumption from / improve efficiency in space cooling was the replacement of split systems with heat pumps. No financial incentive was planned for this action type, as it was estimated to be cost-effective already (positive Net Present Value).
- District cooling was not originally planned. However, using heat from district heating system in summer to power central absorption chillers for cooling larger non-residential buildings (e.g. hospitals, hotels, shops, etc.) already connected to the network is now considered as a way to replace compression chillers that rely on refrigerants with high environmental impacts.

Lessons learned from the example of Austria's 2024 comprehensive assessment (see the annexes of this report for more details):

- Integrating space cooling into a comprehensive assessment requires additional data sources, new modelling routines, and close coordination between national statistics, technical modelling teams, and policymakers.
- One challenge was dealing with limited historical data on cooling systems, especially in the service sector. This can however be addressed using disaggregated technology stock estimates and assumptions from previous EU-level studies.
- From a policy perspective, the inclusion of space cooling improved the comprehensiveness and policy relevance of the assessment. It helps highlight the role of energy efficiency and demand-side measures in the cooling sector, and it provides a transparent framework for evaluating future investment needs and strategies.
- The Austrian case shows that it is feasible—and valuable—to integrate space cooling into national energy planning using structured methods and realistic scenarios. The approach developed through the CooLIFE project is applicable in other Member States and can support the broader effort to align national planning with EU climate and energy objectives.

5.1. Overcoming the data issue

Data limitations should not be an excuse to exclude or neglect cooling in the comprehensive assessments.

The size of the cooling issue varies very significantly from one country to another. However, the literature shows that, even in Nordic countries, space cooling needs to be addressed to avoid increasing overheating risks in existing buildings in the coming years.

The previous chapters have shown that **the literature about space cooling is quickly growing, and more and more resources are available** to support an assessment of cooling needs and a review of available solutions (see also the references section).

In any case, **the CoolLIFE tool can provide a first basis or benchmark** to assess the cooling demand in a Member State up to 2050. The results from the CoolLIFE tool should be taken with caution, as explained in the Wiki of the tool and in the example about Austria in the annexes of this report. For example, because it includes a number of assumptions (that can be changed by the user). Keeping this in mind, these results can help prioritize data collection and research to improve the reliability of the assessment.

About future weather files, **more datasets become available**, such as the one developed by the IEA EBC Annex 80 (Machard et al. 2024).

5.2. Using sensitivity analysis to anticipate upcoming challenges

Tools like the CoolLIFE tool can be used to do sensitivity analysis. This is essential to address key sources of uncertainty (e.g. in climate projections), explore contrasted scenarios and assess what types of solutions or policy interventions can be the most relevant.

Sensitivity analysis can help identify the most influential variables (e.g. temperature extremes, humidity, building stock characteristics), to test the robustness of measures under different future conditions, and to prioritise investments where they will have the greatest impact under different future conditions (e.g., hotter summers, urban densification, new cooling technologies). It can also support prioritising adaptation measures and targeting assistance to vulnerable groups where risks are projected to be highest.

5.3. What the Energy Efficiency First principle means for comprehensive assessments: considering a broader scope of options

Energy Efficiency First (EE1st) means to consider and compare a broad of options that could be used to meet given needs and policy objectives. In general, this is about providing a level-playing field to compare options related to energy supply and options related to energy demand. More specifically about space cooling, this means that the set of options considered should include options that can reduce space cooling needs (e.g. passive measures). In other words, the Cost-Benefit Analysis of space cooling options in the comprehensive assessments should not be limited to compare air-conditioning devices (including heat pumps) with different levels of efficiency.

Ideally the assessment would compare for example, building insulation, sun shading options, ventilation options, district cooling, and various individual cooling systems, with a cost-benefit analysis that would consider multiple impacts (final energy consumption, peak load, GHG emissions, comfort/productivity, health impacts…).

Being comprehensive in the assessment is however challenging. Stakeholder consultation can help select the options and assumptions for the scenarios to be assessed in priority.

5.4. Discussing the coordination between the national and local level

Article 25 of the EED recast set that the newly required local heating and cooling shall align with the comprehensive assessments. Comprehensive assessments should therefore now be developed with, among other purposes, the aim to provide reference data and a solid starting point for local heating and cooling plans.

This could be seen as an iterative process:

- the comprehensive assessment provides a basis / inputs (e.g. heating and cooling maps; cost-benefit analysis of typical solutions) for local heating and cooling plans
- then local heating and cooling plans may provide refined local data, revised assumptions, and raise solutions that might have been overlooked in the national assessment

Coordination should also occur in terms of policies and implementation, clarifying the roles and interactions between the different jurisdiction levels.

6. Conclusions

The literature about sustainable strategies for space cooling and climate-resilient buildings is quickly growing, showing how space cooling is becoming an increasingly important priority across research and practice and is interconnected with multiple areas (e.g. energy, health, adaptation). Selecting and designing solutions for sustainable space cooling goes beyond technical considerations about air-conditioning systems and buildings. Factors influencing thermal comfort and heat-related health risks are key, highlighting the need to consider the differences among building occupants, building usage, as well as the interactions with - and impacts of - the surrounding environment.

The complexity to address all these issues and the expected growing cooling needs call for policy interventions to help plan and coordinate relevant strategies, building on the knowledge and experience gained from research and previous policies and measures.

The following table provides an overview of the recommendations suggested from the knowledge and experience gained along the CoolLIFE project, structured in main categories.

Table 1. Overview of the suggested recommendations.

Main category	Axis	Actions
Starting from the needs, anticipating changes	Starting from the building occupants – citizen	✓ Promoting studies to improve knowledge and data availability about space cooling-related behaviours ✓ Facilitating multi- and inter-disciplinary exchanges and knowledge gathering ✓ Revising standards in line with current knowledge and allowing flexibility (cf. national/local specificities) ✓ Specifying enabling conditions for efficient and adaptative behaviours ✓ Involving citizen and building occupants in the process to define strategies for sustainable space cooling
	What solutions for what conditions: considering operating limits and risks	✓ Linking implementation, monitoring and research to grow science-based evidence ✓ Maintaining future weather files including typical weather years ad heatwave events ✓ Providing methodologies to streamline sensitivity analysis ✓ Promoting heat-resilience assessments to anticipate overheating risks and prioritize asset managers' actions

		✓ Categorizing typical situations, operating limits and mix of solutions ✓ Involving building designers, owners and occupants in the definition of scenarios and analysis of results
	Linking mitigation and adaptation	✓ Mapping possible synergies and adverse effects of mitigation and adaptation measures ✓ Ensuring consistency among mitigation and adaptation policies ✓ Valuing co-benefits through co-funding
	Planning to avoid ineffective and expensive actions in a hurry	✓ Setting clear and measurable targets with regular monitoring ✓ Structuring action plans from short-term to long-term ✓ Providing stability and visibility about funding
	Sustainable space cooling for all: addressing summer energy poverty	✓ Prioritizing decent living conditions over energy savings ✓ Identifying priority target groups ✓ Using targeted and dedicated measures
A multilevel approach to provide whole-year comfort in a sustainable way	Towards efficient and climate-resilient buildings	✓ Ensuring renovation programmes are ‘fit for cooling’ ✓ Favouring deep renovations and synergetic actions ✓ Ensuring that building regulations address summer comfort and overheating risks ✓ Revising Energy Performance Certificates to include information about summer comfort
	Promoting broader markets of sustainable space cooling solutions linked to adaptation and resilience strategies	✓ Raising awareness about alternatives to air conditioning systems ✓ Providing professionals with set of technical recommendations ✓ Including space cooling solutions in the plans about skills and supply chain for the buildings sector ✓ Supporting innovation, demonstration and performance-based approaches
	Ensuring an effective enforcement of regulations applicable to	✓ Strengthening cooperation in market surveillance ✓ Accompanying the transition to natural refrigerants

	cooling systems, from design to disposal	✓ Strengthening the measures dealing with AC systems' end of life
Considering space cooling in the overall energy and climate framework	Assessing the main issues raised by space cooling in the country	✓ Mapping and quantifying the expected impacts of warmer summers and extreme heat events ✓ Ensuring up-to-date information of stakeholders
	Coordinating the way space cooling is addressed in national planning	✓ Strengthening the links between National Building Renovation Plans and Comprehensive Assessments on heating and cooling ✓ Ensuring visibility of space cooling or heat resilience in umbrella plans and strategies ✓ Defining a coordinator in charge of cross-cutting communication and cooperation ✓ Considering the needs of dedicated budget for cross-cutting measures
	Providing support for local authorities to develop solutions relevant to their territories	✓ Supporting cross-country experience sharing through European programmes ✓ Developing national platforms to provide support in national language and based on local examples ✓ Providing local authorities with funding proportional to their responsibilities ✓ Enabling local authorities to design and implement holistic cooling strategies
Improving the way space cooling is addressed in the comprehensive assessments		✓ Overcoming the data issue ✓ Using sensitivity analysis to anticipate upcoming challenges ✓ What the Energy Efficiency First principle means for comprehensive assessments: considering a broader scope of options ✓ Discussing the coordination between the national and local level

7. References

Alessandrini, J.-M., Ribéron, J., & Da Silva, D. (2019). Will naturally ventilated dwellings remain safe during heatwaves? Energy and Buildings, 183, 408-417.

Arup (2022). Addressing overheating risk in existing UK homes. Report commissioned by the UK Climate Change Committee. https://www.theccc.org.uk/publication/addressing-overheating-risk-in-existing-uk-homes-arup/

Ballester, J., Quijal-Zamorano, M., Méndez Turrubiates, R. F., Pegenaute, F., Herrmann, F. R., Robine, J. M., Basagaña, X., Tonne, C., Antó, J. M., & Achebak, H. (2023). Heat-related mortality in Europe during the summer of 2022. *Nature Medicine*, 29(7), 1857–1866.

Baniassadi, A., & Sailor, D. J. (2018). Synergies and trade-offs between energy efficiency and resiliency to extreme heat – A case study. *Building and Environment*, 132, 263-272.

BPIE (2024). Towards a Climate-Resilient Built Environment: A discussion paper on opportunities and priorities for adaptation in the EU. Buildings Performance Institute Europe.

Broc, J.S., Lionggo, I., Athanasiou, D., Karalaiou, K., Pomper, P., Clero, J., Duplessis, B., Bottino Leone, D., Conforto, G., Malla, A., Gelesz, A., Trovalusci, F., Pezzutto, S. (2024). Review and mapping of legislations and regulations on sustainable space cooling at EU and national levels. Deliverable D4.1 of the CoolLIFE project, co-funded by the LIFE programme

Conforto, G. (2024). Review of Financing Schemes Relevant for Sustainable Space Cooling at the EU and National Levels. Deliverable D4.2 of the CoolLIFE project, co-funded by the LIFE programme.

Cornelis, M. (2025). Framing summer energy poverty – Insights and recommendations for a resilient future. Final report to the European Commission.

Dolques, G., Dépoues, V. (2024). Adapting French buildings to heatwaves: what do we know? Report of I4CE (French Institute for Climate Economics).

Dragovic, M., Broc, J.S., 2018. Nordsyn (Market Surveillance of Ecodesign and Energy Labelling) and the Effect Project in the Nordic Countries. Case study prepared by IEECP for the EPATEE project, funded by the European Union's Horizon 2020 programme.

Duplessis, B., Elnagar, E., Fontenaille, T., Fraboni, R., Gelesz, A., Radice Fossati, V. (2024). Taxonomy of space cooling technologies and measures. Deliverable 2.1 of the CoolLIFE project.

Durand-Daubin, M., Laurent, M. H., & Binet, G. (2024). Staying cool in France: an extensive survey of summer comfort, natural home cooling practices and emerging air conditioning use in the French residential sector. Proceedings of the ECEEE 2024 Summer Study.

Elnagar, E., Pezzutto, S., Duplessis, B., Fontenaille, T., & Lemort, V. (2023). A comprehensive scouting of space cooling technologies in Europe: Key characteristics and development trends. Renewable and Sustainable Energy Reviews, 186, 113636.

European Commission, (2023). DIRECTIVE (eu) 2023/1791 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast).

Eurostat, (2024). Living conditions in Europe – housing.

Gelesz, A., Casio, D., Kumarage, O., Elkarymy, O., Fakhari, M., Belleri, A., Radice Fossati, V., Duplessis, B., & Kranzl, L. (2024). Multiple, socioeconomic impacts of sustainable space cooling. Deliverable 3.3 of the CoolLIFE project.

Gelesz, A., Reith, A., Szabó, H., Hurtado-Verazaín, L., Kranzl, L., Duplessis, B., Caballero, N., Pezzutto, S. (2023). Analysis of Behavioural Interventions Across Europe. Deliverable 3.2 of the CoolLIFE project.

Gayoso Heredia, M. San Nicolás Vargas, P., Torrego Gómez, D., Núñez Peiró, M., Gómez Muñoz, G., Román López, Emilia; Avanzini, Marcello; Ferrer Gabarró, Clara; García París, Marta; Kampouridou, Anneta; Kyrkou, Danai; Sánchez-Guevara Sánchez, Carmen. (2023) How to address summer energy poverty in public policies. Deliverable of the CoolToRise project.

Gerard, F., Smit, T., Rademaekers, K., Braungardt, S., Monejar Montagud, M. E., & Guevara Opinska, L. (2021). Policy support for heating and cooling decarbonisation: Roadmap. Report of Trinomics, Öko Institute and DTU for the European Commission.

Giussani, F., Pezzutto, S., Bottino Leone, D., Duplessis, B., Kranzl, L. and Hummel, M. (2024). Energy Demand Assessment. Deliverable D2.2 of the CoolLIFE project, co-funded by the LIFE programme.

Hinge, A. (2023). Resilience Issues in Building Energy Codes. Report for the Building Energy Codes working group of the IEA EBC (Energy in Building and Communities Programme).

Hoggett, R., Lowes, R., Ugalde-Loo, C. E., & Khosravi, F. (2024). Hot and cold : Policy perspectives on overheating and cooling in United Kingdom homes. *Energy Research & Social Science*, 118, 103803.

Holzer, P., Arens, E., Attia, S., Corrado, V., Gupta, R., Hamdy, M., Homaei, S., Laouadi, A., Levinson, R., Selkowitz, S., Sengupta, A., Sodagar, B., Zinzi, M., Wang, L. L., & Abhishek, G. (2024). Resilient Cooling of Buildings – Key Performance Indicators. Report of the IEA EBC (Energy in Buildings and Communities) Annex 80.

Hurtado-Verazaín, L., Gelesz, A., Csizmady, A., Szabó, H., Ferencz, Z, Vincze, A., Kőszeghy, L. Caballero, N., Reith, A. (2023). Knowledgebase for occupant-centric space cooling. Deliverable 3.1 of the CoolLIFE project.

Iungman T, Cirach M, Marando F, Pereira Barboza E, Khomenko S, Masselot P, Quijal-Zamorano M, Mueller N, Gasparrini A, Urquiza J, Heris M, Thondoo M, Nieuwenhuijsen M. Cooling cities through urban green infrastructure: a health impact assessment of European cities. Lancet. 2023 Feb 18;401(10376):577-589. Doi: 10.1016/S0140-6736(22)02585-5.

Jensen, P. B., Laursen, L. N., & Haase, L. M. (2021). Barriers to product longevity: A review of business,product development and user perspectives. *Journal of Cleaner Production*, 313, 127951.

Levinson, R., Arens, E., Bozonnet, E., Corrado, V., Gilbert, H., Holzer, P., Jaboyedoff, P., Krelling, A., Machard, A., Miller, W., P.Tootkaboni, M., Selkowitz, S., & Zhang, H. (2023). Policy Recommendations from IEA EBC Annex 80: Resilient Cooling of Buildings. Lawrence Berkeley National Laboratory.

Lizana, J., Miranda, N. D., Gross, L., Mazzone, A., Cohen, F., Palafox-Alcantar, G., Fahr, P., Jani, A., Renaldi, R., McCulloch, M., & Khosla, R. (2022). Overcoming the incumbency and barriers to sustainable cooling. *Buildings and Cities*, 3(1), 1075–1097.

Machard, A., Salvati, A., P. Tootkaboni, M., Gaur, A., Zou, J., Wang, L. L., Baba, F., Ge, H., Bre, F., Bozonnet, E., Corrado, V., Luo, X., Levinson, R., Lee, S. H., Hong, T., Salles Olinger, M., Machado, R. M. e S., da Guarda, E. L. A., Veiga, R. K., … Holzer, P. (2024). Typical and extreme weather datasets for studying the resilience of buildings to climate change and heatwaves. *Scientific Data*, 11(1), 531.

Machard, A., Inard, C., Alessandrini, J.-M., Pelé, C., & Ribéron, J. (2020). A Methodology for Assembling Future Weather Files Including Heatwaves for Building Thermal Simulations from the European Coordinated Regional Downscaling Experiment (EURO-CORDEX) Climate Data. *Energies*, 13(13).

Malla, A., Kranzl, L., Gelesz, A., Casio, D., Pezzutto, S., Duplessis, B., & Hummel, M. (2024). Impact Assessment. Deliverable 2.3 of the CoolLIFE project.

Morales, R. D., Audenaert, A., & Verbeke, S. (2025). Thermal comfort and indoor overheating risks of urban building stock—A review of modelling methods and future climate challenges. *Building and Environment*, 269, 112363.

OID (2025). Building in the face of climatic hazards – Guide to action for Climate change adaptation. Report of the French Observatory of Sustainable Real Estate (*Observatoire de l'Immobilier Durable*), as part of ESREI (European Sustainable Real Estate Initiative).

Pérez Rodríguez, F., Sánchez-Guevara Sánchez, C., Gayoso Heredia, M., Torrego Gómez, D., Núñez Peiró, M., Sanz Fernandez, A., San Nicolás Vargas, P., García París, M., Plana Izquierdo, M., (2024). Manifesto for the improvement of our neighbourhoods and their adaptation to heat. Universidad Politécnica de Madrid

Peuportier, B., Monnier, R., Schalbart, P., Lemonsu, A., Leroy, B., François, E., Wurtz, E., Ouvrier-Bonnaz, O., Ziv, N., Serodio, E., Thiers, S., Pionnier, R. (2023). Résiliance : adaptation des bâtiments au changement climatique [*Resilience: adaptation of buildings to climate change*]. Final report for ADEME.

Qi, D., Hofer, G., Jaboyedoff, P., Ji, L., Shu, C., Ge, H., Wang, L.L., Schoisengeier, S., Lampersberger, P., Stipsits, A., Zinzi, M., Zhang, G., Hu, Y., Ai, Z., Sengupta, A., Breesch, H., Chiesa, G., Binnemans, S., Zhang, X., Baba, F., Akander, J., Bakhtiari, H., Hayati, A., Amaripadath, D., Attia, S. (2024). Resilient Cooling of Buildings – Field Studies. Report of the IEA EBC (Energy in Buildings and Communities) Annex 80.

Quefelec, S. (2023). Cooling buildings sustainably in Europe: Exploring the links between climate change mitigation and adaptation, and their social impacts. Briefing no. 20/2022 of the European Environment Agency.

Ramboll, & CE Delft. (2023). EU-level technical guidance on adapting buildings to climate change : Best practice guidance. Report for the European Commission (DG CLIMA).

Ribeiro, D., E. Mackres, B. Baatz, R. Cluett, M. Jarrett, M. Kelly and S. Vaidyanathan (2015). Enhancing Community Resilience through Energy Efficiency. Report of ACEEE (American Council for an Energy Efficient Economy).

Roccamena, L., Alessandrini, J.-M., Gervasi, P., Guilhot, J., Kyriakodis, G., Molesin, S., Sabre, M., & Wei, W. (2024). Assessing the level of adaptation to heat waves in Parisian housing. Proceedings of the 44th AIVC - 12th TightVent - 10th venticool Conference.

Sanz Fernandez, A., Sánchez-Guevara Sánchez, C., Ferrer i Gabarró, C., García París, M., Karamitreva, G., Kyrkou, D.,; Simeonov, G.,; Zimelli, D. (2024). Why should we stop seeking energy savings in summer energy poverty policies? Health and thermal comfort matter. Universidad Politécnica de Madrid.

Stern, P., Psomas, T., Jaboyedoff, P., Zinzi, M., Krelling, A., Gediz Ilis, G., ... & Keller, T. (2024). Resilient Cooling of Buildings – Technology Profiles. Report of the IEA EBC (Energy in Buildings and Communities) Annex 80.

Thomson, H., Simcock, N., Bouzarovski, S., & Petrova, S. (2019). Energy poverty and indoor cooling: An overlooked issue in Europe. *Energy and Buildings*, 196, 21-29.

Tobías, A., Armstrong, B., Gasparrini, A., & Diaz, J. (2014). Effects of high summer temperatures on mortality in 50 Spanish cities. *Environmental Health*, 13(1), 48.

Velashjerdi Farahani, A., Jokisalo, J., Korhonen, N., Jylhä, K., & Kosonen, R. (2024). Simulation analysis of Finnish residential buildings' resilience to hot summers under a changing climate. *Journal of Building Engineering*, 82, 108348.

Viguié, V., Lemonsu, A., Hallegatte, S., Beaulant, A.-L., Marchadier, C., Masson, V., Pigeon, G., & Salagnac, J.-L. (2020). Early adaptation to heat waves and future reduction of air-conditioning energy use in Paris. *Environmental Research Letters*, 15(7), 075006.

Zhang, C., Kazanci, O. B., Levinson, R., Heiselberg, P., Olesen, B. W., Chiesa, G., Sodagar, B., Ai, Z., Selkowitz, S., Zinzi, M., Mahdavi, A., Teufl, H., Kolokotroni, M., Salvati, A., Bozonnet, E., Chtioui, F., Salagnac, P., Rahif, R., Attia, S., … Zhang, G. (2021). Resilient cooling strategies – A critical review and qualitative assessment. *Energy and Buildings*, 251, 111312.