ADAPTATION

I4CE INSTITUTE FOR CLIMATE ECONOMICS
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Adapting French buildings to heatwaves: what do we know?

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CONTEXT

This report was produced as part of a project aimed at analysing the **economic implications of adaptation pathways**, conducted by I4CE and its partners between February 2023 and March 2024. The summary, **"Anticipating the impacts of a 4°C warming: what is the cost of adaptation?"**, was published in April 2024. It provides an up-to-date overview of what we know about adaptation costs of adaptation to heat waves for the building sector in mainland France and identifies gaps and needs for additional studies in order to move forward.

This study was carried out with the participation of **Cristhian Andres Molina Calderon**, **Morgane Moullie**, **Marie Andrieux**, **Pauline Vilain** and **Sakina Pen Point** (Observatoire de l'Immobilier Durable), who conducted the analysis of building stock exposure, **a summary** of which was published in March 2024.

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SUMMARY FOR DECISION-MAKERS

To address the growing impacts of heatwaves on economic activities and populations, the adaptation of the building sector is becoming a new imperative. While the question of "how" to adapt has been the subject of numerous studies, the question of "how much" has so far received little attention. To move forward on this issue, we present in this report:

- **An overview** of current knowledge regarding the costs of adapting the building sector to heatwaves.
- **The methodology we used to estimate the additional costs of adapting to heatwaves**, based on available information and discussions with experts.

This analysis enables us to draw seven lessons and one recommendation:

1. **The absence of a shared and consensual common framework is one of the main obstacles mentioned by sector stakeholders who wish to embark on an adaptation process.** Although they increasingly identify summer comfort as a key issue, sector stakeholders currently lack standardized weather files aligned with the *French reference warming trajectory* (TRACC based on a warming of 4°C on average for mainland France by 2100), as well as technical references, specifications and labelling processes for adaptation.

> **RECOMMENDATION**
>
> Set up and facilitate working groups to produce a common reference framework for adaptation to climate change in buildings, similar to the ongoing CAP 2030 initiatives that anticipate the next regulation on new construction.
>
> **→ Building this common reference framework is emerging as the next critical step for adapting existing buildings to heatwaves.**

2. **Recent events have shown that buildings are ill-adapted, leading to significant impacts that are likely to increase if nothing is done.** While heatwaves do not directly damage buildings, they do impact economic activities and the health of people living, studying or working indoors. These impacts are already significant: at the European level, recorded productivity losses stand at between 0.3% and 0.5% of GDP in years with heatwaves, although it is difficult to determine the share of these losses attributable to buildings. In France, between 2015 and 2020, estimated health impacts were between 22 and 37 billion euros. **As the climate continues to warm, the exposure of the building stock will increase.** At just 2°C warming in mainland France (by 2030 according to the TRACC), nearly half of all buildings will already be highly or very highly exposed, rising to almost all of the building stock at +4°C. Dense urban areas will be particularly affected and cities that currently have low exposure could become highly exposed in the future. **If nothing is done to adapt, the economic and health impacts of heatwaves will also increase.** On a European scale, they could reach several GDP points by the end of the century in the most exposed countries and cause 30 more deaths than at present.

3. **The prevailing response to the evolution of this problem is to install air conditioning.** This is the reactive measure seen in most cases and already represents investments estimated at around 3.5 billion euros annually for housing. If this pace continues, almost all of the building stock could be equipped by 2050. Often described as maladaptation, the mass deployment of air conditioning raises questions about the externalities it generates : increased electricity consumption, greenhouse gas emissions and especially a significant rise in outdoor temperatures in urban areas, which could reach several degrees.

4. **Other adaptation solutions are available and can be integrated into existing planning dynamics.** These solutions are well documented and can mostly be used in combination with planned operations. **Where new construction is concerned, they entail going beyond current regulations**, which do not yet take account of climate projections. For the existing building stock, **adaptation needs to be integrated into the energy retrofitting policy**, which aims to renovate the majority of the stock by 2050 (according to the French National Low-carbon Strategy). The first step should be to redirect investments towards deep retrofits, which are the most effective for summer comfort and which currently lack almost nearly 27 billion euros per year to meet targets. This adaptation effort represents an additional cost, which we have estimated in this study at between 2% and 5% for new construction and at 10% for retrofitting compared to operations without adaptation. In relation to the public and private investment needed to achieve carbon neutrality objectives, this would represent additional requirements of 1 to 2.5 billion euros for new construction and 4.8 billion euros for retrofitting.

	New buildings that go beyond the regulations for summer comfort	Deep retrofits that integrate adaptation to heatwaves
Housing	+0.7 to +1.8 billion euros per year	+3.1 billion euros per year
Commercial buildings	+0.3 to +0.7 billion euros per year	+1.7 billion euros per year

Average for the period 2024-2030.

5. **These additional investments could prove insufficient beyond a certain level of climate warming.** Few prospective studies exist to date. However, the initial available information shows that for some climate zones (particularly the Mediterranean region), it will become increasingly difficult to cope without air conditioning from the middle of the century (+2.7°C). But these studies also agree on the effectiveness of adaptation solutions and urge the adoption of a sequenced approach, meaning first implementing other solutions before considering air conditioning.

6. **Adapting to heatwaves will not be limited to a series of works on buildings,** as adaptation solutions are only effective if used correctly. User awareness and behaviour are therefore crucial. More broadly, a systemic and integrated approach will guarantee the resilience of economic activities and populations facing heatwaves. At the city level, territorial policy must be consistent with adaptation challenges and attach importance to the quality of the social fabric, thus avoiding situations of isolation. It must also ensure the health system and emergency services are sufficiently robust to limit the health impacts of heatwaves. Finally, for economic actors and public services, other initiatives can be implemented to address heatwaves, such as installing water points or adjusting working hours.

7. **Further research is needed to enhance understanding of the economic needs for adaptation in buildings.** This includes: improving knowledge about the consequences of disrupting or closing an essential public service during heatwaves; better determining the effectiveness and limitations of adaptation solutions at the building stock level; and enhancing knowledge about their costs. Exercises of this type have been conducted abroad and could be replicated in France by sector experts.

1. INTRODUCTION: ADAPTATION, THE NEW CLIMATE CHALLENGE OF THE BUILDING SECTOR

With 64 MtCO2e emitted in 2022, the building sector is currently the third largest emitter of greenhouse gases in France. In order to meet the French carbon neutrality objectives, this sector faces a huge challenge: dramatically reducing its emissions by 2050. To achieve this, substantial planning efforts (structured around the National Low-Carbon Strategy) have been made and have resulted in the effective implementation of tools to incentivise (*e.g.* financial aids *MaPrimeRénov'* and *CEE*) and to oblige (*e.g.* tertiary decree, revision of building standards) building sector stakeholders to commit to this path.

However, the transition to a carbon-neutral economy has not progressed as rapidly as hoped at the global level. The climate has already warmed and the impacts of this warming are being felt across all sectors. For buildings, this is already translating very clearly into rising insurance costs and a contribution of the sector to the economic, social and health impacts identified during extreme weather events. These effects present the building sector with a new challenge: ensuring its adaptation to climate change.

This challenge of adaptation raises new technical questions for engineers and architects, as well as economic questions for all sector stakeholders. As noted by the French Court of Auditors in its 2024 annual public report on adaptation, "*knowing the price* is a key element of arbitration to define and implement financially sustainable solutions" (Cour des Comptes, 2024b). Although significant progress has been made in the economic assessment of carbon neutrality policies, the issue of the costs of adaptation is only just emerging. To move forward with this estimation, I4CE and its partners led a project between February 2023 and March 2024 with the goal of analysing the *economic implications of adaptation pathways*, a summary of which was published in April 2024, entitled **"Anticipating the impacts of a 4°C warming: what is the cost of adaptation?"**.

This complementary study is primarily intended for building sector stakeholders and aims to provide a more detailed and up-to-date overview of knowledge and knowledge gaps concerning the costs of adaptation to heatwaves for this sector.

Our approach is based on an analysis of the scientific literature and of documentation produced by the government, industry and civil society at the French and European levels on the cost of impacts and climate adaptation solutions connected to the building sector. It also builds on the work of a technical committee involving around 15 stakeholders, including sector experts (engineering consultancies, property managers) and state operators (ADEME, CEREMA, CSTB), supplemented by bilateral exchanges.

Our work has also led to the development of a methodology, presented in this study, aimed at making an initial estimate of adaptation costs for the building sector. Finally, we have identified the need for further studies, which we underline throughout our analysis, to provide a better understanding of the economic issues surrounding the adaptation of buildings to heatwaves.

2. HEATWAVES HAVE IMPACTS ON ECONOMIC ACTIVITIES AND POPULATIONS

Unlike floods or shrink-swell in clay soils, heatwaves do not have a major direct impact on buildings[1]. They do not damage the structure, as is the case with cracks caused by shrink-swell, or the other essential parts of buildings, such as insulation or systems damaged by floods.

However, they do affect indoor comfort conditions, commonly referred to as "summer comfort". This concept has only very recently emerged in regulations, meaning that for the vast majority of the building stock, summer comfort conditions were not taken into account when they were designed and built. This oversight has already led to significant disruptions observed during extreme heat events. These can include disruptions to essential services (*e.g.* hospitals, schools, police stations, barracks), to certain productive activities (*e.g.* industrial buildings, offices), or directly to public health (*e.g.* residential care homes, social housing).

Recent climate events have shown that these disruptions are already having economic and health impacts that weigh heavily on the French economy. As the climate warms, buildings will be increasingly exposed to heatwaves (see **box 1**). Inevitably, if nothing is done to adapt, these impacts will increase in the coming decades.

Indirect economic consequences

Several recent studies have sought to estimate the impact of rising temperatures on work productivity. At the global level, Orlov *et al.* (2020) show that productivity could decrease by up to 1.4% by the end of the century (RCP 8.5, or almost +4°C in France). At the European level, heatwaves are already causing significant productivity losses: in 2003, 2010, 2015 and 2018 they stood at between 0.3% and 0.5% of European GDP (García-León *et al.* 2021). In comparison, the reference period (1981-2010) saw an average loss of 0.21%. Without adaptation measures, these losses could increase to 0.77% between 2035 and 2045 and reach 1.14% from 2060 onwards (RCP 8.5). However, there is a marked geographical disparity in these losses, which reach 1.8% in France by 2060, whereas they could be as high as 3% in Portugal and Spain, but close to zero for the United Kingdom and Ireland.

At the European level, Szewczyk, Mongelli and Ciscar (2021) estimate a 1.6 point decline in GDP by 2080 (RCP 8.5) due to a reduction in work productivity during extreme heat events. Again, the spatial distribution is very heterogeneous: the Mediterranean regions would be the most affected, at 3% on average, potentially reaching 8% by 2080 (RCP 8.5). Costa *et al.* (2016) estimate that during a hot year (in the period 2080-2100), productivity loss could reach 0.4% in London (or 1.9 billion euros[2]), 2.1% in Antwerp (670 million euros) and 9.5% in Bilbao (2.5 billion euros).

For certain types of buildings, functions could be reduced or even halted during extreme heat events. For example, a WWF study (2021) notes that of the 60 344 collective sports halls in France, half were built before 1987. In the Île-de-France region, 23% of sports halls have never been renovated. Consequently, indoor sports, which are already impacted, will become increasingly problematic during heatwaves.

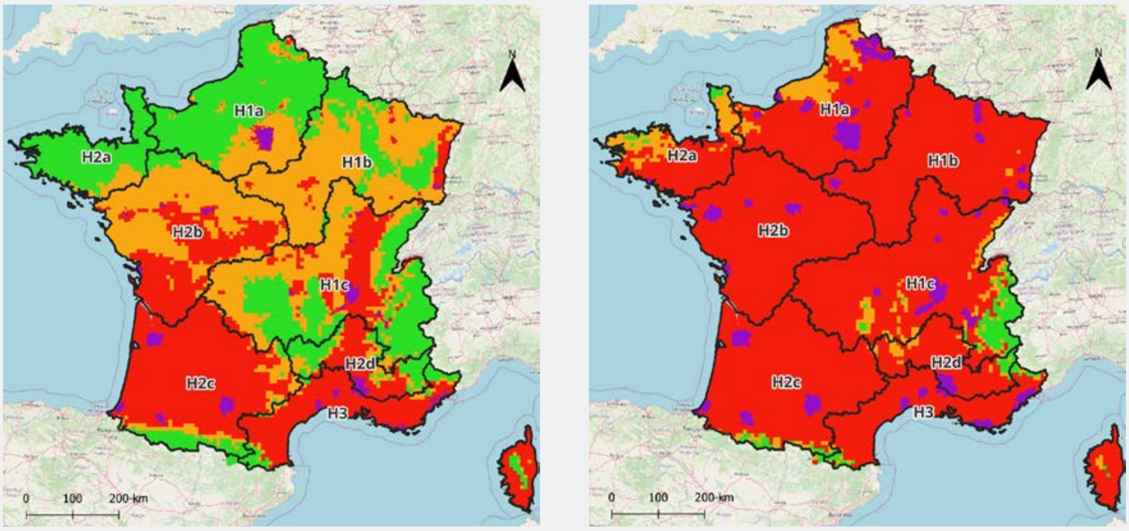
1 Or only very marginally. For example, solar radiation (generally associated with periods of high heat) can accelerate the deterioration of PVC rainwater harvesting systems.
2 Costs are expressed in constant 2005 euros.

BOX 1: BUILDINGS ARE INCREASINGLY EXPOSED TO HEATWAVES

As part of this project, the Observatoire de l'Immobilier Durable (OID 2024a) assessed the number of buildings exposed to heatwaves under various levels of warming in France[3]. The results show that from just 2°C of warming (2030 according to the TRACC), almost half of all buildings will already be exposed to a high or very high risk[4]. From 4°C of warming, most parts of the territory will be at least highly exposed, with many dense urban areas being very highly exposed.

EXPOSURE OF THE BUILDING STOCK TO HEATWAVES ACCORDING TO THE LEVEL OF WARMING IN FRANCE

French warming level +2°C | French warming level +4°C



Risk Level: *Low* *Medium* *High* *Very High*

Source: (OID 2024a).

IDENTIFIED FURTHER STUDY REQUIREMENT N°1: WHAT COST SHOULD BE ASSOCIATED WITH THE CLOSURE OF AN ESSENTIAL PUBLIC SERVICE?

Extreme heat events lead to disruptions to public services. With timetable changes and suspended services, hundreds of schools have already closed during heatwaves. In France, these disruptions are nevertheless limited for the time being, but could worsen in the future[5], for example with disruptions to (or even closures of) certain essential services located in exposed buildings, such as barracks, hospitals, police stations and prisons. These disruptions entail socio-economic costs that could be high, but which have not yet been the subject of in-depth studies[6].

3 This work was limited to establishing the exposure of the building stock and did not seek to determine its vulnerability.
4 The level of risk is determined by combining the number of cooling degree days (CDD) with the existence of an urban heat island (UHI). The detailed methodology is available in the dedicated publication (OID 2024a).
5 Foreign examples indicate the potential scale of these disruptions: in 2022, a heatwave in the UK caused a complete shutdown of the IT systems in the two largest UK hospitals. This led to cancelled appointments and operations and to transfers of critically ill patients.
6 This type of costing is already done in other sectors. For example, SNCF monetises cumulative minutes of delays during heatwaves (which reached several hundred thousand euros per day during the 2019 heatwave, I4CE 2024).

Health and social impacts

At the European level, the PESETA IV research programme (JRC, 2020) estimates the number of deaths currently attributable solely to intense heatwaves (with a 50-year return period) at 2 700 per year. Without additional adaptation measures, the study estimates that deaths could reach 28 800 for 2°C warming in France and 89 000 for 4°C, or 30 times more than at present. The study notes that people living in dense urban areas are among those at highest risk.

In France, considering both heatwaves and moderate heat events, the COACCH research programme (2020) estimates the number of annual deaths at around 10 800 in the near future (2030-2039, RCP 8.5). This figure could quadruple to stand at more than 46 000 deaths per year in France by the end of the century. Another study (Gasparrini *et al.* 2017) sought to estimate excess mortality by considering both the effect of heat and the reduction in mortality due to less cold episodes. The excess mortality would be 1% by the middle of the century and could reach 4% by the end of the century (RCP 8.5).

In terms of costs, for 2022, the number of emergency department visits attributable to heatwaves alone represented an additional cost for the healthcare system estimated at 54 million euros (Cour des Comptes 2024a). More broadly, Santé Publique France (2021) conducted an initial quantification of the health impacts recorded during extreme heat events in France. The study concludes that from 2015 to 2020, the impacts analysed[7] represent between 22 and 37 billion euros in total over the period (depending on the method used for monetary valuation of excess mortality). Excess mortality was the largest component (between 16 and 30 billion), with activity restrictions assessed at around 6 billion euros. Given that the number of abnormally hot nights is expected to double globally by 2050 (RCP 8.5), if nothing is done to adapt, the Observatoire de l'Immobilier Durable (OID 2023) proposes that these costs could double to between 44 and 74 billion euros over the period 2045-2050.

? DEALING WITH UNCERTAINTY: THE SHARE OF RESPONSIBILITY ATTRIBUTABLE TO BUILDINGS IN ECONOMIC AND HEALTH IMPACTS IS UNDETERMINED

Few doubts remain about the effective contribution of buildings to the economic and health impacts observed during heatwaves. In this sense, the report of the National Assembly's investigate committee on the impacts of the 2003 heatwave concluded that "architecture, especially in the northern region, is not designed with heatwaves in mind", and that "large windows with no shutters or blinds contributed to the devastating effects of the heatwave" (Assemblée Nationale 2004). However, the exact share of responsibility of buildings in these costs remains unknown.

Not all costs can be attributed solely to buildings. In the case of excess mortality observed during heatwaves, for example, it is necessary to establish the exact distribution of responsibilities between: conditions inside the building (*e.g.* temperature, humidity), the vulnerability level of the person (age, comorbidity factors), other social factors (such as isolation, whether or not the person is registered as vulnerable), or the response time of emergency services. In practice, the cause of death (or, in other cases, visits to emergency departments or emergency doctors) is due to an inextricable combination of these factors. **This uncertainty must therefore be addressed.**

The same applies to the loss of productivity at work. This is mainly attributable to outdoor work (construction, agricultural sector), in other words not primarily related to buildings. However, the data available is fragmented, as existing studies have mainly focused on differentiating types of work (level of exertion) and their exposure to the sun. Thus, outdoor work under shade and indoor work are often merged. The European research project PESETA III (JRC 2018) attempted to estimate the difference between indoor work and outdoor work. The study gives a productivity loss of between -0.5% and -4% for indoor work by the end of the century (RCP 8.5, or almost 4°C in France). By way of comparison, it would be between -2% and -11% for outdoor work by the same horizon. Another example: considering a reduction in productivity beyond 25°C, a Dutch study (Daanen 2020) estimates the loss of work productivity in non-air-conditioned offices at almost 400 million euros per year by 2050.

7 Excess mortality, emergency department visits, doctor's visits and loss of wellbeing.

3. THE PREVAILING RESPONSE TO HEATWAVES: INSTALLING AIR CONDITIONING SYSTEMS

In response to heatwaves, those who live in, manage and operate buildings are not passive. They are already engaging in a form of reactive adaptation, typically by installing air conditioning systems.

Installing air conditioning outstrips other adaptation options

For housing, the household survey conducted by ONRE (2022) shows that the installation of air conditioning equipment accounts for more than 90% of the adaptation measures (excluding ventilation[8]) taken to cool a home, far ahead of alternative adaptation options (such as installing solar shading or ceiling fans). Over the past decade, there has been a significant shift in sales of air conditioning units: after a period of relative stability until 2015, sales have steadily increased, reaching and then exceeding 800 000 units sold every year[9] (Coda Stratégies 2020[10]). Thus, in 2020, the rate of installation of air conditioning in homes was estimated at 25% (ibid), whereas it was only 11% in 2017 (INSEE 2017).

Where commercial buildings are concerned, Coda Stratégies estimates the air conditioning penetration rate at around 40% (or 370 million m² air conditioned). This figure masks significant disparities depending on the type of building: shopping centres are almost all air conditioned, while educational buildings have the lowest rate (around 7%). VRF-type air conditioning systems (comparable to air-to-air heat pumps) dominate the market, with 84% of installations in 2021 (compared to only 50% in 2010).

Towards a fully equipped stock by 2050?

In some countries (Japan, United States), more than 9 out of 10 homes are equipped with air conditioning systems. In France, RTE (2021) predicts that one in two households will be equipped by 2050. This trend is driven more by the tendency to install equipment (under the current climate) than by anticipated climate change by 2050. The Transition(s) 2050 scenarios (made by ADEME) incorporate higher installation rates (between 80 and 95% depending on the scenario), with varying degrees of usage of the equipment installed. Considering the current deployment rate (1.3 million systems sold in 2020[11]), almost all of the housing stock is expected to be equipped with air conditioning by 2050[12].

An adaptation response that nevertheless raises concerns

This form of adaptation is termed "reactive" because although in some cases the act of installing equipment is part of an overall renovation process, it is often done just before or in response to a crisis. The hasty implementation of this type of response means its massive use raises concerns, particularly regarding the externalities it generates[13].

An increase in temperatures recorded in urban areas and a question of social equality

Installing a high-performance air conditioning system (such as a heat pump) is expensive, and the lowest income households cannot necessarily afford it. It is therefore mostly the owners of detached houses in southeastern France who are equipped (Coda Stratégies 2020). Paradoxically, this is the opposite profile of the people most affected by heatwaves, who are mainly found in dense urban areas (Assemblée Nationale 2004) and among low-income social categories (Institut de Veille Sanitaire 2003; Fondation Abbé Pierre 2023). These populations are also more frequently faced with problems of overcrowding or poor housing (Fondation Abbé Pierre 2023). Some 70% of people living in a priority urban neighbourhood (*quartier prioritaire de la politique de la ville* – QPV) thus say that the temperature in their home is too high in summer (compared to 56% for the rest of the French population, Harris Interactive 2022).

By expelling hot air outside, air conditioning systems exacerbate these inequalities and can even make city centres less attractive. In Paris, Météo France (2010)

8 Which is in most cases associated with a desire to reduce energy consumption.
9 Excluding mobile air conditioning units, sales of which now stand at 400 000 units per year.
10 The Coda Stratégies study, frequently cited in what follows, is one of the few available studies that identifies current and prospective dynamics associated with air conditioning. It was conducted on behalf of ADEME and is based on a robust methodology resulting from discussions with numerous sector experts.
11 Including fixed systems (air-to-air heat pumps, multi-split and mono-split) and mobile systems.
12 Considering that a household only installs one system (which may contain several units).
13 To learn more about this subject, see: https://politiquedulogement.com/2022/10/lentree-de-la-climatisation-dans-les-foyers-francais-1-2-etat-des-lieux/

estimates that the use of air conditioning increases the temperature of the city by 0.25°C to 1°C (during the period of use). This value could reach 0.5°C to 3°C if the number of units doubles.

Greenhouse gas emissions are nevertheless expected to remain limited

On average, the refrigerants used in these systems have a global warming potential (GWP)[14] up to 2 038 times that of CO_2. In 2020, they were responsible for greenhouse gas emissions of approximately 3.5 MteqCO_2 (of the total 4.4 MteqCO_2 emissions associated with air conditioning, Coda Stratégies 2020). In the future, the new European F-Gas III regulation adopted in February 2024[15] should help to limit emissions associated with new equipment. Based on the preparatory work related to this regulation, Coda Stratégies (2021) estimates that by 2050, 70% of the refrigerants used will have a GWP reduced to 3. Thus, despite the deployment of these systems, the emissions associated with air conditioning equipment could decrease to between 0.2 and 0.4 MteqCO_2 by 2050.

Electricity consumption is highly dependent on system usage

Electricity consumption generated by these systems is significant, already amounting to around 11.5 TWh for commercial buildings and 5.1 TWh for housing (Coda Stratégies 2020). For households, ADEME (2022) estimates that in some cases, this can result in monthly bills exceeding 130 euros during periods of use. By 2050, anticipated electricity consumption depends largely on the prospective exercise. Indeed, the temperature and the amount of time equipment is used have a major impact on consumption. For example, in ADEME's "sober" scenarios (S1 and S2), consumption for housing is reduced by a factor of 3.5, whereas it doubles for the other scenarios (S3 and S4) reaching 10 TWh. RTE (2021) estimates that consumption should more than double to reach 14 TWh by 2050. Nevertheless, this electricity consumption remains relatively low compared to the energy consumption (all sources combined) of residential buildings, which currently stands at around 500 TWh, with an objective of reaching 300 TWh by 2050 (Pouget Consultants 2020). RTE thus concludes that "this upward trajectory does not make air conditioning a major component of household energy consumption by 2050".

Regarding the summer peak (in other words peak electricity demand during periods of high heat driven by the use of air conditioning), the grid operator anticipates a peak (with a probability of one in ten by 2050) of around 35 GW during extreme heat events (compared to 20 GW today). This remains well below the winter peak (currently around 80 to 100 GW), which determines the capacity of the French grid[16]. However, the summer period is generally when routine maintenance occurs (at nuclear power plants, for example) and some supply sources are less available (*e.g.* hydroelectric). Trade-offs could therefore be necessary to cope with increasing electricity consumption in summer.

Investments associated with this form of adaptation are well-tracked but very real

To date, there is no robust evaluation of the costs associated with this form of adaptation[17]. Trade unions provide estimates in terms of revenue for the sector, but they do not differentiate between heating and air conditioning equipment. These costs are poorly documented, mainly because they are widely distributed and absorbed by households and private actors, often directly before or after a major climate event.

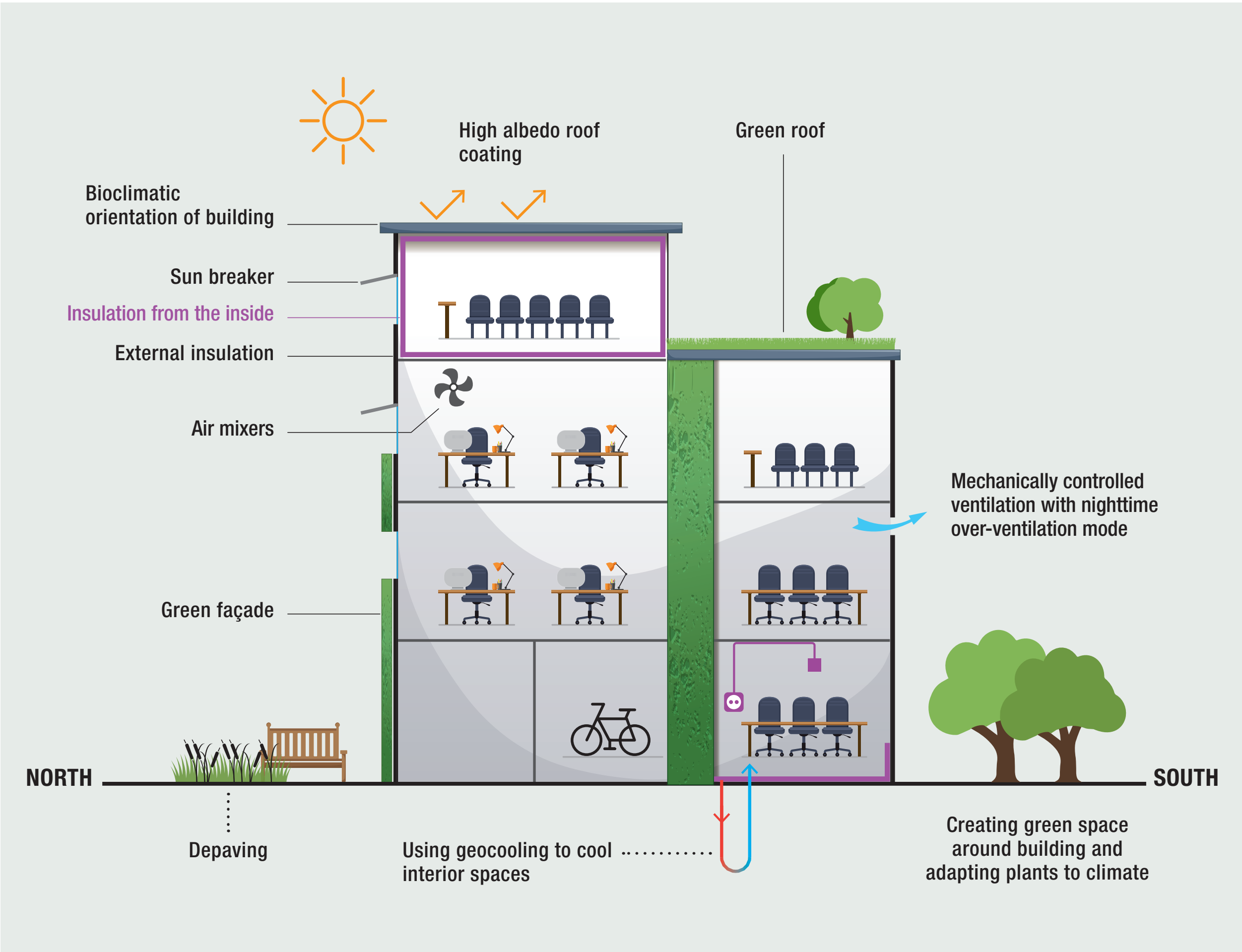
Based on current prices and market shares of air conditioning systems, we estimate annual investments made in these systems for housing at almost 3.5 billion euros. This level of investment (if maintained) would mean almost all of the housing stock would be equipped by 2050: this is far beyond the proportion of homes exposed to a high or very high risk by the same horizon according to the TRACC[18]. If this level of investment were limited to the proportion of homes exposed, it would represent investments of around 2.3 billion euros per year (or 1.2 billion less than today) and would mean equipping 900 000 homes every year (compared to 1.3 million today). Where commercial buildings are concerned, current annual investments remain unknown. At the current price of systems, 800 million euros would need to be invested every year to cool the commercial buildings at high and very high risk by 2050.

14 Cumulative radiative forcing over a 100-year period expressed relative to that of CO_2.
15 See https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202400573
16 In some countries, however, the use of air conditioning systems is already straining the power grid. In 2022 in California, the governor asked residents to reduce their electricity use and to stop charging their electric cars to prevent the grid from collapsing, as air conditioning accounted for almost 70% of consumption.
17 Unlike other hazards affecting buildings. For example, for the risk of shrink-swell or flooding, the CCR (a French public-sector reinsurer) provides an estimate of the cost of managing natural disasters both today and by 2050. See, for example, https://www.ccr.fr/-/ccr-rapport-climat-2023.
18 Estimated at 70% by 2050 (2.7°C) in studies by the Observatoire de l'Immobilier Durable.

4. OTHER SOLUTIONS ARE AVAILABLE FOR ADAPTING BUILDINGS TO HEATWAVES

Adapting a building to heatwaves means taking action to maintain an indoor temperature that is compatible with habitability or usability during extreme heat events. Although installing air conditioning is often the first solution identified, other options exist, and these are well-known and documented. They entail, for example, working on a building's shape, orientation and cross-ventilation where possible. They also include limiting solar gain by avoiding glazed surfaces on exposed façades or installing solar shading devices (awnings, sun breakers, blinds, etc.), installing green roofs and exterior walls, or using ventilation systems (mechanical ventilation, Canadian wells) during the coolest hours (OID 2024b; ADI 2018; Cercle Promodul/INEF4 2020).

OVERVIEW OF SOLUTIONS FOR ADAPTING BUILDINGS TO HEATWAVES



Source: authors from (OID 2024b)

The costs of these solutions are very variable. For example, for a new one-storey educational building (445 m²) in the H2b climate zone, the preparatory working group on the RE2020[19] gives the following costs:

EXAMPLES OF COST OF ADAPTATION SOLUTION FOR A COMMERCIAL BUILDING.

Adiabatic cooling	Sun breaker	Ceiling fan	Rainscreen cladding	Canadian well
10 €/m²	14 €/m²	13 €/m²	58 €/m²	40 €/m²

Source: Preparatory working group on the RE2020.

However, the adaptation of a building (and thus the associated costs) is not limited to these specific actions: when constructing or renovating buildings, some of the work automatically contributes to adaptation. Examples include insulation or ventilation which, while implemented to reduce energy consumption, also help to improve summer comfort. In this case, the costs to consider may be zero (if the work would have been carried out in any case and in the same manner) or may represent an additional cost (if the work needs to be undertaken or sized differently).

THE DIFFERENT TYPES OF COSTS FOR BUILDING ADAPTATION

1 Zero additional costs for adaptation

When certain works automatically contribute to summer comfort, but whether or not this aspect is taken into account does not alter the technical provisions. For example, replacing windows or insulating an attic.

2 Shared costs

These correspond to additional costs associated with integrating adaptation into the different works. This may entail, for example, installing thicker wall insulation or using a different insulating material, or different ventilation sizing, etc. These costs must be shared when constructing or renovating a building.

3 Costs of specific actions

These correspond to the costs of actions that can be implemented relatively independently: ceiling fans, solar shading, etc. It is nevertheless often best to share these costs (cost optimisation, disturbance, interface, etc.).

19 The full results are available at: http://www.batiment-energiecarbone.fr/IMG/pdf/20200722_reunion_de_concertation_no4_confort_d_ete.pdf

5. KEY INVESTMENTS IDENTIFIED FOR INTEGRATING ADAPTATION INTO PROJECTS ALREADY PLANNED

For new construction: going beyond regulations

In 2022, 91 billion euros were invested in the construction of new housing and commercial buildings (I4CE 2023c), 23.7 billion of which went towards energy performance. This trend is nevertheless expected to slow down after 2024, partly to meet the requirements of the French National Low-Carbon Strategy (SNBC), which provides for a steady reduction in new building projects every year. These new buildings are constructed according to the RE2020 environmental regulation, which takes account of a specific event in its calculation engine: the 2003 heatwave. While this choice enables the simulation of the average climate in a few decades (close to the TRACC at 2.7°C by 2050), it does not simulate extreme climate events for the same horizon or the average climate beyond 2050, even though the buildings will still be inhabited and used at that time. **Taking account of prospective scenarios leads to significant differences in the values used for thermal calculations.** For example, the number of hours exceeding 35°C in an “extreme” year in urban Nîmes would be 457 hours (+4°C), compared to only 39 hours at present (Peuportier *et al.* 2023). **Ultimately, the risk here is that buildings will need further specific action to adapt them, or, more likely, that air conditioning systems will be needed.** Without waiting for a possible review of the regulation[20], it is already possible to go further by using prospective climate data, which will automatically constrain the requirements in terms of summer comfort.

For the existing building stock: opting for deep retrofits and integrating adaptation

Where the existing building stock is concerned, substantial investments are planned to reduce building sector greenhouse gas emissions. For housing, the SNBC3 provisional scenario provides for a rapid increase in the pace and quality of retrofits, and aims specifically to eliminate all *“passoires thermiques”* (thermal sieves), in other words poorly insulated homes heated by gas or oil, soon after 2030. To achieve this, I4CE (2023c) estimates that investment needs for retrofits will stand at around 31 billion euros per year on average between 2024 and 2030. However, while current investments are spread across numerous operations involving individual upgrades, the needs are concentrated on deep retrofits, where several aspects of a single building are addressed simultaneously. According to the goals set by the General Secretariat for Ecological Planning (SGPE), up to 900 000 deep retrofits per year will thus be needed by 2030 for housing, aiming for the “low consumption” level, a pace far higher than the number of deep retrofits financed by the aid MaPrimeRénov’ today, or around 66 000 per year (I4CE 2023c).

Most energy retrofitting measures also improve summer comfort. However, a comprehensive approach that integrates summer parameters during works needs to be taken in order to:

1. **Ensure the solutions chosen are consistent with summer comfort,** asking questions such as: *does the insulating material provide good thermal inertia? Is the night ventilation rate sufficient to remove heat stored during the day?*
2. **Use this opportunity to integrate complementary solutions,** such as solar shading when replacing windows;
3. **Avoid counterproductive situations,** such as heavily insulating for winter without ensuring adequate ventilation for summer[21].

However, this type of approach is still underdeveloped at present.

20 RE2020 is an evolving regulation, with requirements for energy consumption and greenhouse gas emissions being reviewed over time according to a predefined schedule (2025, 2028, 2031). Currently, the criterion for summer comfort is not subject to a review clause. I4CE has already made recommendations for this issue to be the subject of specific work during the next renewal cycles (I4CE 2022).

21 This problem has been mentioned several times during discussions with sector experts, although its exact extent remains unclear.

For the adaptation of the existing building stock, the main challenge therefore lies in consolidating the deep retrofit policy by integrating the issue of summer comfort, rather than taking isolated measures specific to adaptation.

What if deep renovation policy is not implemented?

Deep energy retrofits are the best way to adapt and a major goal of the French ecological planning. With a building stock that is now ill-adapted to heatwaves, failing to act on building retrofitting poses the risk of experiencing more severe health, economic and social impacts of heatwaves, for which the most likely response will be to install air conditioning. However, assuming that the deep renovation policy is assured in order to estimate additional needs is to take an optimistic stance. France is currently not meeting its objectives on deep energy retrofits. To do so, an additional annual investment of 15.2 billion euros compared to 2022 would be required for housing and 12.5 billion euros for commercial buildings (I4CE 2023c).

IDENTIFIED FURTHER STUDY REQUIREMENT N°2: DETERMINING THRESHOLD VALUES - HOW LONG CAN WE COPE WITHOUT AIR CONDITIONING?

While there is consensus on the effectiveness of solutions other than air conditioning for improving comfort inside buildings under the current climate, there are few prospective studies to guarantee this effectiveness in the long term. On the contrary, the first available studies show that the more the climate warms, the more difficult it will be to cope without active cooling.

Simulations conducted as part of the ADEME Resiliance project (Peuportier *et al.* 2023) under different climates (Nîmes, Paris) and across several types of new and existing buildings show that comfort conditions are significantly improved by a strong adaptation strategy (which combines a large number of measures), but that this remains insufficient in the long term. The study thus concludes that *“adaptation actions on buildings alone are not sufficient to ensure comfort conditions for the climates projected by the end of the century […]:*

- *In commercial buildings, comfort is only guaranteed for the climates projected for 2050 (up to +2.7°C in France)*
- *In housing, comfort is only guaranteed for the least critical climates projected for 2050”.*

It also says that *“to ensure comfort under all climates projected by the end of the century, in addition to action for the adaptation of buildings that is a necessary priority, the implementation of active cooling systems will ultimately be required to mitigate the most significant heatwaves”.*

At the scale of the city of Paris, Viguié *et al.* (2020) show that even a truly ambitious adaptation policy (combining a retrofitting policy, reflective materials, urban greening and energy conservation) will not be enough to entirely avoid air conditioning during extreme heat events by the end of the century. At best, implementing these actions can reduce daily consumption of air conditioning by 60% but cannot eliminate it entirely. Usage efficiency remains the most effective measure, ahead of policies on insulation, reflective materials and urban greening.

What additional costs should be considered for adaptation?

Assumptions regarding the additional costs of adapting buildings presented here are based on a review of the literature on available cost elements, supplemented by several discussions with consulting firms. These assumptions have been presented and discussed within a working group bringing together building sector experts and state operators.

In new construction

In the new RE2020 regulation, although several indicators are involved in modelling summer comfort and calculating energy needs and consumption for cooling, it is especially the DH (degree-hours) indicator that sizes the building for summer aspects. This indicator assesses the duration and intensity of periods of discomfort in the building over the course of a year, based on a climate scenario calibrated to the 2003 heatwave. To comply with regulations, the DH indicator must not exceed a certain threshold. Within the regulatory zone, if the value is too high, a penalty is applied to the building resulting in increased energy needs (simulating the use of air conditioning) and thus bringing the building closer to the authorised levels.

During the design phase of this regulation, simulations were conducted to test the sensitivity of the new indicators[22]. The results show that the new regulation is generally no more restrictive than the old one, except in the Mediterranean zone (climate zone H3). For this zone, additional measures for summer comfort need to be implemented for the building to comply. For the others, a building designed according to the previous standard is generally sufficient to meet the thresholds.

Complying with the regulation…	… under the current climate	… taking account of the future climate
Mediterranean zone (H3)	Now requires significant work on summer performance to comply with all indicators	Mainly involves an increase in consumption? As few other measures available according to thermal engineering firms consulted
Other climate zones	Is not very restrictive and does not require ambitious work on summer performance	Requires using the measures currently not used

Outperformance for adaptation to climate change

For new buildings, taking account of the reference warming trajectory therefore implies voluntarily going beyond the regulation in most climate zones. To determine the additional cost of this "voluntary effort", we base it on the type (and cost) of solutions already required in the Mediterranean zone. The simulations conducted during the design phase of the new regulation are accompanied by cost estimates produced by a group of construction economists. The results show that the cost of solutions is highly variable (see annex). For a multi-family residential building, costs range between 25 and 65 €/m^2 (similar orders of magnitude for other building types). By comparing these upper and lower limits to average construction costs[23], we propose additional costs that range between 2% and 5% (when combining one or more solutions) for buildings that go beyond the regulation on summer comfort.

22 See, for example, the work of the "GT Modélisateur" available at: http://www.batiment-energiecarbone.fr/outils-re2020-et-resultats-de-simulation-r76.html, or the sensitivity studies on the RE 2020 regulatory calculation engine conducted by the thermal engineering firms Bastide Bondoux, Pouget Consultants and Tribu Energie at: http://www.batiment-energiecarbone.fr/IMG/pdf/20210604_rapport_final_consortium_cim_beton_cilt_ignes_edf_filmm_tuiles_briques_uniclima.pdf

23 Based on an average construction cost for the period 2024/2030 of 2 500€/m^2 expressed in constant 2022 euros, but taking into account an endogenous component of inflation in the building sector (assuming an annual increase in construction costs of 1%).

THE EXAMPLE OF SOCIAL HOUSING BY LE FOYER STÉPHANOIS

To meet the requirements of the *Mon Logement Santé* label managed by the Arcade VYV group, the social landlord *Le Foyer Stéphanois* conducted dynamic thermal simulations with two variants for two new construction projects, with both rental housing and affordable housing. The baseline variant aimed for a performance level of "RT2012-20%" (generally similar to the current RE2020 standard), while the second variant aimed for the same energy performance but using prospective meteorological data (RCP 8.5 for 2050, or close to +2.7°C in France). In the second variant, the designers had to work on adaptation measures (inertia, automatic shutters, sun breakers, fans, air-conditioned refuge areas) to maintain acceptable comfort conditions in summer. Overall, the specific additional cost for summer comfort was estimated for the projects at 2.7% and 3.8%. This practical example – along with the few others we have found – seems consistent with the additional cost estimates used in this study.

For the existing building stock

A similar process was undertaken to determine the additional cost for adaptation in retrofitting operations. This additional cost represents the difference in cost between a deep energy retrofit and the same operation that would have considered summer comfort. It corresponds to the implementation of different actions that result in an "outperformance" for adaptation:

EXAMPLES OF ADAPTATION ACTIONS ASSOCIATED WITH ENERGY RETROFITS

Actions planned for energy retrofits	Measures implemented or sized differently	New measures
Replacement of windows		Installation of automatic solar shading / sun breakers, etc.
Installation of a dual-flow ventilation system	Installation of a "boosted ventilation" mode for night ventilation	Installation of a Canadian well
Insulation of walls	Choice of insulation with good thermal inertia, increase in thickness	

Outperformance for adaptation

Similarly to new construction, adaptation solutions have highly variable costs, ranging from tens to more than one hundred euros per square metre (see annex). Considering the costs of deep retrofits[24], we propose an average additional cost for adaptation of 10% compared to a deep retrofit project that does not take account of summer comfort.

IDENTIFIED FURTHER STUDY REQUIREMENT N°3: ENHANCING KNOWLEDGE ON THE COST OF ADAPTATION SOLUTIONS INTEGRATED INTO NEW CONSTRUCTION AND RETROFITTING OPERATIONS

The additional cost assumptions presented in this study should be used with caution. They were developed to provide a preliminary estimate of the level of investment required for large-scale building adaptation. However, they are not intended to represent a "generic additional cost" for adaptation that would apply to every project. In reality, they mask very different situations specific to each project, for which adaptation costs can be very heterogeneous. Further work, similar to the initial cost assessments made by construction economists during the design of the RE2020, are necessary (particularly for retrofits) in order to better determine these costs according to different building types, climate zones, etc.

24 An I4CE study (I4CE 2023b) gives deep retrofit costs for a range of buildings partially representing the building stock of between 330 and 826 €/m², with an average of 586 €/m².

Additional investment needs for adaptation in investments identified

Applying these additional costs for adaptation to investments identified in new construction and retrofitting gives an initial order of magnitude for the additional effort required to adapt buildings to heatwaves.

In new construction

This effort stands at between 1 and 2.5 billion euros per year on average between 2024 and 2030.

Billion euros per year	Investment needs to reach the interim targets of the SNBC3*	Additional costs for adaptation to heatwaves	
		Lower range	Higher range
Housing	36.2	0.7	1.8
Commercial	14.9	0.3	0.7

* These needs represent the total investments in new construction needed to reach the interim targets of the SNBC3; they decrease over time (I4CE 2023c). Values are expressed in constant 2022 million euros.

For the existing building stock/retrofits

The additional effort required is estimated at between 4 and 5 billion euros per year, to be added to the needs for deep retrofits that are not yet covered.

Billion euros per year	Investment needs to reach the interim targets of the SNBC3*	Additional costs for adaptation to heatwaves
Housing	31.4	3.1
Commercial	16.7**	1.7

* These needs represent the total investments in building stock retrofits needed to reach the interim targets of the SNBC3 (I4CE 2023c). Values are expressed in constant 2022 million euros.

** This amount has been revised upwards slightly between the publication of the summary in April 2024 and this study, resulting in slightly higher adaptation requirements.

These needs represent the investments that would have to be made each year to go a step further in adapting buildings, without knowing exactly what level of adaptation will be reached (see Identified further study requirement n no. 3 and 4). As such, they are not directly comparable to investments in air conditioning systems.

These investments are aimed at adapting the entire flow of new buildings and energy retrofit projects needed to achieve the carbon neutrality objectives. They are therefore expressed for all stakeholders combined: private (households, businesses) and public (State, local authorities). However, not all adaptation options currently have a clear economic model (I4CE 2024), which raises questions about how the adaptation effort should be shared between the public and private sectors. In a context of constrained public budgets, a first approach could be, at least initially, prioritising spending on the populations most vulnerable to extreme heat. These funding issues have not been addressed in this study.

IDENTIFIED FURTHER STUDY REQUIREMENT N°4: DETERMINING THE BENEFITS ASSOCIATED WITH AN AMBITIOUS ADAPTATION POLICY

From an economic perspective, investing these amounts in building adaptation is only worthwhile if they reduce by at least an equivalent amount the costs associated with air conditioning (purchase, using, externalities) and the socio-economic impacts of heatwaves. We could add to these effects the losses in well-being and comfort indoors, but the monetisation of these remains poorly documented to date. However, in order to make this comparison, it is necessary to know the cost-effectiveness of the options available. While such studies exist at the scale of one or several buildings, they have not been conducted at the scale of the entire building stock in France.

Several foreign studies provide initial benchmarks and avenues for progress in this respect. For example, a Canadian study (Boyd *et al.* 2022) sought to estimate the effects of two adaptation measures on mortality and work productivity. The first involves installing solar shading devices for half of all private housing by 2085. The second aims to create green roofs on all residential and commercial buildings in urban areas by 2085. For solar shading systems, the study estimates the number of deaths avoided per year at 21 out of several hundred. It also estimates energy savings at 580 million dollars per year. The investment (estimated at 199 million dollars per year) only pays off when energy savings are taken into account. Following the same logic, for green roofs, the annual investment is estimated at 6.9 billion dollars and prevents 46 deaths every year. The annual co-benefits are 9.7 billion dollars. The return on investment is essentially linked to the co-benefits on biodiversity and storm rain management.

In the UK, a study by the Climate Change Committee (CCC 2023), the UK equivalent of the Haut Conseil pour le Climat (High Council for Climate), proposes a budget of 1 billion pounds per year over the first decade to implement an adaptation policy for overheating in private housing. This estimate is based on several recent studies, including one by the Department for Business, Energy & Industrial Strategy (2021). In this study, the authors model energy savings according to three adaptation scenarios: the “no intervention” scenario, in which most households install inefficient air conditioning systems and a few implement passive measures; the “efficient technologies” scenario, which takes the same approach but with more efficient systems; and, in contrast, the “passive first” scenario, which initially prioritises passive measures. The authors estimate that the efficient technologies and passive first scenarios reduce electricity consumption for air conditioning by 21% and 34% respectively compared to the no intervention scenario. Moreover, the associated investments are lower for the passive approach. The total cumulative investment cost for the no intervention and efficient technologies scenarios stands at around 60 to 70 billion pounds (between 2020 and 2050). This same cost is between 20 and 30 billion pounds for the passive first scenario. The authors nevertheless note that the level of comfort achieved by the different scenarios is not the same.

Regarding productivity losses associated with heatwaves, Szewczyk, Mongelli and Ciscar (2021) estimate that 30% to 40% of these losses could be reduced by a combination of adaptation measures, including the dissemination of air conditioning. Another example, Costa *et al.* (2016) estimate that in London, Antwerp and Bilbao, air conditioning could reduce indoor productivity losses by 80% to 95%. Shutters are also highly effective and could prevent 55% to 80% of losses.

The need to establish an implementation process

A growing number of stakeholders now identify summer comfort as a major issue for their buildings. Social landlords, for example, were among the first to take steps in this direction[25]. At the state level, the French Minister for Economic Affairs explicitly requested in February 2024 that there be no more *"investment in real estate that does not address climate change where public property is concerned"*[26]. Another example is the EduRénov programme, led by the Banque des Territoires, which aims to conduct 10 000 operations on school buildings with a view to "energy retrofitting and adaptation to climate change".

Identifying the issue is only the first step and although the solutions are known, the implementation process for adaptation in new construction and retrofitting operations still needs to be developed.

First, it is important to agree on the baseline climate data to be used in dynamic thermal simulation (DTS) tools. In the absence of a common reference, recent exercises have systematically created their own datasets, choosing the assumptions themselves (climate change scenario, time horizon, etc.). In this sense, the reference trajectory (2.7°C by 2050, 4°C by 2100) will enable stakeholders to agree on a common climate scenario, but **the prospective data that can be used directly by DTS software are still unavailable at present**.

In addition to the unavailability of meteorological data, **stakeholders wishing to begin adapting their buildings also lack a common reference framework to do so**. At present, there are no building standards, specifications or labelling processes for adaptation. Although initiatives exist, such as the Bâtiment Durable Méditerranéen process[27] (Mediterranean Sustainable Building) or the guide to adaptive actions (OID 2024b), these remain isolated and do not constitute the reference framework requested by sector professionals. The absence of this framework is currently one of the major obstacles to the implementation of adaptation processes for the building sector: many stakeholders are uncertain due to the many possible responses, not knowing which level of adaptation to aim for or which solutions to prioritise.

> Like the ongoing CAP2030 working groups, which aim to build a common reference framework through a flexible, phased approach to anticipate the evolution of future regulations on new construction[28], a similar process could be envisaged for adapting the existing building stock to climate change. This approach could be led by the Plan Bâtiment Durable and should bring together all stakeholders in the profession.

25 For example, the CDC Habitat group has developed its own vulnerability assessment tool and aims to use it at the 500 highest-risk sites by 2027 in order to conduct a priority work programme for adaptation.

26 https://www.vie-publique.fr/discours/292962-bruno-le-maire-08022024-rechauffement-climatique

27 This voluntary initiative is led by the EnvirobatBDM association, which is a member of the Réseau Bâtiment Durable (Sustainable Building Network): https://www.envirobatbdm.eu/la-demarche-bdm.

28 Among the working groups, one (GT8) is dedicated to climate change adaptation issues. See https://www.planbatimentdurable.developpement-durable.gouv.fr/presentation-generale-a1641.html

6. PREPARING FOR HEATWAVES: A TERRITORIAL AND SOCIAL CHALLENGE RATHER THAN A SERIES OF TECHNICAL ADJUSTMENTS TO BUILDINGS

In this study, we have limited our analysis to the costs of adaptation at the level of the built environment[29]. However, other levers exist and must be mobilised for an integrated and truly effective approach to the health, economic and social risks reduction of heatwaves.

In the area around a building, numerous solutions help to limit overheating

Greening, for example, creates shade and actively contributes to evapotranspiration (a process that helps to lower temperatures locally by releasing water vapour into the atmosphere). These effects help to maintain a cooler environment around (and therefore inside) buildings. The choice of exterior materials also plays a role; for example, selecting materials with high reflectivity (albedo) can prevent heat being stored during the day and help to mitigate the urban heat island effect (OID 2024b).

On a larger scale, urban morphology, the presence of water and greening also play a role

By designing a planning policy consistent with adaptation challenges, local authorities also have a role to play. This means integrating requirements on greening, the presence of water in urban areas and urban ventilation corridors, particularly into territorial climate-air-energy plans (PCAET) and urban planning documents (PLU, PLUi, PPR). Above all, it means taking advantage of every urban planning or renewal operation to ensure the technical solutions chosen are consistent with the changing climate conditions (I4CE 2023a). The integration of adaptation can sometimes run counter to other public policy objectives. For example, when the installation of water fountains complicates the objectives of reducing water consumption, or when the creation of a park impacts on housing production objectives. It is therefore necessary to deal with this multitude of parameters and make trade-offs that are necessarily dependent on each situation and each project.

29 In other words, the elements that make up the building: the walls, roof, windows, equipment and systems, etc.

Mitigating health impacts also requires a robust healthcare system and effective emergency services

The health impacts observed during heatwaves can be triggered by buildings that are ill-adapted, but the existence of an early warning system, the robustness of the healthcare system and the responsiveness of emergency services all have a major role to play in limiting them. In this respect, the parliamentary report on the impacts of the 2003 heatwave rightly stressed that “the French health monitoring and alert system proved ineffective in the face of the heatwave” and that “the lack of anticipation, the very imperfect nature of information, monitoring and alert systems, and the compartmentalisation of government agencies and structures made it difficult to grasp the extent of the problem” (Assemblée Nationale 2004). Many improvements have been made since then, in particular with the creation of a registry of vulnerable people, a heatwave and health alert system (SACS), and the activation every year of a national heatwave plan[30]. However, it is clear that there is still room for improvement, whether in increasing the use of the municipal registry or in the operational response to crisis situations (Cour des Comptes 2024a).

For economic activities, the answer is not necessarily to carry out works

For a business or public service, heatwaves can lead to activities being reduced or even completely halted, for example when it gets too hot in a factory or a public building to ensure the safety of workers or visitors. The response to these disruptions may involve conducting adaptation works directly on the building. But other solutions are possible. For example, a business may decide to extend break times for its workers and to provide them with water points; a local authority may decide to adjust the opening hours of its building to avoid the hottest time of the day[31]. These measures can either replace works directly conducted on buildings or supplement them if they are not sufficient.

The level of preparedness of the population: a key factor

To maintain a comfortable temperature inside buildings during extreme heat events, user behaviour is a key factor. For example, the effectiveness of solar shading devices depends on their proper use: if they are not closed when solar radiation is highest on glazed surfaces, the benefit of the adaptation measure is lost. Similarly, adding insulation to opaque walls can increase thermal inertia, but it is only effective if heat is evacuated during cooler hours, by opening windows at night when possible. A research project financed by ADEME (Peuportier *et al.* 2023) conducted several simulations of summer comfort for an old renovated house according to user behaviour. The results show that the duration of discomfort increases from 52 hours when occupants open windows and use solar shading devices to 405 hours with inappropriate behaviour. Furthermore, the maximum temperature recorded inside the building rises from 31.5°C to 40.2°C.

Where air conditioning is concerned, a shorter usage time and a higher setpoint temperature can significantly reduce electricity consumption. Coda Stratégies (2021) thus estimates that electricity consumption would be four times higher in 2050 under a technology-based scenario (S4 ADEME) than in a sober scenario (S1 ADEME). Half of this increase is due to longer usage and a lower setpoint temperature[32]. These parameters can be directly controlled by users. Socio-cultural norms, such as office dress codes, also play a role as they have a direct impact on comfort levels. In recent years, several communication campaigns have been launched to raise awareness among users about the best practices to adopt during extreme heat events[33].

30 See https://www.ecologie.gouv.fr/vagues-chaleur-plan-national-anticiper
31 As being tested by the city of Montélimar, which has adjusted the opening hours of its schools, a first in France.
32 Between the sober and technological scenarios, the average usage time increases from 8 hours to 12 hours, and the setpoint temperature rises from 22°C to 26°C. Among the factors with the least influence are growth in the number of devices (the equipment rate rises from 80% to 95%), behind building stock evolution dynamics and system efficiency.
33 See for example the ADEME communication campaign https://librairie.ademe.fr/7208-comment-garder-son-logement-frais-tout-l-ete-.html

However, the role played by people is not limited to adopting good practices within their homes. During heatwaves, the social fabric that connects neighbourhoods contributes to increasing population resilience. For example, it helps to prevent the isolation of elderly or vulnerable people and enables people to share cooler areas. By way of example, during the 1995 heatwave in Chicago (United States), two neighbouring districts had very different mortality rates despite having seemingly comparable social conditions (poverty rates, population vulnerability levels). The less affected district had a much more developed "social infrastructure" (through shops, public services and community organisations) compared to the more severely impacted district, which was experiencing demographic decline. A US analysis of this problem (Klinenberg 2022) shows that this situation contributed to the high excess mortality recorded in this district.

THE COSTS OF ADAPTING BUILDINGS: MORE THAN A SERIES OF TECHNICAL ADJUSTMENTS TO THE BUILT ENVIRONMENT

Action directly on the building

Zero additional costs for adaptation

When some works contribute to summer comfort by their very nature, but taking this aspect into account or not does not change the technical provisions.

E.g.: Wall and roof insulation, joinery, ventilation, etc.

Shared costs for adaptation

They correspond to the additional costs associated with taking adaptation into account in work items.

E.g.: Extra thickness and insulation materials, night-time ventilation, etc.

Costs of work specific to adaptation

They correspond to the costs of actions that can be implemented relatively independently.

E.g.: ceiling fans, solar protection, etc.

Action at the city level

By designing a planning policy that is consistent with adaptation challenges through:

- The presence of vegetation
- Work on the presence of water and urban morphology

Action on other public policies

By ensuring:

- Reactive emergency services
- A robust healthcare system
- A well-developed social infrastructure

Action through a suitable environment

By deploying organisational and support resources to :

- Lead working groups to define a common framework
- Go a step further in the knowledge of solutions via research programmes
- Mobilise around training and awareness-raising

@I4CE_

The conclusion of this work is that climate change is leading the building sector to a new challenge: ensuring its adaptation. The building stock is currently ill-adapted, which is already resulting in high costs that are expected to increase as the climate warms. To address this problem, the prevailing response is the massive use of air conditioning, which already represents substantial investments, raising concerns about the externalities it generates. The alternative is that adaptation could be better integrated into existing planning policies, in new construction or during energy retrofitting operations. This additional effort for adaptation would, however, represent several billion euros per year, yet the precise economic benefits of such a policy remain difficult to determine. A growing number of stakeholders now want to immediately embark on the adaptation of their building. Although progress has been made in documenting the adaptation solutions available, sector stakeholders currently lack both support and a common reference framework to agree on the way forward.

ANNEXES

Annex 1. Example of measures to improve summer comfort and associated additional cost in new construction

Collective housing Climate one H2b 3669m² GFA – 60 units	DH indicator		Total additional cost	Additional cost per m²
	Home without cross-ventilation	Home with cross-ventilation		
Base simulation (RT2012)	790	500		
Double flow (DF) + Canadian well	Not available	Not available	237,781 €	64 €/m²
Adjustable sun breaker + auto control	346	269	229,681 €	62 €/m²
Rolling shutters + auto control	621	452	161,556 €	44 €/m²
Ceiling fans	703	457	93,181 €	25 €/m²
DF + adiabatic cooling	699	451	234,181 €	63 €/m²
Rainscreen cladding	791	494	146,621 €	40 €/m²

Source: extract simulation LC77 – GT Modélisateur RE2020.

Commercial building – Climate zone H2b – 413m² NFA – Two levels	DH indicator	Total additional cost	Additional cost per m² (compared to 2019 standard)
RT2012 simulation	386		
2019 standard simulation (with manual motorised solar shading)	236	80,258	
Adjustable sun breaker + Canadian well	42	87,758	18 €/m²
Adjustable sun breaker + ceiling fans	48	86,858	16 €/m²
Adjustable sun breaker + adiabatic cooling	703.1	84,758	11 €/m²
Adjustable sun breaker + rainscreen cladding	100	99,599	47 €/m²

Source: extract simulation BB26 – GT Modélisateur RE2020.

Annex 2. Example of measures to improve summer comfort and associated additional cost in retrofitting

Adaptation solutions	Total cost
Change from traditional to bio-based insulation	~30% of the cost of insulation, which itself represents ~30% of the total cost of the retrofit (overall additional cost 10%)
Motorised exterior shutter	130 €/m² of glazed surface
Adjustable sun breaker	300 €/m² of glazed surface
Ceiling fan	19 €/m²

Source: various sources were used (interviews, feedback etc.).

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