MOUNTADAPT

ELEVATING HEALTHCARE CLIMATE ADAPTATION

D2.3 - Guidance and recommendations co-creation

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Executive Summary

The climate crisis is a major public health emergency of the 21st century. Rising temperatures, increasing frequency and severity of extreme weather events, air pollution, and ecosystem degradation are already driving profound and unequal impacts on human health, while placing growing pressure on health systems and essential services. Despite this, most health systems remain underprepared to face the scale, complexity, and acceleration of climate-related threats.

This deliverable provides practical, evidence-based guidance to help close the gap between high-level policy commitments and local implementation of climate-health action. It addresses four key domains where climate mitigation, adaptation, and health co-benefits intersect: building performance through nature-based and hybrid solutions, health system preparedness for climate-related disasters, integration of climate resilience into healthcare governance, and safe physical activity during climate alerts in mountain regions.

The development of the guidance has been grounded in a co-creation process carried out with the demonstration sites. Local stakeholders (i.e. public authorities, healthcare professionals, and technical experts) actively contributed to the definition of needs, the contextualisation of solutions, and the validation of the outputs. This participatory approach ensured that the guidance reflected the diversity of risk profiles, institutional capacities, and environmental conditions specific to mountainous areas. By encouraging local ownership, the process also supports the feasibility and uptake of the recommendations.

The first section presents results from simulations evaluating the performance of two nature-based and hybrid solutions designed to improve indoor cooling in mountain environments. Targeting building designers, operators, and owners, these simulations provide insights into how selected technical solutions can reduce exposure to indoor heat under different climate scenarios. The analysis is grounded in a real-world case study and supports the selection of context-sensitive, reliable design strategies.

The second section introduces a disaster preparedness checklist and accompanying guidance aimed at supporting health professionals and authorities in assessing and strengthening their preparedness for extreme weather events. Rooted in existing WHO frameworks and developed through stakeholder consultation, the guidance addresses multiple levels of care — from public health to hospitals and emergency services — and is tailored to the specific risk profiles of mountain demonstration sites.

The third section supports the integration of climate health system resilience into governance and operations. Building on an existing health system resilience guidance document, it provides practical tools for identifying, prioritizing, and implementing adaptation measures within health facilities and organisations. The guidance was tested and refined through workshops with healthcare actors in demonstration sites.

The fourth and final section delivers personalised recommendations for maintaining safe physical activity during periods of extreme heat and air pollution in mountain areas. Drawing on physiological, territorial, and meteorological data, the recommendations are tailored to individual and environmental risk profiles and aim to support both vulnerable populations and healthcare professionals in making informed decisions during climate alerts.

Collectively, the solutions presented in this deliverable contribute to the objectives of the Work Package 2 “Co-design and co-development of forecasting and transformative adaptation solutions” offer actionable guidance to reduce climate-related health risks, promote health co-benefits, and support decision-makers in building more climate-resilient systems in vulnerable mountain regions.

Project partners

Acronym	Full Name of Organisation
CHUGA	Centre Hospitalier Universitaire De Grenoble
CSTB	Centre Scientifique Et Technique Du Batiment
HCWHE	Healthcare Without Harm Europe
HWWI	Hamburgisches Weltwirtschaftsinstitut Gemeinnutzige Gmbh
TIKLI	Tirol Kliniken Gmbh
UGA	Université Grenoble Alpes
UPO	Università Degli Studi Del Piemonte Orientale Amedeo Avogadro

Acronyms

BMI – Body Mass Index

ECG – Electrocardiogram

EU - European Union

EWE – Extreme Weather Event

GAM - Grenoble Alpes Métropole

GHG – Greenhouse Gas

H-EDRM – Emergency and Disaster Risk Management

IPCC - Intergovernmental Panel for Climate Change

NBS – Nature Based solutions

WHO – World Health Organization

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Introduction to the Deliverable

Overview of the climate challenge

The climate crisis is one of the greatest challenges that the world faces in the 21st century. Its far-reaching and interconnected impacts, such as rising temperatures, extreme weather events (EWEs), air pollution, biodiversity loss and the degradation of ecosystems, are already disproportionately impacting human and animal health, straining health systems worldwide and disrupting the socio-economic sectors that sustain societal wellbeing.

The pace and scale of climate impacts are accelerating. Key indicators that monitor the impact of human-induced climate change reached alarming record levels, underscoring the severity of the impact across different scenarios [1]. The concentrations of key greenhouse gases (GHGs), namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), have reached record highs due to fossil fuel combustion, land-use change, and industrial processes [2, 3]. Since 2010, global concentrations of CO_2 and CH_4 have increased annually by approximately 0.6% and 0.5%, respectively [3]. While N_2O levels offer less accurate data, it is estimated that it has risen by 40% in the last 40 years [3, 4].

GHG concentrations are considered one of the primary drivers of the raise in temperature [5]. In 2024, for the first time, the global surface temperature experienced a 12-month period with an average temperature clearly exceeding 1.5°C, the threshold established by the Paris Agreement to avoid the most dangerous climate impacts [1, 6].

Air pollution remains a major environmental health threat. In 2021, exposure to fine particulate matter (PM2.5), a pollutant strictly regulated under World Health Organization (WHO) air quality guidelines, was associated with an estimated 4.1 million deaths globally [7]. While there has been a modest decline in mortality attributable to fossil fuel-related PM2.5 (a 6.9% reduction between 2016 and 2021), levels remain well above health-protective thresholds in many regions [6].

The frequency, intensity, and duration of EWEs (e.g., heatwaves, floods, storms) are increasing, often with devastating consequences. These events directly endanger lives and livelihoods while straining public infrastructure and emergency services. While the health impacts of climate change are rapidly escalating - the WHO projects that climate change could cause an additional 250.000 deaths annually due to malnutrition, malaria, diarrhoea and heat stress, and estimates a loss on health of about 2-4 billion dollars per year by 2030 [8] - health systems are largely unprepared to cope [9].

During this historical moment, health systems are facing a dual challenge. On one hand, they are on the frontline of responding to climate-related direct and indirect threats, facing surging service demand and increasing health needs, damaged infrastructure, and workforce shortages. On the other hand, they contribute to 4–5% of global GHG emissions, making decarbonization of the sector both an environmental and ethical imperative.

According to the 2024 Lancet Countdown on Health and Climate Change [6], most health systems remain underprepared to meet the rising risks. Infrastructure is often outdated, early warning systems are insufficient, and long-term resilience planning is rarely embedded in health governance strategies. At the same time, climate-related shocks further magnify existing health inequities, both within and between countries.

International objectives

It is precisely in order to counterbalance the growing impact of climate change on our society and the environment that global climate objectives have grown more ambitious in the past decade, with a strong emphasis on limiting warming to 1.5°C, reducing air pollutants, protecting ecosystems, and enhancing resilience through national and local adaptation plans. These objectives are increasingly being supported by cross-sectoral strategies that align mitigation and adaptation with broader development and health goals.

In recent years, health has begun to take a more prominent place in climate negotiations and international policymaking, also driving changes at country level. This shift is reflected in growing attention to health co-benefits of mitigation actions as well as the urgent need to make health systems more resilient to the growing impacts of climate change.

Institutions such as the WHO have played a key role in embedding health within global climate frameworks, offering operational tools, country support, and a strong advocacy platform. Nevertheless, the integration of health considerations into climate policy remains uneven and underdeveloped at many levels.

At the European Union (EU) level, several initiatives have been undertaken to address the intersection of climate change and health. The EU has integrated health considerations into its climate policies, including the European Green Deal [10] and the

EU Strategy on Adaptation to Climate Change [11], which emphasize protecting citizens from climate-related health risks. The EU has also supported research and innovation through Horizon Europe and strengthened early warning systems and cross-border health preparedness.

THE CLIMATE-HEALTH NEXUS: FRAMING THE CHALLENGE

Climate change is increasingly recognized as a fundamental threat to human health, magnifying existing public health challenges and creating new ones via the effect of climate-sensitive health risks. Its effects are both direct and indirect: extreme heat increases mortality and exacerbates cardiovascular and respiratory conditions and more frequent disasters disrupt essential services and displace populations. At the same time, slower-moving environmental changes, such as air pollution and the degradation of ecosystems, undermine the social and environmental determinants of health in lasting ways, and changing weather patterns affect food and water security. The impacts hit the most vulnerable and disadvantaged people the hardest. This includes women, children, ethnic minorities, poor communities, migrants or displaced persons, older adults, and those with existing health problems [8].

These interconnected climate-sensitive health risks reveal how deeply entwined health outcomes are with climate and environmental conditions. They also underscore the urgent need for responses that are not only supporting mitigation but also adaptation, with strategies addressing public health needs and strengthening the systems that support them.

GOALS OF THE GUIDELINES IN ADVANCING PROGRESSES

Translating global commitments, such as those articulated under the Paris Agreement and the Sustainable Development Goals into effective local action remains a persistent challenge. This is where guidelines can play a critical role. **Evidence-based guidance helps to bridge the gap between international ambition and everyday practice by offering clear, actionable pathways for integrating health into climate policy and planning**.

The guidelines presented in this document are designed to meet that need. They provide practical direction for improving health outcomes while reducing climate risks and emissions, tailored to four priority areas where co-benefits are particularly strong: **active mobility and physical activity, indoor environmental quality, decarbonization of health systems, and preparedness for climate-related disasters**. Grounded in scientific evidence and policy relevance, these recommendations aim to support decision-makers in building healthier, more resilient, and more sustainable systems.

The guidelines and recommendations presented in this document (Table 1) address diverse aspects of climate change mitigation and adaptation, ranging from the integration of climate resilience into healthcare planning and indoor air quality, to healthcare system preparedness for extreme weather events and recommendations for safely maintaining physical activity despite extreme heat and poor air quality. By covering various facets of managing climate change's health impacts, these recommendations offer solutions for different end-users. They present opportunities for health co-benefits and provide tools to enhance the resilience of systems currently working to counteract the effects of climate change.

Table 1. Overview of guidelines and recommendations presented as part of D2.3

Title	Solution provider	Objective	Target audience
Nature-based and hybrid solutions sensitivity simulation	CSTB (Centre Scientifique et Technique du Bâtiment)	To give recommendations outlining the extent to which two nature-based and hybrid solutions contribute to indoor cooling.	Building owners, designers, builders, operators, and users.
Disaster Preparedness Checklist and Guidance	UPO (University of Eastern Piedmont)	To facilitate the monitoring of the health system's preparedness status and provide guidance to decision-makers aiming to enhance health system preparedness.	Health sector professionals, authorities, policymakers, health managers, and others interested in evaluating health system preparedness for EWEs in mountain areas.
LIFE RESYSTAL health system guidance	HCWH (Health Care Without Harm)	To help organisations integrate climate resilience into healthcare planning and is aimed at those responsible for developing a Climate Resilience Plan for their health system or organisation.	Health system managers, hospital sustainability managers, policymakers and stakeholders working closely with the healthcare sector (e.g.: local authorities, insurance companies, medical product suppliers), as well as healthcare professionals interested in working on climate resilience within their own organisations.
Personalised recommendations on physical activity in the mountains	UGA (Université Grenoble Alpes)	To create personalised recommendations based on risk/benefit balance of physical exertion during heatwaves or poor air quality.	Focus on, but not limited to: citizens in mountainous regions, vulnerable populations, healthcare professionals.

The goal of this document is:

- To provide clear, actionable recommendations that align with global climate targets and national health priorities
- To leverage health co-benefits as a driver for more ambitious climate action
- To support the decarbonization and resilience of health systems, ensuring they are prepared for and responsive to climate shocks
- To promote collaboration across key sectors toward climate resilience.

Nature-Based and Hybrid Solutions Sensitivity Simulation (PR5.3)

Introduction

This work aims to give recommendations outlining which **nature-based and hybrid solutions** perform best, the extent to which they contribute to limiting indoor overheating, and their potential energy-saving benefits. The aim is to provide objective arguments for choosing one technical solution over another. To achieve this, a specific protocol is proposed to identify the **limiting climatic sequences** in summer that cause the building to malfunction.

Purpose of the thermal-aeraulic simulations

The **thermal-aeraulic simulations** aim to predict a building's thermal performance under various climate and occupancy scenarios. This helps optimize building operation, energy efficiency, and thermal comfort with regard to local climate conditions, building envelope materials, and ventilation systems, enabling stakeholders to make decisions for new construction or renovation projects.

Co-creation with the MOUNTADAPT demonstration site in Tyrol

To develop thermal-aeraulic simulations for hospital buildings in the context of climate change and heat waves, this study was conducted at a demonstration site in Tyrol, focusing on the thermal environment in patient rooms during summer. The University Hospital of Innsbruck is thus a demonstrator for the MOUNTADAPT project. Its main issue concerns **heat exposure** of occupants during summer. Annex I presents meeting minutes to illustrate the importance of the exchanges, and the methodology developed through them.

Target audience

The target audience for the building simulations includes building owners, designers, builders, operators, and users. The methodology should be transferable to other European hospitals located in mountain regions, which is why the limits of the results will be specified.

This document presents the proposed methodology to assess building performance, and results obtained for the Innsbruck hospital.

METHODOLOGY

The proposed methodology aims to provide reliable information for each technical solution, based on the probability of exceeding operating limits, i.e. when the building cannot perform its intended function adequately. The different steps are introduced in Figure 1. This is an iterative work which starts from the needs of users and the behaviour of the building under thermal stress.

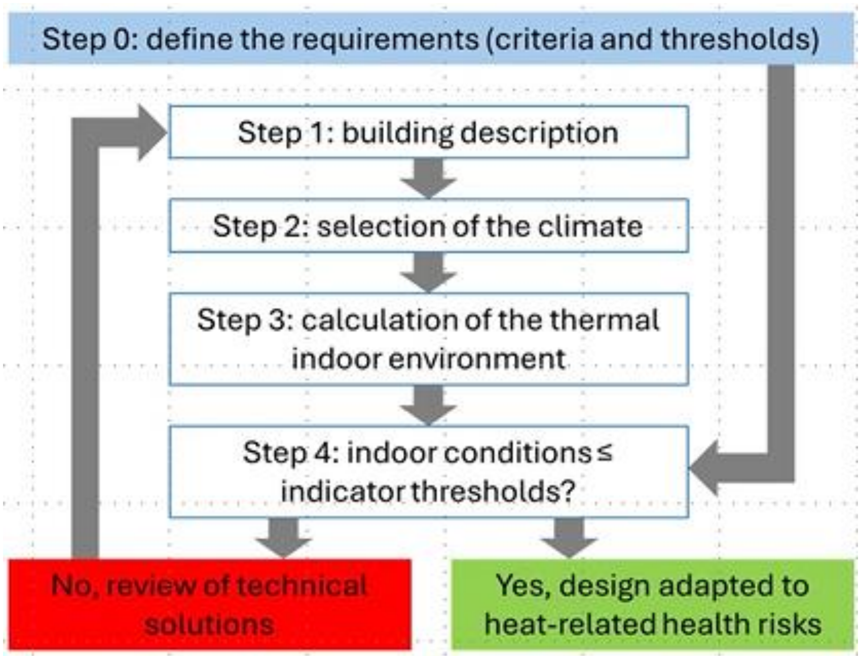

Figure 1. Methodology steps

Step 0: Requirements definition

Operating limits are the indoor conditions beyond which the building is considered to be malfunctioning. They may characterise uncomfortable situations or present a health risk. They depend on the function of the building and must therefore be discussed and agreed upon with the building manager.

The first step is thus to define the requirements with the stakeholders, i.e. criteria and thresholds for the indoor environment representing fault-free operating conditions. For this case study, the operating limits are chosen based on ÖNORM H 6020 (12). This Austrian standard establishes appropriate conditions for both patients and healthcare staff. The specific requirements of this standard vary based on the function of the room and the needs of its users. Indoor air temperatures below 26°C are recommended in patient rooms during the cooling season. The same threshold is recommended for computer rooms. No threshold is indicated for rest rooms. It should be noted that a higher threshold could be adapted for rooms where only medical staff are present: they have more flexibility and can use ventilators, unlike patients. More detailed comfort indicators would be needed to take these effects into account. However, this issue will not be addressed in this report, and we will limit our analysis to the conditions required by the standard ÖNORM H 6020 (12). **Therefore, 26°C will be used as the operating limit for all rooms in the studied zone.**

This criterion and its threshold are consistent with the other values available in the ISIAQ database (13). Dry Bulb Temperature (DBT) must remain between 18 and 28°C. The maximum value is 28.5°C, but it reaches 31°C in India with an adaptive approach. However, the value of 38.5°C is ambiguous. It must be the range of outdoor temperature variation for the application of adaptive comfort. Few texts address the issue of exposure duration. A threshold of 25°C is noted, which must not exceed 5% of the exposure time. For workers in Germany, thermal conditions must not exceed 35°C for DBT. In Norway, it is recommended not to spend more than 50 hours above 26°C for operative temperature.

About humidity, a broad range of 20% to 75% is recommended in the ISIAQ database (13). Apart from Norway, all other texts recommend a minimum of 30%, while the most restrictive recommend not going below 40%. Most recommend not exceeding 70%, while the most restrictive recommend 50%. The optimal range of 40-60% appears in some texts (Estonia). In offices in the United Kingdom, annual exposure is recommended 95% of the time between 30-50%. To conclude, we have several ranges: optimal: 40-50%, common: 30-70% and wide: 20-75%.

The indoor operative temperature ($T_{op,int}$) is chosen because it gives a more accurate indication of human experience than air temperature alone, as it includes the temperature of surface and thus the heat flux of long-wave radiation. **The $T_{op,int}$ > 26°C condition is therefore used to define the periods when the building is considered to be malfunctioning.** This temperature limit is in line with the recommendations, and even the regulatory requirements, observed in other technical and official texts. It is also within what is referred to as the moderate thermal environment, as defined in standard NF EN ISO 7730 (14), as opposed to a hot environment which may present a health risk linked to exposure to heat. Nevertheless, it does not presume a satisfactory response to the occupants' feelings.

A minimum temperature control is also introduced for an optimal ventilation scenario. In accordance with the Austrian standard ÖNORM H 6020 (12) during heating period, if the indoor temperature goes below 22°C, the windows are closed to prevent patients from complaining about the cold thermal environment.

Hospital buildings present particular complexity with patients at rest and a medical team engaged in physical activity. For people at rest, humidity within the range presented has a secondary influence compared to temperature. However, for people engaged in physical activity, it plays a more important role, as sweat must be evacuated to cool the body. Increasing air speed with a fan can counteract the increase in humidity. It is then a question of thermal balance between the heat to be evacuated and the constraints on evaporation.

Step 1: Building description

To limit modelling time, only one part of the hospital building is modelled. The selected building should be an old one that can be renovated to provide a demonstration for a wider audience in Europe. The building contains both sleeping areas for patients and office spaces subject to overheating. The demonstrator can then cover a wide range of situations, with vulnerable people, night-time and daytime conditions.

Figure 2. Exterior view of the chosen building

We choose to study the ward Gyn 2 of the University Clinic for Gynaecology and Obstetrics (Figure 2). Located on the 6th floor, it is composed of 10 patient rooms, but also staff rooms (Figure 3). Patients are women with high-risk pregnancies. They can stay in the clinic for several weeks (6 to 8). When they are not with the patients, nurses and doctors can stay in the work room with several computers or the break room. Occupation and scenarios are detailed in the following paragraphs.

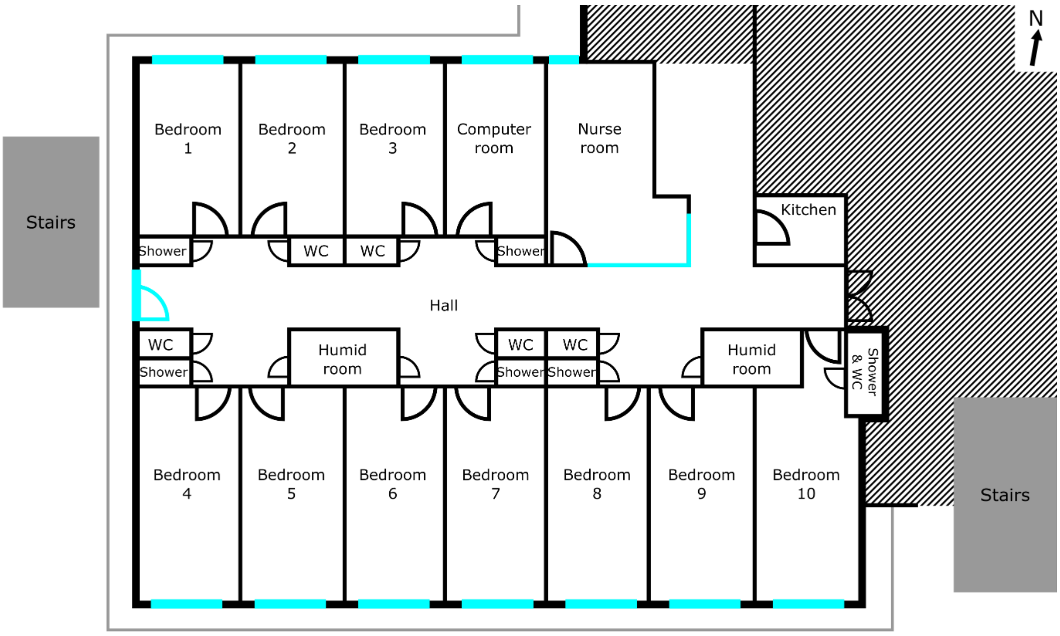

Figure 3. Floor plan

Technical documents and plans are completed with an on-site visit to understand how the service works. The modelling hypotheses are detailed in Tables 2 to 5.

Building characteristics

The characteristics and the dimensions were given and checked with a designated team from Tirol Kliniken, consisting of nurses from Ward Gyn 2 and technical staff. The on-site visit allowed to see the quality of the construction and the details, particularly for the floor coverings, the solar protection, and the opening of the windows (Figure 4).

Figure 4. Windows and solar protections

The characteristics are available in the tables below. Thermal bridge losses of 0.10 W/(m².K) for the envelope area are also considered. It is a surface value applied to all exterior walls to simplify modelling.

Table 2. Openings

Opening	Dimension	Opening type	Trnsys library
Window 1	1.2m x 1.2m	Fixed	ID 3200
Window 2	1.2m x 0.3m	Tilt	
Window 3	0.4m x 1.6m	Casement	
Window nurse	1.2m x 1.2m	Casement	
French window	1.2m x 2.5m	Casement	
French window	0.7m x 2.5m	Fixed	
Door	1.2m x 2m	Casement	X

Table 3. Wall characteristics

Name	Materials	Thickness [m]	Conductivity [W/(m.K)]	Density [kg/m3]	Rsi [m².K/W]	Rse [m².K/W]
Outdoor wall	Plasterboard	0.025	0.27	1180	0,13	0,08
	Air layer	0.023	R = 0.156 W/(m².K)			
	Rock wool	0.05	0.045	70		
	Steel concrete	0.12	2.5	2400		
	Rock wool	0.08	0.045	70		
Indoor wall	Plasterboard	0.013	0.27	1180	0.13	
	Rock wool	0.05	0.045	70		
	Plasterboard	0.013	0.27	1180		
Intermediate floor	Plasterboard	0.025	0.27	1180	0.10 (up) 0.17 (down)	
	Air layer	0.3	R = 2.041 W/(m².K)			
	Steel concrete	0.2	2.5	2400		
	Vinyle	0.03	0.2	1330		

Scenarios

Discussions during the on-site visit in February 2025, with project managers from the Department of Buildings & Technology and the Technical Service Center, as well as actual building users, are necessary to understand their needs, the daily operation of the building, and explanations of the obstacles and levers related to actions to protect ones elf from the heat.

All windows are open from 7h30 to 9h. Doors are always open. Solar protections are closed from 9 to 19h. This scenario may seem optimistic, but the medical team is particularly vigilant in applying these protective measures. As Figure 5 shows, they promote this practice among patients.

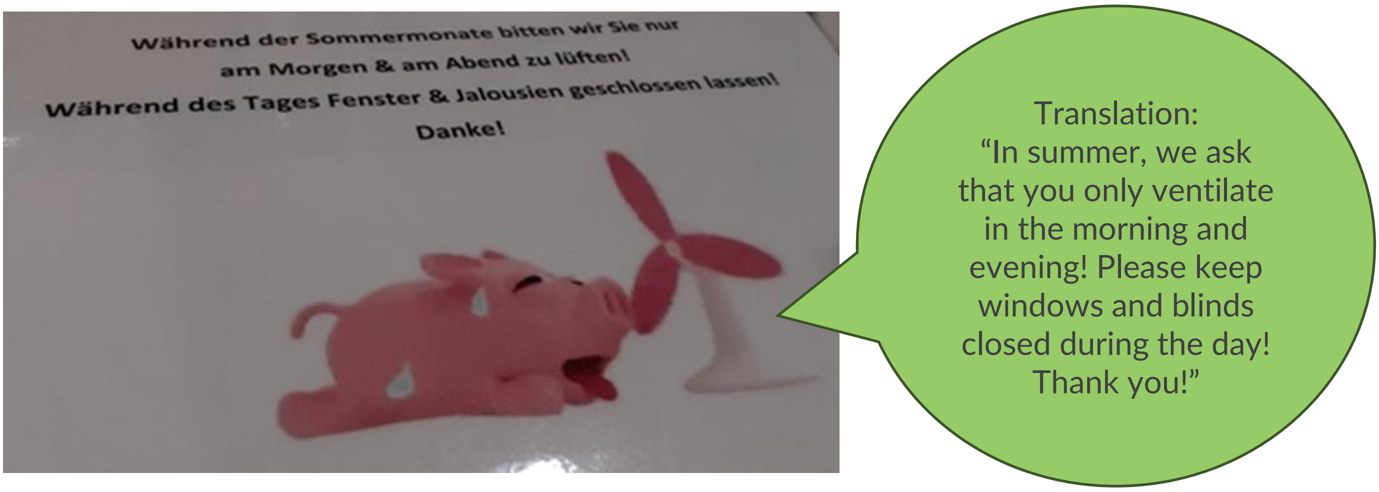

Figure 5. Image presented to patients during summer

The occupation scenarios are available in Table 4. Gains associated with each activity come TRNSYS library constructed on 2013 AHSRAE handbook [(15)].

Table 4. Occupation scenarios

Zone	Period	Description	Number of occupants	Activity
Bedrooms	Always	Patients	2 (north) or 3 (south)	Lying rest
CH7	Day (7-19h)	Visitors	5	Sitting rest
Computer room	Day (7-19h)	Medical staff	7	Sitting active
	Night		1	
Nurse room	Day (7-19h)		1	Sitting rest
	Night		2	

The electronic equipment in each room was also noted during the on-site visit. They are associated with internal gains (Table 5). Gains and radiative part associated with each equipment were derived from Calise et al.[16] and those of artificial light from Marchio et al. [17].

Table 5. Equipment scenarios

Room	Period	Description	Number	Gain (W)	Radiative part (%)
Bedrooms	Day (7-19h)	TV	1	240	40
Computer room	Day (7-19h)	PC stationary	7	90	10
		Laptop	1	59	25
	Night	PC stationary	1	90	10
Nurse room	Always	Laptop	1	59	25
Kitchen	Always	Fridge	2	40	0
Wet rooms	Always	Fridge	2 (HUM1) or 1 (HUM2)	40	0
Nurse room	Always	Artificial light	10 W/m²		
Computer room	Always (depending on natural light)				
Rooms without windows	Day (7-19h)				
Bedrooms	7 to 21h (depending on natural light)				

Showers take place between 7h and 11h. We assume that a shower emits 1440 g/h of absolute humidity [18], and that bathrooms are occupied 1/3 of the time over this period.

Building challenges

This department was chosen because it addresses a number of issues. The main problem is related to indoor summer overheating. It is occupied 24 hours a day, 7 days a week. It is a hospital unit dedicated to caring for women with high-risk pregnancies who may require hospitalization for extended periods, sometimes lasting several months. The high density of occupancy and the presence of numerous small appliances lead to high internal gains. It should be noted that the facility accommodates occupants engaged in different activities, primarily patients who are at rest, as well as the medical team, who performs tasks both standing and sitting, including work in the computer room. Their thermal experiences can therefore be very different, as thermal comfort depend on environmental variables (air and surface temperatures, humidity and air speed) but also personal variables (clothes and activities) [(14)].

Clothing insulates the body from the surrounding thermal environment. It plays a vital role in the thermal comfort of occupants. Given their physical activity, medical staff are particularly sensitive to this thermal environment, which may feel too warm, while patients at rest may consider it appropriate. Workwear that is unsuitable for the season can hinder activity. The ISO 9920 standard, "Estimation of thermal insulation and water vapor resistance of a clothing ensemble" [(19)], provides valuable recommendations on this subject.

Although the concrete structure of the building is heavy, the presence of a non-ventilated false ceiling, rather light intermediate walls with a lot of equipment and furniture applied to the walls, a limited surface area of external walls due to the compactness of the building and the bays, as well as the presence of thin plastic cladding, mean that the daily inertia is low (in other words the ability to store energy during the day and release it at night). The walls appear to have insufficient thermal effusivity to effectively absorb and redistribute the emitted heat.

Step 2: Climate selection

Historical climate data are collected at the meteorological station located 200m from the site since 1987. As the station is located particularly close to the clinic and the floor studied is sufficiently far from the ground, we assume that the station's measurements reflect outdoor conditions at building level. However, it would be interesting to correct the wind speed due to the very high height of the weather station. It is indeed on the top of the building at about 35m high (Figure 6).

Figure 6. Meteorological station location

These data provide information on the past and present conditions of the outdoor environment of the hospital. They are collected from GeoSphere Austria [(20)]. They are used to construct meteorological files for the simulations at an hourly time step, covering 8 summers (2013, 2015 and 2019 through 2024) all characterized by notably hot conditions. These are recent and hot summers. Results are analysed from 1st May to 30th September.

For this work, a methodology based on the evaluation of limit climatic sequences is proposed. The first step is to determine the building's memory. The second step is to select indicators to characterise the climatic sequences.

Determining the building's memory

The building memory is the period of time beyond which the thermal conditions of the indoor environment will no longer be sensitive to the initial variations in the external climate. By analogy, the building envelope can be considered as a tank that can contain a certain quantity of liquid (following Lavoisier's representation, heat is assimilated to a fluid). We are looking for the time to fill it for a constant flow rate.

It is difficult to know exactly how long the load will last, because it depends on variations in the signals, i.e. internal gains, solar gains, variations in outside temperature, or occupancy scenarios. We therefore try to estimate the maximum load time with a simulation under a step signal, when all the stresses that could generate a variation are cancelled out.

A specific simulation is therefore carried out to calculate the building's memory (called t1). Temporal variations are not considered:

- No internal gains are included.
- All windows are kept closed at all times.
- To avoid heat leakage, the emission of longwave radiation towards the sky is not considered, by cancelling the longwave emission coefficient of the external walls, assuming that the walls are Lambertian.

A fictional weather file is generated to simulate a temperature step. Solar radiation and wind are set to zero, and relative humidity is kept constant at 50%. The outdoor temperature is maintained at a constant value of 15°C at each time step for 15 days, then increased to 25°C and maintained at this value until the indoor temperatures no longer vary from one time step to the next.

Equilibrium is considered to have been reached when the inside temperature exceeds: $0.95 \times (value_{final} - value_{initial}) + value_{initial}$. More details on this representation of the structure as a low-pass filter are available in the article by Tanchou et al., 2023 [(21)].

Choice of intensity indicators to represent the climatic sequence

In reality, the building is not subjected to a direct step in the outside temperature, which also varies during the day. Intensity indicators must therefore be chosen to represent the climatic sequence. This choice is not immediate, as it depends on the indicator used to define the operating threshold, the time it takes for external climatic variations to have an impact on the indoor thermal environment, the occupancy scenario and the characteristics of the building.

Since internal gains are high throughout the day and the diffusivity of materials is altered by the presence of a false ceiling in the building studied (and to a lesser extent by plastic cladding), our assumption is that diffusivity is insufficient to prevent temperature drift over the course of the day. The evacuation of heat by ventilation at night is usually the dominant effect. However, heat diffuses slowly through the structure and the night-time cooling time is potentially too short to allow heat to be removed by ventilation at night. The return to equilibrium will be facilitated by the transfer of heat through the walls, including the glazing. Equilibrium will therefore depend on the average outside temperature over the duration of the transfer. For these reasons, the average daily temperature is used to represent as the criterion for one day.

For periods longer than a day, temperature drift does not mean that the threshold is systematically exceeded. Depending on the initial state, internal inputs, solar inputs and the management of window openings, it will take several days of a specific intensity to exceed the operating threshold. **Therefore, to characterise the climatic sequences, we use two indicators:**

- **the average temperature of the previous days ($T_{mean,N-1days}$)**
- **the difference between the temperature of the last day and the average temperature of the previous days ($\Delta T = T_N - T_{mean,N-1days}$).**

Figure 7 is a schematic representation of the characterisation of a climatic sequence. The loading time (N) is smaller than the building's memory (t1). It will be determined thanks to the next step.

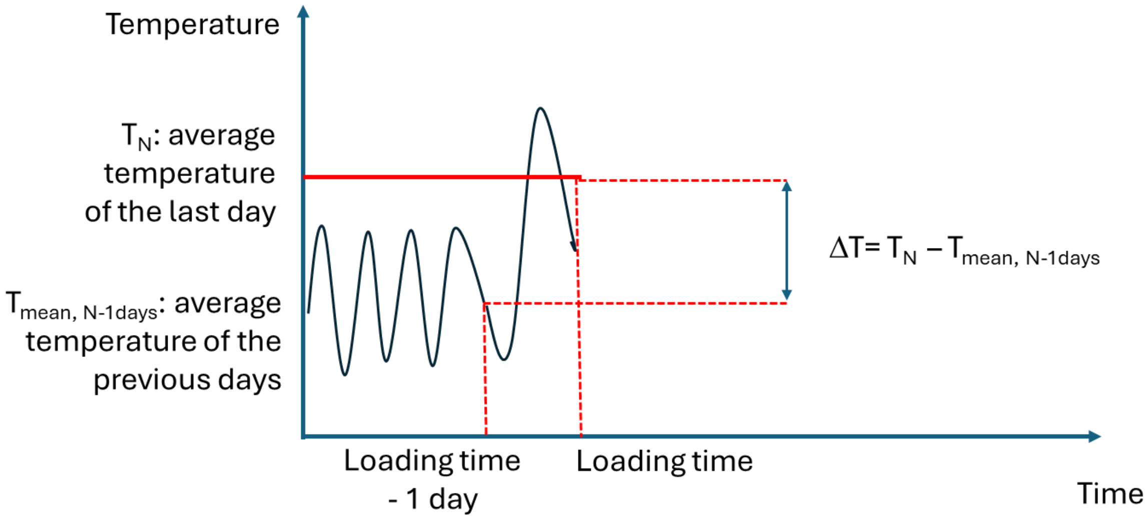

Figure 7. Schematic view of the climatic sequence indicators

Step 3: Indoor environment simulation

Having characterised the climatic sequences using these two indicators, we now need to identify the sequences that cause the building to malfunction. To do this, as no measurements are taken indoors, we model the building and simulate its behaviour during previous hot summers. The use of dynamic thermal simulation is necessary to understand the thermal, humidity, and airflow behaviour of the building under study.

The building's dependence on the outdoor climate is studied in the absence of an air conditioning system. Identify the outdoor climate variables that influence the thermal conditions of the indoor environment will allow us to select and prioritize climate sequences according to their probability of occurrence.

As passive solutions and their operating limits are studied, a calculation of air exchange must be integrated in the model. Indeed, the indoor temperature depends on the air entering from outside, and the amount of air entering depends on the temperature difference between the inside and outside. This exercise is not simple because a pressure balance software to determine the airflow rates must be coupled to a thermal balance software to determine the indoor temperature and humidity.

Therefore, to simulate the evolution of the indoor environment, a thermo-aeraulic model is constructed (Figure 8). TRNSYS (thermal model) is coupled with CONTAM (aeraulic model) with the methodology explained by Dols et al., 2015 [(22)]. This second type of model is needed to assess the efficiency of solutions such as natural ventilation.

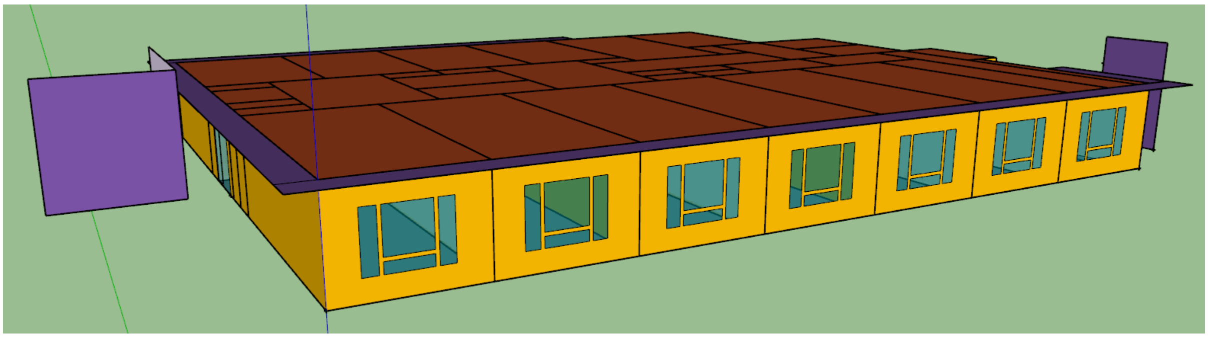

Figure 8. Thermo-aeraulic model

Furthermore, given the accuracy of the calculation, the heterogeneity of the indoor environment and the precision of the measuring devices, it is difficult to achieve a level of precision beyond one degree. For this reason, the calculated temperatures will be rounded to the nearest 0.5 degrees.

For each situation (the initial situation, i.e. the current situation, and the situations with the building and solutions in place), the behaviour of the building is simulated over 8 summers. Building model results with nature-based or hybrid solutions implemented will be compared with the initial model (current situation without solutions).

Step 4: Climate impact analysis of the indoor environment

The results of the simulations of the evolution of the indoor environment under different external conditions are then used to identify critical climatic sequences that will cause the building to malfunction during the summer period.

The boundary distinguishing climatic sequences that meet the required indoor thermal conditions from those that do not, is established in three stages:

1. The thermal conditions of the indoor environment are simulated over 8 hot summers.
2. 80% of these results are used to establish the regression and identify the boundary.
3. 20% of the simulation results are used to validate the regression.

Once the regression is validated, it is applied to multi-years periods of climate observations and prospective climate simulations, to calculate the probability that a technical solution does not meet the required comfort conditions.

Simulations are carried out with a 5-minute time step from 20th April to 30th September. Results are analysed from 1st May to 30th September. The first 11 days correspond to the model stabilisation period. The results are analysed on an hourly basis: the detailed temperatures (5 minutes) are first rounded to the nearest 0.5°C, then averaged on an hourly basis, given that:

- The model cannot give a more accurate account of indoor temperatures beyond the degree.
- The calculation is carried out at the scale of the room, reduced to a node, which assumes that there is no temperature heterogeneity in the volume.
- A difference of one degree per hour has no impact on the sensation.

For each day, the number of hours where $T_{op,int}$ > 26°C in the hottest bedroom and in the computer room are the calculated. The hottest bedroom corresponds to the maximum value of all the bedrooms for each day. A day is then considered unacceptable if there is at least one hour above 26°C. It can also be characterised by the two climatic indicators $\Delta \boldsymbol{T}$ and $\boldsymbol{T_{mean,\ N-1days}}$.

Logistic regression is then used to calculate the decision boundary. It is used to identify critical climatic sequences. The 8-summer data set is separated into a training set (80%) and a test set (20%) in a stratified way. This means that of the 1224 days (153 days per summer for 8 summers), 80% are used to train the model and 20% are used to calculate a performance indicator. They are split up so that the proportion of acceptable days (the variable to be predicted) is similar in the training set and the test set. Python's scikit-learn library v1.6.1 is used for data preparation, and model training and evaluation.

The input variables are $\Delta \boldsymbol{T}$ and $\boldsymbol{T_{mean,\ N-1days}}$, while the output variable to be predicted is the presence or absence of a malfunction (a day with at least one hour where $T_{op,int}$ > 26°C). In the initial situation, 30% of days are unacceptable in the hottest bedroom, and this value reaches 40% in the computer room. Several logistic regressions are calculated on the training set for different loading times (N) from 2 to 11 days. The choice of the loading time finally used is made by calculating the recall on the test set. Recall measures the model's ability to detect all true positives. It is calculated using the formula: $recall = \frac{True\ positive}{True\ positive + False\ negative}$. A high recall minimises the risk of wrongly classifying a positive case as negative. This is important in our case for a fail-safe approach.

It is then possible to calculate the probabilities of occurrence of climate sequences that exceed the limits in different climates (for example, under future climate).

To assess the level of adaptation of the current building and after refurbishment to climate change, prospective climates were used. The method developed performs this assessment only with the daily average temperatures. This simplicity is a major advantage because it is rare to have variables at hourly time steps in the output of climate models. Furthermore, with climate models, the consistency between climate variables (temperature, radiation, wind, humidity, for example) is not at the same quality as the observations, and it is not easy to assess the influence of the lack of consistency on the conditions of the indoor thermal environment.

Future climate files are extracted from the GeoSphere Austria website [(20)]. These are bias-corrected EURO-CORDEX ÖKS15 models containing precipitation, radiation, and temperature at daily time steps. 14 models from the EURO-CORDEX ensemble were bias-corrected using the Scale Distribution Mapping (SDM) method as explained by Switanek et al., 2017 [(23)] using observational data for the historical period and future projections under the RCP4.5 and RCP8.5 scenarios. In our study, we consider the daily dry air temperature with RCP 8.5 for the period 2025 and 2050. The 14 models selected are in Table 6.

Table 6. Climatic models used for future climate analysis

Id	Model
1	**cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_clmcom-cclm4-8-17-v01**
2	cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_clmcom-cclm4-8-17-v02
3	cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_cnrm-aladin53-v01
4	**cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_cnrm-aladin53-v02**
5	cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_smhi-rca4-v01
6	cnrm-cerfacs-cnrm-cm5_rcp85_r1i1p1_smhi-rca4-v02
7	ichec-ec-earth_rcp85_r12i1p1_clmcom-cclm4-8-17-v01
8	ichec-ec-earth_rcp85_r12i1p1_clmcom-cclm4-8-17-v02
9	ichec-ec-earth_rcp85_r12i1p1_smhi-rca4-v01
10	ichec-ec-earth_rcp85_r12i1p1_smhi-rca4-v02
11	ichec-ec-earth_rcp85_r1i1p1_knmi-racmo22e-v01
12	ichec-ec-earth_rcp85_r1i1p1_knmi-racmo22e-v02
13	**ichec-ec-earth_rcp85_r3i1p1_dmi-hirham5-v01**
14	ichec-ec-earth_rcp85_r3i1p1_dmi-hirham5-v02

In the list, it appears that each model under the same initial conditions has two versions V01 and V02. The comparison of the average daily temperatures between the two versions over the 25 projected years shows very small differences. For the daily average temperature, it is reasonable to say that 7 models are sufficient in either version. For practical purposes, only 3 models were used: 1, 4 and 13[1].

Our generic approach means that it is not necessary to simulate the behaviour of the building under a different climate. Any point above the straight line would indicate a sequence that exceeds the threshold, while a point below the straight line would indicate that the threshold is respected. This representation enables the effect at the end of the heatwave to be evaluated, when the building remains hot due to its inertia.

This methodology therefore meets a twofold objective:

- To provide a level of reliability for the passive or green solutions requested by the client in the context of climate change.
- Extend or extrapolate the solution to other climates with transposable requirements.

Results

Indoor environment simulations for the initial situation

Several simulations are carried out using historical meteorological data measured in Innsbruck during the 8 past summers that were considerably hot. Results highlight the existing overheating problems in the building. Figure 9 shows the temperature evolution outdoor and in the bedroom receiving visitors during the summer of 2023.

[1] However, a calculation carried out with the 14 models showed that the results were equal to the nearest %.

Modelisation	Hottest bedroom		Computer room	
	14 models	3 models	14 models	3 models
Initial situation	30	29	40	39
Optimal ventilation scenario	28	27	37	36
Green façade and optimal ventilation	25	25	36	34

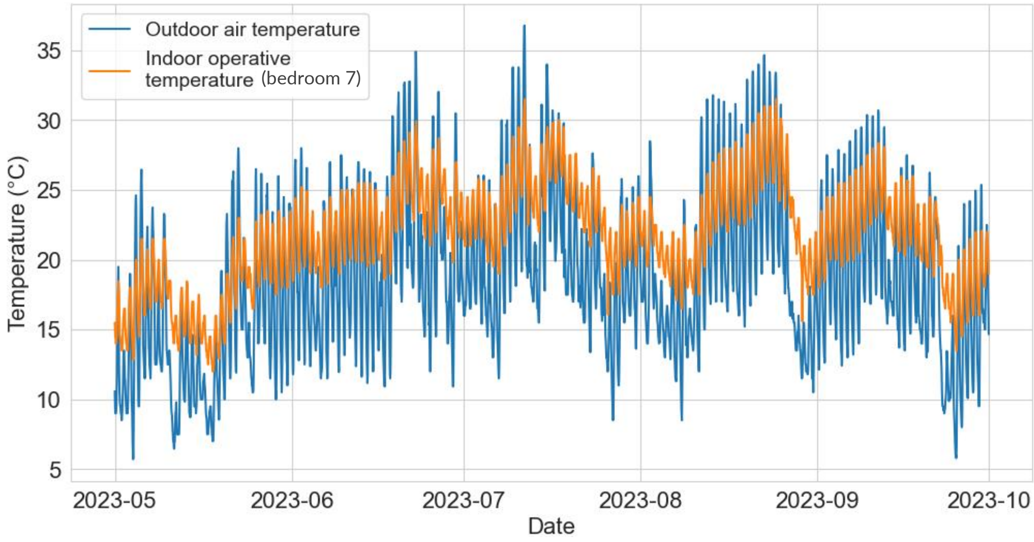

Figure 9. Temperatures evolution outdoor and in bedroom 7 during the summer of 2023

The temperature inside the building regularly exceeds 26°C, sometimes for several days at a time. Closing solar shading during the day reduces solar gains (although fixed solar shading due to the balcony is always in place) and opening windows in the morning evacuates some of the heat, but it is not enough. Internal gains are indeed considerable. Figure 10 shows the percentage of hours when the operative temperature exceeds 26°C in the various rooms.

Figure 10. Indoor overheating by room

There are significant differences between the rooms. Bedroom 7 (receiving visitors) is slightly warmer than the other bedrooms, but it is not critical. However, the room reserved for medical staff, with many computers running, reach 17% of hours outside acceptable temperature ranges. Specific solutions need to be implemented in this room. Fans are an appropriate solution for this room as it does not accommodate patients.

For the entire department, heat accumulated during the day must be evacuated, because internal heat gains are very high. Electronic equipment, and in particular computers grouped together in one room, must function to meet the needs of the department. In addition, occupancy density is quite high. It is thus not possible to reduce internal gains.

Indicators representing climatic sequences

Building memory

The first requirement is to determine the building's memory. The climate sequences will then need to be selected from this time frame. Figure 11 shows the results of the simulation of the building behaviour when subjected to a step signal, when all factors that could generate a variation are cancelled out.

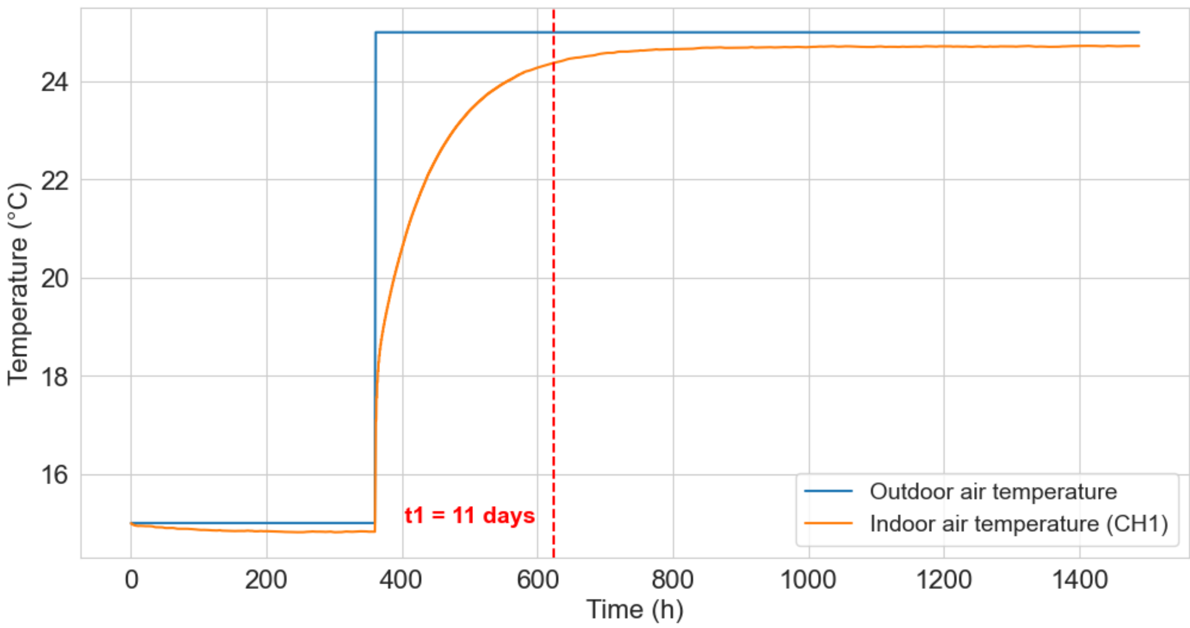

Figure 11. Simulation of indoor temperature evolution (bedroom 1) as a function of an outdoor temperature step

t1 is the length of time beyond which the thermal conditions of the indoor environment will no longer be sensitive to the initial variations in the outdoor climate. Different values of t1 are obtained for each room. As we are looking for a maximum duration, the longest duration for all the rooms will be used, i.e. **11 days** as in bedroom 1.

Loading time

As internal heat gains and window openings have been eliminated in the calculation of the building memory (t1), the climatic sequences to consider are necessarily shorter than this period. Calculations are therefore made for periods of 2 to 11 days (Table 7) for the building in initial situation. The logistic regression with optimal recall is then used as the load time value.

Table 7. Logistic regression performance for initial situation for different load times

	Recall (%)	
Load time	Hottest bedroom	Computer room
2	89,19	90,34
3	89,19	93,15
4	90,91	95,17
5	93,69	96,55
6	94,59	96,55
7	94,55	95,86
8	94,55	96,55
9	95,5	96,55
10	95,5	97,26
11	92,73	97,24

For the hottest room, the recall improves as the number of days taken into account in the climatic sequence increases. The computer room has higher internal gains and is therefore less dependent on external conditions. We chose to use **six days** for the following work, a value above which the improvement is no longer noticeable. Results of the logistic regression for climate sequence of six days are presented in the following parts.

For the computer room, a 5-day charge could have been chosen. An identical loading time for both types of rooms was preferred, with a view to using this information in a technical management of the building, it seems easier to control the interior thermal comfort from a single sensor.

Critical climatic sequences

The following figures (12 to 21) show the results of the simulations for eight hot summers. These graphs serve two main purposes: first, to identify the boundary between days that fall below and above the comfort threshold; and second, to determine the regression line that characterizes this boundary.

Initial situation

Figure 12 and Figure 13 show the climatic conditions that lead to the building malfunctioning, for the hottest bedroom and the computer room. Each point represents one day. The green dots illustrate the days when indoor conditions remain acceptable in the room(s), while the red ones represent the days when the building fails to operate, i.e. when the average hourly indoor operative temperature exceeds 26°C for at least one hour. The separation boundary is used to identify the limit sequences, beyond which the building will exceed the operating limit. Each climatic sequence is characterised by its horizontal and vertical coordinates. The x-axis indicates the average outdoor temperature of a climatic sequence ($T_{mean,\ 5days}$), while the y-axis gives the difference between the mean temperature of the following day (T_6) and the average outdoor temperature on the 5 previous days ($T_{mean,\ 5days}$).

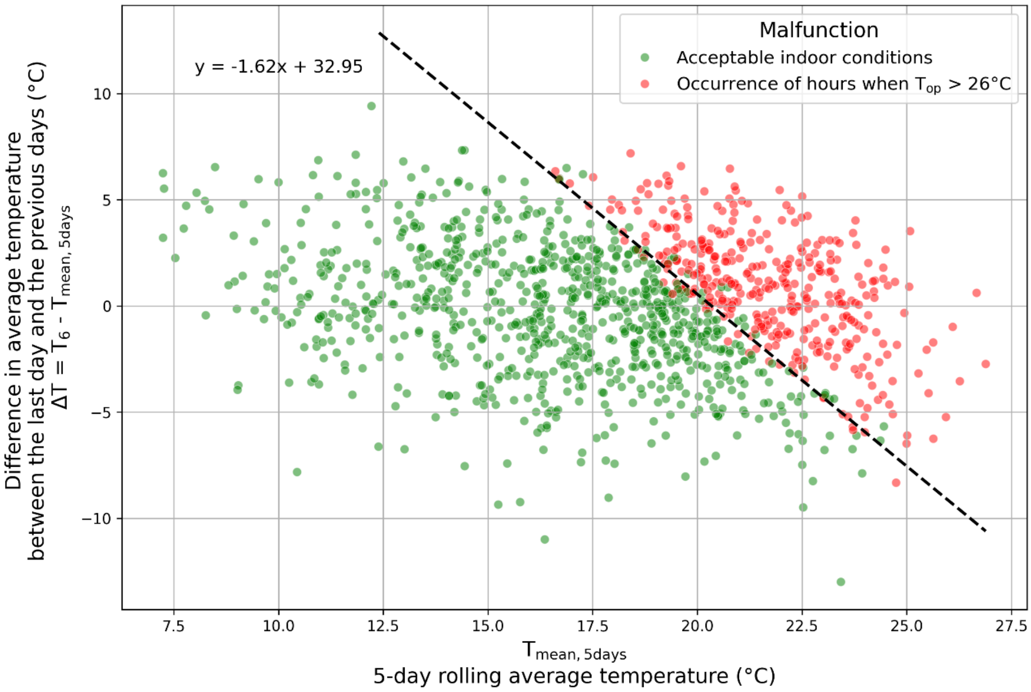

Figure 12. Critical limits of the climate sequences for the hottest bedroom in initial situation

For the hottest bedroom, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.62 \times T_{mean,5days} + 32.95$.

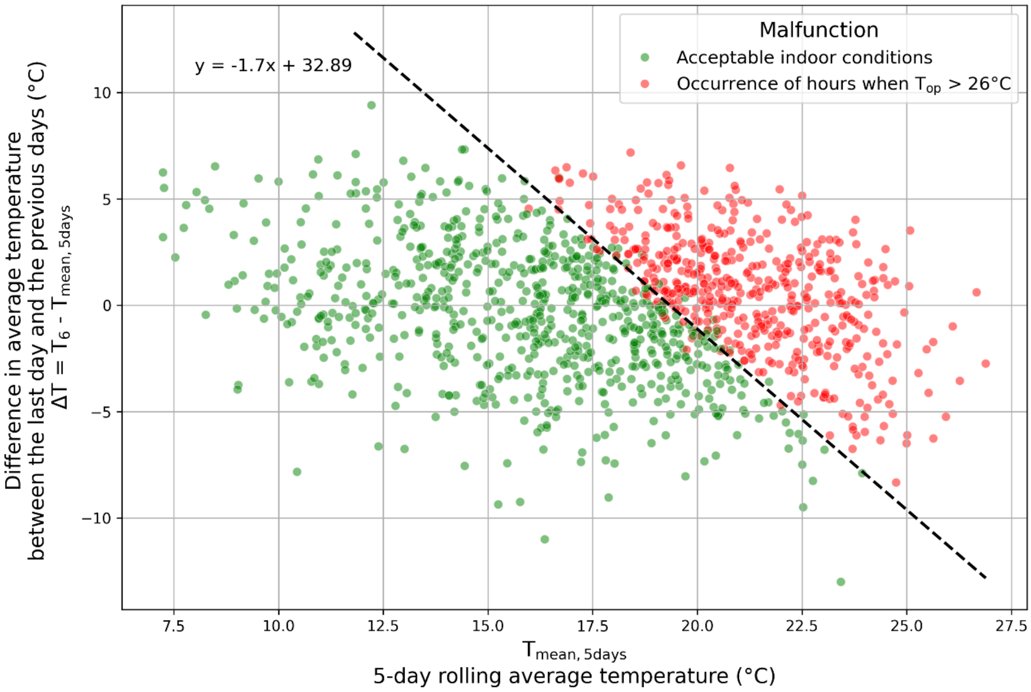

Figure 13. Critical limits of the climate sequences for the computer room in initial situation

For the computer room, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.7 \times T_{mean,5days} + 32.89$.

The decision boundary is used to identify limit climatic sequences. For example, in the hottest room, if the average outdoor temperature over 5 days is 17.5°C, then the average temperature on the following day must not exceed 17.5°C+5°C, i.e. 22.5°C. Otherwise, the operating limits will be exceeded.

Optimal ventilation

As internal gains cannot be reduced because they are due to the department's functioning, heat accumulated during the day must be evacuated. To look at the potential of **natural ventilation**, an optimal ventilation scenario is implemented (Figure 14 and 15). Windows are opened in each room when the outdoor air temperature is below indoor operative temperature and when indoor operative temperature is hotter than 22°C. The first condition ensures that opening the window will enable the indoor environment to be cooled. The second condition checks that opening the window will not cause cold discomfort to the occupants.

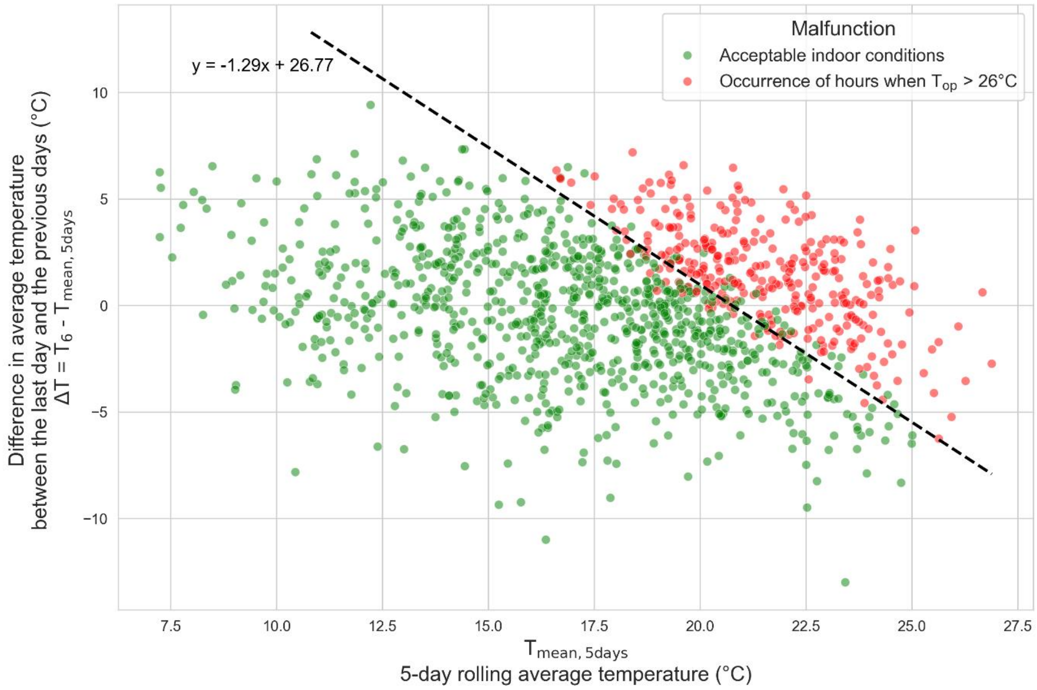

Figure 14. Critical limits of the climate sequences for the hottest bedroom with optimal ventilation

For the hottest bedroom, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.29 \times T_{mean,5days} + 26.77$.

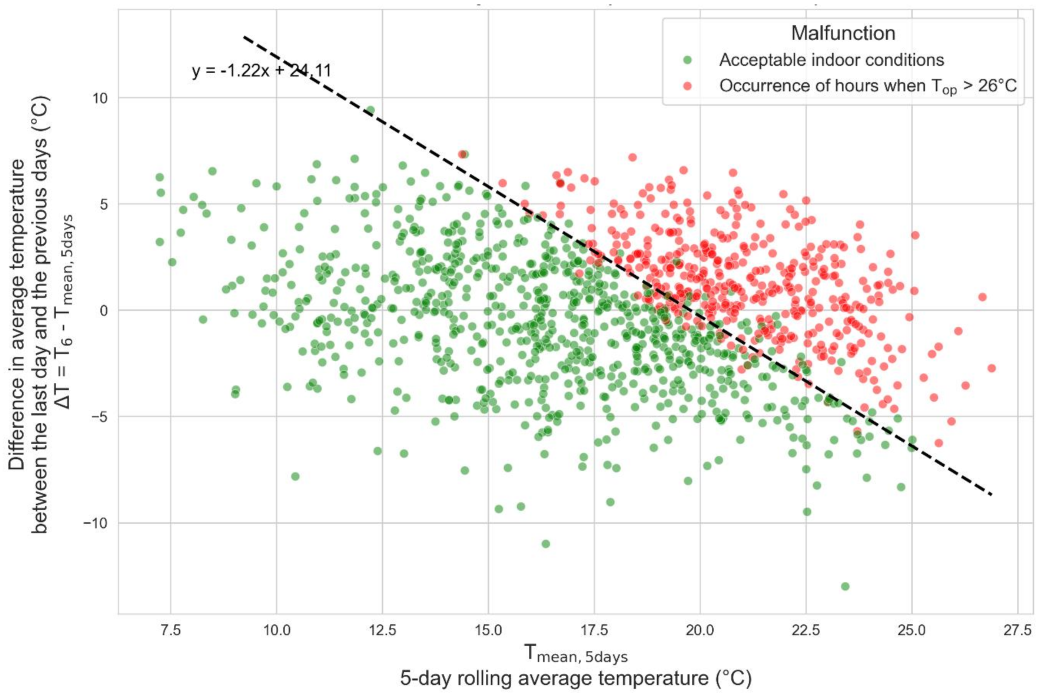

Figure 15. Critical limits of the climate sequences for the computer room with optimal ventilation

For the computer room, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.22 \times T_{mean,5days} + 24.11$.

Vertical Greenery System

To study the potential of climbing plants against the wall, the absorption coefficient is set to zero. Evapotranspiration is neglected but could have an even greater cooling effect. The choice of zero absorption of solar radiation leads to overestimating the benefit of vegetation. Conversely, cancelling the effect of water evaporation into the air leads to underestimating the cooling effect of the plant. However, plants tend to limit their evaporation when the heat flux reaching them is low, typically at night. On the other hand, this increases when the solar flux increases. Consequently, the choice to cancel the solar flux on the wall is optimistic. This result should be understood as the maximum benefit expected from the presence of vegetation on the walls. A more in-depth study could be carried out with a detailed model of the green façade.

Figure 16 and Figure 17 show examples of green walls. Due to the density of the leaves, plants are not placed directly in front of windows to ensure sufficient natural light can enter the building.

Figure 16: Heavy-covered wall Berlin 2025

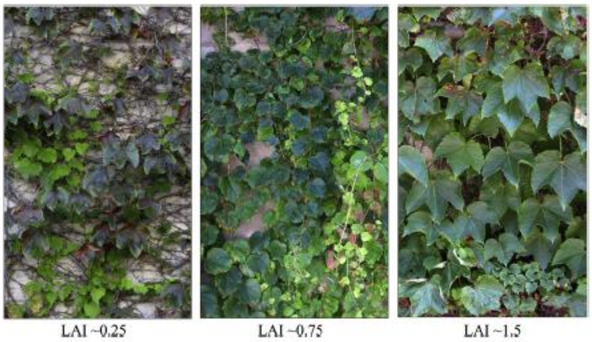

Figure 17: Plant layer with different leaf area index. Source: Susorova et al., 2013

Figure 18 and Figure 19 show the results for the green façade.

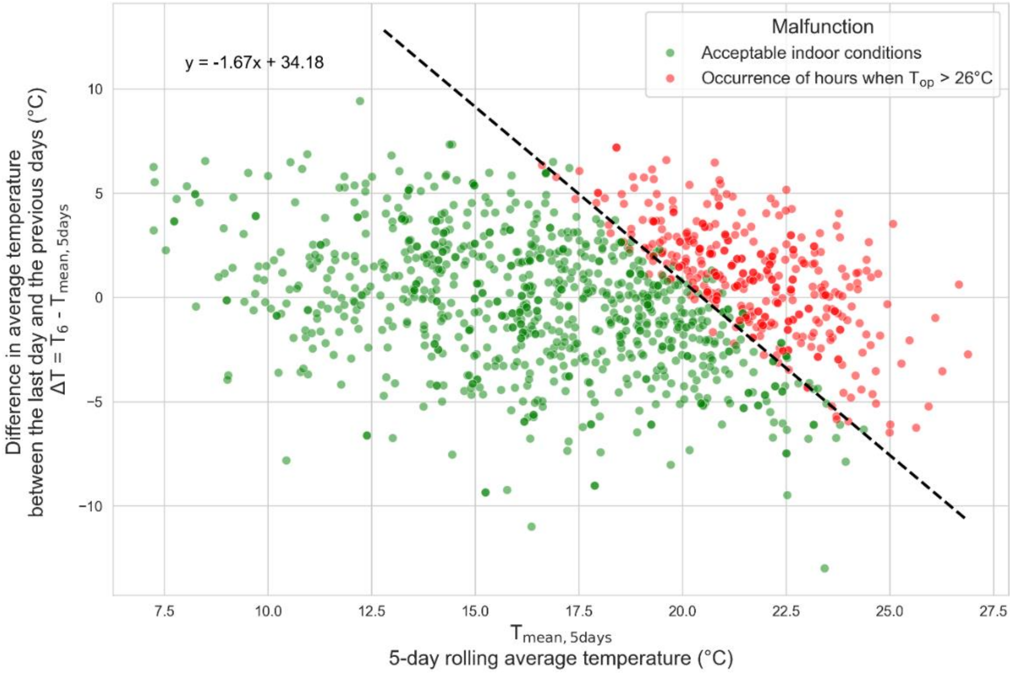

Figure 18. Critical limits of the climate sequences for the hottest bedroom with green walls

For the hottest bedroom, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.67 \times T_{mean,5days} + 34.18$.

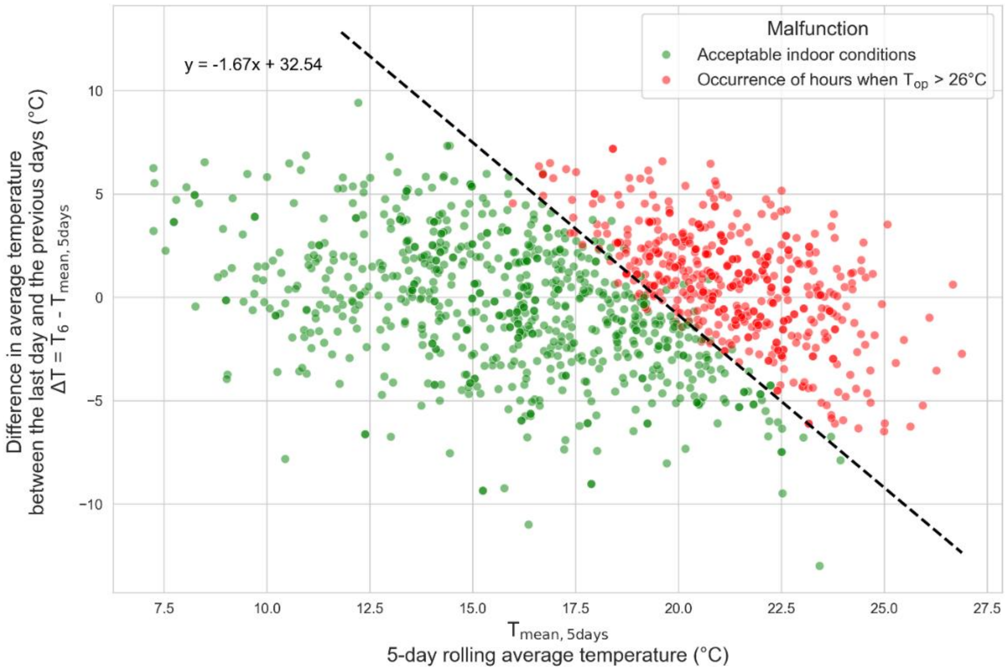

Figure 19. Critical limits of the climate sequences for the computer room with green walls

For the computer room, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.67 \times T_{mean,5days} + 32.54$.

Please note that this is not a realistic assumption, but rather a demonstration of maximum potential. The assumption is that no solar energy is absorbed by the wall for all the direct radiation. It is as if the foliage is perfectly opaque and all the energy reaching the leaves is absorbed and used to evaporate the water. To put it simply, it is assumed that the wall does not absorb any direct sunlight, as if the foliage completely blocks the sun. This effect is modelled using a zero-absorption coefficient, such as an ideal foliage totally opaque and perfectly reflective so the leaf is kept at the outside air temperature.

Optimal ventilation and green façade

Figure 20 and Figure 21 show results for the combination the two previous solutions.

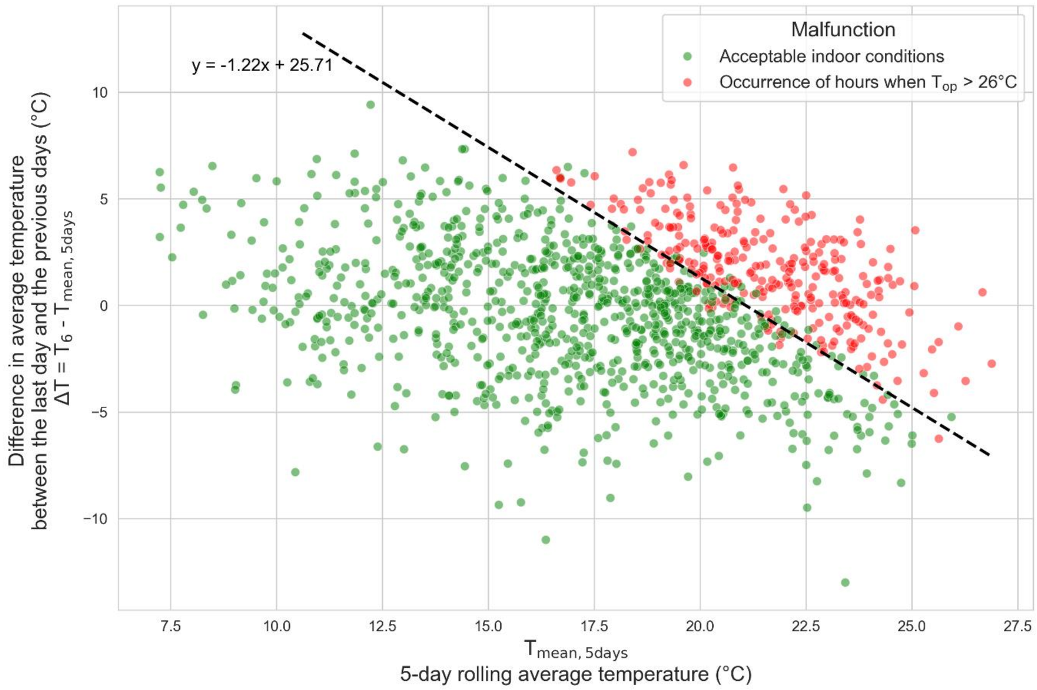

Figure 20. Critical limits of the climate sequences for the hottest bedroom with optimal ventilation and green walls

For the hottest bedroom, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.22 \times T_{mean,5days} + 25.71$.

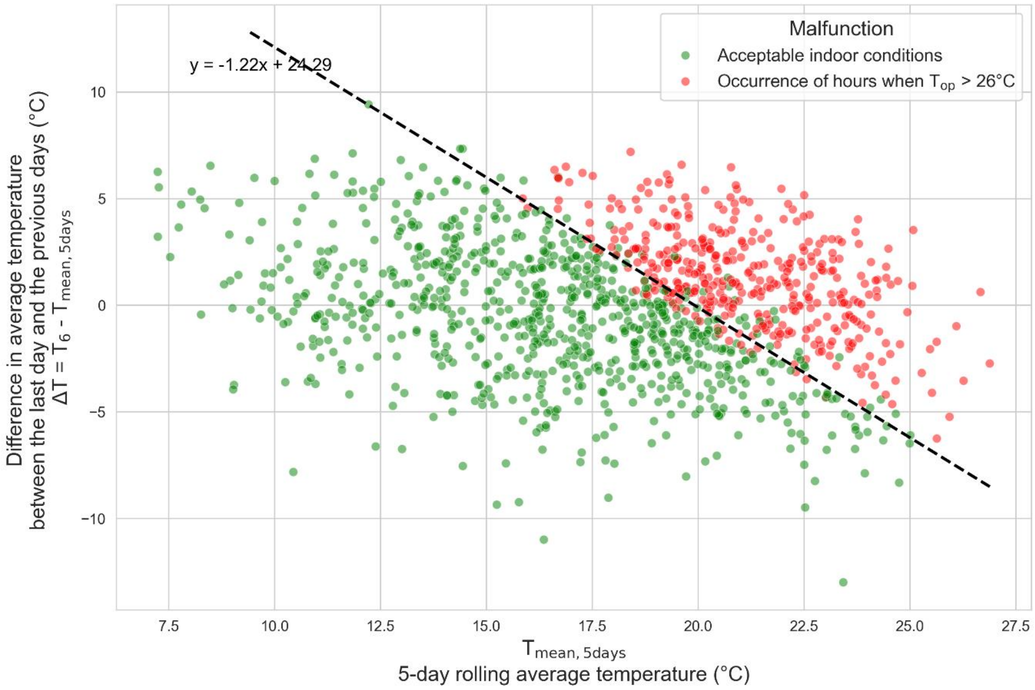

Figure 21. Critical limits of the climate sequences for the computer room with optimal ventilation and green walls

For the computer room, the clear separation between the red points and the green points leads to a simple linear regression which characterizes the operating limit of the building: $\Delta T = 1.22 \times T_{mean,5days} + 24.29$.

Comparison between solutions

We can see the contribution of the proposed solutions with the shift in the limit for high temperatures compared with the initial situation (Figure 22).

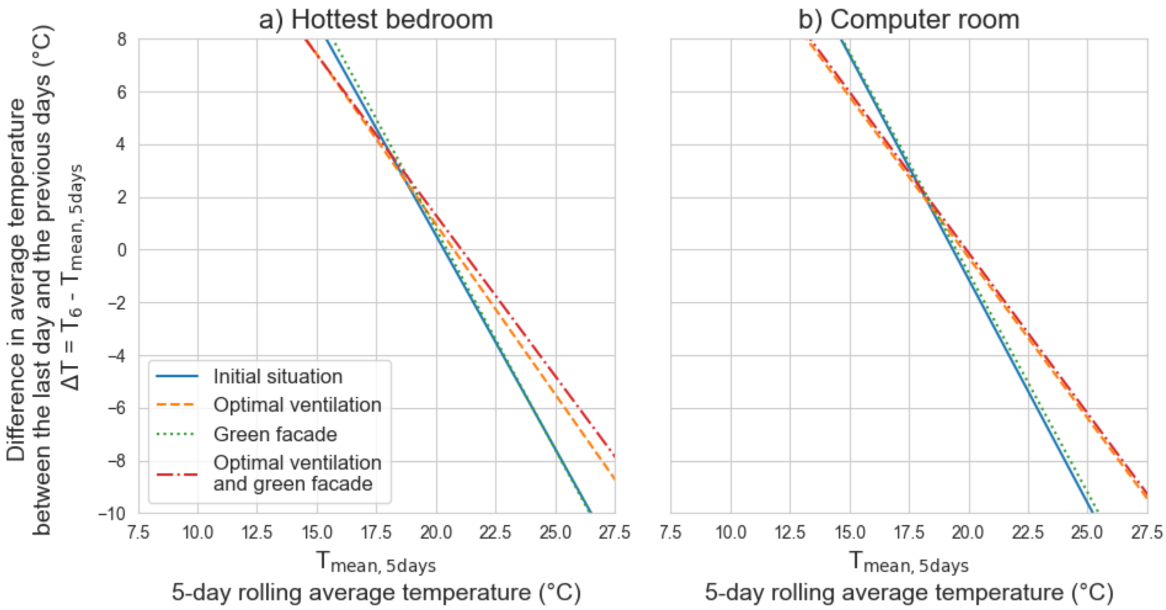

Figure 22. Comparison of critical climate sequences

This figure shows that it would take a succession of hotter outdoor conditions to cause the building to malfunction, or that the building would resist prolonged hotter periods. The four situations can be compared. The cooling effect of shading from the plant-covered wall is minimal, especially in the north-facing computer room. However, when combined with optimal ventilation, this shading can provide a modest benefit in the hottest bedroom.

Occurrence probability in future climate

Once the simulations have been carried out on eight recent hot summers, the results can be analysed over longer periods (Table 8). The historical period corresponds to observations at the meteorological station during summers from 1999 to 2024, while the future period corresponds to summers from 2025 to 2050, i.e. the near future. The results of three climate models with the RCP 8.5 scenario are used.

Table 8. Percentage of unacceptable summer days for pluriannual period

Hottest bedroom				
	Historical period (1999-2024)	Near future period (2025-2050 RCP 8.5)	Intermediate future (2050-2075 RCP 8.5)	Distant future period (2076-2100 RCP 8.5)
Initial situation	22 %	29 %	43 %	61 %
Optimal ventilation	20 %	27 %	40 %	57 %
Green facade	21 %	28 %	42 %	60 %
Optimal ventilation and green facade	17 %	25 %	37 %	54 %
Computer room				
	Historical period (1999-2024)	Near future period (2025-2050 RCP 8.5)	Intermediate future (2050-2075 RCP 8.5)	Distant future period (2076-2100 RCP 8.5)
Initial situation	32 %	39 %	53 %	70 %
Optimal ventilation	28 %	36 %	49 %	65 %
Green facade	30 %	37 %	52 %	69 %
Optimal ventilation and green facade	27 %	34 %	48 %	64 %

In the future, the percentage of unacceptable days increases for all situations. There is a cumulative effect of the two solutions, as they do not have the same consequences: over-ventilation at night allows the heat accumulated during the day to be evacuated, while the green façade protects the external walls from direct solar radiation.

The solutions implemented reduce the percentage of days when the operative temperature exceeds 26°C for at least one hour in the rooms studied. Compared to the initial situation, percentage of unacceptable days during historical period is reduced from 22 to 17% for the hottest bedroom, and from 32 to 27% for the computer room.

An optimal ventilation scenario is more effective than the green façade, because the main issue for the modelled hospital building in Innsbruck, as we have seen for the initial situation, is linked to the high internal gains that cannot be avoided.

The choice of a probability of occurrence of exceeding the threshold over a period was made to express a level of risk. Thus, the result is not to qualify or disqualify a technical solution but rather to indicate its limits. Thus, the combination of the ideal green facade[2] and optimized ventilation provides strict comfort in more than 80% of the days in the rooms for the current period. On the other hand, this percentage is reduced to approximately 70% of the time in the computer room. In the future, these level decrease. A black-and-white answer for a technical solution or design is not given. Instead, limits are established with the aim of enhancing reliability,

By reading these percentages, the project owner will be able to consider corrective actions and their benefits. In other words, "forewarned is forearmed."

For a project owner who would like to test similar solutions on their project, they can follow the steps detailed here. Once the thermal signature of the building is established (the regressions), it is theoretically possible to evaluate the building's performance with regard to thermal comfort in all environments. However, there are limits to this extrapolation, which we address in the discussion.

Discussions and perspectives

Firstly, the results obtained are closely linked to the specific characteristics of the site, and any extrapolation to other contexts must be preceded by an exercise aimed at identifying and distinguishing the particularities of each situation.

We summarize here the main specific features that make the studied site unique, particularly those related to its usage:

[2] We draw the reader's attention to the result obtained with the green facade which corresponds to the maximum benefit that can be obtained with this equipment.

- Many patients stay for several weeks. Constant daytime closure of solar protection can have a depressive effect, even if it is a preferred solution for reducing incoming solar gain.
- The false ceiling hides the mass of the structure and potentially reduces the absorption of heat emitted inside.
- Overheating problems are associated mostly with internal gains rather than with external gains. However, these internal gains are unchangeable, since they are due to the clinic's activities and the high occupancy density.
- The heterogeneity of physical activities due to the presence of patients and the medical team is an additional difficulty. Indeed, comfort depends on the subject's activity. However, the homogeneity of the indoor thermal environment makes compromise necessary between the needs of patients and those of the medical team.
- In particular, nurses wear thick uniforms. It would be interesting to consider lighter uniforms for the summer period.
- Finally, fans are an effective solution for summer thermal comfort. Although they are not allowed in patient bedrooms for hygienic reasons, their inclusion in areas dedicated to the medical team is a useful solution.

The method was developed specifically for this project, with two ongoing concerns: to provide specific answers for the demonstrator's building, and to present examples with limitations for extrapolation to other situations.

The method contains limitations for its application and the objective of this discussion is to introduce them. We will extract the perspectives necessary for its improvement. The discussion covers each step of the method.

The choice of the indicator and its threshold

Upon reviewing the results, which show that the time spent beyond the comfort threshold is significant, it may be tempting to modify the threshold, both in terms of intensity and duration. Indeed, the exceedance may be of low intensity, which could warrant a degree of tolerance. However, it should be noted that the threshold value has already been rounded to the nearest 0.5°C, meaning that some deviation from the initial guideline has already been allowed. Furthermore, for strenuous physical activity such as that carried out by the medical team, a temperature of 26°C is already relatively high. As for the duration of exposure, it was counted per day, regardless of how long the exposure lasted within that day.

To assess both the intensity and duration of exposure without identifying continuous periods, the distribution of temperatures above 26.5°C was plotted. Only the initial configuration and the combination of optimal ventilation with vegetated façades were studied (Figure 23 and Figure 24). At total of 29 376 hours were simulated over the course of 8 summers.

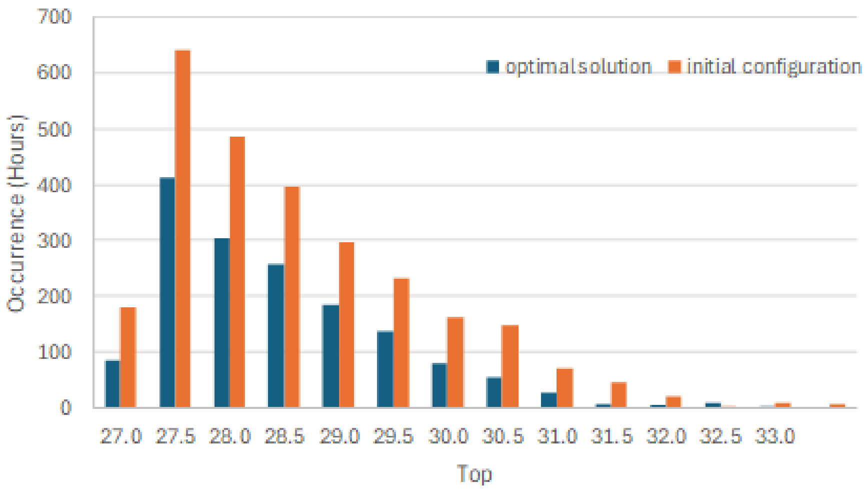

Figure 23: Indoor operative temperature above 26.5°C in the hottest bedroom

For the hottest bedroom, the figures are given in Table 9 and Table 10.

Table 9. Temperatures ranges

Temperature range (°C)		Hottest bedroom (initial configuration)	
Low value	High value	Occurrence (h)	Percentage of time over the 8 summers
26.5	27	179	0.6
27	27.5	642	2.2
27.5	28	485	1.7
28	28.5	398	1.4
28.5	29	296	1
29	29.5	233	0.8
29.5	30	162	0.6
30	30.5	148	0.5
30.5	31	70	0.2
31	31.5	44	0.2
31.5	32	20	0.1
32	32.5	2	0
32.5	33	7	0
33	33.5	6	0

Total number of hours above 26.5°C: 2692 h (9% of the total simulated hours).

Table 10. Temperature ranges

Temperature range (°C)		Hottest bedroom (optimal solution)	
Low value	High value	Occurrence (h)	Percentage of time over the 8 summers
26.5	27	84	0.3
27	27.5	412	1.4
27.5	28	304	1
28	28.5	257	0.9
28.5	29	185	0.6
29	29.5	137	0.5
29.5	30	79	0.3
30	30.5	53	0.2
30.5	31	27	0.1
31	31.5	6	0
31.5	32	4	0
32	32.5	7	0
32.5	33	2	0

Total number of hours above 26.5°C: 1557 h (5% of the total simulated hours).

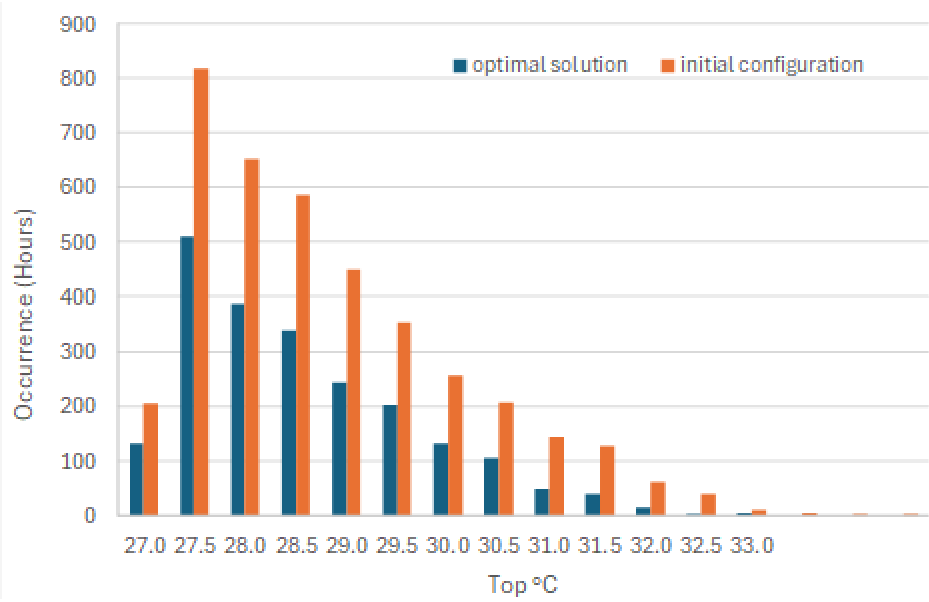

Figure 24: Indoor operative temperature above 26.5°C in the computer room

For the computer room, the figures are given in Table 11 and Table 12.

Table 11. Temperature ranges

Temperature range (°C)		Computer room (initial configuration)	
Low value	High value	Occurrence (h)	Percentage of time over the 8 summers
26.5	27	206	0.7
27	27.5	819	2.8
27.5	28	651	2.2
28	28.5	585	2
28.5	29	448	1.5
29	29.5	355	1.2
29.5	30	256	0.9
30	30.5	207	0.7
30.5	31	144	0.5
31	31.5	127	0.4
31.5	32	60	0.2
32	32.5	38	0.1
32.5	33	9	0
33	33.5	5	0
33.5	34	3	0
34	34.5	2	0

Total number of hours above 26.5°C: 3915 h (13% of the total simulated hours).

Table 12. Temperature ranges

Temperature range (°C)		Computer room (optimal solution)	
Low value	High value	Occurrence (h)	Percentage of time over the 8 summers
26.5	27	132	0.5
27	27.5	511	1.7
27.5	28	388	1.3
28	28.5	339	1.2
28.5	29	245	0.8
29	29.5	202	0.7
29.5	30	131	0.5
30	30.5	105	04
30.5	31	48	0.2
31	31.5	40	0.1
31.5	32	15	0.1
32	32.5	3	0
32.5	33	4	0

Total number of hours above 26.5°C: 2163 h (7% of the total simulated hours).

The calculation was carried out over the eight summers (2013, 2015, 2019, 2020, 2021, 2022, 2023, 2024) used to establish and test the regression model. These were particularly hot summers. When exposure duration is calculated in hours, the resulting percentages are lower (Figure 11). For the initial configuration, the exposure duration (hours) amounts to 9% and 13% for the hottest bedroom and the computer room, respectively. The optimized solution leads to threshold exceedance for 5% and 7% of the time, respectively, for the hottest bedroom and the computer room.

The absolute values in terms of time show that the optimal combination reduces the exposure duration by more than 40% (the % is calculated regarding the number of time above 26°C at the initial configuration). The maximum intensity decreases by at least 1°C.
These durations are much lower than those calculated on a daily basis (percentage of unacceptable summer days). In our case, this highlights that we have chosen a high level of stringency.

However, caution is needed when expressing results in relative terms: the percentage strongly depends on the reference period used for the calculation. If the period from 1st May to 30th September were reduced to the core summer months, the percentage of exposure time would likely have been higher.

Therefore, sensitivity to indicators and their thresholds is a recurring issue that often needs to be reconsidered in light of the results. This line of questioning should also be extended to the actions to be taken once the thresholds are exceeded, in order to maintain activity and protect occupants.

Building Description and Occupancy

The technical description requires meticulous work, but the extensive available documentation and the project managers' thorough knowledge of the building enabled a detailed modelling. Describing the building's operation is time-consuming and, in the case studied, crucial, as the high occupancy density and continuous activity have a strong impact on the indoor thermal conditions. On-site visits and discussions with the medical team helped to reduce uncertainties.

An optimal ventilation scenario was selected to frame the passive technical solutions and to maximize their benefits within the overall approach of understanding operational limits. This scenario may be incompatible with the service's actual functioning; if so, the outcome will lie somewhere between the initial situation and the optimal combination. Typically, if plants are disregarded, the benefit of ventilation corresponds to an exposure duration between 20% and 22%, which demonstrates the relevance of the protective measures adopted by the medical team.

Modelling Tools

The modelling tools used are TRNSYS and CONTAM. The use of a thermal model coupled with an airflow model based on a multi-zone pressure balance is essential in the configurations studied. Indeed, air circulation is what homogenizes the temperature throughout the facility. Ventilation through window openings acts as a mechanical system, where the driving forces are the temperature difference and wind speed. However, the temperature difference between the interior and exterior—which itself depends on airflow exchanges between inside and outside—justifies the use of a dynamic coupling between the thermal balance and the airflow balance. These pressure-based models require numerous input data that are rarely available, such as façade pressure coefficients, making it difficult to obtain precise airflow rate estimates. Nevertheless, the coupling of thermal and airflow models ensures coherent values between indoor temperature and ventilation rates. Regarding the thermal model, the TRNSYS software has undergone extensive validation against measurements as well as inter-software comparisons according to the ANSI/ASHRAE standard 140-2001 [(25)].However, the modelling of the vegetated façade was carried out in a partial and simplified manner due to limited resources and the complexity of:

- Accounting for thermal and airflow effects on porous façades that limit radiative transfers, restrict air flow, and cause cooling through phase change,
- Parameterizing variables such as leaf size and the plants' evaporative potential, for which databases are scarce and non-standardized.

For pragmatic reasons and in continuation of the work on defining boundary conditions, we opted for a modelling approach that highlights the maximum achievable benefit from these products. This information is crucial and should be kept in mind when interpreting the results. For a well-balanced understanding of the cooling potential of these products, it is preferable to consider simultaneously the two exposure time percentages: The exposure time percentage without vegetation, The exposure time percentage with vegetation.

Thus, the actual building performance lies within a range; in the case of the optimal configuration, the exposure time under current climate would be between 17% and 20%, providing a reasonably narrow order of magnitude.

Operational Limits

The regression that establishes the boundary between climatic sequences leading to degraded indoor conditions (beyond the defined threshold) and those ensuring thermal comfort depends on the building model and the boundary conditions, including both climate and usage.

As a result, its extrapolation is not straightforward. Despite the care taken, including a validation procedure with test sequences, further verification and consolidation work would be necessary.

Regarding the regression line, it may seem surprising that the initial configuration appears to withstand higher temperature deviations on the sixth day—the final day of the load sequence—than those observed under the optimal solution. As illustrated in the figure below (Figure 25), we observe that comfort is maintained on any day with a daily mean temperature equal to or below 24 °C, provided that the average temperature over days N–1 to N–5 is equal to or below 16 °C. However, for the same five-day average, the sixth day's mean temperature must not exceed 22 °C in the case of the optimal combination (Figure 25).

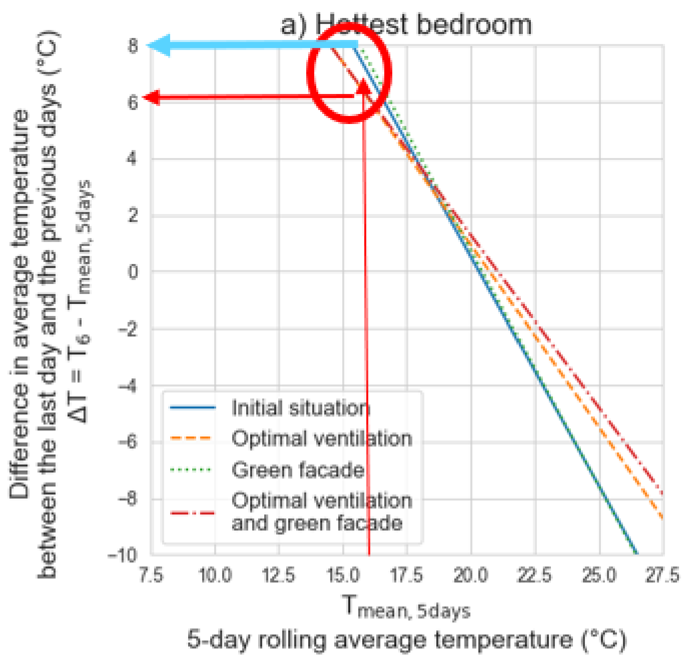

Figure 25. Visualization of results to be discussed in the hottest bedroom

Several reasons may explain this. First, it might be interesting to use a non-linear relationship. Furthermore, the number of data points available to compute the regression in this zone is insufficient, and the regression is heavily influenced by temperature areas with a high concentration of points. It would therefore be advisable to use piecewise regression—at the very least, to distinguish between zones where:

- $\Delta T < 0$
- $\Delta T > 0$

A phenomenological explanation still needs to be developed. However, as a first hypothesis, it is possible that the thermal behaviour of the room during the end of a hot sequence —thus during the heat discharge phase ($\Delta T < 0$) differs from its behaviour during the heat build-up phase ($\Delta T > 0$).

The number of thermal data points used to establish the regression within each zone should be quantified in order to assess the level of confidence in the regression results. For example, the zone beyond $\Delta T > +5$°C contains few points, as does the zone below $\Delta T < -5$°C and $T_{mean,5days} > 22$ °C. The number of points is even lower when $T_{mean,5days} > 25$ °C. Yet, in the following figure (Figure 26)—onto which future climates have been projected— the number of sequences with $T_{mean,5days} > 25$ °C is significant, with five-day average temperatures potentially exceeding 30 °C.

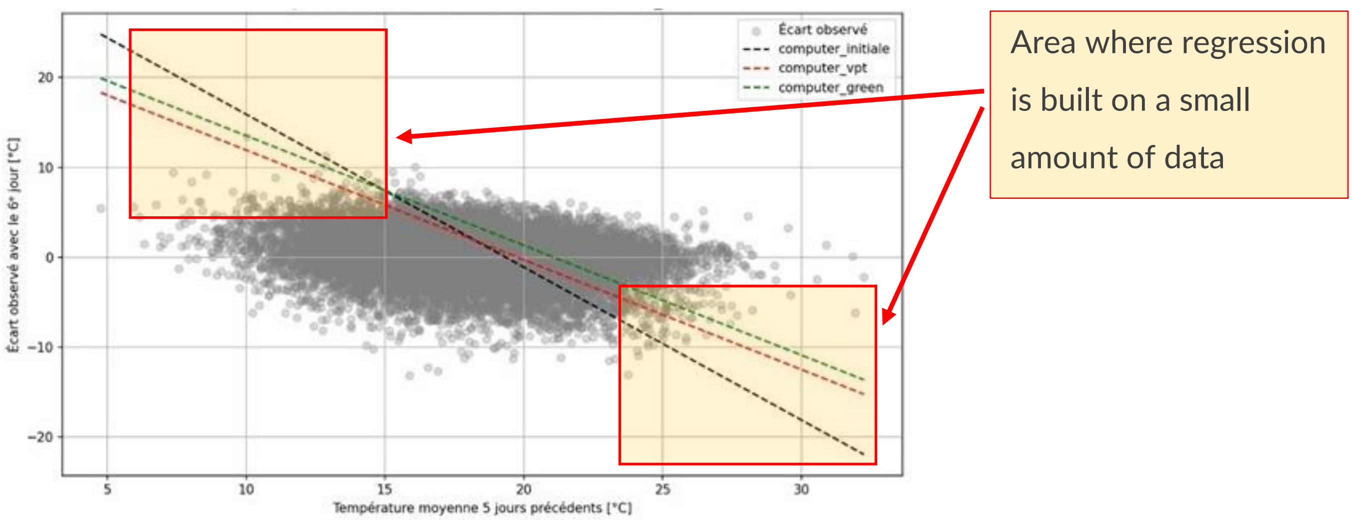

Figure 26. Area where regression is built on a small amount of data.

One way to consolidate the regression would be to construct it using warmer climate data, while ensuring the retention of key Alpine climate characteristics such as solar radiation, wind, and humidity. This improvement should be seriously considered for future work, particularly in the context of the MOUNTADAPT project, whose objective is to deploy technical solutions across other territories.

Notwithstanding the need for further progress in consolidating the regression models, it remains essential to preserve the overall approach and the development of an evaluation framework that defines both the limits and the potential of a technical solution —or of a combination of technical solutions. Rather than qualifying or disqualifying a given design, understanding its limits encourages the project owner and design team to anticipate and plan appropriate actions when those limits are exceeded.

Conclusions

The methodology proposed in this work enables the identification of the climatic periods that would cause a building to malfunction. It is based on a close working relationship with the stakeholder, starting with a joint choice of the required indoor conditions for the building. The appendices show rich exchanges that took place. The building's behaviour is then simulated over several summers using a thermo-aeraulic model. If available, measurements can be used to represent the actual behaviour of the building, but the models can also be adapted to simulate potential solutions.

Based on the results of the simulations, logistic regression is performed to calculate the decision boundary, allowing the critical climatic sequences to be identified (Table 9). The climatic sequences are characterised by the average temperature of N-1 days and the difference in average between the next day and the previous N-1 days. This approach is adapted to the evolution of a building's behaviour during heatwaves, which are the succession of several particularly hot days.

Once the decision boundary has been defined, it is only necessary to process meteorological data to calculate the number of days beyond the boundary without having to simulate the indoor environment again (Table 13). This probability of occurrence means that the modelled solution can be transposed to other climates (future climates or other geographical zones).

Results show that optimal window opening (when outdoor temperature is appropriate) can reduce overheating. Even if it is suitable from a thermal point of view, other factors can reduce the possibility of opening (visual and acoustic comfort, security, etc). In addition, this solution is not sufficient to meet the needs of the demonstration hospital, because 20 to 28% (depending on the room) of historical summer days are still unacceptable. The shading potential of the plant facade is lower (21 and 30%), but this is a potential maximum. Combining the two solutions further reduces overheating (17 and 27%). Moreover, in the future, the percentage of unacceptable days increases, reaching 70% in the initial situation in the computer room for the distant future.

Table 13. Main results

Situation	Room	Boundary equation	% of unacceptable summer days			
			Historical (1999-2024)	Future (RCP 8.5)		
				2025-2050	2050-2075	2076-2100
Initial	Hottest bedroom	y = -1.62x + 32.95	22	29	43	61
Optimal ventilation		y = -1.29x + 26.77	20	27	40	57
Green wall		y = -1.67x + 34.18	21	28	42	60
Both solutions		y = -1.22x + 25.71	17	25	37	54
Initial	Computer room	y = -1.70x + 32.89	32	39	53	70
Optimal ventilation		y = -1.22x + 24.11	28	36	49	65
Green wall		y = -1.67x + 32.54	30	37	52	69
Both solutions		y = -1.22x + 24.29	27	34	48	64

Given the high occupancy density and activity levels, internal heat gains are significant compared to the capacity of the building walls to store energy. To reduce exposure to heat, it would be necessary to act on this internal load, either by:

- *Reducing them*, for instance by limiting visits or scheduling activities according to climatic sequences. Indeed, the regression models allow forecasting up to six days in advance whether indoor thermal comfort conditions will be met or not.
- *Storing internal heat gains*, for example by using phase change materials (which liquefy around comfort temperatures) placed in the suspended ceiling. The metallic ceiling has good thermal conductivity, which promotes the transfer of heat from the indoor environment to containers filled with these phase change materials.

These options could not be explored within the scope of our study. But it would be interesting to study their potential in an in-depth study and depending on the results consider tests with a view to a technical solution.

On the methodological side, the limitations of the regression approach have been qualitatively identified, and the paths for strengthening it have been clearly laid out:

- *Balancing the dataset* with warmer climates, for example by incorporating data from other regions more representative of future climate change conditions.
- *Constructing piecewise regressions* to avoid data-dense climate sequences skewing the results in underrepresented climate sequences. Climate sequences

are characterised, here, by the average temperature of N-1 days and the difference in average between the next day and the previous N-1 days.

It follows that any extrapolation to other sites requires a thorough comparison exercise to identify similarities and differences, which would either support or constrain the transferability of the findings. From our experience, we believe that the methodology itself represents the most valuable asset when studying other sites. Locally, however, the insights into the benefits of ventilation and the maximum protective potential of vegetative solutions for the building are convincing.

The construction of operational limits was made possible by simplifying the problem of thermal behaviour as a function of external (climate) and internal (use) signals into a binary outcome. Defining these limits enhances the reliability of the proposed solutions, as they pave the way for the development of targeted actions to be taken once these limits are exceeded.

In conclusion, both the method and performance are highly dependent on the indicators used. It is crucial to develop these indicators after clearly identifying the intended information and the end user. To go further, the threshold associated with the indicator should be defined with regard to the intended action when it is exceeded, and its likelihood. This approach would make it possible to establish a continuum between risk analysis, its management, and ideally, its prevention.

Acknowledgements

We would like to warmly thank the teams at the Innsbruck clinic for welcoming us and for the enriching discussions, including Carina Figl, Belinda Steiner and Miriam Mark, the nurses from the ward we studied, who explained exactly how the department worked.

Disaster Preparedness Checklist and Guidance (PR5.1)

Introduction

The European continent is characterised by a wide variety of habitats and ecosystems [(26)]. The Habitats Directive (92/43/EEC) promotes biodiversity protection by identifying areas based on biogeographical boundaries. As a result, nine biogeographical regions have been distinguished in Europe: Alpine, Atlantic, Black Sea, Boreal, Continental, Macaronesian, Mediterranean, Pannonian, and Steppic [(27)]. These areas are classified according to their distinct ecological, climatic, and geographical characteristics.

Alpine biogeographical regions in Europe encompass some of the oldest and youngest mountains in the world, including the Alps, the Scandinavian Mountains, the Pyrenees, the Carpathians, the Rhodopes, the Urals, the Caucasus, and the Dinaric Alps [(28)] . These areas are characterised by low population density, significant disparities between urban and rural zones, and a higher proportion of elderly individuals compared to younger ones. Climate conditions vary considerably with altitude, with lowlands experiencing a temperate climate and higher-altitude regions experiencing colder conditions, including substantial snowfall in winter [(29)].

European Alpine regions are vulnerable to anthropogenic influences. Specifically, these areas suffer from the detrimental impacts of tourism, transportation, and atmospheric pollution. Changes in land-use practices, abandonment of small-scale agriculture, and habitat fragmentation exacerbate these impacts [(28)]. Projections indicate substantial physical alterations by the end of the century, with significant mass loss anticipated for large glaciers and subsequent impacts extending to lower hills and floodplain environments [(30)].

Climate change-induced EWEs pose a significant threat to European Alpine regions, with a rising occurrence of floods and storms, heatwaves, cold spells, and wildfires. In the past 40 years, the European Alps have experienced a 26% rise in disasters, increasing from over 60 incidents in 1981-1990 to over 85 events in 2011-2020. Hydro-meteorological disasters are prevalent, with floods accounting for 44.7% of the events [(31)]. The growing risks of these events are underscored in the Intergovernmental

Panel for Climate Change (IPCC)'s 6th Assessment Report (2022), which highlights the increasing impact of floods and landslides on both mountain communities and downstream populations [32].

A recent disaster in the Alps happened in May 2025, when a huge glacier collapse destroyed most of the Swiss village of Blatten in Valais. The ice and rocks came down after warm weather melted the ground holding them in place. Luckily, people were evacuated in time, so no major injuries were reported [33]. Another significant event occurred in Aymavilles, Italy, in July 2023, when a wildfire became the largest in Valle d'Aosta since 2005, burning over 200 hectares of forest, threatening homes and forcing evacuations [34].

The challenges posed by EWEs underscore the need for robust adaptation measures with a whole-of-system approach and cross-sectoral collaborations between authorities, civil protection agencies, and the health system. There is growing recognition that effective responses to EWEs require strong disaster management capacity. Despite these recognised needs, significant gaps persist in adaptation efforts in the health sector, with only 68% of countries having strong disaster management capacities and fewer than 35% having health-specific early warning systems for climate-related threats; furthermore, insufficient climate-health education hinders the resilience of health systems [6].

Health systems need to proactively enhance their preparedness by strengthening surge capacity, enhancing intersectoral collaboration, ensuring adaptable service delivery, and maintaining secure infrastructure during crises, as highlighted by the Health Emergency and Disaster Risk Management (H-EDRM) framework [35]. This demands the health systems to be ready to respond promptly by having, among others, adequate plans and protocols, and pre-established agreements to coordinate actions such as evacuations or the procurement of additional supplies.

Despite the existence of local protocols and agreements for health emergency management, there is a notable lack of practical, user-friendly tools for conducting rapid assessments of disaster preparedness, and for outlining evidence-based guidance for disaster preparedness in case of EWEs. These tools are beneficial to health systems for periodically monitoring the state of preparedness and identifying areas that require investment in anticipation of future EWEs, as well as for setting user-friendly guidelines that can enhance disaster management, especially in vulnerable regions such as mountain areas.

Purpose of the checklist

The present Checklist has been developed to provide an operational and accessible tool for health sector professionals and authorities of demonstration sites within the MOUNTADAPT project. Its purpose is to **facilitate the self-assessment of the health system's preparedness status and provide guidance to decision-makers aiming to enhance disaster management** in the context of EWEs. The tool is not designed to positively or negatively assess the system's readiness at the time of completion, but rather to identify weaknesses and areas needing improvement. Additionally, it offers guidance on actions to enhance the preparedness of various health system components considering the increasing frequency of climate change-induced EWEs. This Checklist is not intended to replace periodic review and monitoring processes that each health system routinely undergoes but rather serves as a consolidated instrument that compiles information on health system preparedness and disaster management practices, which might be difficult to obtain otherwise.

Target audience

The target audience for this Checklist includes health sector professionals, authorities, policymakers, health managers (such as hospital directors), and others interested in evaluating health system preparedness for EWEs in mountain areas. Designed as a comprehensive tool, the Checklist provides an overarching framework to assess preparedness across the health system to respond to floods, landslides, heatwaves, cold spells, and wildfires.

How to use the checklist

Health sector professionals or designated health system representatives are expected to be able to complete most items on the Checklist. However, for certain specific items, they may consult key informants pertaining to relevant health system components (e.g., pre-hospital system, pharmacies). Each demonstration site’s health system can complete a single Checklist, ensuring all answers are compiled collaboratively. Although we have designed this Checklist to address diverse site-specific needs, users may need to adapt some items to fit their unique context. All questions are in yes/partially/no format, and most of the items include action points, namely suggestions to proactively address shortcomings. Each user of the Checklist can generate a report of the results in the format most appropriate for their target audience, to summarise the state of preparedness or highlight areas requiring improvement. This can be based on an initial report that UPO will develop following the first completion of the Checklist by the demonstration sites. Although the tool does not currently allow for automatic report generation, the aim of providing an initial draft to the demo sites is precisely to serve as a template and guide for producing internal reports in the future. Planned improvements to the Checklist are intended to support the systematisation of this reporting process. Moreover, the tool can also be consulted purely as guidance without requiring data input. In particular, the action points can be considered standalone evidence-based guidelines that support the implementation of adaptation solutions and resource allocation.

Methodology and co-creation with demonstration sites

The methodology used for developing the Checklist comprises three main methodological approaches: 1) leveraging existing resources; 2) expert validation; and 3) co-creation activities with MOUNTADAPT demonstration sites for context validation.

Leveraging existing resources

This initial phase involved the collection of existing checklists aimed at evaluating health system disaster preparedness, including **a primary care preparedness checklist previously developed by the University of Eastern Piedmont (Università del Piemonte Orientale – UPO) and piloted in Piedmont, Italy** [(36)]. The collection process involved searching various scientific databases, and websites of healthcare organizations and national or international agencies. After confirming the checklists collection's comprehensiveness—with a total of 28 checklists reviewed—the research team systematically grouped the items of all the retrieved checklists into the following thematic areas, based on the H-EDRM framework [(35)] and refined inductively from emerging themes: (1) Disaster planning and coordination; (2) Staff training and human resources; (3) Infrastructure and resources management; (4) Communication and early warning; (5) Partnerships and community integration; (6) Patient care and service continuity; (7) Recovery and monitoring and evaluation.

Expert validation

A group of researchers and professionals with expertise in various aspects of disaster management, including EWEs in mountain areas, was identified within the leading institution's network (Table 14). These experts were contacted and agreed to participate in the validation process by allocating time for a critical, independent review of the tool and providing feedback and comments to enhance it. The feedback and suggestions received from this group of experts were subsequently implemented, leading to the development of a second version of the Checklist.

Table 14. Profile of experts involved in the expert validation process of the Checklist

ID	Area of expertise
Expert 1	Primary care disaster preparedness
Expert 2	Disaster medicine in mountain areas
Expert 3	Hospital disaster preparedness
Expert 4	Disaster medicine in mountain areas
Expert 5	Rescue operations and evacuations in mountain areas

Co-creation activities for context validation

Two primary co-creation activities were employed to ensure context validation throughout the Checklist development process: (1) a questionnaire was developed and disseminated to the demonstration sites in November 2024 via the Google Forms platform, to gather information on country-specific health emergency management practices, and (2) a structured feedback process was carried out, including a dedicated workshop and a feedback round conducted via email with health system representatives of demonstration sites.

Disaster management survey to demonstration sites

To encourage that the Checklist was tailored to the specific conditions of the demonstration sites, a short questionnaire was developed and disseminated in November 2024 among health systems representatives. The aim was to gather information on their disaster management practices, which was used to refine and tailor the final Checklist to address the specific needs of the health systems of demonstration sites. Below, the most significant findings are summarised (Figure 27).

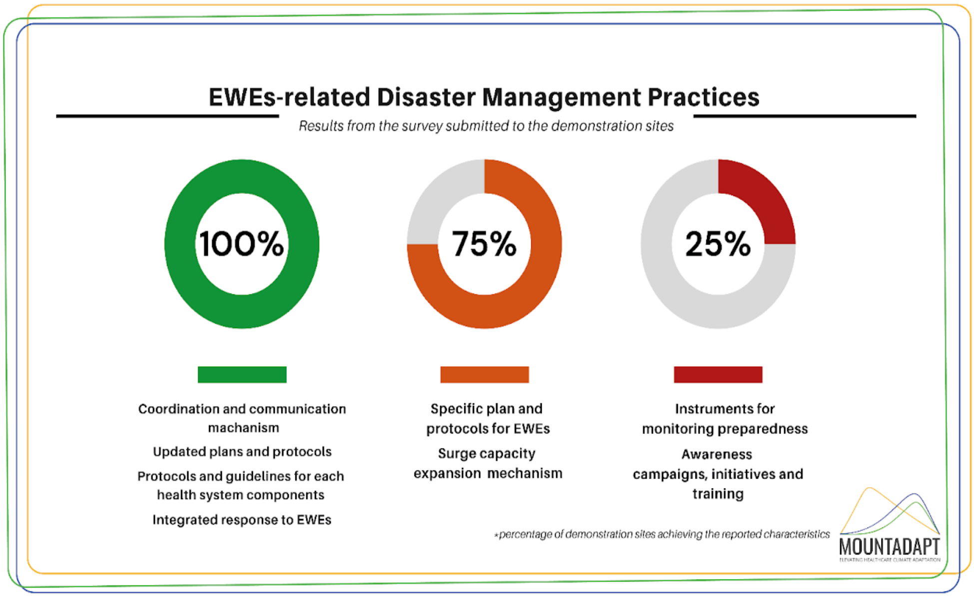

Figure 27. Overview of EWEs-Related Disaster Management Practices in Demonstration Sites

In all four demonstration sites, the health system response strategy is integrated into the national disaster management framework and coordination mechanisms are in place to address the response in case of need. For instance, in Alba Iulia, the Emergency Unit, the Public Health Directorate, and the Ambulance Service are represented in the County Committee for Emergency Situations (CJSU) and have established agreements to coordinate their efforts during emergencies. Furthermore, all four sites reported well-established communication channels between sectors—such as the health system, logistics, and Civil Protection—which can be activated in response to EWEs.

The survey results revealed that 75% of the demonstration sites have health systems equipped with specific plans, protocols, or guidelines for responding to EWEs. In all cases, these plans are tailored to the various components of the health system, including pre-hospital care, hospitals, primary care, pharmacies, and public health services. Nevertheless, while there is a general awareness of the need to prepare for emerging scenarios driven by climate change and to continuously update these plans, not all of them include detailed provisions specific to EWEs.

Notably, despite all sites reporting that the monitoring process is nationally advised and mandated, only 25% have the necessary instruments to periodically assess the health system's preparedness for responding to EWEs.

In the event of an emergency requiring the mobilization of surge capacity in response to EWEs, three out of the four demonstration sites are equipped with a variety of mechanisms. These mechanisms include reserves of anti-epidemic products, plans for resource redistribution, hospital bed capacity expansion, designated duty officers, and automated software integrated into the telephone network to facilitate reporting by on-duty employees.

As for monitoring systems, the results revealed the absence of awareness campaigns, initiatives, and training programs aimed at enhancing the preparedness and resilience of the health system in the context of EWEs. Only one demonstration site reported having such initiatives or programs, particularly those focused on addressing the challenges posed by EWEs. Nevertheless, the demonstration sites recognise the need to develop punctual plans and organisational systems specifically adapted to EWEs resulting from climate change.

One demonstration site highlighted the need to develop targeted strategies for addressing specific events, such as “heat domes”, to provide sheltering options for vulnerable individuals during heatwaves. Another, while pointing out how bureaucratic mechanisms contribute to hindering the creation of strategies and plans for H-EDRM, suggested implementing contractual agreements with Health Insurance Houses, which do not include provisions for response services to EWEs.

Online workshop and exchange with demonstration sites for context validation

A second co-creation activity involved a structured feedback process with health system representatives of demonstration sites. The second version of the checklist, enriched by the survey results and validated by experts, was presented in an online workshop with demonstration sites in February 2025. This initiative allowed participants to engage in discussions, share insights and provide recommendations for improvement. Following the workshop, the Checklist was sent to representatives of health systems in the demonstration sites for additional feedback and context validation, ensuring further refinement based on their specific needs. After receiving feedback, final adjustments were made, leading to the development of the final version of the Checklist, which can be found in the Appendix A. This iterative process ensured that the final Checklist was co-developed by solution providers and demonstration sites.

Results

The Checklist is provided as Appendix A.

Use and Dissemination

The Checklist that UPO CRIMEDIM has developed is based on a tool previously created by UPO, which has been adapted and enhanced for MOUNTADAPT. It is designed to be a practical and user-friendly tool for representatives of health systems in demonstration sites, replication sites, and potentially other locations in the future. This tool can be utilised in two complementary, non-mutually exclusive ways. Firstly, it may be periodically completed to monitor the state of preparedness and identify areas requiring adjustment and/or resource allocation. Secondly, it can be consulted as a guide, offering insights into the necessary actions for preparedness and response to EWEs, with the objective of enhancing emergency management.

This instrument is intended to support health authorities as well as decision-makers and healthcare managers, including those operating within specific sectors who may wish to consult only the relevant sections of the Checklist. While the action points outlined in the Checklist are not intended to be an exhaustive list of all possible actions that can be taken, adhering to these recommendations may facilitate an effective response.

The Checklist, developed within the MOUNTADAPT project, will be disseminated among the demonstration sites, where health system representatives will be encouraged to complete it and integrate it into their preparedness strategies. The same will happen for replication sites at a later phase of the MOUNTADAPT project, ensuring scalability and wider implementation beyond the initial test locations. The Checklist will also be presented in the context of the Disaster Preparedness Training Package (Solution 10 in MOUNTADAPT).

The aim is to extend its implementation to other mountainous regions and, potentially, non-mountainous areas. To ensure broad adoption and impact, UPO will leverage the established MOUNTADAPT dissemination strategy by promoting the Checklist through scientific publications, congresses and conferences. The tool may also be further scaled, tailored, and/or upgraded within the framework of other European projects in the future.

To increase accessibility, the Checklist will be also available as an open-access resource on the MOUNTADAPT website and into the Climate-ADAPT platform within the Tools Database to enhance visibility among EU climate adaptation stakeholders. The tool will also be disseminated through UPO's CRIMEDIM (Research and Training Center in Disaster Medicine, Humanitarian Aid, and Global Health) institutional website, social media channel, and partner networks to maximize reach.

LIFE RESYSTAL Health System Guidance

Introduction

Europe is currently the fastest-warming continent on the planet (37), and it is projected that by 2100, up to 1,400 hospitals in Europe will be at high risk of total or partial shutdown due to EWEs (38). According to the Lancet Countdown, 67% of global cities surveyed expect climate change to "seriously compromise their public health assets or infrastructure" (39). The European Environment Agency, in its recent European Climate Risk Assessment, identifies health systems and infrastructure among the five major climate risk clusters for Europe (37).

As climate change and more severe and frequent EWEs continue to challenge health systems, the health sector must also become resilient to the impacts of climate change and support community health against the associated health risks.

According to the definition of the WHO, a climate-resilient health system is one "capable of anticipating, responding to, coping with, recovering from, and adapting to climate-related shocks and stress, to bring about sustained improvements in population health, despite an unstable climate" (40). Additionally, a climate-resilient health system must provide healthcare services without additionally contributing to climate change and exacerbating already severe climate-induced events. The healthcare sector is a major contributor to global carbon emissions (41), and according to the latest estimations, it is responsible for 4.6% of global net emissions (39). Therefore, the climate resilience of the health systems depends also on whether they can decarbonise their operations through mitigation measures and to what extent they will be prepared to face climate change impacts.

Climate change and climate-induced EWEs impact health systems in various ways. The impacts can be divided into two categories: direct and indirect (42, 43).

Examples of direct impacts include:

- A sudden influx of patients during EWEs
- Patients presenting particular kinds of illness and disease (e.g., increased respiratory and circulatory distress during a heatwave)
- Damage to hospital infrastructure (e.g., building and equipment failure) caused directly by the EWE

Examples of indirect impacts include:

- Degradation of other critical infrastructure that the hospital needs to operate, and interruption of supply chains (e.g., transport, energy supply)
- Loss of utilities or reduced supply due to over-demand from other users
- Reduction in staffing availability
- Decrease in the healthcare workforce's well-being

In this context, Health Care Without Harm Europe has developed the Practical Guide for Building Climate-Resilient Health Systems (hereafter the Guide) as part of the LIFE RESYSTAL project. The project's goal is to develop resources that increase the climate resilience capacity of the European healthcare sector and related critical infrastructures. The Guide is divided into two sections. The first defines key concepts related to climate resilience and health systems, explaining how climate change affects health systems, infrastructure, and services.

The second section offers a detailed, step-by-step approach (Figure 28), outlining the essential actions required to strengthen resilience and including practical guidance for implementation.

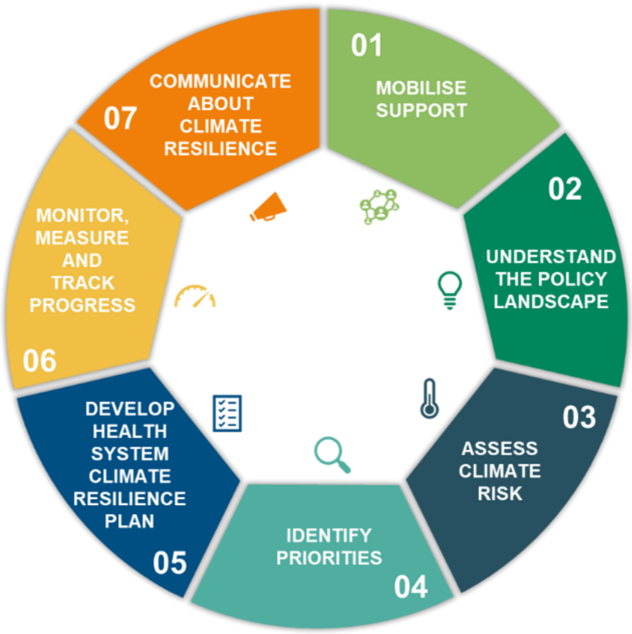

Figure 28. 7-step approach of the Practical Guide for Building Climate-Resilient Health Systems (40)

Purpose of the Practical Guide

The Guide was created with insight from two pilot health systems but has been designed to be applicable to any European health system, irrespective of their structure and governance. The purpose of the Guide is to help organisations integrate climate resilience into healthcare planning and is aimed at those responsible for developing a Climate Resilience Plan for their health system or organisation.

Target audience

The primary audience of the Guide is health system managers. However, the Guide can also serve as a valuable tool for policymakers and stakeholders working closely with the healthcare sector (e.g. local authorities, insurance companies, medical product suppliers), as well as healthcare professionals interested in working on climate resilience within their own organisations.

Methodology and co-creation with demonstration sites

The development of the Guide has five phases: 1) workshops with the LIFE RESYSTAL pilot health systems; 2) desk research; 3) internal review; 4) external review and expert validation; 5) co-creation activities with MOUNTADAPT demonstration sites for context validation.

Workshops with the LIFE RESYSTAL pilot health systems

For the development of the Practical Guide for Building Climate-Resilient Health Systems, two workshops were held with the two LIFE RESYSTAL pilot health systems: the Galician Health Service (SERGAS) and the Agence régionale de santé (ARS) Occitanie. The workshops aimed to understand the health systems' main priorities, challenges, policies, current plans and activities related to climate resilience.

Desk research and leveraging existing resources

The information gathered during the workshops was increased and validated through desk research. The main resources on which the Guide is based are the WHO Operational framework for building climate resilient and low carbon health systems [(40)] and the WHO guidance for climate-resilient and environmentally sustainable health care facilities [(44)].

The Guide presents a practical approach to developing a comprehensive climate resilience plan at the health system level. It outlines essential steps, supported by case studies and best practices, to help health systems navigate the complexities of climate preparedness. While inspired by and based on the WHO Operational Framework for Building Climate-Resilient and Low-Carbon Health Systems [40] and the WHO guidance for climate-resilient and environmentally sustainable healthcare facilities [44], which both discuss the climate resilience of healthcare infrastructure, this Guide offers a distinct approach. The Guide provides a clear, actionable path for health systems, guiding them from the initial stages of building climate resilience to the development of a comprehensive, implementable plan. It places particular emphasis on the broader European context, rather than focusing on a single country as other guides have done[45, 46] and addresses the entire health system rather than focusing on healthcare facilities[44, 45] offering a more holistic and system-wide perspective.

Internal review

The following people from Health Care Without Harm were involved in the review of the Practical Guide (Table 15).

Table 15. HCWH people involved in reviewing the guide

Name	Position	Organisation
Mireia Figueras Alsius	Climate Programme Manager	HCWH Europe
Hope Robinson	Climate Communications Officer	HCWH Europe
Will Clarke	(Former) Executive Director	HCWH Europe
Diana Picon Manyari	International Climate Director	HCWH

External review and experts' validation

The University of Cambridge, a technical partner of the LIFE RESYSTAL project, was the main reviewer of the first and final draft of the Practical Guide. The Guide was also reviewed by the members of the Facilitation Board, a network of experts, part of the LIFE RESYSTAL project (Table 16).

Table 16. Facilitation Board people involved in reviewing the guide

Name	Position	Organisation
Louise Elstow	Research Associate in Infrastructure Climate Adaptation	University of Cambridge
Kristen MacAskill	Associate Professor in Engineering, Environment and Sustainable Development	University of Cambridge
David Brasfield	Chairperson, Norwegian Association for Green Infrastructure	Norwegian Association for Green Infrastructure and World Green Infrastructure Network
Federica Tommasi	Chemical engineer	Italian National Institute of Health - ISS
Aleksandra Kazmierczak	Expert on Climate change and human health and coordinator of the European Climate and Health Observatory	European Environment Agency
Vladimir Kendrovski	Technical Officer (Climate Change and Health)	WHO - Regional Office for Europe
Stefan van Heumen	Senior Project Manager - Mobility & Built Environment	Netherlands Organisation for Applied Scientific Research
Cristina Enjamio	Manager of the Consulting Department	Galician Health Service (SERGAS)/ Galarie

Co-creation activities for context validation

Step 1: Workshop 3: Introduction of the Practical Guide to Demonstration Sites

The Practical Guide for Building Climate-Resilient Health Systems was presented and shared during Workshop 3 in February 2025.

Step 2: Checklist dissemination among demonstration sites

To test the Practical Guide with the demonstration sites, a checklist was shared with the demonstration sites.

The structure of this checklist follows the steps of the Practical Guide. The purpose of the checklist is to evaluate which steps the respondent has taken and the actions and measures that have been implemented regarding climate resilience. This checklist will not assess the level of climate resilience of the system and its capacity to withstand EWEs but will provide an overview of the actions that can contribute to enhancing the climate resilience that the health system has taken or needs to take.

The demonstration sites are required to fill in the checklist and provide feedback on it for future dissemination of the checklist.

Step 3: Checklist responses and results

The responses collected through the checklist will be represented during MOUNTADAPT workshops, showing similarities and differences among the healthcare providers. The checklist will be also adjusted and further developed to better evaluate actions necessary to enhance climate resilience.

Use and Dissemination

The Practical Guide for Building Climate-Resilient Health Systems, developed as part of the LIFE RESYSTAL project, will be disseminated beyond the project through HCWH Europe's events and activities. The resource has already been presented in various events, such as the European Climate Resilient Health Systems Course (organised by ASPHER and Columbia University Mailman School of Public Health) and the IFMSA | International Federation of Medical Students' Associations webinar "Climate Resilience: One Day at a Time!".

The Practical Guide is available as an open-access resource on the HCWH Europe website, LIFE RESYSTAL website, Climate-ADAPT platform, and ATACH community website.

The Practical Guide will be further disseminated and supported in its use by the checklist. The checklist represents a practical tool to assess the respondent's performance for each of the steps of the Practical Guide and to provide an overview of actions taken by the respondent to enhance climate resilience. The implementation of those actions does not ensure that a healthcare organisation is climate resilient. However, implementing the actions can contribute to increasing climate resilience.

The checklist has been developed in the framework of the MOUNTADAPT project and has been disseminated among the demonstration sites' representatives. After the feedback and testing provided by MOUNTADAPT demonstration sites, the checklist will be used as an initial assessment tool in other HCWH Europe projects and activities.

Personalised Recommendations on Physical Activity for Mountain Regions (PR5.2)

INTRODUCTION

Physical activity is a priority for public health prevention. With the development of sedentary jobs, people tend to reduce their physical activities. As a result, individuals with risk factors - such as chronic illnesses, older age, or a sedentary lifestyle - are increasingly encouraged to engage in physical activity, sometimes contradicting government prevention measures that advise limiting exertion during events like heatwaves or pollution alerts. In times of EWEs and poor air quality in cities, the recommendations for physical activity must be adapted based on environmental data.

Personalised Physical Activity Recommendations project aims to provide recommendations on physical activity for vulnerable people according to environmental data, such as air quality and pollution.

Pollution and heatwaves alerts are increasing with climate change. During these periods, the population is often confronted with contradictory messages on physical activity. On one hand, it is recommended to use ecological means for transportation, such as bikes, in terms of health and ecology. On the other hand, during pollution and heatwaves alerts, public health messages advise against physical exertion, in particular for vulnerable people.

The exposure to poor air quality and ultraviolet radiations is estimated to be responsible for various health issues. In addition, the lack of physical activity among vulnerable people accelerates health decline and worsen pre-existing conditions.

The project deals with the study of pollution exposure during physical effort. The objective of the study is to answer the problematic: On which exposure the public is exposed in terms of air pollution? According to the level of pollution exposure, is physical activity recommended?

Therefore, UGA will organize electric bike tours with volunteers in Grenoble. Participants will be equipped with various external sensors to collect health data (heart and respiratory rate). This activity is conducted according to a French clinical research protocol (named “Velis et Pollution”). This protocol is authorized by a local ethics committee in Grenoble: French regulations (“Code de la Santé Publique”) and European regulations (General Data Protection Regulations).

By collecting pollution and health data during physical activity with electric bikes in the mountain area of Grenoble, we plan to evaluate if physical activity could be beneficial even during pollution alert, under certain conditions. Our final goal is to create recommendations for physical activity depending on pollution and population, particularly vulnerable people in mountainous areas.

METHODOLOGY

Target audience

The target audience for the recommendations was: all citizens in mountainous regions.

The project enables to communicate recommendations through the general population of mountain areas. More precisely, the vulnerable people are preferably targeted because of their risks during periods of pollution alerts and heatwaves.

Materials and Methods

The study lasted 3 years and collected data from 100 participants. The sample size was adjusted, if necessary, with approval from the ethics committee. Participants took part in a minimum of two outings and up to six within and around the city of Grenoble in the Auvergne-Rhône-Alpes region of France.

Participants were recruited within the geographical study area through posters and emails. In addition, our team collaborated with GAM (Grenoble Alpes Métropole) to recruit participants deemed “vulnerable.”

For the purpose of the research, a vulnerable adult was defined as someone with a cardiovascular condition, cardiac or respiratory impairment, asthma, or over the age of 65. While the definition from the French Ministry of Health includes children and pregnant women; these populations were excluded from our sampling.

Inclusion criteria

- Adults aged 18 and over, without any contraindications to cycling outdoors or moderate physical activity.

Exclusion criteria

- Contraindication to physical activity
- Protected persons (for example, individuals under guardianship)

All participants signed a non-opposition form prior to their first outing, informing them of the study objectives, methods, and their rights throughout the research process.

Outings

Participants attended two to six outings, during which they rode an electric bike while equipped with a number of sensors. Each outing lasted approximately one hour and was accompanied by a trained instructor. Routes were selected to reflect common cycling routes and conditions (urban cycling paths, riverbanks, mountainous areas) within the city of Grenoble and more generally within mountainous regions. A set of seven fixed routes was proposed. Routes A and B were prioritised as the first rides for all participants.

In addition to the outing itself, participants took part in a 30-minute debrief session where they were given time to reflect on their experience based on the environmental conditions.

Surveys

Participants completed a debrief/feedback form at the end of each outing

The trained instructor completed a debrief/feedback form at the end of each outing, outlining technical difficulties and needs for improvement.

Equipment

1. **VELIS electric bikes** ("Vélo Intelligent pour la Santé"). VELIS bikes are electric bikes that can be tailored ergonomically as well as allow fine-tuning of assistance levels for each cyclist. They are also equipped with tracking equipment including: pedal count and power output. These parameters can be tracked on the eBikeSport app.
2. **Safety equipment:** helmet, reflective vest, water bottle.

3. **Sensors**:
    a. The Etisense shirt: A sports shirt (by Kalenji, Decathlon) equipped with multiple non-invasive sensors to monitor respiratory and cardiac activity. There is a chest strap with two electrodes (by TAOPE, CE marked) to provide an electrocardiogram (ECG) tracing, as well as an inductive respiratory plethysmography to provide abdominal and thoracic breathing tracings. The data collected by the sensors will be transferred to a central receiver on the bike via bluetooth. All data will be pseudonymised and stored securely after each outing.
    b. Heart Rate Monitors (Polar OH1): a heart rate monitor (arm band) that can track participants' heart rate in real time.
    c. Air quality and pollution sensor (Plume Labs): a sensor that monitors real-time air quality, measuring pollutants such as particulate matter (PM1, PM 2.5, PM10), NO2 and VOCs (volatile organic compounds). The data is then transmitted via the Plume Labs app.
    In addition, a sensor (Air Beam3) provided by ATMO (French entity in charge of air quality evaluation) and calibrated by their services, will be used on certain outings to enhance detection of particulate matter (PM 2.5). Data collection is provided through a web service dedicated to citizen pollution data sharing platform.

Data collection

Data collected: heart rate, respiratory rate, abdominal and thoracic breathing tracings, ECG tracing, pedal rate and power output, and environmental data on air quality.

At the end of each outing, the Polar OH1, Plume Labs sensor, Etisense shirt, and VELIS bike devices will be returned to the research team, who will securely extract and transfer the data to a central server within the TIMC laboratory and prepare it for analysis. All data will be handled in compliance with data protection regulations and all data will be pseudonymised.

Statistical analysis

Data will be pseudonymised and analysed using Stata 15.

1. An ANOVA for repeated measures will be performed to assess the relationship between pollutant concentration, level of exertion and respiratory patterns.
2. A simple correlation test will be conducted to assess the relationship between heart rate and respiratory rate.

3. Comparisons of pollution levels during rides will be made against publicly available air quality maps with 95% confidence intervals.

Co-creation: Personalised recommendations on physical activity in the mountains

The personalised recommendations on physical activity for mountain regions were the result of a co-creation process. Once the data from the research program outlined below was collected, we invited a diverse group of stakeholders, including health experts, and local actors on physical activity, pollution and public health, and voluntary citizens, to participate in a co-creation session. This participatory approach allowed for the development of realistic and actionable recommendations for physical activity during periods of peak pollution and heatwaves, especially for vulnerable people.

The co-creation process took place in Grenoble, organised by FLORALIS/UGA, who invited various groups to contribute. Each session was structured by a number of activities, and participants had access to real data collected on cyclists in Grenoble during the VELIS ET POLLUTION study.

Use and dissemination

The recommendations of physical activities will be disseminated beyond the project through local authorities, and health establishments in Grenoble area. They will be shared between all Mountadapt partners from the Demo Site. Public health campaigns will be conducted to communicate recommendations through the general population of mountain areas.

NEXT STEPS

The clinical research project is ongoing. The results below are preliminary.

How will the guidelines be developed in Grenoble?

Once all data is collected a local process of co-creation will support the creation of the final guideline. This guideline will then be delivered to demonstrators and replicators.

Why did we encounter delays?

The study requires data from 100 participants, each completing at least two outings. However, data collection is constrained by the limited availability of essential equipment, particularly the Etisense t-shirts. Expected timeline is showed in Figure 29.

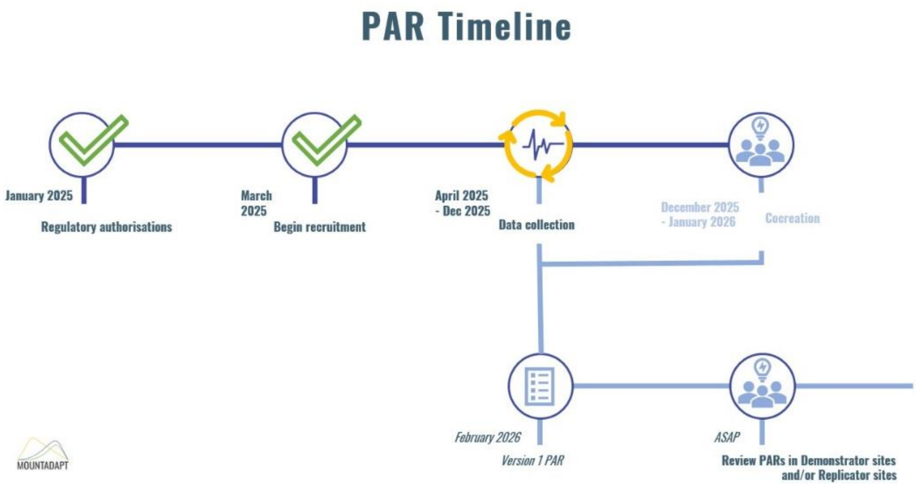

Figure 29. PAR Timeline

PRELIMINARY ANALYSIS

Population description

The number of participants included in the study is 71. The population consists of 50 female participants and 21 male participants, which is about a 2/3 to 1/3 distribution.

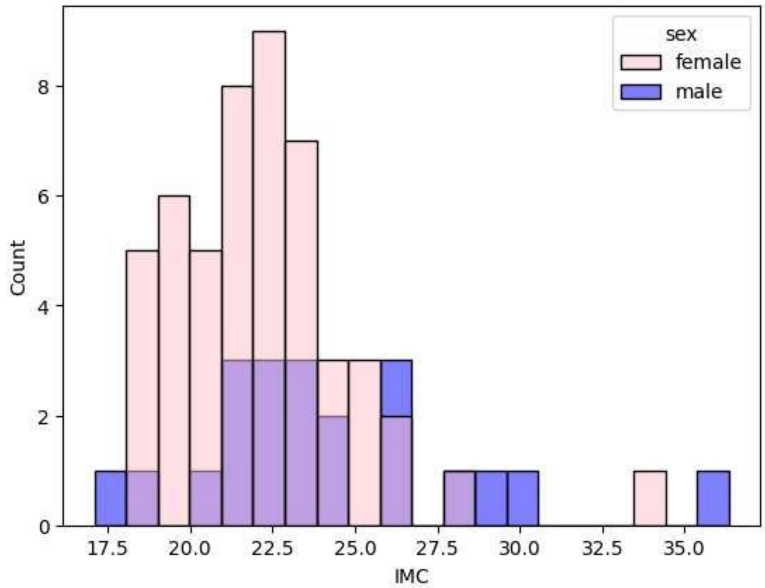

Figure 30: Body Mass Index (BMI) distribution of the population.

The population sampling is skewed towards more physically active participants, especially among women, as suggested by BMI distribution (Figure 30) and reported daily activity habits.

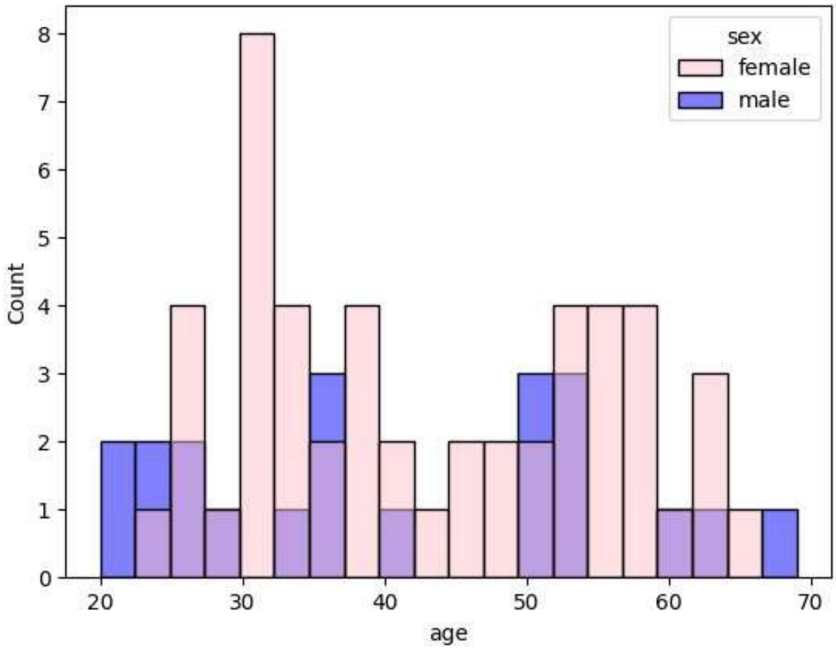

Figure 31. Age distribution of the population

All age categories are well represented, except the individuals int their 40s (Figure 31).

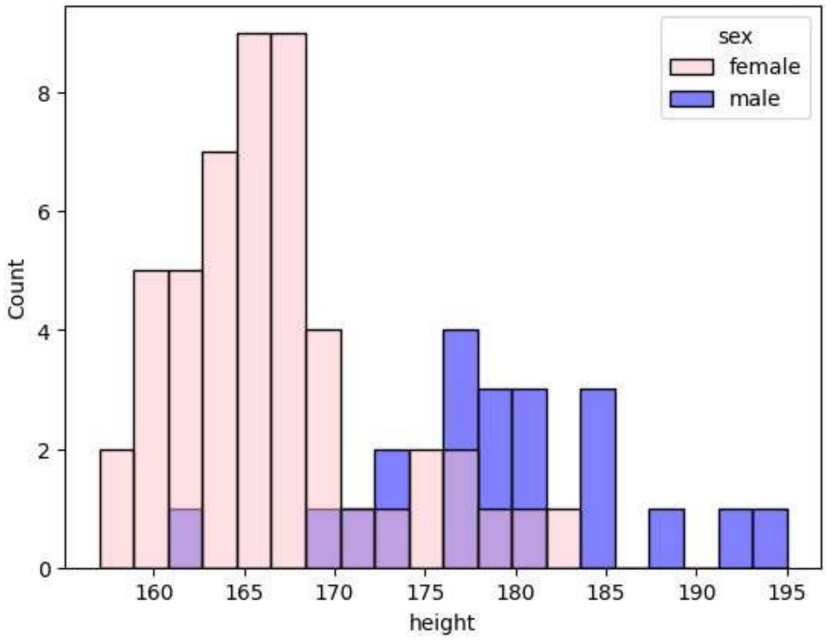

Figure 32. Height distribution of the population

The population height distribution (Figure 32) is the expected distribution both for men and women.

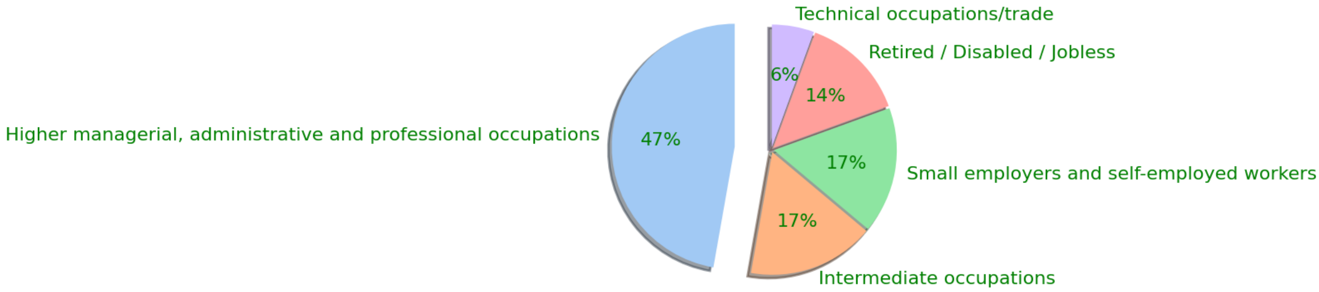

Figure 33: Pie chart showing the distribution of participants across occupational categories.

Among occupational categories (Figure 33), apart from "higher managerial, administrative and professional occupations" category, which accounts for almost half of the participants, the remaining individuals are fairly evenly distributed among the other occupational groups.

Preliminary Analyses

Among the seven routes, five loops are located within Grenoble's Metropolitan urban area, as shown in Figure 34.

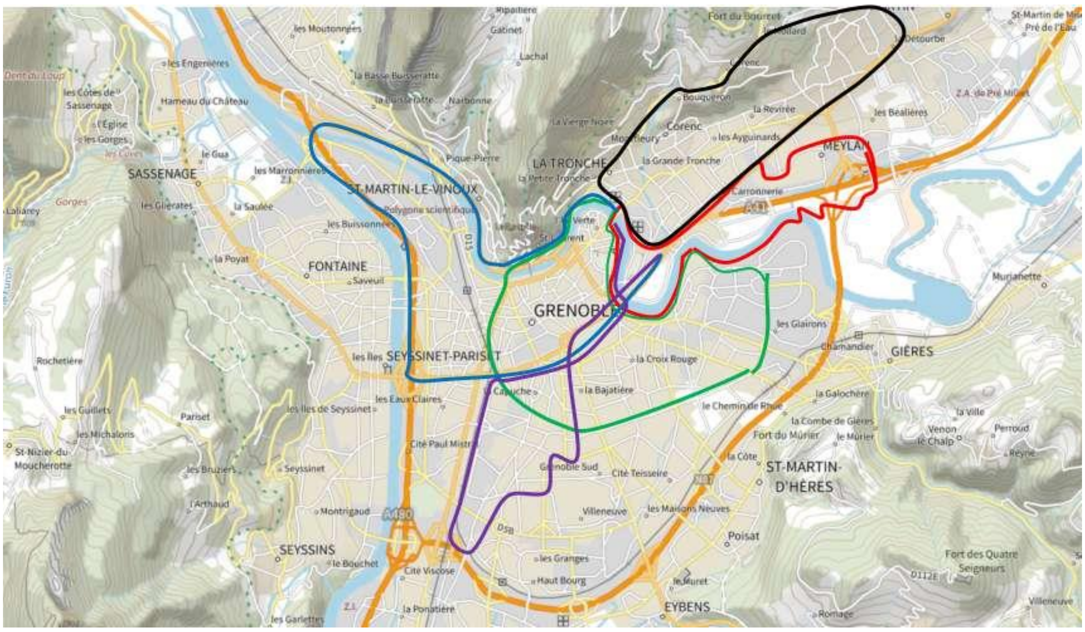

Figure 34: The five loops present in the Grenoble area

Protocol short description

Most of Grenoble's metropolitan area is remarkably flat. This makes Grenoble an attractive biking city. Circuits were split into segments in order for each participant to lead one segment.

On the four main loops (blue, green, purple and red on Figure 34) all of the segments are equivalent in terms of steepness with no hill climbing.

Figure 35 shows an example of how the red loop of Figure 34 is split. During leading time, the leader of the segment set the pace for the group at their own commuting pace. This pace was defined as a comfortable yet efficient pace to get to work without it being too tiring.

Figure 35: Map of one of the 6 loops tested by the participants. Blue: segment lead by the first participant Green: segment lead by the second participant. Red: final segment.

Two participants splitting the circuit

Power measurement is the instant muscular power measurement produced by the participant's legs during cycling.

The example in Figure 36 illustrates one participant’s power measurements throughout their segment and the following leader’s segment.

This data was collected on 12th May on a two-participant outing.

Figure 36: Human power of one participant during the loop. Blue arrow corresponds to the blue segment of Figure 35. Green arrow corresponds to the green segment of Figure 35.

Each segment was about 4km long. We can see that each participant was able to maintain an almost constant power output throughout the entire segment they had to lead, indicating a comfortable pace

Participant A

The two different commuting rhythms corresponding to the two segments are clearly differentiable on physiological signals with a significant increase in heart rate (Figure 38), respiration amplitude, and body activity level (Figure 37). However, respiration frequency does not show a permanent increase during the process.

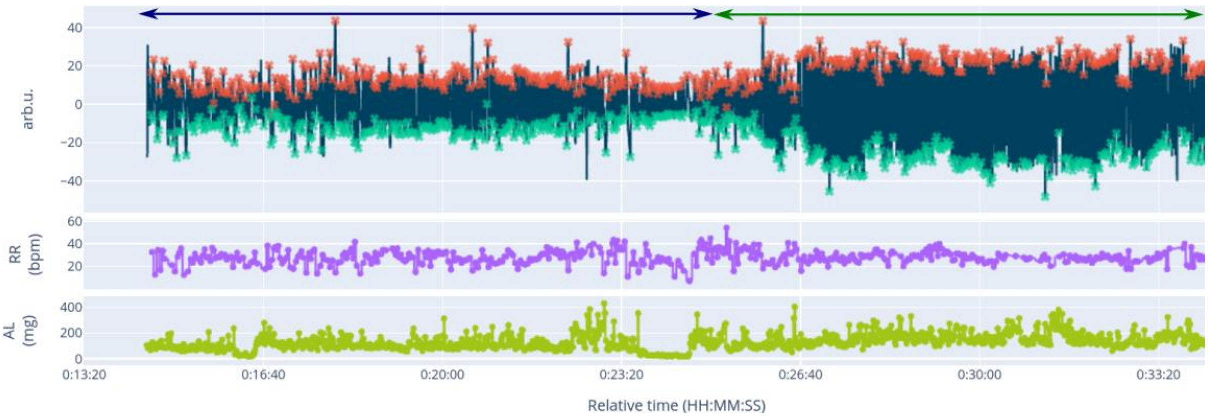

Figure 37: Activity of Participant A. Respiration signal oscillation (blue), frequency of the signal (purple) and Activity level (green). Blue arrow corresponds to the blue segment, and green arrow corresponds to the green segment of Figure 35.

Figure 38: The heart rate evolution of Participant A in bpm.

Participant B

A slight increase in patient's heart rate as well as respiratory rate and activity level (AL) can be observed when the lead changes, but the breathing amplitude (Figure 39 - blue signal) stays almost constant during the whole commuting exercise.

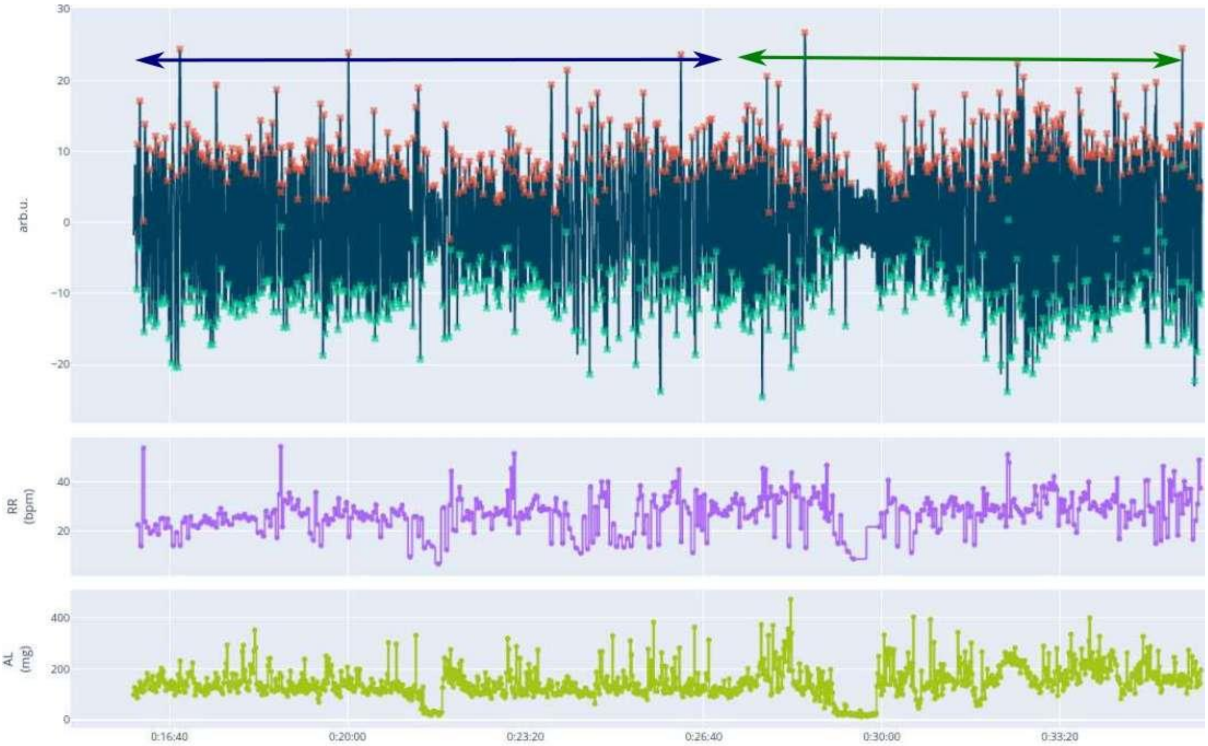

Figure 39: Activity of Participant B. Respiration signal oscillation (blue), frequency of the signal (purple) and activity level (green). Blue arrow corresponds to the blue segment of Figure 35. Green arrow corresponds to the green segment of Figure 35.

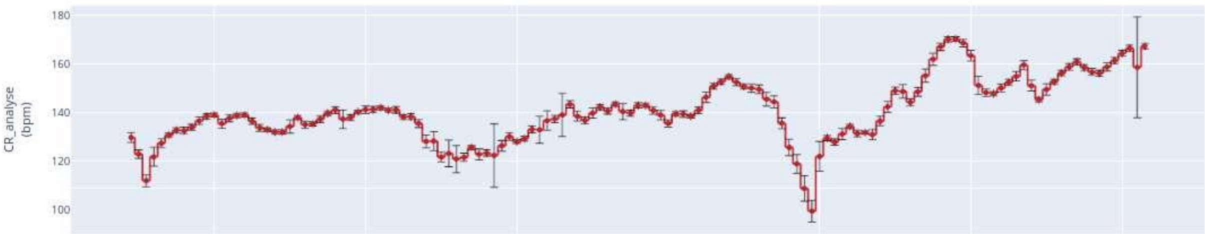

Figure 40: The heart rate evolution of Participant B in bpm.

Patient comparisons

Physiological reaction to change in commuting effort induced a different effect on each participant. A visible large incremental cardio-respiratory change (Figure 37-38) when the commuting velocity is speed up is experienced by the former leader (participant A) whereas the new leader (participant B) does not increase as much its physiological response (Figure 39-40) to the new rhythm he feels comfortable to maintain.

Final segment

A last segment at the end of the outing (red segment on Figure 39) is dedicated to determining for each participant, which level of physical effort is needed to significantly shorten the breath, inducing a higher air (and associated pollutant) volume inspiration.

The human power output enabling the bicycle to move forward is a function of the leg force applied and the pedalling cadency.

In this last segment of the ride, incremental leg pressure on pedals is progressively increased while maintaining at best the muscle contraction cycle time of the leg muscles (pedalling cadency). The goal is to find the point at which sharp rise in air ventilation increase occurs in response to a linear effort increase of the participant.

The instructions for the final segment were as follows: starting at 50 watts of human power, increase the provided power incrementally every minute by 50 watts, until up to 350 watts. Participants were advised that they could stop whenever they wished and were briefed in advance on warning signs that would indicate the need to interrupt the effort. Participants could follow their power on the app provided and placed on their handlebars. Heart rate and respiratory rates from this segment were analysed. Figure 41 shows how switching from a commuting rhythm to an intense activity in order to speed up the commute impacts the breathing response.

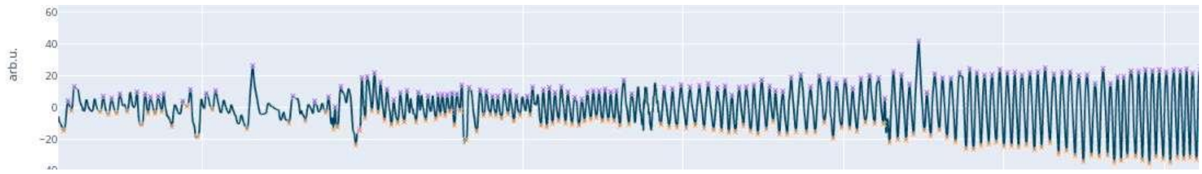

Figure 41: Respiration signal with increasing effort.

Figure 42. Heart rate (red) increased linearly with effort, so is the activity level (green).

The heart rate increase trend, measured by the accelerometer on people chest, is similar to the cardio-respiratory system (Figure 42).

The next figure (Figure 43) shows how an Amplitude and frequency variation after panting happens during a continuously increasing effort.

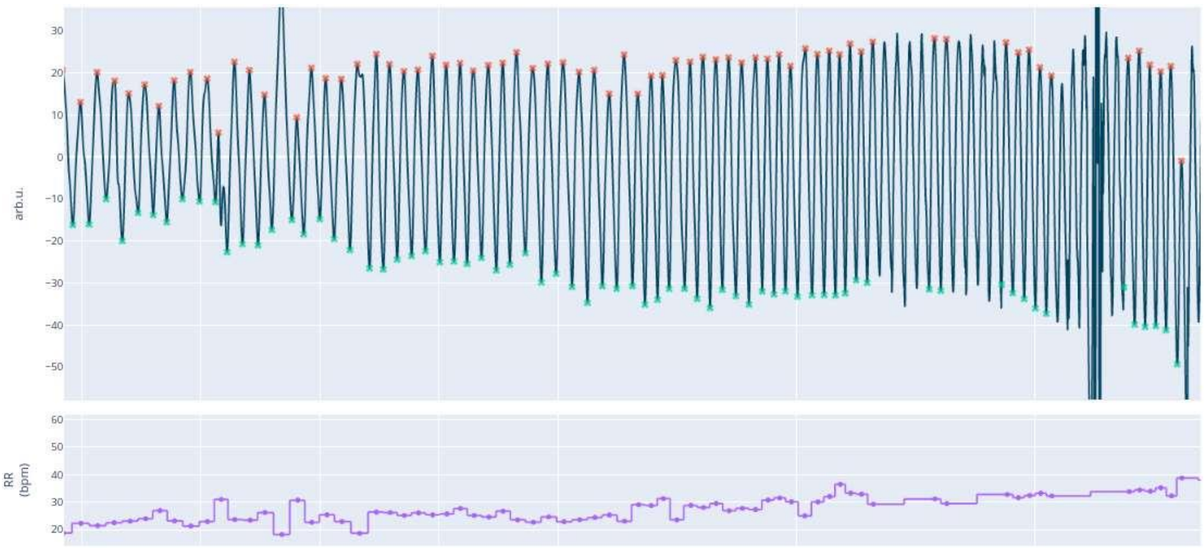

Figure 43: Respiration frequency (purple) and respiratory raw signal (blue) when panting occurs.

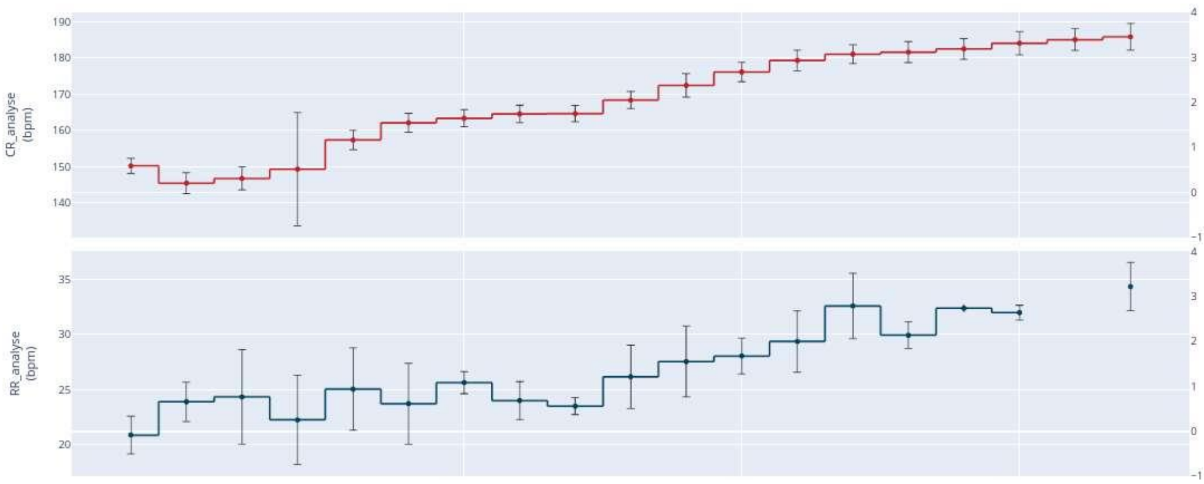

Figure 44: Heart rate (red) and respiratory frequency increase (blue).

Figure 45. Corresponding Human Power increase.

When both frequency and amplitude increase jointly significantly (Figure 43 and Figure 44 – blue signals), in response to a human power increase (Figure 45), the total inhaled volume of air becomes important.

Pollution

Air pollution data in Grenoble is available from the organisation responsible for local air quality monitoring: ATMO AuRa. This simulation is computed every hour each day with a 10m resolution inside the streets of the city. A simulation result for PM2.5 concentration is shown in Figure 46.

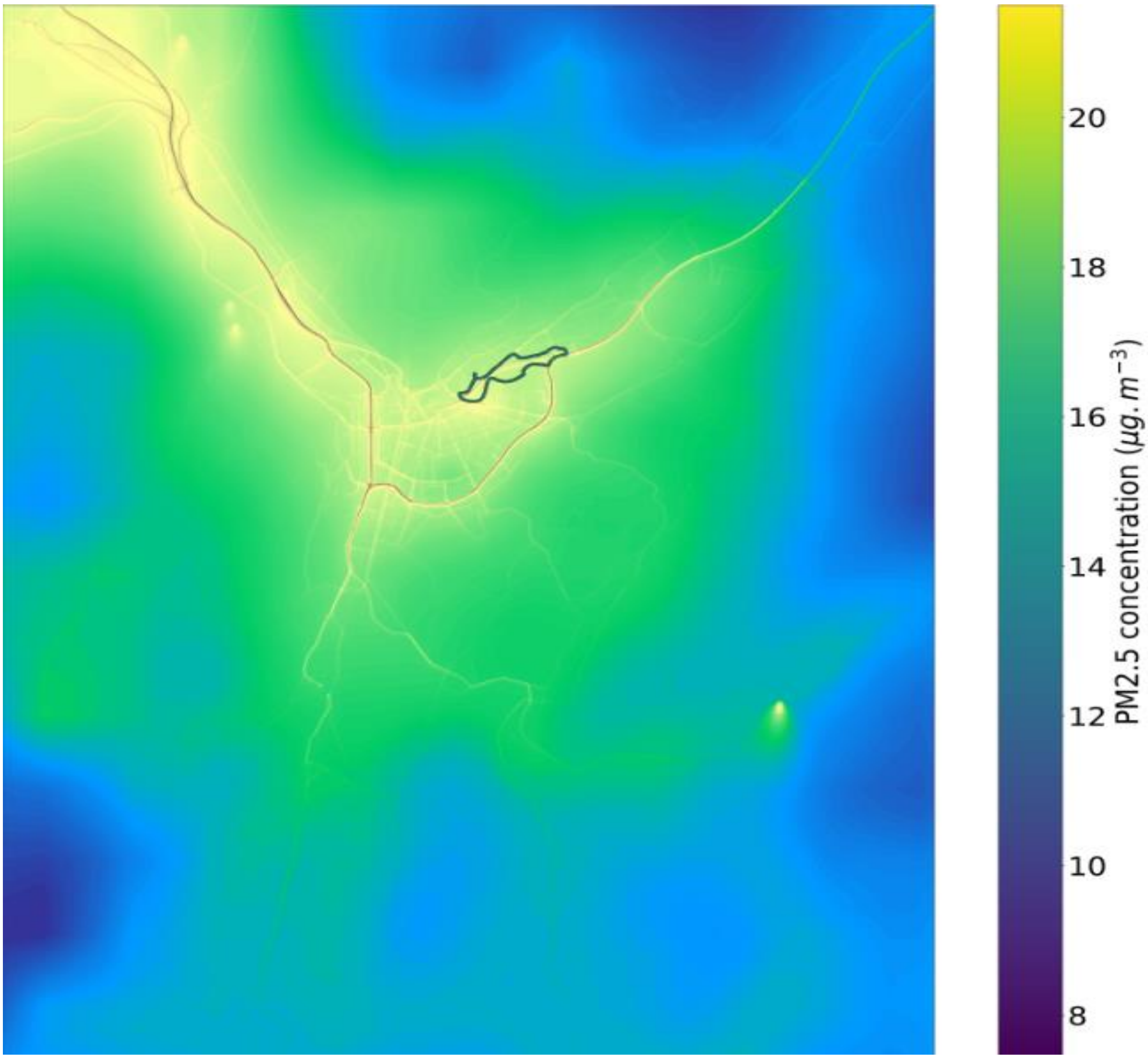

Figure 46. PM2.5 concentration modelling map (ATMO AURA) on Grenoble Metropolitan Area and the bike circuit of interest (black).

At the end of the day, only daily averaged concentrations are stored by the air quality institute. To visualise exposure along the route, pollution concentration values are extracted at each point of the path, allowing concentration levels to be graphed as shown in Figure 47.

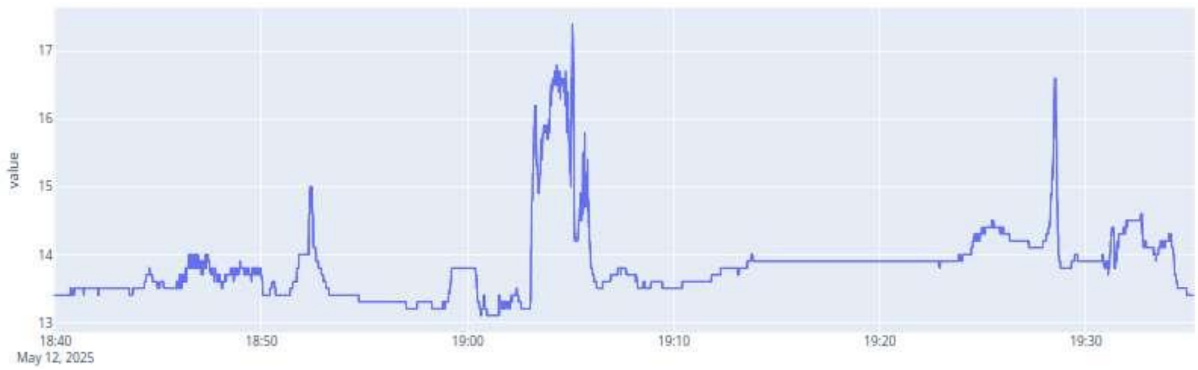

Figure 47. Pollution concentration levels of PM2.5 along the distance according to ATMO simulations.

There are three sources of field data:

- Fixed sensors located throughout the urban area and ATMO AURA monitoring stations.
- Simulations based on the localization of emission sources and the modelling of their dispersion and propagation within the urban canopy.
- Mobile sensors that continuously measure air pollutant concentrations along the route.

These data sources can be cross compared to provide a range of pollutant values encountered along the journey. Such comparisons also allow for an assessment of the relevance of the modelling by comparing simulated results with in-situ measurements, as well as evaluating the reliability of the data collected by mobile sensors:

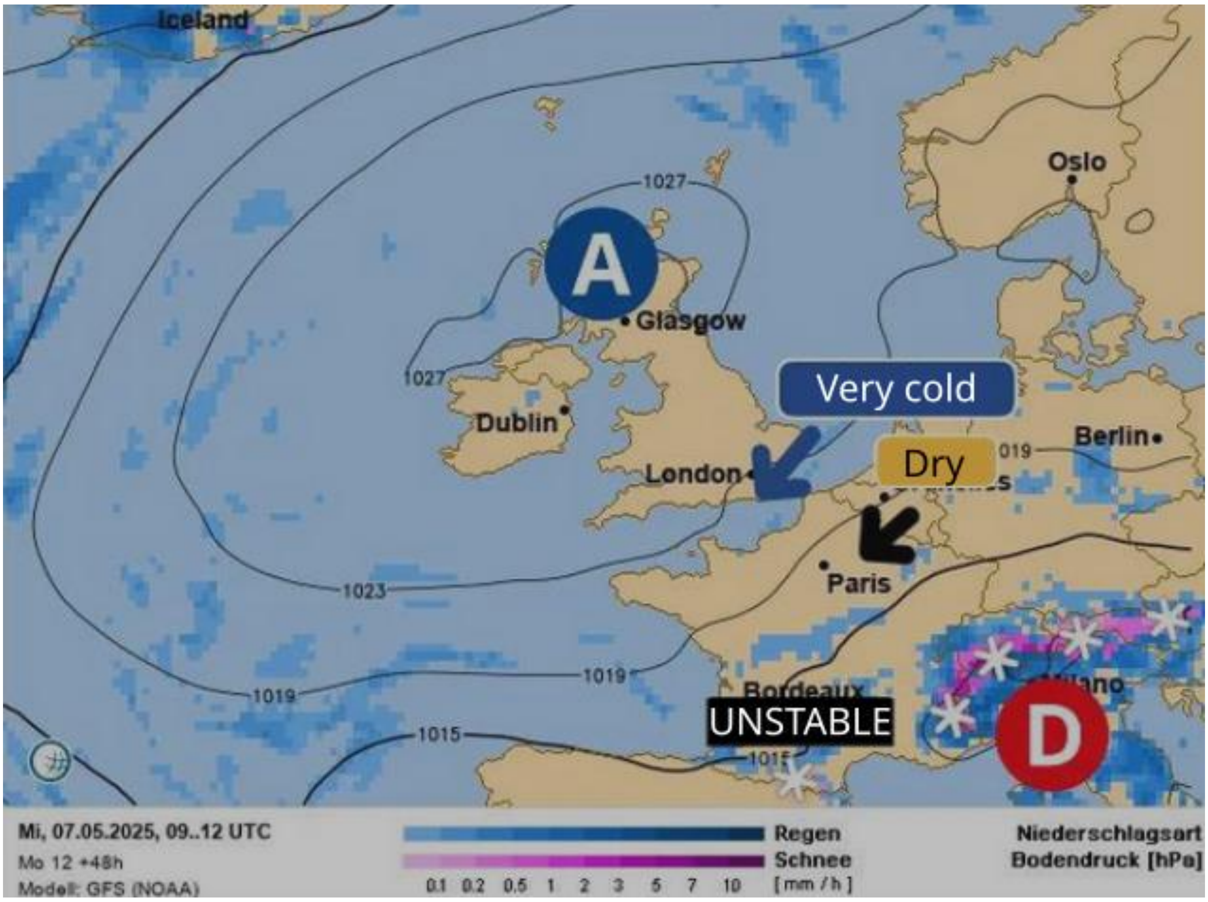

Figure 48. Weather map / pressure map on May 7, 2025.

Another objective is to identify the meteorological conditions that lead to these situations, such as anticyclonic blocking, wind, or temperature inversion. Using weather map as shown in Figure 48 helps to characterize these specific situations to explain and anticipate pollution episodes in Alpine valleys.

By combining respiratory data with various air quality assessment sources, it is possible to estimate the quantities of pollutants inhaled during a cycling trip under different meteorological conditions, along various routes, and at different times of day. This is the aim of the present study, which seeks to capitalize on data from a substantial number of participants with diverse backgrounds.

Discussion

The adverse effects of air pollution on health are well documented. While the European Union's zero pollution vision for 2050 aims to relieve this burden, air quality remains an active public health concern, particularly amongst the most vulnerable populations.

Concurrently, and despite efforts to encourage physician activity, a large proportion of people remain insufficiently active. Approximately 80% of adolescents and over a quarter of adults do not meet the WHO's recommended activity levels [(47)]. In addition, levels of inactivity are increasing in higher-income countries and women are notably less active than men [(48)].

Physical activity plays a crucial role in supporting lung health by improving lung function, slowing its decline, and reducing mortality, particularly in those with chronic lung conditions [(49)]. These benefits stem from deep breathing and muscle engagement, which may help lower inflammation and increase oxygen intake. Therefore, if air quality does not improve and levels of physical activity continue to decline, the risk of adverse health effects will persist and possibly increase.

Currently, and in an effort to protect both its general and most vulnerable population, French Health Authorities advise limiting physical activity during episodes of heatwaves [(50)] and high air pollution episodes [(51)]. Yet, it is precisely vulnerable groups who stand to gain the most from adopting regular physical activity as part of a long-term strategy for improved health. In addition, most models suggest that for active travel, the health benefits of physical activity generally surpass the risks linked to air pollution[(52)]. However, there seems to be a lack of evidence to integrate this into public health recommendations. As a result, *Personalised Physical Activity Recommendations* aims to challenge current public health advice by assessing the risk/benefit balance of physical exertion during heat waves or high air pollution episodes.

This observational trial took place in Grenoble's metropolitan area, home to approximately 450 000 inhabitants, interesting through its unique topography. Grenoble is not only in a valley, but in a Y-shaped valley at the confluence of two rivers (Isère and Drac), surrounded by three mountains ranging more than 1800 meters above the city. Within the MOUNTADAPT project, Grenoble was paired with Andorra, which has a capital with comparable topology.

In the winter, Grenoble's topology makes it prone to thermal inversions [(53)], which have been suggested to be related to most PM10 pollution spikes [(54)] and generally associated with residential wood heating. PM10 has been suggested to be less harmful as unable to penetrate the lower respiratory tract than fine particulate matter. Indeed, fine particulate matter (0.1 ≤ 2.5 µm, and more generally referred to as $PM_{2.5}$) has been linked to adverse health effects for a number of decades now, through excess mortality and higher rates of accident and emergency attendances [(53)].

Globally, research suggests that meteorological conditions in winter are more prone to hosting higher concentrations of particulate matter than other seasons [(55)].

Nevertheless, while winter is a critical season for air pollution levels, summer, and especially heatwaves, pose a unique and growing public health risk due to and increased human exposure to the combined effects of ozone, particulate matter from fires, and heat stress. Research local to Seoul suggests that heat waves may increase the concentration of fine particulate matter, therefore increasing the risk of adverse health effects [(56)]. Whether this effect can be observed elsewhere remains uncertain.

For the observational trial segment of the project, Vélis et Pollution, routes were selected to reflect the most commonly used cycle lanes in the local area, spanning urban, suburban and **suburban**-rural fringe areas. As a result, the study successfully captured both a realistic and varied picture of local cycling. This was important in order to ensure that the cardiopulmonary strain and levels of pollutants were reflective of realistic commuting exposure.

The present study focused on one of the most health-hazardous pollutants: fine particulate matter. This enabled true insight into the health impacts of physical exertion during high air pollution episodes, allowing the data to be used to formulate data-driven public health recommendations.

Fine particulate matter data collected by the PlumeLabs mobile sensor was compared to the ATMO AuRa fine particulate matter data. PlumeLabs was expected to provide superior local data on real-time air quality than ATMO AuRa. It was hypothesised that the ATMO AuRa data could likely be used as a reliable representation of real-time air pollution along a given (within sensor range) route.

A significant constraint with ATMO AuRa is the storage of its data. ATMO AuRa retains hourly PM2.5 and NO2 data for 24 hours, covering the city and its surrounding area in 10 meters quadrants. The data is then processed and summarised as a daily average for $PM_{2.5}$ levels and a daily maximum NO2 value. As a result, the process of requesting daily transfers of ATMO AuRa data to the research team was in progress with the aim of being able to analyse the reliability of their data on a larger scale. However, this is currently not a user-friendly solution for curious commuters.

It was hypothesised that a state of hyperventilation would expose participants to a higher volume of harmful pollutants. Indeed, hyperventilation, characterised by rapid and deep breathing, increases the volume of air drawn into the lungs. As a result, this can lead to greater deposition of fine particulate matter in the lower respiratory tract [(52)].

While the physiological shift to hyperventilation is well-documented in laboratory settings, such assessments are often costly and time-consuming.

Consequently, the present study attempted to assess whether the physiological shift to hyperventilation could be observed accurately in field settings (i.e.: outside of a laboratory setting). The data collected allows the detection of the shift towards hyperventilation. This therefore illustrates that it is possible to capture the shift to hyperventilation in a field setting, involving lesser diagnostic costs and increased flexibility in examination methods.

This presents a clear goal for future studies: the aim to identify the shift towards hyperventilation in order to integrate this into instructions in the form of a heart rate limit. If hyperventilation increases susceptibility to inhaling harmful volumes of pollutants, then it should be advised that individuals remain below the heart rate that triggers their hyperventilation, allowing them to exercise safely during high air pollution episodes. The shift towards hyperventilation is person-specific and a generic recommendation cannot be provided.

Bias

Given that the target audience for the recommendations is “vulnerable populations”, sampling bias was a true risk throughout the recruitment phase. Indeed, the most likely spontaneous volunteers were health-conscious, frequent cyclists concerned about climate change and air quality. Throughout the project, the team faced this challenge by reaching out to local authorities to help recruit individuals classified as vulnerable adults.

In practice, and to mitigate sampling bias, Floralis and CHUGA collaborated with GAM (Local Metropolitan Authority) to recruit GAM employees deemed “vulnerable”” to take part in the study during working hours. This incentivised a difficult to reach population to take part in the research.

The preliminary sample analysis, which did not yet include the GAM participants, showed a heterogeneous age distribution. However, the population was around two thirds female, with a predominantly low to average BMI individuals and from more middle-class backgrounds; 95% of participants declared regular exercise and 80% of those exercising at least three times a week.

In light of this and in order to ensure ensure participation among less physically active individual, the bikes used during the study were tailored to participants' needs. In practice, this meant that the standard settings could be adjusted at any time during the outing for the participants comfort, needs, or ease. Flexibility enabled broader participation and sample diversity for the final analyses (results to be published).

Technical Challenges

As the project relied on experimental equipment, the t-shirt units available were limited to three when experimentation began and later increased to four. Importantly, the ECG and respiratory readings relied on these Etisense t-shirts with integrated sensors. As a result, each t-shirt needed to be washed and dried between uses, limiting the possible frequency of outings. In addition, the original t-shirt samples were available in sizes S, M and L. This limited initial outings to participants that could fit into one of these three sizes. As a result, a further t-shirt was ordered and an adjustable option ranging size XL-XXXL was provided by Etisense. This allowed more inclusive sampling, crucial to answer the research questions centering around vulnerable populations.

Conclusion

While current public health recommendations advise limiting physical activity during heatwaves and high air pollution episodes, this advice may overlook the significant long-term health benefits of regular exercise, particularly for the most vulnerable groups. Accounting for the unique topological factors and resulting pollution profile in the mountainous region of Grenoble, the present study suggests the need for more nuanced *Personalised Physical Activity Recommendations*. Public health recommendations should carefully balance the risks of pollutant exposure and heat stress against the benefits of physical activity. In order to guide individuals, we suggest incorporating physiological markers such as hyperventilation to guide levels of physical exertion during periods of poorer air quality. In addition, we conclude that the levels of pollutants around water sources or in higher altitudes should be further explored as certain geographical features may host lower density air pollution.

In short, public health recommendations should be designed with the ability to be personalised to tailor to individual needs and physiological parameters, and they should be designed to better support vulnerable populations in maintaining regular physical activity as a key strategy for resilience against climate-related health challenges, especially considering the increasing levels of inactivity amongst our population and the known health benefits of regular physical activity.

The Value of Co-Creation as a Key Tool for Guidance and Recommendations Development

Co-creation is "*the process of joint production and the valorisation of knowledge between industry, academia and other Research and Innovation (R&I) actors, such as public authorities, social partners and civil society*" (57). It is about bringing together academia or technical experts and non-academic stakeholders, like healthcare professionals and institutions, to work collaboratively. This transdisciplinary approach benefits everyone involved: it encourages the joint development of knowledge that directly responds to real-world challenges and helps close the gap between research and practice. By fostering mutual understanding and shared accountability, co-creation builds stronger and long-lasting relationships, which make it easier for public health innovations to be successfully implemented and adopted in the long-term. Co-creation is a win-win: researchers gain valuable access to data, infrastructure, and the opportunity to see their ideas put into practice, while end-users benefit from solutions that are tailored to their needs. It also supports continuous learning, skill development, and better communication between sectors, contributing to a more climate resilient and prepared public health system (57).

The solutions outlined in D2.3, developed under T2.3, were co-created in collaboration with one or more demonstration sites, as outlined in each of the preceding chapters. This process aimed to ensure that the outcomes were as closely aligned as possible with the specific needs of the respective sites. The partners employed a variety of engagement methods, including email exchanges, in-person or online meetings (eg: Annex 1), consultations, and data sharing. In some instances, particularly in relation to built environment solutions such as those presented by CSTB in the chapter *Nature-based and hybrid solutions sensitivity simulation*, on-site observations were carried out. Further activities included surveys, structured feedback loops to adapt solutions to local requirements, as for the chapter *Disaster Preparedness Checklist and Guidance*, as well as workshops and participatory sessions. The very objectives of the guidelines and recommendations were often co-designed or adapted based on the existing needs and practices within the demonstration sites, to ultimately ensure the creation of tools that can be genuinely useful in daily practice.

This co-creation approach closely supports key European initiatives like Horizon Europe and the European Green Deal. The former emphasises co-creation in its "Missions" for ensuring practical, locally relevant solutions. In line with the "quadruple helix" model [(58)], promoting the engagement of academia, industry, public authorities and civil society, is central to Horizon Europe's goals [(59)]. As for the European Green Deal, it also calls for a climate-neutral, resilient Europe via societal change, and co-creation is a well-recognised instrument to building local resilience [(60)].

Although from a scientific research perspective co-creation approaches present both advantages and some challenges, and are part of an iterative, ongoing process with no clear endpoint, the benefits far outweigh the limitations. This collaborative method enables the development of more resilient and long-lasting solutions that effectively address the real needs of the involved sites, ensuring greater sustainability and utility over time.

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Annex I – Minutes of CSTB & TIKLI Meetings

This annex contains all minutes of meetings shared between the MOUNTADAPT partner organisations CSTB and TIKLI. These meetings were held to coordinate and conduct the nature-based and hybrid sensitivity simulations. The minutes provide detailed records of discussions, decisions, and progress related to the simulations.

All meetings, except for the site visit in early February, were conducted online via the TEAMS platform. At least one representative from both CSTB and TIKLI was present at every meeting.

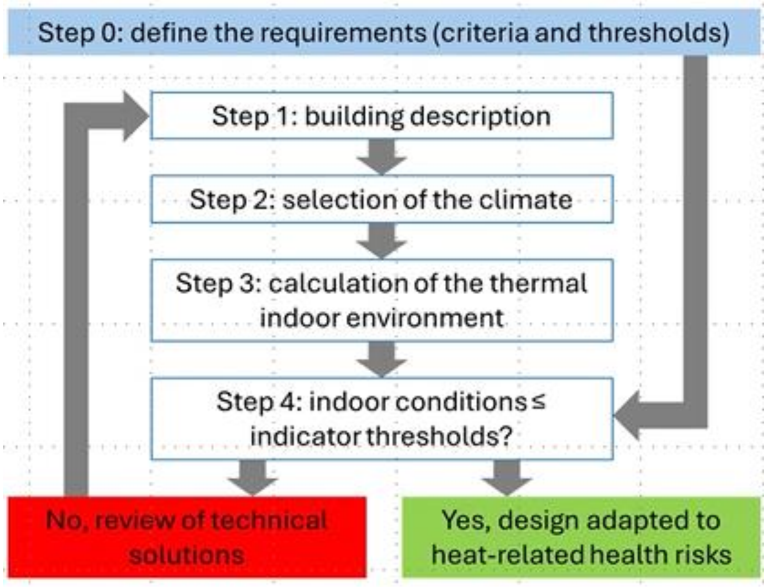
Additionally, this annex contains the interview guide used to gather insights from building users - specifically, nurses at the University Hospital in Innsbruck - regarding their perceptions of thermal comfort during summer and the measures they currently take to protect themselves and their patients from increasing temperatures.

These documents are valuable in highlighting the importance of interactions and the methodology developed through them.

Minutes

Meeting 1

Date: 26.07.2024
Time: 09:00 – 09:50



(0) **Define the requirements (criteria and thresholds)**

- E.g., hygiene (e.g., Sporen, Vögel, Mosquitos), thermal requirements (in the French environmental and energy regulation for building (RE2020), summer thermal comfort is assessed against target temperatures below 26°C or 28 °C, depending on the outside temperatures in the previous days), ventilation
- Requirements must be defined together (different stakeholders TIKLI + CSTB)

(1) **Step 1: Description of the building**

- 2 plans are needed
  1: Building (design) plan – construction, structure, insulation, occupation/usage
  2: Ventilation (system) plan – do the buildings have air conditioning, air change rates, natural or mixed ventilation, passive shading etc.

(2) **Step 2: Selection of the climate**

- Information needed on outside temperature, relative humidity, wind
- What climate event is relevant for us (e.g., heat or cold wave)
- Climate now and/or projections for 2050 (so they can run simulations for today vs. tomorrow)

(3) **Step 3: Calculation of the thermal indoor environment**

- Design building inside CSTB's tool, implement building usage and test different solutions (nature based and hybrid) and performance for each scenario is calculated
- They have a list of typical solutions that can be tested, thermal engineer Jean-Marie Alessandrini can provide this list and we choose what is most relevant for us. He will run the simulation, together with Maéva Sabre and Mathilde Hostein.
- Outcomes: Temperature, relative humidity, energy consumption
- Results compared with Step 0 (requirements)

(4) **Step 4: Indoor conditions ≤ indicator thresholds?**

Meeting 2

Date: 04.10.2024

Time: 10:00 – 11:00

Agenda

1. Introduction
2. Adaptation to Climate Change
3. Needed Information from TIKLI

Outcomes

Ad 1. Introduction

- Jean-Marie > energy and buildings engineer
- Maéva > specialist in climatology, nature-based solutions
- Jonathan > meteorological and climate research engineer
- Mathilde > explores impact of climate change on summer comfort, energy department, modelling and simulations

Ad2. Adaptation to Climate Change: Selecting a Building for Simulation

- The simulation will focus on one of our buildings or specific sections within it.
- Ideally, the selected building will be an older structure that will be renovated in the future.
- The building should be a representative choice, typical of similar structures in other cities.
- Both patient rooms and offices should be included to address varying thermal comfort requirements.
- Note: Treatment rooms and operating theatres will be excluded from the study due to their highly controlled environments.
- Initial suggestion (from Jürgen): Frauen-Kopf-Klinik (Women's Head Clinic) refurbishment project
- We will provide a building plan, from which a selection of rooms and offices will be chosen for simulating NBS solutions.

Ad 3. Needed Information from TIKLI

- Investigate whether thermal comfort criteria exist for patient rooms and offices; if not, explore available recommendations.
    - Review local regulations and guidelines regarding temperature and humidity.
    - Consult Önorm H 6020:2024-03 for specific criteria.
- Identify the demographics and occupations of building users (e.g., patients, staff, and specific health conditions of patients).
- Analyze climate factors, including temperature, humidity, precipitation, air pressure, and wind conditions.
- Collect technical information about the buildings, focusing on wall and window characteristics (e.g., shading, solar protection), the ability to open windows, frequency of window usage, and the presence of green roofs.
- If limits are frequently exceeded, cooling requirements will be calculated by CSTB.

Meeting 3

Date: 20.11.2024
Time: 14:00 – 16:00

Agenda

1. Introduction
2. Building Choice
3. What Nature-based Solutions are
4. Agenda for Next Meetings

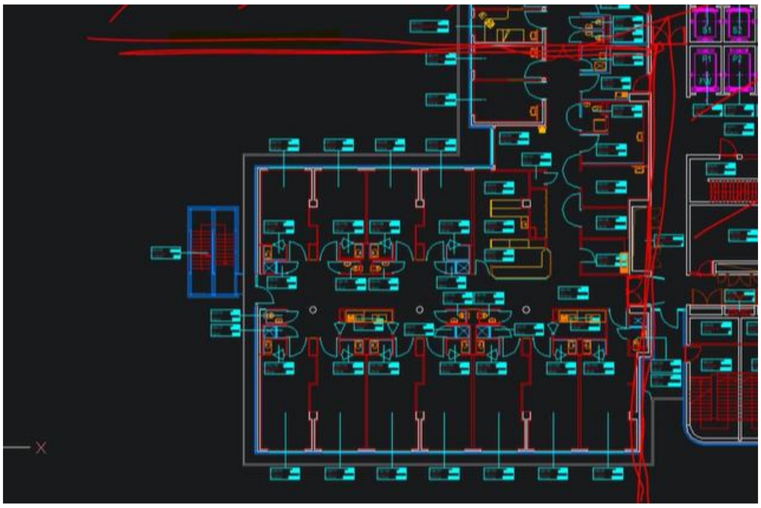
Outcomes

Ad 1. Introduction

- New team member: Aya Mansouri
- Jean-Marie: Engineer, heat and mass transfer, energy
- Maeva: Impact of climate on structures, NBS to reduce heating of cities
- Mathilde: Engineer in thermal comfort, especially summer thermal comfort, impact of climate change on overheating
- Kathi, Jürgen, Julia, Dagmar

Ad 2. Building choice

- Section of Frauen-Kopf-Klinik building which is in total 9 stories high
- We want to simulate one section of 6th floor of the building, SW exposition
- Old building that will be refurbished, no air conditioning
- Is there air flow contact with other parts of the building?
  - Jürgen has to check independence
- Patient rooms, one office, one visitors' room, rooms for staff, treatment rooms
- Balcony around the building where you can put some troughs / pots for greening
- Floor plans are already up on One Drive



Ad 3. What are nature-based solutions?

- Cooling through external airflow, humidification, and solar protection.
- Green façades: Installed primarily on the first floor to ensure accessibility for maintenance.
- Green roofs: Their impact is limited to the building's top floor.
- Shade from trees: This provides cooling but only affects the ground floor.
- Nature-based solutions often target specific areas of a building, such as the ground floor.
- Shading plants: If we simulate the effects of shade from plants, what impact would it have?

How do green façades affect airflow? They could reduce it, so airflow needs to be minimized carefully.

Simulation Example: Simulate 1-2 patient rooms and one office space, each with different usage patterns.

- Simulation outputs: Measure indoor temperature, humidity, air temperature, and wall temperature.

Key factors to consider:

- Wall types (external/internal), thermal insulation, thickness, insulation material, and roof characteristics.
- Heat storage within walls and their heat capacity in the first simulation.

What is the most effective protection? What is a realistic protection?

Ad 4. Agendas for Next Meetings

Agenda for next online meeting (09/01/25)

- Short presentation of the selected softwares
- Show test results and discuss hypothesis
- Final choice on which building section and how many rooms to model
- How to assess the thermal impact of green walls on indoor thermal environment?

Agenda for on-site visit (04/02/25)

- Define scenarios we want to model

Meeting 4

Date: 09.01.2025
Time: 09:00 – 10:30

Agenda

1. On-site Visit

2. Modelling Progress
3. Other Matters

Outcomes

Ad 1. On-site Visit

3rd to 4th February

- Start at 10 AM on Monday
- Finish latest at 12 PM on Tuesday

Proposed agenda:

- Meeting with the maintenance team
- Meeting with medical staff
- (Meeting with additional, interesting stakeholders)
- Inspection of clinic
- Visit meteorological station
- Lunch

Meeting with Technisches Service Zentrum (Technical Service Center); show machines, ventilation and air conditioning system…

Meeting with medical staff; how do they perceive working in the building section being modelled, how is solar protection used…

Mathilde and Jean-Marie will join the visit.

Ad 2. Modelling Progress

Some modelling has been conducted, though not as extensively as anticipated by this point. However, CSTB has initiated modelling for four rooms and a hallway, focusing on scenarios such as cross-ventilation and closed-door conditions. Two software tools are being used for these simulations,.

There are still some uncertainties regarding the plan, such as whether certain features are included, like closets, showers, windows, or doors, and whether temperature measurements are being recorded inside the rooms.

Modelling efforts are currently underway to evaluate green walls and solar protection systems for windows. Once the calculations are complete, CSTB aims to produce something like a list of recommendations outlining which green solutions perform best, the extent to which they contribute to cooling, and their potential energy-saving benefits.

It's also important to remain mindful of hygienic standards, potential infection risks, and clinical considerations when implementing green facades in healthcare environments.

Ad 3. Other Matters

The French Heat Health Watch Warning System (*Vigilance Canicule*) is a system implemented in France to monitor, predict, and manage the public health impacts of extreme heatwaves. It operates as part of the country's broader heatwave plan (*Plan Canicule*), which was introduced following the devastating 2003 heatwave that caused thousands of deaths.

- **Monitoring and Forecasting:** It relies on meteorological data provided by Météo-France to predict and track heatwaves. Heatwave alerts are issued when thresholds of temperature and duration are expected to have significant health impacts.
- **Alert Levels:** The system uses a color-coded warning scale (green, yellow, orange, and red) to indicate the severity of heat events and their potential risk to the population. Red alerts signal the most extreme conditions, requiring immediate and coordinated actions.
- **Public Health Focus:** The watch aims to protect vulnerable populations, such as the elderly, children, individuals with pre-existing conditions, and those working outdoors. Local and national authorities implement preventive measures, including public cooling spaces, communication campaigns, and monitoring of at-risk individuals.
- **Collaboration:** It involves coordination between public health agencies, emergency services, local governments, and social services to ensure a rapid response during heatwaves.
- **Preventive Actions:** Dissemination of advice to the public, such as staying hydrated, avoiding outdoor activities during peak heat, checking on isolated individuals, and reducing the speed limits for vehicles. Activation of heatwave emergency plans in hospitals and care facilities.

The French Heat and Health Watch is a critical part of France's strategy to mitigate the health effects of climate change and protect its population during increasingly frequent and intense heat events.

Questions to Katharina:

- What is the definition of "heatwave" used in Austria?

A heatwave is typically defined as a series of at least three consecutive days with temperatures exceeding 30 degrees Celsius. (Source: Hitzeschutz: Praktische Tipps gegen Hitze | Land Tirol)

- Is there a similar warning plan in Austria?

Katharina has contacted national health institute, answer still outstanding

Meeting 5

Date: 27.01.2025
Time: 14:00 – 15:00

Agenda

1. On-site Visit

Outcomes

Ad 1. On-site Visit

Katharina provided details about the pre-visit to the Gyn 2 ward. Pictures from the pre-visit of patient rooms (2 beds, 3 beds) and staff room will be uploaded to the shared point by Kathi.

- Link to see pictures of patient and staff rooms: Gyn2

CSTB prepared questions for the meeting but emphasis will be on having an open discussion with the staff rather than a rigid questionnaire.

Focus on clarifying the regulatory framework with Technisches Service Zentrum.

Notable regulation: Temperature must not exceed a threshold (e.g., 28–30°C) for more than three days—could be useful to share with staff.

J. Marie will bring tools for measurements, including a large sensor for humidity, temperature, and pollutants. Ensuring connectivity between France and abroad.

Meeting 6 – On-site Visit

Date: 03.02.2025 – 04.02.2025
Time: 9:30 (03.02.2025) – 12:00 (04.02.2025)

Agenda

1. Introduction
2. Meeting with Technisches Service Zentrum (Technical Service Center)
3. Meeting with Gyn 2
4. Visit of Weather Station
5. Meeting with Energieagentur Tirol
6. Questions

Outcomes

Ad 1. Introduction

- Mathilde; climate change and thermal comfort
- Jean-Marie; heat and mass transfer, thermal regulations in France, energy consumption reduction

Ad 2. Meeting with Technisches Service Zentrum (Technical Service Center)

Contact: Richard Bartl

During the meeting, key discussions focused on the challenges of cooling in extreme temperatures, particularly during hot days and nights when free cooling becomes unfeasible. It was emphasized that while passive solutions are important, anticipation and prevention are crucial to avoid heat risks, potentially through energy-efficient air conditioning systems. The importance of understanding the system limits was highlighted, with reference to the ÖNORM H-6020 standards.

Various cooling methods were explored, including groundwater cooling and the use of mixed systems, but there were concerns about the increased flow needed as outdoor temperatures rise. Solar shading and green facades were also discussed as potential solutions, with attention given to their limitations in extreme wind conditions. Energy consumption and internal loads were addressed, particularly in rooms with numerous appliances, and the need for proper simulation data was noted to better understand cooling requirements. Future climate scenarios and the associated risks were also part of the conversation, with an emphasis on defining thresholds and ensuring adequate energy management.

Ad 3. Meeting with Gyn 2

A visit to the Gyn2 ward was arranged to meet with two nurses who shared their experiences and insights regarding patient care during extremely hot summer days.

Ad 4. Visit of Weather Station GeoSphere Austria

Schöpfstraße 45 (old) and Innrain 52f (new)

J.-Marie and Mathilde took pictures.

Ad5. Meeting with Energieagentur Tirol

Ad 6. Questions

When is the next online meeting between tirol kliniken and CSTB?

Could CSTB present the initial simulation results during Consortium Meeting 3 in Innsbruck (June 2025)?

Meeting 7

Date: 14.03.2025
Time: 11:30 – 13:00

Agenda

- Updates
- Consortium Meeting
- Exchange with Public Health Agency

Outcomes

Ad 1. Updates

Updates CSTB; How far with simulations?

CSTB uploaded a new document on our shared folder today

- Name: "Progress_report_v1"
- Interesting figures, e.g., figure 3

ÖNORM 6020 is used as threshold requirements

Mathilde shows model to Tikli

The model displays both outdoor and indoor temperatures across various rooms.

The time period analysed spans from July 1st to August 31st.

The analysis includes data from 10 patient rooms, 1 nurse's station, and 1 computer room.

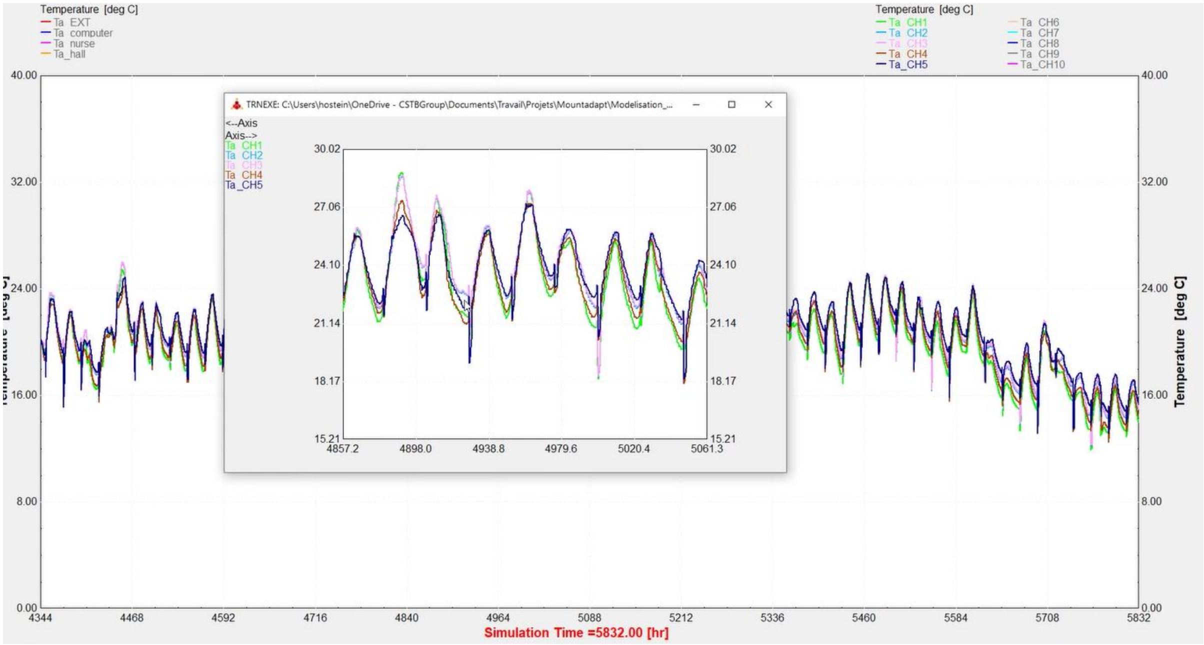
- Smaller rooms with higher occupancy density tend to experience higher temperatures.
- Rooms located on the north side include 2 two-person bedrooms and a computer room, while the south-facing rooms are larger and accommodate three people. Despite these variations, temperature differences remain minimal due to the constant airflow created by open doors.
- Room 7 and 8 represent the same type of room, with bedroom 7 displaying temperatures when visitors are present.
- Internal heat gains play a significant role in temperature variations.

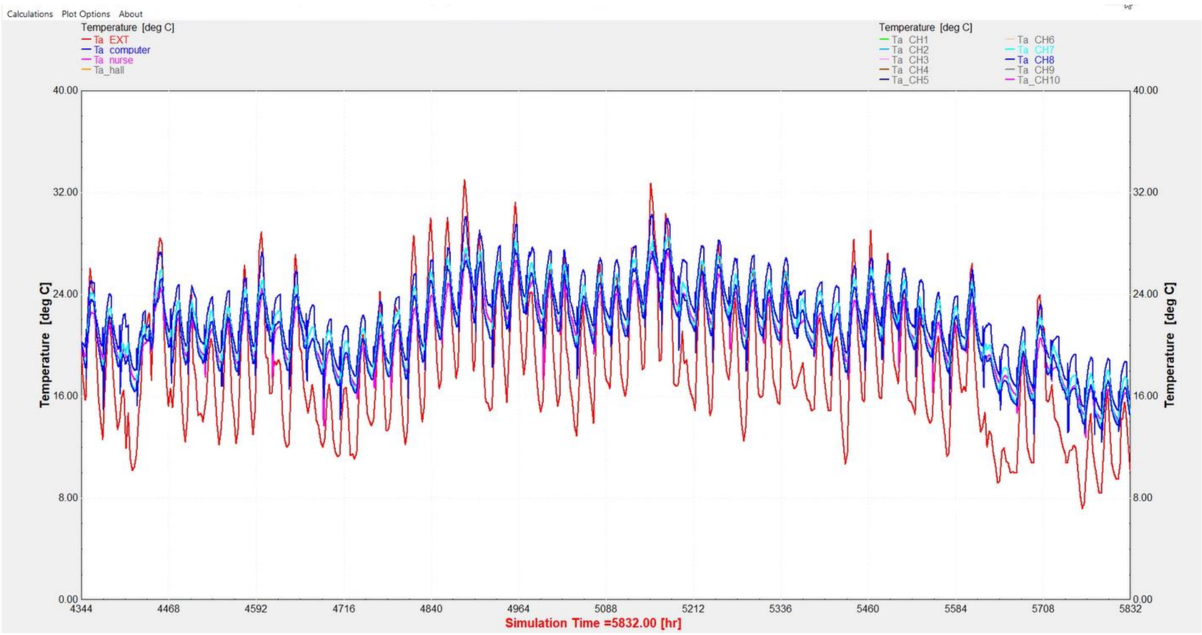
In the following steps, CSTB will select a particularly hot night to simulate and analyse the impact of repeating these extreme heat conditions.

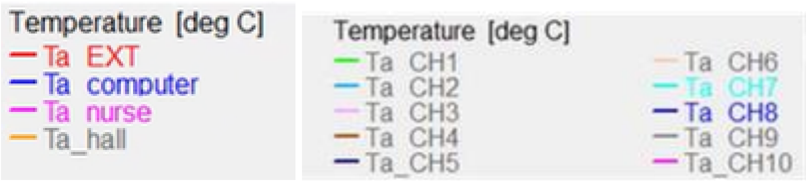
Potential recommendations:

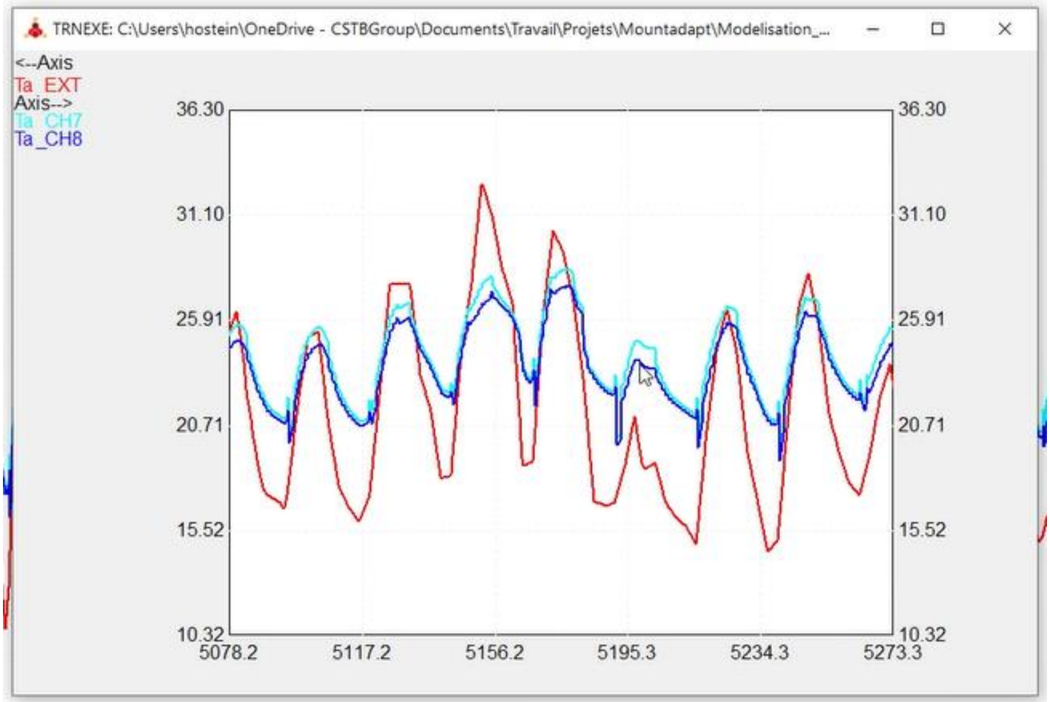
- It may be beneficial to develop guidelines for when it is appropriate to open windows for temperature control, maybe even during the day.
- Keeping patients in the dark may not be necessary.
- Restricting visitor access is not recommended, as it could negatively affect mental health.
- Consideration should be given to utilising ceiling and building structures to aid room cooling.

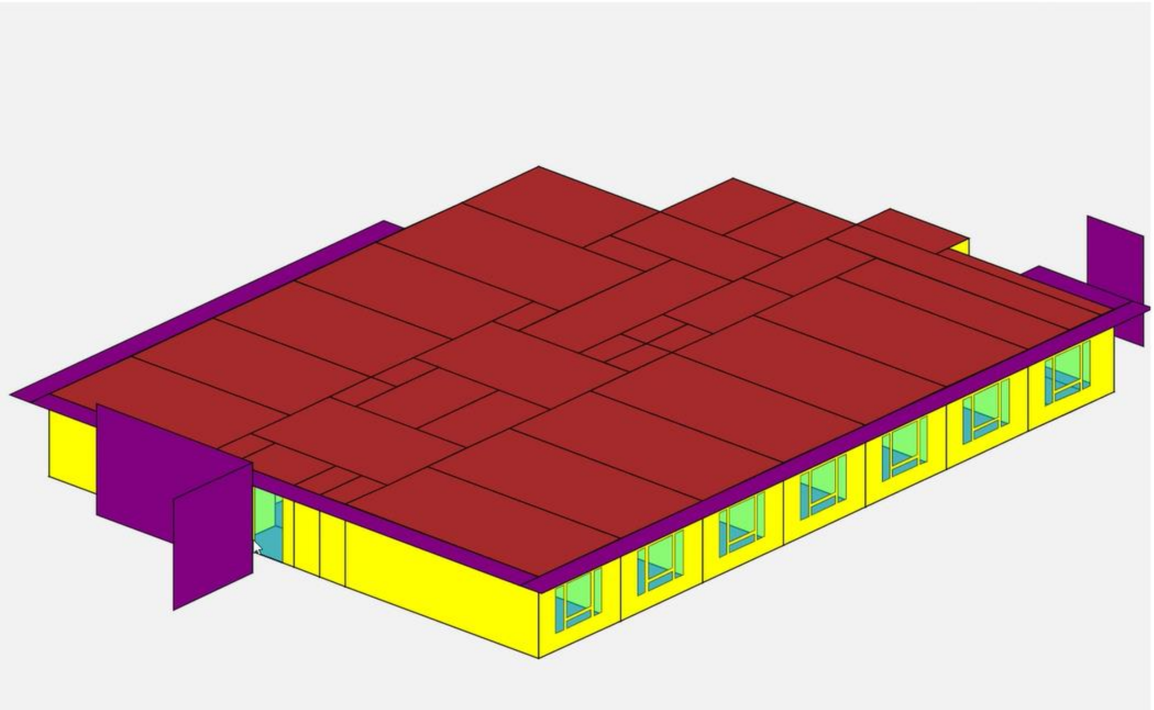
Member checking is necessary to ensure that the analysis align with the actual observations.











Kathi needs to confirm whether the names of the nurses and Technisches Service Zentrum can be included in the acknowledgment section of the advancement report. For the time being, a general thank you is written.

Ad 2. Consortium Meeting

Can CSTB already present results during Consortium Meeting 3 in Innsbruck?

It needs to be discussed with the CSTB project manager (Wenjuan), if it is possible for a member of CSTB to come (budget?). If so, Mathilde can present first findings during CM3 in Innsbruck, or Jean-Marie if a meeting with Austrian Public Health Agency can be held at the same time.

Ad 3. Exchange with Austrian Public Health Agency

GÖG is interested in exchange about French Heat Health Watch Warning System

Jean-Marie will discuss with Wenjuan the feasibility and desirability of holding a meeting. Following that, he will share potential dates for further discussion. Mathilde has uploaded an article on heat and health to the climate folder.

Meeting 8

Date: 24.04.2025
Time: 10:00 – 11:30

Agenda

1. Progress on modelling:
2. Variation of indoor thermal environment
3. Calculation of the loading time
4. Operating limit exceeded depending on outdoor temperature
5. Limits
6. Perspectives

Outcomes

Ad 1. Progress on Modelling

Variation of indoor thermal condition

Occupation scenarios

Zone	Period	Description	Nb occupants	Activity
Bedrooms	Always	Patients	2 (north) or 3 (south)	Lying rest
CH7	Day (7-19h)	Visitors	5	Sitting rest
Computer room	Day (7-19h)	Medical staff	7	Sitting active
	Night		1	
Nurse room	Day (7-19h)		1	Sitting rest
	Night		2	

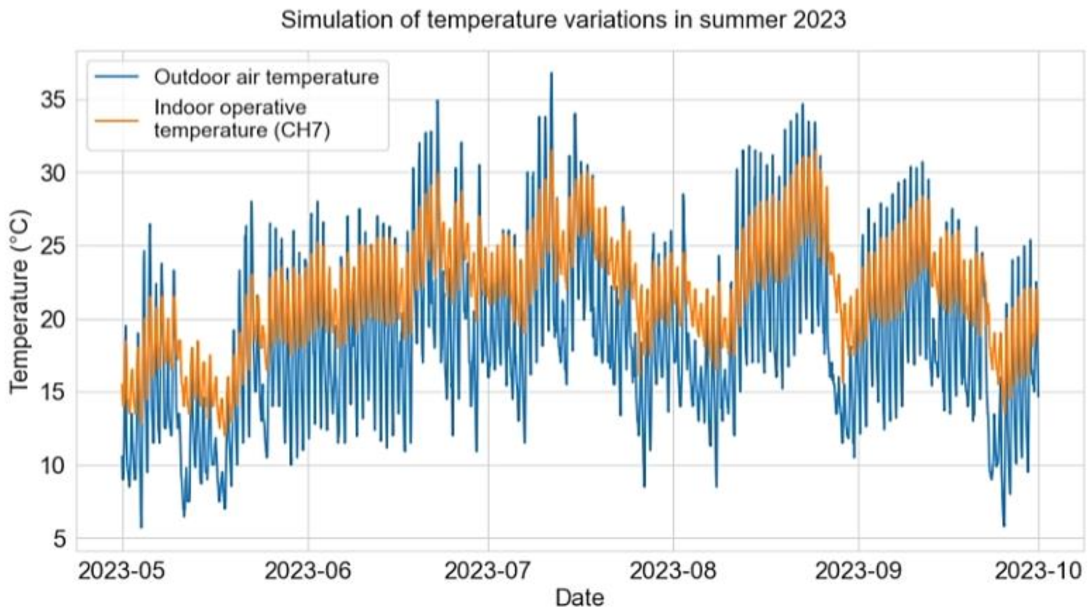
Windows are opened from 7:30 – 9:00, doors are opened, solar protections closed from 9:00 – 19:00 CH7 is bedroom 7, if there are no visitors

- Visitors do not have a huge impact and is necessary for patient's mental health

Equipment scenarios

Room	Period	Description	Number	Gain (W)	Radiative part (%)
Bedrooms	Day (7-19h)	TV	1	240	40
Computer room	Day (7-19h)	PC stationary	7	90	10
		Laptop	1	59	25
	Nuit	PC stationary	1	90	10
Nurse room	Always	Laptop	1	59	25
Kitchen	Always	Fridge	2	40	0
Wet rooms	Always	Fridge	2 (HUM1) or 1 (HUM2)	40	0
Nurse room	Always	Artificial light	10 W/m²		
Computer room	Always (depending on natural light)				
Rooms without windows	Day (7-19h)				
Bedrooms	7 to 21h (depending on natural light)				

It is not easy to translate these appliances into heat load



This is the result of summer 2023

- Blue: outdoor air temperature
- Orange: indoor air temperature

During certain periods (marked with a red "X"), the indoor temperature exceeds the outdoor temperature. This suggests that opening windows during the day could help cool the rooms. However, during these times, the outdoor temperatures are relatively low – possibly due to a cold snap – which raises concerns about exposing patients to cold air.

All the services have been modelled, but only the results for the Room 7 were presented; the computer room will follow next. Between May and the end of September, Room 7 is the warmest room in the facility most often, followed by Room 6. Nevertheless, indoor temperatures across rooms appear quite similar, possibly because doors remain open most of the time.

Heat wave event and its impact on indoor thermal conditions through building interaction

- How long does it take for the building to absorb heat? How much time is needed for the building's temperature to match the outside temperature? This process takes a significant amount of time and depends on factors such as the building's characteristics (especially its mass and its heat capacity), outdoor temperature fluctuations, and whether the windows are open…
- How much heat can the building release during night ventilation?
- What is the maximum acceptable step for a given load level?

Calculation of the loading time

Outdoor air temperature is the only variable, while other factors like internal load are held constant

How long does it take for the building to reach the same temperature as the new setpoint? 11 days (without opening windows). This is the longest loading time that can be reached.

The time is shorter if greater exchange with the outdoor environment is allowed and if a small amount of heat can be lost each day, for example by opening the window at night. An analogy can be proposed to explain what is happening:

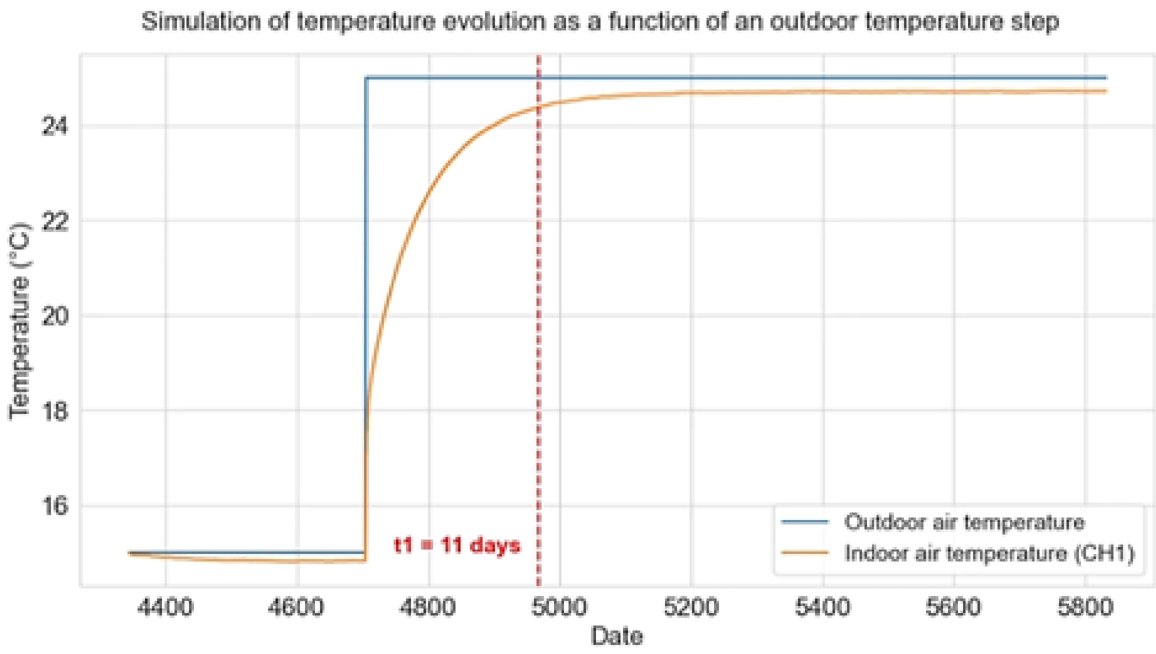
- First: The building envelop is like a big tank and it is filled from a constant flow (the step drawn below), it takes h1 hours.
- Second: The big tank is cut in two tanks little one Tk1 and an another one Tk2. The volume V of the big tank V=Vtk1+Vtk2 and Vtk1<Vtk2

Every day, the tank 1 is filled with heat (brought by internal heat because of activity and appliances and solar gains) then partially emptied toward the outside, thanks to night ventilation, and toward the tank 2 (we consider we are at the beginning of the heat wave and that the previous days have been colder, so the level of tank 2 is lower than the level of tank 1).

Because the tank number 2 is smaller than the big tank, it can be filled quicker than the big tank for the same heat flow.

The level of the heat flow is nearly the same if its level is given by the mean outdoor temperature mean on the day and mean on the time to fill the tank number 2. Because in the mean daily temperature there is the information about the load and the unload (night ventilation)

Therefore, heat discharge is accounted for by using the average temperature as an indicator of both the temperature difference for the step_picture below - (daily mean temperature vs mean loading time temperature) and long time thermal load.

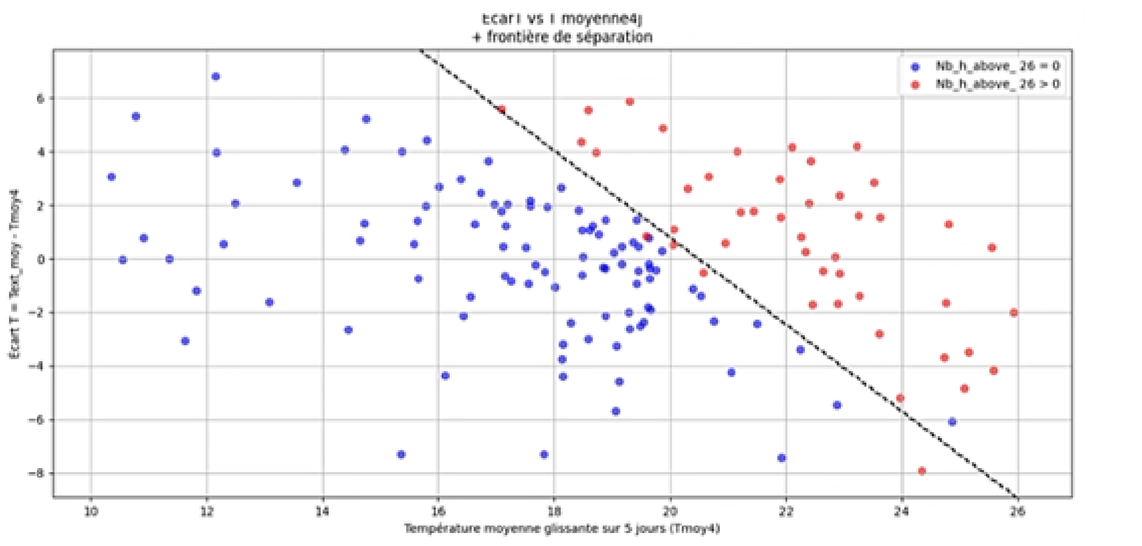


Comment from Jürgen: The initial temperature should be higher, as patients would never be exposed to 15°C. On picture above the test has been done to calculate the longest loading time. This information is independent from the level of the step.

This information is used after to determine a more realistic loading time, that is 5 days for this room.

Operating limit exceeded depending on outdoor temperature

The main results – first representation of summer 2023 (May to September)



- Horizontal axis: Average temperature of the past 4 days

- Vertical axis: Average daily outdoor temperature (day number five) minus average temperature of the past 4 days (first day to 4th day)

The red dots represent the climate sequences for which the indoor temperature set point (26°C) is exceeded

The blue dots represent the climate sequences for which the indoor temperature set point is respected.

A clear separation is observed between red and blue dots. The separation is clear enough to draw a dotted border line in black. This proves that for this situation the indoor thermal environment of the room seven (the worst one for heat exposure) can be anticipated thanks to indicators calculated on the x and Y axes.

It is now necessary to extend the validity of this representation to other situations (climate). For this, the work carried out on the summer of 2023 will be extended to other summers.

30% of the days in which the temperature days are too high

Each dot represents a climate sequence, and at each day correspond a climate sequence (e.g: the day number 5 of a given month represents the climate sequence from the day 1 to the day 5, and the day number 6 represents the climate sequence from the day number 2 to the day number 6, et.).

Limits

- The thermal loading time depends on building characteristics and scenario variables such as internal heat gains, ventilation rates, and thermal inertia
- Increasing the number of hours with windows open can help reduce the thermal loading time
- Extending the night-time ventilation period can limit the duration during which indoor temperatures exceed acceptable thresholds
- To achieve a robust and reliable limit curve, the model should be trained across multiple simulation sequences

Perspectives

- Consolidate curve using several summers (ongoing)
- Study variants to evaluate performance of solutions
    - Model plants (ongoing)
    - Insulation level
    - Inertia (suppress false ceilings – dust problem, increase indoor walls thickness, is this planned for renovation?)
    - Different ventilation scenarios
- Other climates
- Calculate probabilities of occurrence
- Consider other possible representations

Will the insulation level change as part of the refurbishment? What will the building's insulation standard be after the renovation?

- Windows will be a key focus during the refurbishment.
- It would be helpful to specify design and usage aspects of the windows—for instance, they should ideally open at the top to allow airflow that does not directly affect patients
- 30% of window area might remain open throughout night to ensure sufficient ventilation
- Consider implementing different window-opening strategies:
    - Direct airflow toward the ceiling rather than across patients
    - Model airflow rates to optimise ventilation while mitigating indoor temperature fluctuations

Questions to be clarified by Kathi:

- Are nurses permitted and/or able to open the windows at night?
- Under what conditions can windows be opened during night-time hours?
- How exactly can the windows be operated—can they be fully opened, partially opened (e.g., one window only), or just "gekippt"

Meeting 8

Date: 23.05.2025
Time: 09:00 – 11:00

Agenda

1. Update on Modelling
2. Next Steps
3. **Limitations & Open Questions**

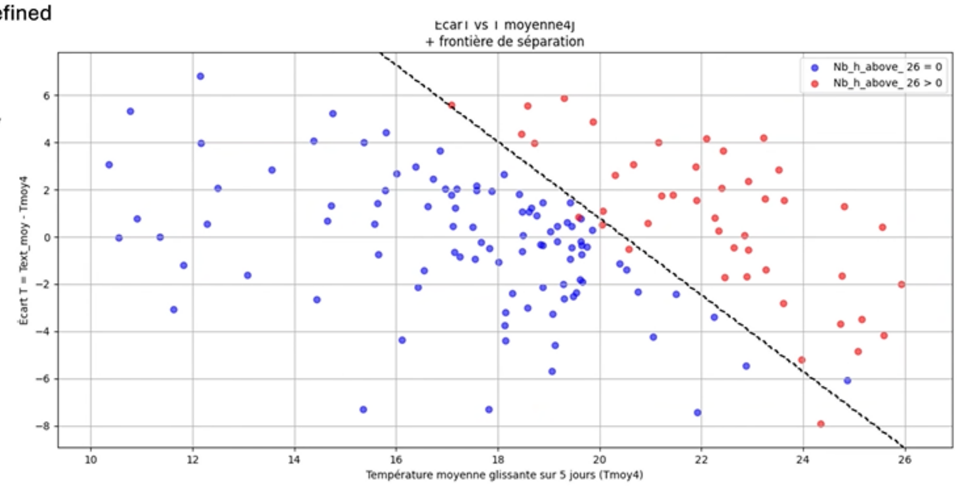
Outcomes

Ad 1. Update on Modelling

Operating limit exceeded depending on outdoor temperature

The main results: first representation (summer 2023)

Each climate sequence are put on the plan defined by :
X axe : T_{m4D}
Y axe: ΔT
Calculated previously



- Horizontal axis: mean daily temperature in four days (Tm4d)
- Vertical axis: difference in temperature between 5th day and Tm4d
- Colours represent indoor comfort (blue: comfortable, red: not)
- Interesting to look at the number of red dots

An efficient solution aims to minimise (or completely eliminate) all red dots. The simulation above corresponds with nurses' observations that many days are uncomfortable and hot.

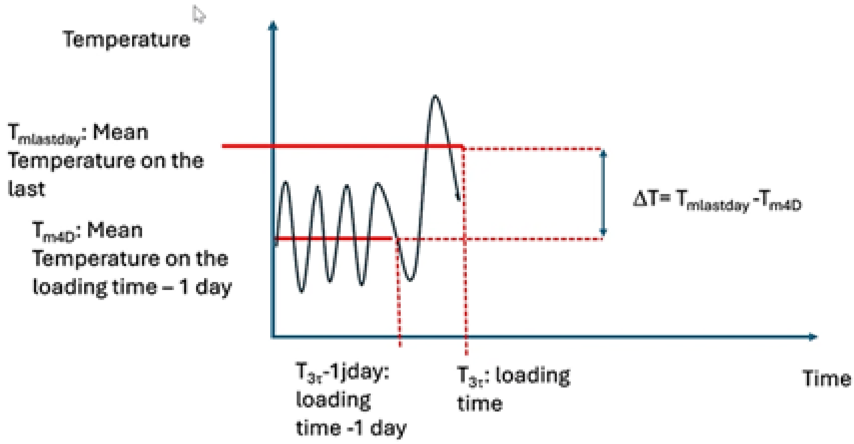
26 degrees is the threshold (based on ÖNORM 6020)

Evolution of outdoor temperature during the loading time

Each outdoor climate sequence is defined with two criteria:

- T_{m4D}: the mean Temperature calculated from the first day to the penultimate day of the loading time
- $\Delta T = T_{mlastday} - T_{m4D}$: the difference between the T_{m4D} and the mean temperature of the last day of the loading time

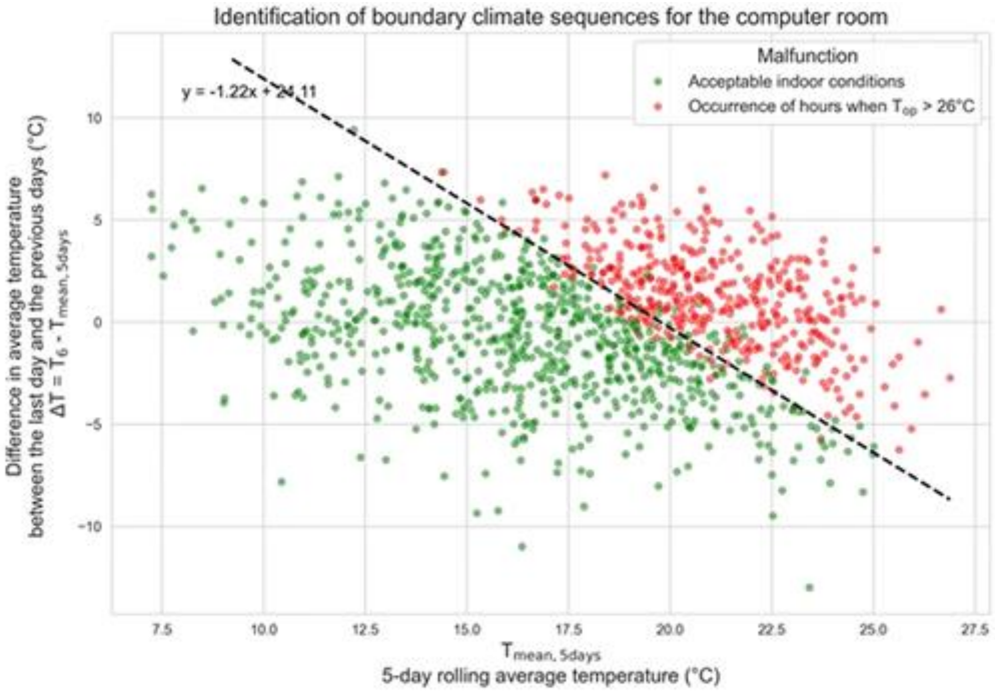
This is done to find how hot can be the last day of the loading time not to exceed the inside required conditions considering how much the envelop is loaded (information given by the previous outside temperature during the loading time.)



Results

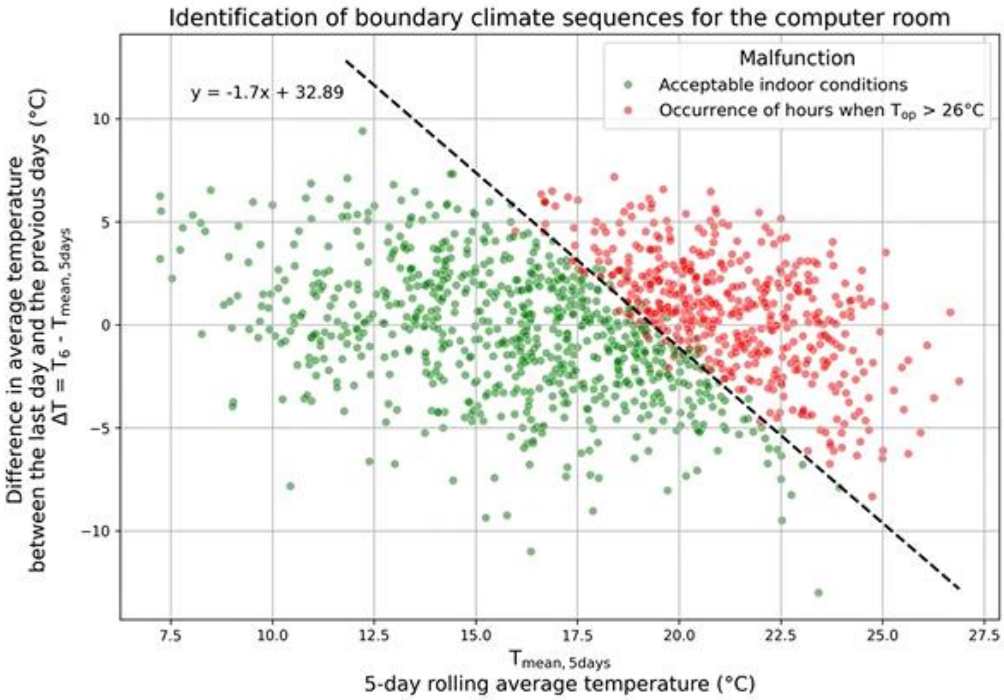
Results for scenarios current (=windows are open from 07:00 to 09:30) and optimal ventilation (=windows are open a lot, also during the night, open if Text > Tint and Tint >22°C to avoid cold).

- Computer room in optimal ventilation



In this scenario, 35% of the dots are red, indicating that nurses experience uncomfortable working conditions 35% of the time (35% of days).

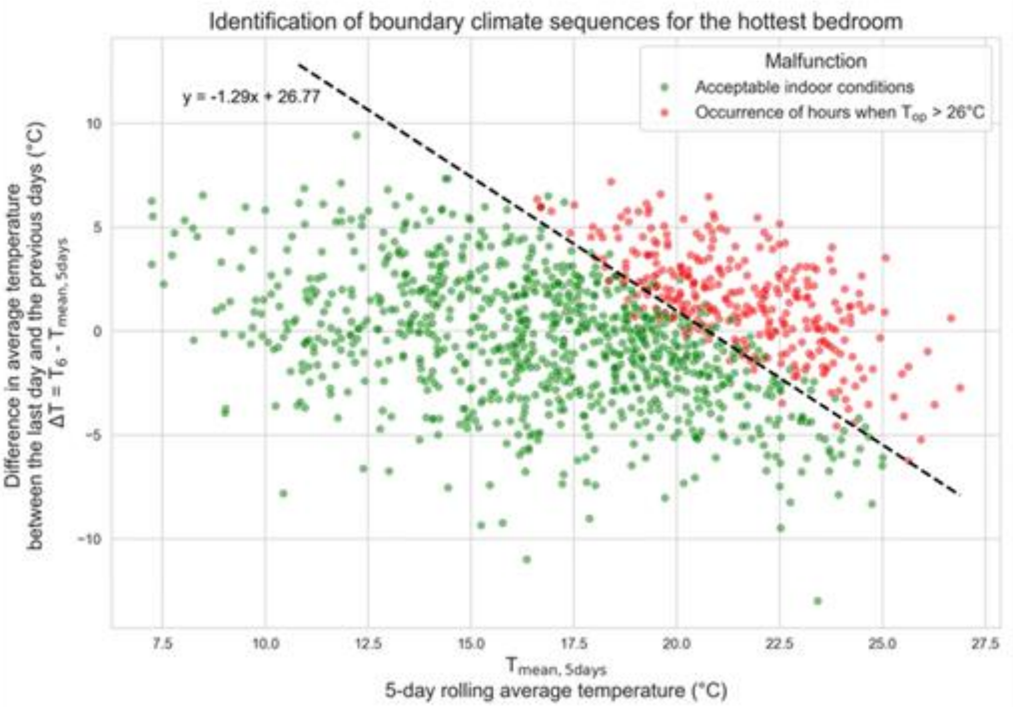
- Computer room in current situation



In this scenario, 40% of the dots are red, indicating that nurses experience uncomfortable working conditions 40% of the time. This suggests that even the optimal ventilation scenario offers only limited improvement compared to the current ventilation management.

This analysis is based on current climate conditions, using data from the past eight summers. As future summers are likely to be even hotter, the percentage of time nurses experience uncomfortable working conditions is expected to rise.

- Hottest bedroom in optimal ventilation



Hottest bedroom current scenario: 30%

Hottest bedroom optimal ventilation: 26%

Ad 2. Next Steps

The next step will be for CSTB to model the impact of plants on indoor comfort. This analysis is scheduled to take place during the first week of June. TIKLI first needs to determine whether the plants should cover walls or windows, as well as what leaf area index would be realistic.

LAI ~0.25 LAI ~0.75 LAI ~1.5

Fig. 9. Plant layer with different leaf area index.

Ad 3. Limitations & Open Questions

Limitations

A red dot is displayed even if the temperature exceeds 26°C for just one hour during the day, potentially overstating the duration of discomfort.

The visualisation does not portray the intensity of thermal discomfort as it could represent a relatively mild 27°C or a much more severe 34°C.

Open Questions

What is the actual temperature during these periods of discomfort? Is it a mild 27°C or a potentially dangerous 34°C? (to be answered by CSTB)

What kind of indicator could better reflect not only the frequency but also the intensity of thermal discomfort – something more informative than just the percentage of time? (to be answered by TIKLI)

Addition Katharina – Answers to Open Questions

- Q: Check how long and to what extent (tilted or fully open) windows can be opened during day and night.

  A: The windows can be fully opened at any time, both during the day and at night. This is occasionally done. For instance, Austrian patients are used to sleeping with open windows and often prefer to do so in the hospital as well. In contrast, many foreign patients tend to prefer sleeping with the windows closed; in such cases, the windows remain shut. Only when it is very windy ("Föhnwind") the windows remain closed in all rooms.

- Q: Assess the need for an additional indicator of indoor thermal comfort – what specific insights should this second indicator provide?

  A: With regard to the additional indicator, it would be helpful to know how warm the room gets on days when the temperature exceeds 26 degrees (intensity), and how long it remains at that elevated level (duration of discomfort).

- Q: Determine the desired placement and extent of plant coverage (walls and/or windows, LAI)?

  A: The plant coverage should primarily be placed close to the walls and not in front of the windows. They cannot be positioned directly on top of the walls, as the building has these "panels" that may not support the weight. However, planters could be installed on the balcony and positioned close to the walls.

  In our case, a realistic Leaf Area Index is likely around 0.25. However, we also think it would be valuable to simulate a higher coverage scenario with an LAI of around 1.5 as an ideal case, to better understand the potential impact.

Meeting 9

Date: 11.06.2025
Time: 14:30 – 16:00

Agenda

1. Updates on Modelling
2. Report final

Outcomes

First, we discussed the open questions from last time

Second, CSTB showed us the progress made on the report

- We addressed several open questions, particularly related to the time periods:
    - 2000–2025 (historical)
    - 2025–2050 (near future)
- For the present period, they used data from 8 summers, including:
    - Some recent hot summers
    - Exceptionally hot years like 2013 and 2015
    - The last 5 summers, which were also notably warm

  This selection ensures that the present period includes a sufficient number of hot summers.

- The results are based on the entire period from 2000 to the present, allowing for a valid historical comparison.
- It was noted that relying solely on passive solutions may not be sufficient to maintain thermal comfort under current and projected heat conditions.

Simulation Setups

- 2 scenarios for the initial situation
- 2 scenarios for optimal ventilation
- 2 scenarios for green façades
- 1 analysis for the hottest room
- 1 analysis for the computer room

Climate Scenarios

- RCP 8.5 was used, although RCP 4.5 could have been selected.
    - By 2050, both RCPs yield similar climate projections.
    - Differences become more pronounced only by 2100.

Climate Models

- 3 different climate models were used.
- A comparative table shows data for both the historical and future periods.

Discussion Points

- Clarify the reasoning behind focusing on either short- or long-term future.
- Include additional questions as part of the feedback process.
- Two options were mentioned for next steps:
    - Either present the analysis as a perspective or conclusion
    - Or conduct further simulations/tests

Key Insight

Passive solutions alone will not be sufficient to fully protect occupants from heat stress — this will likely be a central conclusion.

Meeting 10

Date: 27.06.2025
Time: 09:00 – 11:00

Agenda

1. Rapport-final

Outcomes

During today's meeting, CSTB and TIKLI discussed the feedback and open questions related to the Rapport-final (part of deliverable D2.3).

We agreed that CSTB will implement minor revisions by today (27.06.2025), while TIKLI will provide additional feedback during the following week. Since Jean-Marie is currently on holiday, no major changes will be made to the document before August.

Some detailed notes:

- Step 4: This section is currently unclear — Mathilde will revise it
- Result: The output is the regression analysis.
- Table 8: Add additional period 2050-2100
- Temperature threshold: 5% of the hours are above 26°C
- Period considered: From 1st May to 30th September; if only the summer months were considered, the percentage would be even higher.
- Occurrence is expressed in hours [h]

Interview guide

☐ Plan a free discussion time on how the service works before the guided interview.

☐ Are there particularly hot days or climatic events (summer) that have marked your memory?

What are the issues perceived by occupants during summer or heatwaves ?

To predict a degraded scenario

☐ How do you feel in this zone of the hospital during summer? Do you find it bearable?

☐ Are there difference between rooms? Which rooms are the most uncomfortable?

☐ Do the occupants complain about the thermal environment? the noise? other...?

☐ Are there differences in perception between classic summer and heatwave periods?

How building is used in summer and heatwaves?

☐ Do you take any special measures in summer to ensure your thermal comfort?

☐ What constraints prevent you from adapting to heat, or reduce your ability to do so?

These two general questions can also be used to answer questions about occupancy and equipment.

Occupation

☐ Can you tell me how the building is usually occupied ?

(Personal comment: either let them tell the story and make sure that the essential questions are answered or ask the questions directly)

The objective is to estimate heat flux and the water vapor production emitted by occupants

→ for a typical room and for a room at maximum capacity

Typical room

- Number of people in the different rooms
- Age
- Physical intensity of the occupants' activity (at rest, office activity, standing, walking, ...)
- Level of insulation of clothing: « cotton blouse »

	Week		Weekend	
	Night	Day	Night	Day
Patient				
Staff				
Visitor				

☐ Are there differences depending on the days of the week?

Room at maximum capacity

	Week		Weekend	
	Night	Day	Night	Day
Patient				
Staff				
Visitor				

☐ Are there differences depending on the days of the week?

If the occupation scenario is more complex:

Day	morning	Arrival time	Departure time	Number of people		
				Patient	Staff	Visitor
Monday	Morning					
	Afternoon					
	Night					
Tuesday	Morning					
	Afternoon					
	Night					

Wednesday	Morning					
	Afternoon					
	Night					
Thursday	Morning					
	Afternoon					
	Night					
Friday	Morning					
	Afternoon					
	Night					
Saturday	Morning					
	Afternoon					
	Night					
Sunday	Morning					
	Afternoon					
	Night					

Equipment

Inside appliances

☐ Can/do people use a fan when it is hot?

☐ Is it possible to change the air ventilation speed, and if yes when?

☐ What is the energy consumption of inside appliances and how long do they run? *(information to build indoor heat loads)* fridge, light, health equipment incubator?

This information can be difficult to obtain. To have a figure I propose to

- Inventory electrical appliances (oven, …)
- Roughly assess in the operating time

Electrical appliance and other source of heat	Where (room/ hall)	Power (or energy consumption)	Running time (when how long)	Comments
Oven				

Incubator				
Fridge				
Other				

☐ Do you have an electrical consumption bill or statement of gas electricity energy consumption excluding heating ? (or during summer)

Sanitary equipment

Equipment	Where	number	Roughly Running time	Comments
Shower			At what time How long	
Sink				
WC				

Windows

☐ Are the windows open? At night? During the day?

If yes

☐ Why are they opened? (to hot, to cold, what is the motivation to open the windows ?)

☐ Who manage the windows (patient, staff ??)

☐ Which part of the windows are open?

☐ In which room?

☐ For how long?

If not

☐ Why are there not opened?

This question is to identify the problem, it is not directly link to modelisation, answer is not necessary yet but it could help to build the link between this task and others from the UE project)

- Draught air velocity to strong?
- Outside noise? (roof top?)
- Security problem?
- Pests (insects, mosquitos, rodents, etc.)
- Pollen?
- Smells?

Doors

☐ Are inside doors open? During the day? During the night?

☐ If yes how long and when?

☐ If not what are use obstacles?

☐ Who manages the doors?

Solar shading

☐ Do people use solar protection and why? (radiation or privacy or other reason)

☐ Are there obstacle to use solar shadings? (air velocity to strong, etc)

Solar shading and/or shutters	Where? Who can use it ?	Characteristics Color Outside/inside Opacity	Running time (during the day, during the night)	Comments

Look how the adjustable blades are tilted

☐ Are they easy to use?

Building

Items can be observed and require clarification only if necessary.

Check the size of rooms or some distances if necessary

Take photos if needed

What is the color of the wall, floor, ceiling

Floor characteristics (effusivity: thickness, nature PVC, wood, plaster board, tile, floor paint, resin, raw floor without covering: concrete, cement screed, …)

False ceiling (ventilated yes / not: can air circulate easily or not between the room and the ceiling structure through the false ceiling)

☐ Are there already temperature and/or humidity sensors in the rooms? Can we access the data?

Any other information?

☐ Are there any anecdotes that illustrate how the building works?

On the roof there are rooftop are they running in summer? at night?

Annex II – Disaster Preparedness Checklist and Guidance

PRE-HOSPITAL MEDICAL EMERGENCY SERVICES

DISASTER PLANNING AND COORDINATION	YES	PARTIALLY	NO
Emergency medical services are equipped with a periodically updated disaster plan.	❑	❑	❑

Include in the plan:

- Crisis standards of care (incl. scope of practice and patient destination)
- Instructions on rapid identification and deployment of staff
- Pre-hospital triage/decontamination processes
- Paediatric-specific transportation strategy
- Post-disaster recovery instructions

Ensure that the experiential knowledge of local stakeholders, such as mountain guides and mountain refuge keepers, is integrated into planning processes.

	YES	PARTIALLY	NO
The local emergency medical services disaster response system is part of a larger disaster response mechanism at the regional and national levels.	❑	❑	❑

Participate in coalitions to promote interdisciplinary collaborations for disaster response.

	YES	PARTIALLY	NO
Emergency medical services periodically conduct Hazard Vulnerability Assessment.	❑	❑	❑

Promote:

- Mapping specific risks for emergency medical services (incl. identification of high-risk areas prone to isolation due to heavy snowfall, avalanches and landslides)
- Using these assessments to prioritise measures to reduce risk

STAFF TRAINING AND HUMAN RESOURCES	YES	PARTIALLY	NO
Emergency medical services are equipped with an Incident Command System to respond to disasters, which defines roles and legal responsibilities.	❑	❑	❑

Include in the Incident Command System:

- An updated list of staff contacts (primary and secondary telephone numbers)
- A process to track staff availability and location, response times and mobilisation of additional staff, including standby volunteers
- A strategy with neighbouring providers to enable impacted staff to work at alternate locations during disasters

Emergency medical services staff attend training and simulations to test protocols and surge capacity procedures in case of a disaster.	❑	❑	❑
Include in the training: • Evacuation-specific exercises and drills (incl. paediatric evacuations) • Lessons learned from after action reviews of past disasters • Psychological first aid educational materials for staff • Modules on occupational safety and health (incl. Post-Traumatic Stress Disorder management) • Modules on public health and climate change hazards • Modules on managing hazardous chemicals during disasters • Procedures for using supplies and accessing alternative sources • Cross-training to address staff shortages and expertise backup • Training to work in hostile environments (incl. walking on steep slopes, ice and water, as well as operating in cold, windy and rainy conditions)			
Emergency medical services staff are involved in planning and preparing for disasters. For instance, they collaborate to develop disaster plans or their subsequent periodical revisions.	❑	❑	❑
Emergency medical services have a post-disaster employee recovery assistance programme to activate in case of need.	❑	❑	❑
Establish: • A system to determine whether staff have been affected by the disaster and to assess individual needs (incl. shelter, transportation, food and hygiene, childcare, funding and flexible schedules) • A crisis counseling assistance program including physical, emotional, and psychological support			
INFRASTRUCTURE AND RESOURCE MANAGEMENT			
Emergency medical services create, maintain and update an inventory of essential drugs and supplies, along with their sources, including public and private affiliations, local pharmacies and drug companies.	❑	❑	❑
Include in the plan a Memorandum of Understanding with retail stores to ensure immediate access to pharmacies and supplies (incl. personal protective equipment)			
COMMUNICATION AND EARLY WARNING			
Emergency medical services system is linked to a meteorological service for updates and early warnings (incl. a cross-country weather monitoring system if needed).	❑	❑	❑
Emergency medical services are equipped with notification procedures for key staff and response team members.	❑	❑	❑
Include in the notification system: • The dissemination of clear guidance on safety measures • Action points for immediate response according to the type of event Ensure that: • Staff is appropriately trained in the interpretation of notifications			

• Communications also effectively reach those who are visually or hearing impaired			
Emergency medical services record electronic patient health information that can be made available to receiving facilities in case of evacuations.	❑	❑	❑
Emergency medical services of a cross-border region have a system to communicate and coordinate with emergency medical services in the neighbouring country.	❑	❑	❑
Develop and formalize: • Communication protocols with the neighbouring country • Joint action plans with the neighbouring country • The implementation of cross-border emergency drills and exercises			
PARTNERSHIPS AND COMMUNITY INTEGRATION			
Emergency medical services system coordinates with hospitals, local disaster management agencies and healthcare coalitions for centralised patient transport and distribution in case of evacuations.	❑	❑	❑
Ensure that the system: • Identifies access-to-care challenges in rural, hard-to-reach areas • Utilises essential patient transfer information • Notifies patient families and providers of evacuation destinations • Establishes strategic evacuation points in mountainous regions			
Emergency medical services have ongoing collaborative relationships such as Memorandum of Understanding and mutual aid strategies with traditional and non-traditional partners.	❑	❑	❑
Consider partnerships with public health agencies, private providers, healthcare coalitions, mountain refuge keepers, ski resorts, schools, and transportation services.			
PATIENT CARE AND SERVICE CONTINUITY			
Emergency medical services have continuity of operations plans for delivering services in the event of a disruption, including alternative transportation options.	❑	❑	❑
Include in these plans: • Contingency procedures to ensure that staff can continue providing services at alternative locations • Identification of additional vehicles to be converted for patient care (incl. helicopters, off-road vehicles, and snowmobiles for accessing isolated areas)			
RECOVERY AND MONITORING & EVALUATION			
The disaster plan for emergency medical services includes guidelines for disaster recovery.	❑	❑	❑

The disaster plan for emergency medical services includes guidelines for Monitoring & Evaluation.	❑	❑	❑

These guidelines should:

- Establish a protocol to ensure a comprehensive after-action review
- Assign responsibility for compiling the after-action review
- Use after action reviews to inform future preparedness plans

HOSPITAL

DISASTER PLANNING AND COORDINATION	YES	PARTIALLY	NO
The hospital is equipped with a periodically updated disaster plan.	❑	❑	❑

Include in the plan:

- Process to activate surge capacity (incl. triggers)
- Crisis standards of care
- Instructions for emergency medication stockpiling and distribution
- Plan for occupational health and safety
- Ward-specific considerations (incl. OB/GYN, dialysis, paediatric, intensive care unit)
- Post-disaster recovery instructions

Ensure that the experiential knowledge of local stakeholders, such as mountain guides and mountain refuge keepers, is integrated into planning processes.

The hospital disaster response system is part of a larger disaster response mechanism at the regional and national levels.	❑	❑	❑

Participate in coalitions to promote interdisciplinary collaborations for disaster response.

The hospital is equipped with a periodically updated evacuation plan.	❑	❑	❑

Include in the evacuation plan:

- Facility-wide and ward-specific triggers to signal the need for evacuation
- Contingency plans for access and egress during a disaster for staff and patients
- Procedures for transferring critical equipment and supplies, staff, and patients to another facility, secure storage or unit receiving relocated patients
- Contracts with transportation providers for vehicle supply
- Options for alternative vehicles' use for evacuations (incl. helicopters, off-road vehicles and snowmobiles), considering the possibility of narrow paths and heavy snow

The hospital periodically conducts Hazard Vulnerability Assessment.	❑	❑	❑

Promote:

- Mapping of risks to the facility's structural and non-structural elements
- Using these assessments to prioritise measures to reduce risk

STAFF TRAINING AND HUMAN RESOURCES

The hospital is equipped with an Incident Command System to respond to disasters, which defines roles and legal responsibilities.	❑	❑	❑

Include in the Incident Command System:

- An evacuation decision-making algorithm clarifying legal authority, responsibilities and planned vs immediate evacuation criteria
- An up-to-date list of staff contacts (primary and secondary telephone numbers)
- A process to track staff availability and location, response times and mobilisation of additional staff, including standby volunteers
- A strategy with neighbouring providers to enable impacted staff to work at alternate locations
- The appointment of a disaster recovery office

Hospital staff attend training and simulations to test protocols and surge capacity procedures in case of a disaster.	❑	❑	❑

Include in the training:

- Ward-specific exercises and drills (incl. evacuation procedures, alternate routes)
- Triage protocols
- Lessons learned from after action reviews of past disasters
- Psychological first aid educational materials for staff
- Modules on occupational safety and health (incl. Post-Traumatic Stress Disorder management)
- Modules on public health and climate change hazards
- Modules on managing hazardous chemicals during disasters
- Procedures for using supplies and accessing alternative sources
- Cross-training to address staff shortages and expertise backup

Hospital staff are involved in planning and preparing for disasters. For instance, they collaborate to develop disaster plans or their subsequent periodical revisions.	❑	❑	❑
The hospital has a post-disaster employee recovery assistance programme to activate in case of need.	❑	❑	❑

Establish:

- A system to determine whether staff have been affected by the disaster and to assess individual needs (incl. shelter, transportation, food and hygiene, childcare, funding and, flexible schedules)
- A crisis counselling assistance program including physical, emotional, and psychological support

INFRASTRUCTURE AND RESOURCE MANAGEMENT

The hospital is designed to minimise structural vulnerability to the impacts of disasters.	❑	❑	❑

Implement the following measures:

- Relocate generators, fuel pumps, and related electrical equipment out of basements
- Pre-design evacuation areas with secure access
- Establish a safe storage location for healthcare waste
- Ensure the hospital has separate spaces for lower-priority and critical patients

• Integrate “Safe Hospitals” and “Smart Hospitals” initiatives into the health system strategic plan and use the Hospital Safety Index to periodically assess hospital disaster preparedness			
The hospital has a strategy to address disruption to critical utilities (incl. backup energy solutions).	❑	❑	❑
Make sure this strategy encompasses the following: • A backup generator capable of covering at least all critical service areas and equipment during and after a disaster (plan for high-efficiency generators with fuel reserves protected against freezing) • Identification of priority areas within the facility that require emergency power during and after a disaster • A plan to ensure the availability of adequate lighting, communication and information systems (e.g., analogic backup, satellite and radio systems) • Instructions on how to provide and maintain adequate cleaning and disinfection supplies for water safety • Instructions for the maintenance and restoration of waste management systems • Installation of thermometers in refrigerators and freezers to determine if food, vaccines, and other essential refrigeration-dependent medical supplies are safe during a power outage			
The hospital has an inspection mechanism in place to assess the facility regularly, both internally and externally, for signs of deterioration.	❑	❑	❑
The hospital establishes, maintains and updates an inventory of essential drugs and supplies, along with a register of suppliers, including public and private affiliations, local pharmacies and drug companies.	❑	❑	❑
Consider for the inventory: • Memorandum of Understanding with nearby retail stores for immediate access to groceries, pharmacies and medical supplies • A process to maintain a 72-hour supply of essential drugs in case of shelter-in-place • A procedure to maintain an adequate supply of personal protective equipment • A process to identify and secure a storage space within or external to the facility for stockpiling additional supplies			
The hospital has a plan to accommodate staff if shelter-in-place is required. The plan encompasses the availability of adequate food, transportation, crisis counselling, and rest.	❑	❑	❑
Prepare the hospital for possible displaced community members seeking refuge (e.g., food, water, shelter, electrical outlets, accommodations) during a disaster			
The hospital has adequate resources, supplies and spaces for mass fatality management.	❑	❑	❑
Implement: • Morgue capacity • Portable refrigerated trailers • Spaces with the capability for additional cooling			

COMMUNICATION AND EARLY WARNING

The hospital system is linked to a meteorological service for updates and early warnings (incl. a cross-country weather monitoring system if needed).	❑	❑	❑
The hospital is equipped with notification procedures for staff and a system in place to alert patients.	❑	❑	❑

Include in the notification system:

- The dissemination of clear guidance on safety measures
- Action points for immediate response according to the type of event
- A system to communicate with families

Ensure that:

- Staff is appropriately trained on the interpretation of notifications
- Communications effectively reach also those who are visually or hearing impaired

The hospital has a surveillance system for infectious diseases.	❑	❑	❑
The hospital records electronic patient health information that can be shared with receiving facilities in case of evacuations.	❑	❑	❑

PARTNERSHIPS AND COMMUNITY INTEGRATION

The hospital has ongoing partnerships with regional disaster response teams, public health agencies, private physicians, healthcare coalitions, schools, and transportation services for disaster management.	❑	❑	❑
The hospital has active plans and other documentation, such as Memorandum of Understanding, in place to help facilitate evacuations in case of a disaster.	❑	❑	❑

Consider partnerships with:

- neighbouring hospitals, public health agencies, private physicians, healthcare coalitions, dialysis providers, ski resorts, schools, and transportation services

Consider collaborative networks between:

- mountain hospitals and urban centres to manage patient surges effectively

PATIENT CARE AND SERVICE CONTINUITY

The hospital has triage protocols for disaster events and designated triage areas.	❑	❑	❑

Include reverse triage protocols for early discharge of non-critical patients

The hospital has continuity of operations plans that anticipate prolonged disruption of care.	❑	❑	❑

Include in these plans:

- Contingency procedures to ensure that the staff can continue providing services at other facilities or in local communities
- A list of core health services to be provided during disasters and those to be suspended (incl. surgeries and elective procedures)
- Identification of additional spaces to be converted for patient care
- Specific strategies to guarantee continuity of essential therapies (incl. dialysis)
- Conventional, contingency and crisis resource allocation strategies and related ethical considerations

RECOVERY AND MONITORING & EVALUATION			
The hospital has established processes for incident demobilisation and the restoration of systems to normal operations.	❑	❑	❑

Make sure these processes:

- Include a step-by-step process for returning to normal operations (incl. recovery plan to catch up on missed procedures and surgeries)
- Clear indication of when to begin the recovery phase
- Include communication protocols to keep all stakeholders informed

The disaster plan for hospitals includes guidelines for monitoring & evaluation.	❑	❑	❑

These guidelines should:

- Establish a protocol to ensure a comprehensive after-action review
- Assign responsibility for compiling the after-action review
- Use after action reviews to inform future preparedness plans

PRIMARY CARE AND ELDERLY CARE SYSTEMS

DISASTER PLANNING AND COORDINATION	YES	PARTIALLY	NO
The primary care and elderly care systems are equipped with periodically updated disaster plans.	❑	❑	❑

Include in the plan:

- Process to activate surge capacity (incl. plan to extend working hours)
- Crisis standards of care (incl. phone triage or telehealth)
- Instructions for medication stockpiling and distribution
- Plan for occupational health and safety
- Instructions on managing an influx of patients (incl. paediatric)
- Post-disaster recovery instructions

Ensure that the experiential knowledge of local stakeholders, such as mountain guides and mountain refuge keepers, is integrated into planning processes.

The primary care and elderly care disaster response systems are part of a larger disaster response mechanism at the regional and national levels.	❑	❑	❑

Participate in coalitions to promote interdisciplinary collaborations for disaster response.			
The primary care and elderly care systems are equipped with periodically updated evacuation plans.	❑	❑	❑
Include in the evacuation plan: • An updated registry of vulnerable patients incl. medically fragile individuals with pre-existing conditions (e.g., disabilities, chronic illnesses, and mental health disorders), as well as those who are socioeconomically or culturally vulnerable and individuals facing challenges related to housing, location, or transportation • Procedures for sheltering patients, volunteers and staff • Facility-wide and ward-specific triggers to signal the need for evacuation • Contingency plans for access and egress during a disaster for both staff and patients (incl. Specific considerations for fragile patients) • Procedures for transferring critical equipment and supplies, staff, and patients to another facility, secure storage or unit receiving relocated patients • Contracts with transportation providers for vehicle supply • Options for alternative vehicles' use for evacuations (incl. helicopters, off-road vehicles and snowmobiles), considering the possibility of narrow paths and heavy snow			
The primary care and elderly care systems periodically conduct Hazard Vulnerability Assessment.	❑	❑	❑
Promote: • Mapping of risks to the facility's structural and non-structural elements • Using these assessments to prioritise measures to reduce risk			
STAFF TRAINING AND HUMAN RESOURCES			
The primary care and elderly care systems have active, functional disaster response committees with clearly defined roles.	❑	❑	❑
Designate alternates/backup personnel for each role			
The primary care and elderly care systems' staff attend training and simulations to test protocols and surge capacity procedures in case of a disaster.	❑	❑	❑
Include in the training: • Exercises and drills on evacuation procedures and alternate routes • Paediatric surge capacity exercises and drills • Lessons learned from after action reviews of past disasters • Psychological first aid educational materials for staff • Modules on occupational safety and health (incl. Post-Traumatic Stress Disorder management) • Modules on public health and climate change hazards • Modules on managing hazardous chemicals during disasters • Procedures for utilising supplies and accessing alternative sources • Cross-training to address staff shortages and expertise backup • Triage, basic or advanced life support, bleeding control and management of disaster-specific injuries or diseases • Infectious disease outbreaks, Infection Prevention and Control standards, surveillance/early warning, and case management for relevant public health threats			

• Cross-training for handling medical equipment and alternative methods for care delivery in resource-limited settings			
The primary care and elderly care staff are involved in planning and preparing for disasters. For instance, they collaborate to develop disaster plans or their subsequent periodical revisions.	❑	❑	❑
The primary care and elderly care systems have family support programs for staff and a post-disaster employee recovery assistance program to activate in case of need.	❑	❑	❑
Establish: • A system to determine if staff have been affected by the disaster and to assess individual staff needs (incl. shelter, transportation, food and hygiene, childcare, funding, flexible schedules)			
The primary care and elderly care systems have a structured workforce retention strategy to ensure staff continuity.	❑	❑	❑
Include in the strategy: • Details on workers' competencies, contact information, availability, and roles non-physicians can assume in case of need. • A roster of volunteers who can support health promotion, outreach and preventive measures			
INFRASTRUCTURE AND RESOURCE MANAGEMENT			
The primary care and elderly care facilities are structured and designed to minimise structural vulnerability to the impacts of disasters.	❑	❑	❑
Implement the following measures: • Relocate generators, fuel pumps, and related electrical equipment out of basements • Pre-design evacuation areas with secure access • Establish a safe storage location for healthcare waste • Ensure the facility has separate spaces for lower-priority and critical patients			
The primary care and elderly care systems have a strategy to address disruption to critical utilities (incl. backup energy solutions).	❑	❑	❑
Make sure this strategy encompasses the following: • A backup generator capable of covering at least all critical service areas and equipment during and after a disaster • Identification of priority areas within the facility that require emergency power during and after a disaster • A disaster plan to ensure the availability of adequate lighting, communication and information systems (e.g., analogic backup, satellite and radio systems) • Instructions on how to provide and maintain adequate cleaning and disinfection supplies for water safety • Instructions for the maintenance and restoration of waste management systems • Installation of thermometers in refrigerators and freezers to determine if food, vaccines, and other essential refrigeration-dependent medical supplies are safe during a power outage			

The primary care and elderly care system have an inspection mechanism in place to regularly assess the facility, both internally and externally, for signs of deterioration.	❑	❑	❑
The primary care and elderly care systems create, maintain and update an inventory of essential drugs and supplies and their sources, including public and private affiliations, local pharmacies and drug companies.	❑	❑	❑

Include in the inventory:

- Memorandum of Understanding with nearby retail stores for immediate access to groceries, pharmacies and medical supplies
- A process to maintain a 72-hour supply of essential drugs, including paediatric ones, in case of shelter-in-place
- A procedure to maintain an adequate supply of personal protective equipment
- A process to identify and secure a storage space within or external to the facility for stockpiling additional supplies

COMMUNICATION AND EARLY WARNING

The primary care and elderly care systems are linked to a meteorological service (incl. a cross-country weather control system if needed) for updates and early warnings.	❑	❑	❑
The primary care and elderly care systems are equipped with notification procedures for key staff and response team members along with a system to alert patients.	❑	❑	❑

Include in the notification system:

- The dissemination of clear guidance on safety measures
- Action points for immediate response according to the type of event
- A system to communicate with families

Ensure that:

- Staff is appropriately trained on the interpretation of notifications
- Communications effectively reach also those who are visually or hearing impaired

The primary care and elderly care systems record electronic patient health information that can be made available to receiving facilities in case of evacuations.	❑	❑	❑

Ensure that:

- Computer systems are regularly backed up off-site and key information is kept in hard copy (e.g. contact lists and medical details)
- Specific continuity plans for patients dependent on medical equipment (e.g., O2 concentrators, Continuous Positive Airway Pressure machines) are in place

The primary care and elderly care facilities have communication mechanisms in place to communicate status and availability of services to the population in case of a disaster.	❑	❑	❑

Include:

- A plan for status updates on websites and call lines that are separate from crisis intervention hotlines or disaster service numbers

Ensure that:

- The practice's ability to communicate proactively with patients and their relatives is developed and tested

PARTNERSHIPS AND COMMUNITY INTEGRATION

The primary care and elderly care systems have active collaborations, such as Memorandum of Understanding, to formalise relationships for evacuations and surge capacity.	❑	❑	❑

Establish collaborations with:

- Hospitals
- Local primary care paediatricians
- Companies providing life-support devices
- Local childcare and school directors
- Hospices
- EMS
- Public health agencies
- Healthcare coalitions
- Wellness centers
- Public transportation and school transportation services
- Private providers
- Mountain refuge keepers and ski resorts

The local population is involved in risk reduction management, policy making, planning and implementation.	❑	❑	❑

Make sure this strategy encompasses the following:

- Discussions over disaster plans and preparedness strategies during every clinical encounter, especially with vulnerable patients
- Creation of preparedness plans for patients and families (e.g., emergency contact numbers, safe meeting point)

The primary care and elderly care systems are equipped with a community health educational programme on disaster risk reduction practices.	❑	❑	❑

Instruct patients and their families on:

- How to make a disaster evacuation plan or a disaster go-bag
- How to keep a stock of their essential medications
- How to self-administer treatments (i.e., insulin, antibiotics)
- How to use home medical devices
- How to properly store medications in extreme temperatures
- How to ensure basic WASH (Water Sanitation and Hygiene) standards

PATIENT CARE AND SERVICE CONTINUITY

The primary care and elderly care systems have specific triage protocols for different disasters that consider clinical needs and vulnerabilities.	❑	❑	❑
Develop different disaster triage protocols tailored to the specific health consequences of hazards in the specific area			
The primary care and elderly care systems maintain a registry of vulnerable patients and conduct periodic interdisciplinary assessments to address all factors contributing to vulnerability (e.g., homebound, knowledge of local language).	❑	❑	❑
Undertake regular patient health assessments in order to identify risk factors that influence patient wellbeing (e.g., medical examination, current medications, immunisation status, physical, psychological and social functioning) Consider the specific needs of those with visual or hearing impairments, physical disabilities, etc.			
The primary care and elderly care systems have continuity of operations plans that anticipate prolonged loss of essential infrastructure.	❑	❑	❑
Include in these plans: • Possibility to write prescriptions in bulk so that patients can have at least a month's worth of medication available • Mechanisms to proactively contact patients whose services were interrupted • Instructions for dealing with loss of power, water, gas, communications, cooking and laundry facilities • Measures to continue operations in alternative facilities (incl. neighbouring buildings) or in-home assistance or telemedicine • A plan for drive-up options for testing, screening and distribution of medical countermeasures • A list of core health services to be provided during disasters and those to be suspended • Identification of additional spaces to be converted for patient care • Conventional, contingency and crisis resource allocation strategies and related ethical considerations			

RECOVERY AND MONITORING & EVALUATION

The primary care and elderly care systems have established processes for incident demobilisation and the restoration of systems to normal operations.	❑	❑	❑
Make sure these processes: • Include a step-by-step process for returning to normal operations • Set clear indication of when to begin the recovery phase • Include communication protocols to keep all stakeholders informed			
The primary care and elderly care systems disaster plan includes guidelines for monitoring & evaluation.	❑	❑	❑
These guidelines should: • Establish a protocol to ensure a comprehensive after-action review • Assign responsibility for compiling the after-action review • Use after action reviews to inform future preparedness plans			

PHARMACIES

DISASTER PLANNING AND COORDINATION	YES	PARTIALLY	NO
Pharmacies are equipped with a periodically updated disaster plan.	❑	❑	❑
Include in the plan: • Process for medication distribution • Post-disaster recovery plan • Seasonal plans for peak winter and summer hazards, such as avalanches, floods, and wildfires Ensure that the experiential knowledge of local stakeholders, such as mountain guides and mountain refuge keepers, is integrated into planning processes.			
The pharmacy disaster response system is part of a larger disaster response mechanism at the regional and national levels.	❑	❑	❑
Participate in coalitions to promote interdisciplinary collaborations for disaster response.			
STAFF TRAINING AND HUMAN RESOURCES			
Pharmacists attend training and simulations to test protocols and surge capacity procedures in case of a disaster.	❑	❑	❑
Pharmacists are involved in planning and preparing for disasters. For instance, they collaborate to develop disaster plans or subsequent periodical revisions.	❑	❑	❑
Pharmacists are aware of laws and regulations and know how to request a waiver to expand the scope of practice in case of a disaster.	❑	❑	❑
INFRASTRUCTURE AND RESOURCE MANAGEMENT			
Pharmacies are designed to minimise structural vulnerability to the impacts of disasters.	❑	❑	❑
Implement the following measures: • Relocate generators, fuel pumps, and related electrical equipment out of basements and plan for backup energy solutions • Installation of thermometers in refrigerators and freezers to determine if vaccines, and other essential refrigeration-dependent medical supplies are safe during a power outage • Foresee warming devices for medications that may freeze in extreme cold conditions in cold spells and snowstorms			
COMMUNICATION AND EARLY WARNING			
Pharmacies have communication mechanisms in place to communicate status and availability of services to the population in case of a disaster (incl. alternative pickup points).	❑	❑	❑

Plan for status updates on websites and call lines that are distinct from crisis intervention hotlines or disaster services numbers			
Pharmacies can securely access patients' prescription information during disasters in case of power outages.	❑	❑	❑
Complete a backup of all databases and store the information on a remote server and/or removable media			
PARTNERSHIPS AND COMMUNITY INTEGRATION			
Pharmacies have active plans and other documentation, such as Memorandum of Understanding, in place for potential evacuation support and to ensure continuity of care in case of a disaster.	❑	❑	❑
Consider partnerships with: • Consider partnerships with: neighbouring hospitals, public health agencies, private physicians, long-term care facilities, healthcare coalitions, dialysis providers, ski resorts, schools, and transportation services Create collaborative networks between: • Mountain hospitals and urban centres to manage patient surges effectively			
Pharmacies have a contact list of sources for additional medications, including public and private affiliations, nearby pharmacies and drug companies.	❑	❑	❑
PATIENT CARE AND SERVICE CONTINUITY			
Pharmacies have continuity of operations plans that anticipate prolonged loss of essential infrastructure.	❑	❑	❑
Include in these plans: • Flexible approaches to medications delivery (e.g., dispensing prescriptions in advance, larger-than-usual supplies, alternative locations like mobile pharmacy units, use of drones) • Mechanisms to ensure that the refrigerator/freezer is supported by emergency backup power or that plan are in place to relocate refrigerated medications to an alternate location during power outages • Conventional, contingency and crisis resource allocation strategies and related ethical considerations			
RECOVERY AND MONITORING & EVALUATION			
The disaster plan for pharmacies includes guidelines for disaster recovery.	❑	❑	❑
The disaster plan for pharmacies includes guidelines for monitoring & evaluation.	❑	❑	❑
These guidelines should: • Establish a protocol to ensure a comprehensive after-action review			

- Assign responsibility for compiling the after-action review
- Use after action reviews to inform future preparedness plans

PUBLIC HEALTH SYSTEM

DISASTER PLANNING AND COORDINATION	YES	PARTIALLY	NO
The public health system is equipped with a periodically updated plan for how it will accommodate increased demand for service in case of disaster.	❑	❑	❑
Include in the plan: • A strategy for mass vaccination event • Decontamination • Infection Prevention and Control • Personal protective equipment distribution			
The public health disaster response system is part of a larger disaster response mechanism at the regional and national levels.	❑	❑	❑
Participate in coalitions to promote interdisciplinary collaborations for disaster response			
For heatwaves, public health measures are guided by a Heat-Health Action plan established at the institutional level.	❑	❑	❑
STAFF TRAINING AND HUMAN RESOURCES			
Public health staff attend training and simulations to test protocols and surge capacity procedures in case of a disaster.	❑	❑	❑
Include in the training: • Lessons learned from after action reviews of past disasters • Modules on occupational safety and health • Modules on public health and climate change hazards • Modules on managing hazardous chemicals during emergencies			
The public health system educates all staff on syndromic surveillance and mandatory reporting procedures.	❑	❑	❑
The public health workforce is involved in planning and preparing for disasters. For instance, they collaborate to develop disaster plans or subsequent periodical revisions.	❑	❑	❑
COMMUNICATION AND EARLY WARNING			
The public health system is linked to a meteorological service for updates and early warning (incl. a cross-country weather monitoring system if needed).	❑	❑	❑

The public health system is equipped with notification procedures for key staff and response team members along with a system to alert the population.	❑	❑	❑

Ensure:

- Appropriate interpreter services
- Clear messaging about food and water safety
- Communications effectively reach those who are visually or hearing impaired

If necessary, establish partnerships with local law enforcement, environmental health, social services, and other community-based partners to reach all community members.

PARTNERSHIPS AND COMMUNITY INTEGRATION

The public health system has active partnerships with regional and disaster response teams, public health agencies, private physicians, healthcare coalitions, schools, and transportation services for disaster management.	❑	❑	❑
The public health system has guidelines in place to preserve the health of spontaneous, non-organized volunteers in response to significant damage in affected areas.	❑	❑	❑

Include in the guidelines:

- Instructions on the use of personal protective equipment
- Suggested clothing
- Suggested measures to avoid poisoning and contamination

PATIENT CARE AND SERVICE CONTINUITY

The public health system can activate Infection Prevention and Control and other safety measures in shelters.	❑	❑	❑

Ensure public health measures in shelters (e.g., disease prevention, food safety) and connect residents to offsite care services (e.g., drug treatment programs)

The public health system has continuity of operations plans addressing how it will continue to deliver essential services in the event of a disaster.	❑	❑	❑

Include in these plans:

- A strategy to identify services that are essential under various circumstances
- Alternative sites from which it can provide essential services
- Contingency procedures to ensure the staff can continue providing services at other facilities or in local communities
- Plans to address the loss of power, water, communication and information technology services

Ensure:

Conventional, contingency and crisis resource allocation strategies and related ethical considerations

Public health surveillance systems integrate outbreak data with meteorological information for climate-related analysis.	❑	❑	❑

RECOVERY AND MONITORING & EVALUATION			
Public health staff conducts ongoing research and evaluation of health system preparedness and identifies priority climate change impacts specific to the area of interest.	❑	❑	❑
Research should the following: • Assessment of how different disasters impact healthcare services • Assessment of community resilience and vulnerability (considering the specific needs of those with visual or hearing impairments, physical disabilities, etc.) • Guidance for the performance of Hazard Vulnerability Assessments			
The public health disaster plan includes guidelines for monitoring & evaluation.	❑	❑	❑
These guidelines should: • Establish a protocol to ensure a comprehensive after-action review • Assign responsibility for compiling the after-action review • Use after action reviews to inform future preparedness plans			
The public health system has established processes for incident demobilisation and the restoration of systems to normal operations.	❑	❑	❑
Make sure these processes: • Include a step-by-step process for returning to normal operations • Set clear indication of when to begin the recovery phase • Include communication protocols to keep all stakeholders informed			
The public health system has a surveillance plan to monitor and identify health issues arising from extreme weather events after the disaster has ended.	❑	❑	❑
Ensure: • Implementation of a system to track and monitor health issues that may arise in the aftermath of extreme weather events (incl. emerging and re-emerging infectious diseases) • Public health inter-agency collaboration to analyse health trends and ensure timely interventions • The development of protocols for conducting post-event health assessments and screenings			

ADDITIONAL RESOURCES

The checklist was developed based on established knowledge from diverse sources, incorporating insights from multiple sectors within the health system. For more detailed information on each component, refer to the original sources.

General preparedness	Planning and Caring for Pediatric and Neonatal Patients in Disasters Inpatient and Outpatient Guidelines Quality Criteria for Health National Adaptation Plan Continuity of Operation Plan Climate Change and Healthcare System Considerations A Community Checklist for Health Sector Resilience Informed by Hurricane Sandy Neonatal Disaster Preparedness A Handbook to Assist Home Health Care Providers in Emergency Preparedness Planning Pre-Storm Checklist
Evacuations	Emergency Sheltering, Relocation and Evacuation Plan
Hospitals	Pediatric Readiness in the Emergency Department Hospital-based emergency preparedness: evacuation of the neonatal intensive care unit - the smallest and most vulnerable population Guide de préparation hospitalière face à un afflux massif de victimes Pediatric and Obstetric Emergency Preparedness Toolkit: A Guideline for Hospitals Hospital Repopulation after Evacuation: Guidelines and Checklist Pediatric Disaster Preparedness Guidelines for Hospitals Checklist of Essential Pediatric Domains and Considerations for Every Hospital's Disaster Policies Planning and Caring for Pediatric and Neonatal Patients in Disasters
Primary and elderly care	Preparedness Checklist for pediatric practices Toolkit for Assessing Disaster Resilience for Aged Care Facilities Assessing Preparedness For Disasters at the Primary Health Care Level The Prepared Primary Care (PPC) Tool Development Planning and Compliance Checklist for FQHCs Emergency Preparedness for Hospice Providers Home Care and Hospice Workplace Safety Checklist (OSHA ETS)

Infrastructure	Primary Protection: Enhancing Health Care Resilience for a Changing Climate
	Checklists to Assess Vulnerabilities in Health Care Facilities in the Context of Climate Change
Specialized services	Disaster preparedness and contingency plan for dialysis facilities
	Dialysis Facility Disaster Plan Checklist
	Emergency Power Planning for People Who Use Electricity and Battery-Dependent Assistive Technology and Medical Devices
	Emergency Planning Checklist: Recommended Tool for Persons in Long-Term Care Facilities and Their Family Members, Friends, Personal Caregivers, Guardians and Long-Term Care Ombudsmen.

MOUNTADAPT is a Horizon Europe project aiming to boost the community-driven resilience of the health system in European mountain areas, mitigating the impact of climate change on public health. Leveraging the expertise of 27 partners, including healthcare facilities, public authorities, innovators, and researchers, MOUNTADAPT aims to develop solutions and strategies to enhance healthcare climate adaptation and safeguard the health and well-being of communities living in mountain regions.

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