ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

D4.5 DESIGN GUIDELINES OF CLIMATE POSITIVE CIRCULAR COMMUNITY IN TRENTO (ITALY)

WP4 SUSTAINABLE BUILDING (RE) DESIGN

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[1] *ARV is a Norwegian word meaning "heritage" or "legacy". It reflects the emphasis on circularity, a key aspect in reaching the project's main goal of boosting the building renovation rate in Europe.*

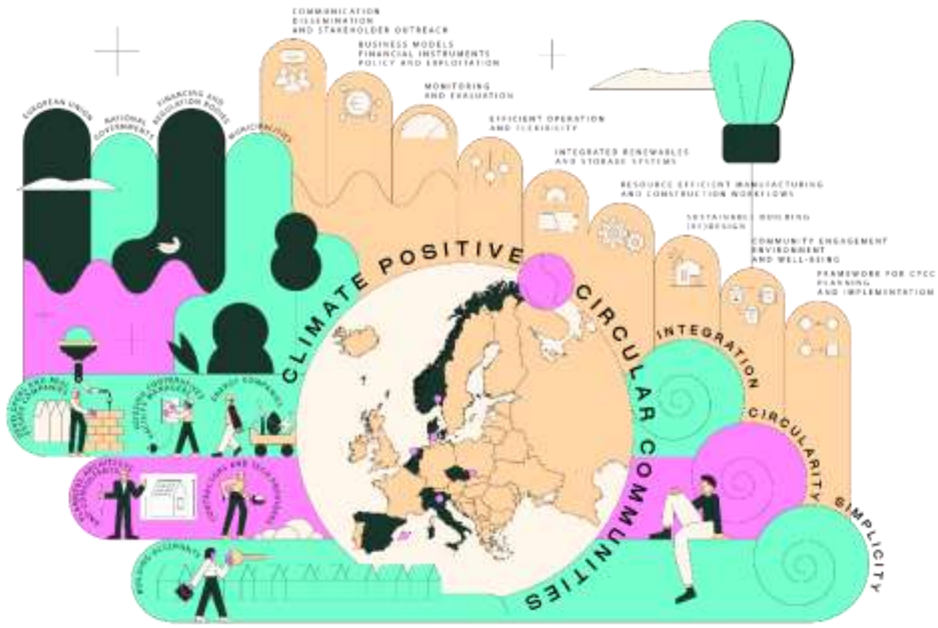
ABOUT THE ARV PROJECT

The vision of the ARV project is to contribute to speedy and wide scale implementation of Climate Positive Circular Communities (CPCC) where people can thrive and prosper for generations to come. The overall aim is to demonstrate and validate attractive, resilient, and affordable solutions for CPCC that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries. To achieve this, the ARV project will employ a novel concept relying on a combination of 3 conceptual pillars, 6 demonstration projects, and 9 thematic focus areas.

The 3 conceptual pillars are integration, circularity, and simplicity. **Integration** in ARV means the coupling of people, buildings, and energy systems, through multi-stakeholder co-creation and use of innovative digital tools. **Circularity** in ARV means a systematic way of addressing circular economy through integrated use of Life Cycle Assessment, digital logbooks, and material banks. **Simplicity** in ARV means to make the solutions easy to understand and use for all stakeholders, from manufacturers to end-users.

The 6 demonstration projects are urban regeneration projects in 6 locations around Europe. They have been carefully selected to represent the different European climates and contexts, and due to their high ambitions in environmental, social, and economic sustainability. Renovation of social housing and public buildings are specifically focused. Together, they will demonstrate more than 50 innovations in more than 150,000 m^2 of buildings.

The 9 thematic focus areas are 1) Effective planning and implementation of CPCCs, 2) Enhancing citizen engagement, environment, and well-being, 3) Sustainable building re(design) 4) Resource efficient manufacturing and construction workflows, 5) Smart integration of renewables and storage systems, 6) Effective management of energy and flexibility, 7) Continuous monitoring and evaluation, 8) New business models and financial mechanisms, policy instruments and exploitation, and 9) Effective communication, dissemination, and stakeholder outreach.



The ARV project is an Innovation Action that has received funding under the Green Deal Call LC-GD-4-1-2020 - Building and renovating in an energy and resource efficient way. The project started in January 2022 and has a project period of 4 years, until December 2025. The project is coordinated by the Norwegian University of Science and Technology and involves 35 partners from 8 different European Countries.

EXECUTIVE SUMMARY

Built environment must make a major contribution to the transformation of the EU towards carbon-neutrality and it is widely accepted that acting at neighbourhood or district scale is one of the chances to face climate emergency.

The vision of the ARV project is to contribute to speedy wide scale implementation of Climate Positive Circular Communities (CPCCs) where people can thrive and prosper for generations to come. The CPCC concept focuses strongly on the interaction and integration between new and regenerated buildings, users, and regional energy, mobility, and ICT systems by means of providing attractive, resilient, and affordable solutions and emphasising circularity, social and architectural quality as key aspects. Passive building design/bioclimatic design have long traditions across Europe. Still, the potential of this powerful approach is not being fully harvested in current practice. This is despite the fact that modern passive design has an even higher potential, by using new knowledge of environmental issues.

The intent of the ARV project is to develop and demonstrate **a new paradigm of 'integrated circular design of CPCCs'**, by taking a multidisciplinary approach to (re)design buildings with maximize energy efficiency, minimize life cycle greenhouse gas emission and costs, optimizing occupant well-being and ensure high architectural qualities. This will be accomplished by using modern digital tools (BIM, Digital Twins) in a multistakeholder cooperation.

The main objective of this document is to provide the first version of the design guidelines of Climate Positive Circular Communities (CPCC) with focus on the demo project in Trento, Italy. The document collects the results of the key actions carried out for the **Destra Adige - Piedicastello** demonstration project in Italy that covers both, new construction, and renovation of existing buildings.

The **current structure of the document** consists of the following sections. After the introduction (chapter 1), the executive summary (chapter 2), the general vision and goals (chapter 3), the chapter 4 provides the urban area presentation. In the first part of this chapter, it gives a brief history of the site, an overview of its current state and the functions expected by the municipality plan of Trento city; the second part presents the design plan in terms of general analysis, stakeholder engagement, goals, strategies, and solutions. Chapter 4 is followed by two chapters with the same structure dedicated to the design of new construction (chapter 5) and the design of existing building refurbishment (chapter 6). The design process is described in its main stages, which are the Early Concept Design (ECD), the Development Design (DD), and the Detailed Design (DeD) with regard to procedure and stakeholders involved, architectural, environmental, social, economic goal, strategies and solutions pursued. A summary and some reflections on the design replicability and transferability in the urban area close the chapters. The innovations in the demonstration project are described in chapter 7, while the lessons learned during the urban planning and the design stages are summarizing in chapter 8. The document ends with the annexes (chapter 9) and Acknowledgements.

This document will be revised and supplemented annually during the course of the ARV project.

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1. INTRODUCTION

Cities play a key role in achieving climate neutrality by 2050, the goal of the European Green Deal. They take up only 4% of the EU's land area, but they are home to 75% of EU citizens. Furthermore, cities consume over 65% of the world's energy and account for more than 70% of global CO_2 emissions. Since climate mitigation is heavily dependent on urban action, we need to support cities in accelerating their green and digital transformation [1]. In particular, European cities can substantially contribute to the Green Deal targets [2]. These will be developed as Climate Positive Circular Communities (CPCCs), which is a concept that rests on three main pillars: 1) circular economy, 2) integration of people, buildings, and energy systems, and 3) simplicity – achieved by means of digitalization and industrialization.

A Climate Positive Circular Community (**CPCC**) is an urban area where people can thrive and prosper for generations to come. The CPCC concept focuses strongly on the **interaction** and **integration between new and regenerated buildings, users** and **regional energy, mobility,** and **ICT systems by means of providing attractive, resilient and affordable solutions** and emphasising **circularity, social and architectural quality** as **key aspects**.

WP4 of the ARV project deals with the **(re) design** of new and retrofitting of existing buildings as zero-emission positive energy buildings in sustainable Climate Positive Circular Communities (CPCCs). The main objectives are: (i) to reduce the embodied energy and emissions; (ii) to increase the energy efficiency; and (iii) to match sustainability with aesthetics and quality of life, by integrated circular design processes.

The activities in WP4 are divided into six main tasks that address design strategies of buildings integrated in CPCCs. This document refers on the **task 4.6** called 'Integrated Circular Design of Demo Project in Trento'.

The **ARV integrated circular design** applied on the case study in Trento includes adaptation to local climate conditions, deep renovation with minimum disruption for buildings occupants, significant reduction of CO_2 emissions, high energy efficiency with active/passive solutions, high focus on circularity i.e. reduce, re-use & recycle of materials, elements & modules, add value, and resource & energy efficient integration of PVs i.e. BIPV & BAPV, while satisfying occupant well-being and architectural considerations. The design considerations addressed the scalability, flexibility, durability, maintainability, safety, aesthetics of the buildings. The buildings and the neighborhood of the case study were embedded in the spatial, economic, technical, environmental, regulatory, and social context of the demo site.

Why do we need the Guidelines?
History has shown that (re)design can play a crucial role in improving our buildings, neighbourhoods, cities, and the quality of life of its residents. Today, architects, engineers, urban planners can help address one of the most urgent and widespread challenges of our time, ecological transition, and its related declinations, by implementing the strategies contained in these *Guidelines*. With the dissemination of the *Guidelines*, the city of Trento signals its commitment to become a CPCC.

Who will use the Guidelines?
The *Guidelines* address all who have a role in the design and construction of the built environment. This encompasses professional designers (such as urban planners, engineers and architects); building owners and private developers; contractors, suppliers of materials, components and services; energy companies and building managers; users including city residents and building occupants and research/educational institutes.

The *Guidelines* are intended to aid and encourage collaboration among different design professionals and stakeholders in promoting a new paradigm of 'integrated circular design of CPCCs'. Although the

Guidelines are written with the city of Trento as the focus, the strategies contained here can also be applied to other cities and communities. The *Guidelines* will also assist architectural, planning, and design educators seeking to incorporate key design factors promoting CPCCs into student projects and curricula.

How should the Guidelines be used?

Readers are encouraged to read the *Guidelines* in their entirety, to get a clear understanding of the contents and the design process pursued. The Guidelines are also intended to provide a possible contribution that could stimulate reflections for possible additions and/or amendments to existing regulatory documents.

2. EXECUTIVE SUMMARY OF THE PROJECT DESTRA ADIGE - PIEDICASTELLO, TRENTO, ITALY

The Italian demo case is located in Destra Adige - Piedicastello (Northern Italian city of Trento). It consists of four areas (Figure 1):

Area 1, the former Italcementi industrial site, will host an entirely new mixed-use district of Trento, containing residential and tertiary buildings. The aim is to develop the district as self-sufficient, by using the very high geothermal potential in the area and its excellent orientation to the southeast for PV production to power the geothermal heat pumps.

Area 2 is an urbanisation from the 50s–70s. Most of the buildings are close to or have already reached the end of their life cycle. The area was developed with a strong focus on social housing and is largely still owned by the Trentino Institute for Social Housing. These residences are to be renovated by using standardised prefabricated timber-based façade elements, implementing the so-called "One-Stop-Shop" which provides technical support at all stages of design and realisation, also the private owners of the area are invited to associate themselves in the redevelopment process, thus guaranteeing a high degree of replicability also for other areas of Trento.

Area 3 includes the former Piedicastello highway tunnels encompassing two 250-m holes in the Dos Trento Mountain, which are currently used as an art and exhibition gallery. This geo-structure is intended to supply and store energy for the new city district in areas 1 and 2.

Area 4 currently used as a parking lot, will be redeveloped with a service HUB for the district and city. It will connect commuter flows to commercial services and will host an energy storage system, following the V2G (Vehicle-to-grid) approach, simultaneously promoting the market penetration of electric mobility.

This demonstration project includes the construction of a new building that demonstrates the ambition of positive energy performance and the innovative energy refurbishment of an existing building with timber-based facades.

The demo case focuses on:

- development of a catalogue of Integrated Circular Design Solutions (ICDSs);
- study the natural and mechanical ventilation concept for climate responsive buildings;
- application of a circular economy-based design process;
- integration the Nature Based Solutions (NBSs);
- development and demonstration of new perspectives and scenarios for timber construction in urban regeneration;
- informing Industry 4.0 via digital surveys;
- improving comfort (psychological, physiological) of the building occupants;
- co-creating one-stop-shop enabling diffusion of design technology: replicability of solutions;
- integrating heat pumps for heating and cooling (connection to NSGE – tunnels, foundations, roads) or integrate passive heating systems integration in buildings envelopes; integrate active/passive systems via Building Automation Systems;
- analyse of existing models for scenarios elaboration to inform hybrid Energy/Nature-based solutions on building/urban surfaces;
- use of innovative materials (new and waste/by-products);
- architectural and aesthetic integration of BIPV/BAPV solutions, integration between PV, Solar Thermal and CMV systems.

Figure 1. *Map showing the four ares of the demo project in Trento (Source: Google Earth).*

3. VISION AND GOALS

3.1. VISION

Cities change and transform. Cities are key drivers of ecological transition and sustainability is most efficient at city level [3].

A CPCC can be an urban area, a city district, and consists of several interconnected buildings with associated infrastructure like grids and technologies for generation, storage, and exchange of electricity and heat.

The vision is to contribute to the transformation process of the Destra Adige - Piedicastello district in order to become a CPCC designing and demonstrating integrated circular buildings for high energy performance, low emissions, low cost, good indoor climate, and high architectural quality (that is WP4 of the ARV project), and with the support and interaction of the other WPs.

The overall aim is to demonstrate and validate attractive, resilient, integrated and affordable solutions for the case study that will significantly speed up the deep energy renovations and the deployment of energy and climate measures in the construction and energy industries.

The challenge is addressed employing methods of integrated design and construction, using digital tools, life cycle analysis to minimize the embodied energy and emissions, and applying the principles of circular economy for the (re) design processes, focusing on local bio-based materials, reuse, recycling, durability, resiliency to achieve reduction in embodied emissions needs compared to current country building standards.

3.2. GOALS

The GOALS of the planning and design phases of the demo project are:

- To (re) design buildings with an **environmental focus** to reduce negative impacts on the environment, and the health and comfort of building occupants as well as increase building resiliency. Improving the energy performance of existing buildings is important to increasing our energy independence. Designing positive or net zero energy buildings is one way to significantly reduce our dependence on fossil fuel-derived energy. Utilizing sustainable materials can also help to minimize environmental impacts such as global warming, resource depletion, and toxicity.

- To (re) design buildings with an **architectural focus** for the urban regeneration based on the use of timber. The intent is to implement integrated tools and technologies towards urban and building transformation processes with results that are simple but aesthetically pleasing and meet the needs and enhance the quality of the experience beyond functionality.

- To (re) design buildings with a **social focus** to foster personal relationships and give new goals to these 'new buildings' enabling communities to identify with shared values. Assessing the benefits of the project for the community and adopting ways of encouraging citizen and stakeholder participation and ensuring that their opinions are heard at the various stages of the project is therefore crucial [4].

- To (re) design buildings with an **economic focus** to achieve a changing process to reduce the costs and revive the local economy. Developing replicable and scalable building solutions for new construction and renovation contributes to an economic growth. Economic growth should bring prosperity and a better quality of life for all of us.

4. URBAN AREA PRESENTATION

4.1 GENERAL OVERVIEW OF THE PIEDICASTELLO AREA

Trento is a city in the North-East of Italy, the capital of the Autonomous Province of Trento (PAT). With approximately 120.000 inhabitants, in 2022, it ranks 37th among the Italian cities with more than 60.000 inhabitants by resident population [5].

The area chosen for the Italian demo case is the Destra Adige - Piedicastello district. It is an area of the city that is primarily flat, bordered to the west and north by Monte Bondone and Doss Trento, and to the east by the Adige River. Together with the historic centre of Trento, it is part of administrative district number 12 of the city of Trento. The connection with the central part of the city is currently provided by the San Lorenzo bridge.

The name Piedicastello presumably originates from its location at the base of Doss Trento, the small mountain originally called ‘Verruca castellum’ located near the Adige River that in the past provided shelter to local residents in case of attack by foreign populations [6].

4.1.1 PARTITIONING OF THE AREA INTO FOUR SUB-AREAS

Destra Adige - Piedicastello district is an urbanised area characterised by an old village, an early 20th century working-class settlement, more fragmented contemporary residential units, a large empty former industrial site, a church, sites of archaeological and naturalistic interest, and two former road tunnels called ‘Gallerie di Piedicastello’ converted into an exhibition space.

Destra Adige - Piedicastello area is primarily made up of public property or property belonging to public institutions (such as State Property, the Autonomous Province of Trento (PAT), the Municipality of Trento, Patrimonio del Trentino SpA, etc.), and to a lesser extent, private subject property.

The district proves to be of strategic importance for the aims of the ARV project in relation also to the “Destra Adige - Piedicastello” Master Plan, which the Municipality of Trento recently approved for the district's redevelopment in accordance with sustainable development principles on the social, economic, and environmental perspectives.

The Trento demo case consists of four areas. See SHEET - **PARTITIONING OF THE AREA** in the **Annex 9.3.1**.

Area 1: the "ex Italcementi" industrial site will host a completely new Trento mixed-use district with residential and tertiary buildings. The objective is to make the new district self-sufficient, exploiting the area's very high geothermal potential for the supply of geothermal heat pumps and its south-east orientation for photovoltaic production.

Area 2: an urbanised area from the 1950s-1970s. Most of the buildings are near or have already reached the end of their life cycle. The area was developed with a strong focus on social housing and is largely still owned by the Istituto Trentino Edilizia Abitativa Spa (ITEA). These buildings must be renovated and refurbished. To do so, the purpose is to use standardised and prefabricated wood-based façade elements, implementing the so-called "One-Stop-Shop'' that provides technical support in all phases of design and construction; private owners are also invited to join in the renovation process, thus ensuring a high degree of replicability for other areas of Trento.

Area 3: this includes the ex Piedicastello road tunnels, consisting of two 300 m holes in the Doss Trento, that are currently used as an art and exhibition gallery. This geostructure is intended to provide and store energy for the new city district in areas 1 and 2.

Area 4: it is a large car park that will be upgraded with a charging HUB station for recharging electric cars, serving those who cannot do so at home. It will connect commuters to commercial services and host an energy storage system, following the V2G approach (two-way bi-directional charging technology that allows electric vehicles to return energy to the grid), while simultaneously fostering market penetration of electric mobility.

4.1.2 HISTORY OF THE SITE

Piedicastello, located on the right side of the Adige River at the bottom of Doss Trento and on the way to the Giudicarie Valleys and to Brescia, was the first human settlement of the city of Trento. Archaeological findings attest to the presence of ancient human cultures in this area, consisting of populations of Rhaetian and Gallic origin.

Later on, the Roman occupation changed the situation: the Romans founded the city on the left bank of the Adige because it was protected by the river and crossed by the Via Claudia Augusta Padana. The local population, feeling safer on the other side of the river, abandoned Doss Trento to settle within the Roman walls.

During the Barbarian invasions, the Doss Trento once again welcomed the population of the city, who returned to take refuge there, abandoning the Roman city, which suffered a contraction in its development. The defences on Doss Trento were strengthened and the village of Piedicastello expanded at its foot, with the need to build a place to carry out religious practices [7].

In mediaeval times, with the subsequent development of the city on the left side of the Adige River, Piedicastello remained outside the walls, isolated, relegated to a ghetto and subject to fires and looting. During the period of the Council of Trent (1545-1563), Piedicastello became the place used to gather the troublesome population, i.e. those who could represent a public order problem for the safety of the Church fathers. Of particular note is the fire in 1703 when the village was bombarded by the French General Louis Joseph of Bourbon-Vendôme during the War of the Spanish Succession.

The area experienced a new commercial development after 1845 as a result of the construction of a new road leading to the Giudicarie valleys via the "Bus de Vela"; a distinctive feature of the area is the fountain in the middle of the Piedicastello square, which was used to rehydrate the cattle of passing merchants [8].

Inhabited by a population of boatmen, sandmen, flint mongers, innkeepers, washerwomen and carters, Piedicastello was one of the first working-class neighbourhoods of the 19th century and the site of early industrialization. Given the massive growth in the building industry at the beginning of the 19th century and the lack of local cement production, the entrepreneur Domenico Frizzera started the construction of a company for the production of bricks and Portland cement at S.Nicolò di Piedicastello. His activities were confined to timber trading up until the 1880s, but in the years that followed, inh started to include brick and lime trading and manufacturing, thus necessitating the construction of a brand-new industrial facility. The cement factory was the first large industrial plant in the city of Trento. The business changed from being a private company to the "Prima fabbrica trentina di Cemento Portland Domenico Frizzera" corporation in 1911. As the First World War broke out, production was interrupted and, after the death of the owner in 1919, the company was subsequently bought by the 'Società italiana e società anonima calci e cementi' of Bergamo and, from 1927, named 'Italcementi'.

The company expanded further until it reached maximum employment in 1939 with 240 workers. However, as the cement factory expanded, the population of Piedicastello began to complain about the air being full of soot, brick and cement dust and frequent mine fires.

The Trento municipality thus decided to implement measures such as the application of filtering systems, but dust continued to surround the district. The cement factory remained active until the 1970s, then increasingly reduced production until it stopped completely in the 1990s. Following the closing of the facility, the area was demolished and partially reclaimed in 2013. Today, only two chimneys remain as evidence of the industrial past.

During the construction of the cement plant, the need to build houses for workers and employees emerged. Some areas to the north of the industrial site were proposed and housing projects were presented, leading to the construction of workers' houses in Via Verruca and Via Papiria. The municipality of Trento looked at the residential area of the Lanerossi industrial plant in Schio (VI) and designed a project adapting it to the local context. The municipality chose to build two-storey in-line residential cells completely above ground level with little gardens.

The first row of 10 cells was built in 1894 thanks to funding provided by Trento's Podestà Paolo Oss Mazzurana. After Podestà's death, the working-class district was sold in 1896 to the "Società di Mutuo Soccorso degli Artieri" which, in the following years, built several terraced houses, a multi-family building and a laundry.

In a building in Via Verrucca 1, in the early 1900s, the “Central School for Embroidery” was founded in place of an artisan atelier, to teach and provide work for boys and girls aged 14 to 18. The embroidery school continued its work until the outbreak of the First World War and was then converted into a primary school in 1933 for children living in the Piedicastello area. It closed in 2000, due to low enrolment and the poor condition of the building. It was then readapted to new needs: it currently hosts medical clinics, the district meeting room and various associations [9].

In the second and third decade of the 1900s, companies specialised in metallurgical activities developed in the north-eastern area of Doss Trento.

In 1913, 'Trafilerie Punterie Trentine Hallier & Vavpetic', a company based along Via Doss Trento after the intersection with Via Caio Valerio Mariano, began its activity. It produced wire drawing machines, punteries, wire nets, locks, broaches, etc., employing an average of fifty workers. In 1932, the factory went into liquidation, presumably due to the financial crisis of 1929. Not far away and still along Via Doss Trento, the factory 'I.M.B.E.T. Industria Meccanica Broccami Elettrica Trentina' also opened, producing shoe broaches, iron, copper and brass rivets, precision tacks, special tacks for saddlers and upholsterers, drawing tacks, etc. It ceased operations in 1927 due to a lack of capital.

In 1928, the company 'Stabilimenti Metallurgici Trentini S.p.a.' was established, which took over the factory from 'Hallier & Vavpetic' until the end of the 1970s, and is remembered as 'The Jug Factory' [10].

In 1935, on the top of Doss Trento, the Mausoleum dedicated to Cesare Battisti was built, designed by architect Ettore Fagiuoli, in which the remains of this Italian irredentist hero (1875-1916) are preserved, and where an interior display tells of his tragic story in the context of the First World War (1914-1918). Other war memorials, created by a town committee and an association of Great War veterans, can be seen on the Doss.

The events of the Second World War (1939-1944) had a severe impact on the village of Piedicastello. Between 1940 and 1947, a unit of the Alpin troops built a new road to reach the summit of Doss Trento and started work on a museum inside the remains of the powder magazine of the Austrian imperial fortress. The museum, opened in 1958 and called the “Museo Storico delle Truppe Alpine”, offers visitors an interesting exhibition that traces the tragic and heroic events of the Alpini.

In 1943, the iron bridge crossing the Adige was bombed. First replaced with a ferry, it was then rebuilt, a little further south, in reinforced concrete to reactivate communication with the Giudicarie Valleys. In the following years Piedicastello expanded with new buildings. Between the 1950s and 1970s, the district was subject to social housing interventions by the ‘Istituto Autonomo per le Case Popolari’ (I.A.C.P.), which worked to rebuild the houses destroyed during the second world war and to respond to the growing housing need generated by industrialisation. Many residential buildings were built on the right bank of the river. In 1972, the institute was transformed into the 'Istituto Trentino per l'Edilizia Abitativa' (ITEA) and other low-income housing was built in Via Doss Trento (1980) and, later on, in the Vela area (2002). In the same years, private single-family or multi-family buildings were also built in some of the district's most outlying areas.

In the 1970s Piedicastello was strongly impacted by the construction of a bypass road and two tunnels crossing the Doss Trento. These works were severely disapproved by the locals from the beginning and throughout their whole existence, since they created a physical barrier dividing the district into two parts, also separating it from the area where the Church of Sant'Apollinare stands. Due to this, a group of residents spontaneously formed the Piedicastello Committee, whose goal is to protect the district against changes that may have a significant negative impact on the local community. In the 1990s, the committee fought for the relocation and redevelopment of the bypass and the district became traffic-free in 2007 when the tunnels were closed. The redevelopment of the urban area of the district started in April 2017 and was completed in November 2018 with the opening of the new district square.
Recent landscape renovation projects have started to put this district's long-torn parts back together, but more interventions are needed to improve the quality of life of its inhabitants and to meet the goals of the ecological and circular transition.

Some historical images of the Destra Adige - Piedicastello district are reported in the SHEET - **HISTORY OF THE SITE** (A and B) in **Annex 9.3.1**.

4.1.3 CURRENT STATUS OF THE SITE

After the recent urban redevelopment works long awaited and strongly desired by the resident population, Destra Adige - Piedicastello is currently characterized by the following elements. Expanded and reconnected to the Sant'Apollinare Church and to the San Lorenzo bridge (over the Adige river), the district square occupies a total area of approximately 8,000 square meters. It consists of three macro-areas: the *historic square*, delimited by Via Brescia and by old buildings, together with the Piedicastello alley, has an area of approximately 2,200 square meters; the available commercial activities provide multiple functions along with the old fountain, a symbolic element not only for the square but for the entire neighbourhood; the *area around the monumental church-rectory* improved by the archaeological-architectural restoration works; the *green area* (approx. 2,800 square meters) including: a flat and equipped area for children (approx. 1,600 square meters) in the north part, a connecting area with shrubs and a pedestrian path (approx. 700 square meters) between the historical square and Via Brescia, and the flowerbed around the plane trees along Via Brescia (approx. 450 square meters). See SHEET - **DISTRICT SQUARE** in the **Annex 9.3.1.**

The current urban roundabout near the San Lorenzo Bridge was built to remove the physical barrier formed by the former ring road and its junction, which had extra-urban characteristics. The roundabout is smaller and crossable by pedestrians in four intersections. It has a central flowerbed planted with cypresses and shrubs. A tree-lined flowerbed, a bicycle path and pedestrian path run along the south side of Via Brescia.

The road system in the Via Papiria - Via Verrucca area is currently a one-way street; the footpaths have been widened, regularized and paved; the parking area has been reorganized and planted with trees both near the roundabout and next to the former Italcementi area to provide an adequate number of parking spaces for the neighbourhood, the nursery school and the church. The car parks are connected to the pedestrian path by stairs and ramps. In addition, a car park has been provisionally located on the site of the former Italcementi area, which seems to be causing dissatisfaction among local boards and the nearby Bruno Social Centre. See SHEET_**ROUNDABOUT and ROAD SYSTEM** in the **Annex 9.3.1.**

North of Doss Trento and near the "Trento centro" motorway exit, there is the free 'ex Zuffo' parking lot with a shuttle bus service to the city center. The large area has parking spaces, a coach area (for loading and unloading travellers only), and camper van spaces for short stays equipped with an area for unloading and water supply. At the southern end of the area, there are parking spaces for private bicycles as well as shared bicycles ones belonging to the 'e-motion' service. There is also a bike share in the neighbourhood square. See SHEET – **EX ZUFFO PARKING LOT** in the **Annex 9.3.1**.

The Doss Trento park includes an itinerary between nature and history. The two main access roads cross footpaths with terraces, steps and ramps recovered at the beginning of this century. On its summit, the park hosts the Alpine Troops Historical Museum, the remains of an early Christian Basilica and the Mausoleum of Cesare Battisti. The park is also a site of great environmental importance for its geomorphological, botanical, and faunal features [11]. Its naturalistic value is the subject of important protection. See SHEET – **DOSS TRENTO PARK** in the **Annex 9.3.1.**

The **Piedicastello tunnels** are two former road tunnels that cross the Doss Trento. They occupy a total area of over 6000 square meters for a length of about 300 meters. Converted into exhibition spaces, they are marked by two colours: black and white. The black gallery is located to the east, the white gallery to the west. They offer spaces for events, temporary exhibitions, and educational activities; they are not a traditional museum but a cultural space promoting history knowledge, a workshop and a participatory space. The tunnels are currently curated and managed by the "Fondazione Museo storico del Trentino" See SHEET – **PIEDICASTELLO TUNNELS** in the **Annex 9.3.1**.

The existing built heritage is both public and private. It mainly consists of residential buildings, multi-family blocks of flats or small single-family buildings located around Doss Trento (old village on the south side), to the north of the former Italcementi area (workers' houses from the early 20th century), and along the Adige river to the north of the bridge (council houses). The buildings require energy retrofitting as they have been mainly constructed before the entry into force of the energy efficiency regulations. Recently, national tax incentives aimed at improving energy, structural and architectural behaviour of the existing building stock (namely superbounus 110% and ecobonus 65%)[2] facilitated renovation works in the neighbourhood, such as interventions on the building envelopes, on architectural quality and on building facilities. However, such actions are punctual, and lack of a circular, innovative and systemic approach aimed at promoting and building a CCP Community. See SHEET - **BUILT HERITAGE** in the **Annex 9.3.1**.

The area is sufficiently equipped with services and collective spaces and hosts cultural and social events. Shops, bars, restaurants, and other commercial activities are mainly concentrated on the sides of via Brescia and to a small extent also along via Lungadige Apuleio. A building in Via Papiria hosts the Portland Theatre. This name clearly refers to the homonymous cement produced for many years in the Italcementi factory, one of the district's principal social landmarks. An old abandoned building has been reused as a space for individual and collective creativity in the district. Portland Theatre collaborates with the local public authorities, the Piedicastello District and the Tunnels to carry out multiple cultural projects. Opportunities for aggregation, rehearsal studios and musical experiences are offered by Area Musica, an association based in Vicolo Piedicastello. Since 2007, the Centro Sociale Bruno has occupied an old building in Via Lungadige San Nicolò in the ex-Italcementi area, granted by the owner to 'Commons' on loan for use until the redevelopment of the area. See SHEET - **SERVICES AND COLLECTIVE SPACES** in the **Annex 9.3.1**.

Recent urban redevelopment works in the district have also renewed and adapted part of the public facilities. New materials and pipe diameters were adopted for the black- and white-water collection systems. The public lighting system serving the entire area has been almost completely replaced by lamps guaranteeing excellent illuminance/consumption efficiency, complying with the new regulations in the field of energy saving and light pollution.

[2] https://www.agenziaentrate.gov.it/portale/web/guest/superbonus-110%25

4.1.4 EXPECTED FUNCTIONS BY THE MUNICIPAL PLAN

The Municipality and the Autonomous Province of Trento agree that the Destra Adige - Piedicastello district has the potential to become a hub for building redevelopment actions towards sustainable buildings and to contribute to the concept of Climate Positive Circular Communities (CPCCs).

Currently, the main urban planning tools defining the conditions for a social, cultural, environmental, and economic reconversion of the urban context of the Destra Adige – Piedicastello are: the General Regulatory Plan (PRG) in force with its variants, the "Destra Adige - Piedicastello" Master Plan definitively adopted by the Municipality of Trento in 2021, and the Urban Plan for Sustainable Mobility (PUMS) adopted in 2022.

With reference to the PRG in the pilot case, the following areas are identified:

- historical settlement (Ais) including the oldest core of the village consisting of the buildings located along Via Brescia and south-east of Doss Trento. The area is subject to conservation and redevelopment constraints. Article 32 of the Implementation Rules regulates the building interventions [3].

- saturated built-up areas (B1) mainly located along the streets surrounding Doss Trento, especially along Via Brescia and Via Doss Trento. In these areas, all renovation works are allowed, but any increase in the existing above-ground volume is forbidden. Article 37 of the Implementation Rules regulates the building interventions[4].

- integration and completion zones (B3 - B4) are partially built-up areas and located in the northernmost and southernmost part of Doss Trento. Article 38 of the Implementation Rules regulates them[5].

- areas equipped for public green spaces (VP), located near the S. Apollinare Church, the roundabout and in the north side of Doss Trento. They are subject to Article 69 of the Technical Implementation Regulations[6].

- zone subject to urban requalification (C5), located in the urban void of approximately 9,000 hectares left by the demolition of the Italcementi factory; it requires infrastructural and building retrofitting to improve the settlement quality through residential and tertiary uses. Article 42 of the Implementation Rules deals with this zone[7].

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[3] http://webapps.comune.trento.it/gis/archivioweb/prg/norme/prgvigente/norme.pdf#nameddest=32
[4] http://webapps.comune.trento.it/gis/archivioweb/prg/norme/prgvigente/norme.pdf#nameddest=37
[5] http://webapps.comune.trento.it/gis/archivioweb/prg/norme/prgvigente/norme.pdf#nameddest=38
[6] http://webapps.comune.trento.it/gis/archivioweb/prg/norme/prgvigente/norme.pdf#nameddest=69
[7] http://webapps.comune.trento.it/gis/archivioweb/prg/norme/prgvigente/norme.pdf#nameddest=42t

Figure 2. *Aerial view of the Destra Adige - Piedicastello district (Source: Google Earth).*

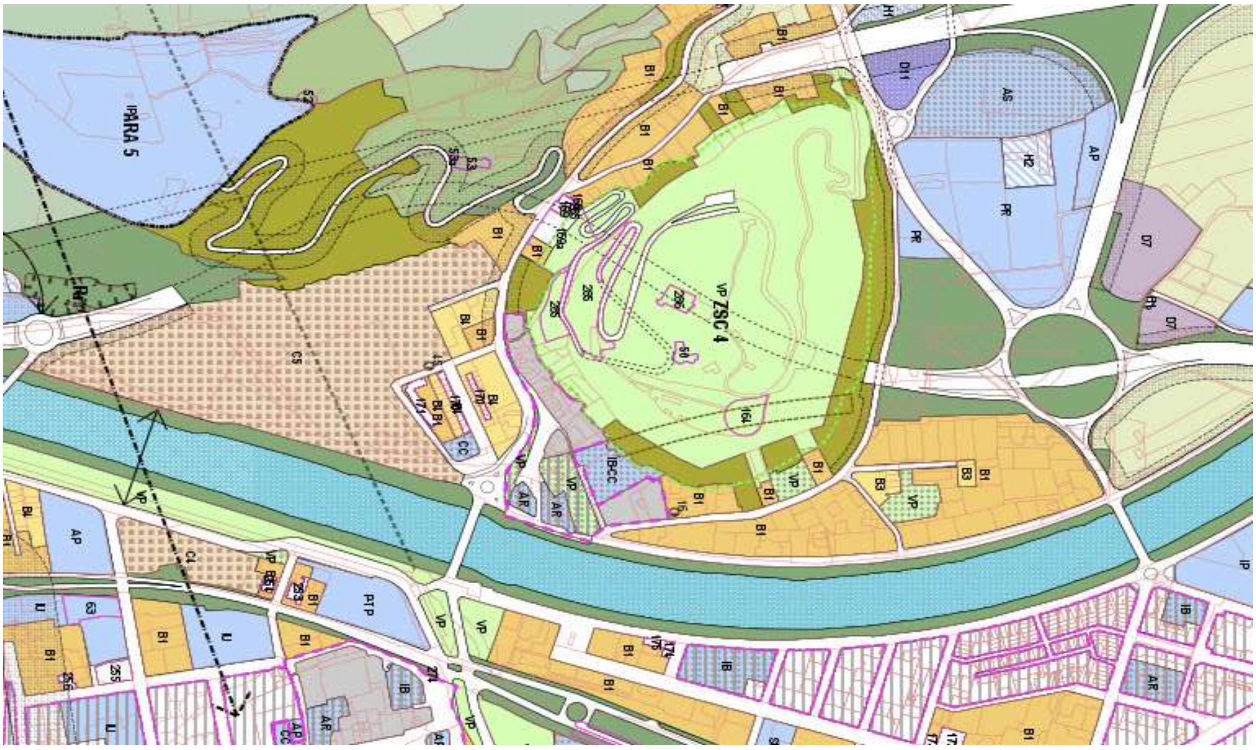

Figure 3. *Zoning of the General Regulatory Plan (PRG) of Trento (Source: City of Trento).*

The "Destra Adige - Piedicastello" Master Plan was drawn up by Patrimonio del Trentino Spa, the company dealing with the real estate assets of Trentino's public bodies [12]. The Master Plan aims to complete the redevelopment of the neighbourhood, to reduce traffic along Via Brescia and to accommodate a plurality of well-balanced functions in the former Italcementi area (almost entirely publicly owned). The content of the Masterplan is the outcome of a long process of consultation involving Patrimonio del Trentino Spa, political decision-makers (at provincial, municipal and district level), technical services (at provincial and municipal level) and the Piedicastello community (district and committee).

The functions proposed by the Master Plan are aligned with those envisaged by the PRG, but have been dislocated by means of a hierarchy of relations and contiguity with existing buildings and functions. Specifically, the plan sets 20 facilities including residential buildings, public green spaces, cycle paths and commercial spaces, a research centre, a university student housing complex, a large car park with at least 2,000 spaces. Moreover, a cycle-pedestrian bridge south of the San Lorenzo bridge is planned to create a stronger connection with the part of the city across the river, while the former Italcementi chimneys are kept as a landmark of industrial archaeology (**Figure 4** and **Figure 5**).

In 2021 the Trento City Council approved the adoption of the Master Plan and the urban planning variant for the Destra Adige -Ex Italcementi area. This is an important moment for the city facilitating the beginning of the regeneration process of a widely discussed area. The objective is to strengthen the connection of the new neighbourhood with the Bondone Mountain and with the rest of the city, and to shift towards environmental sustainability and innovative mobility systems.

To shift territorial transformations towards low environmental impact building models, the Municipality of Trento approved the "Regulations to spread sustainable buildings" in 2006[8]**.** In addition to the regulations, building bonuses are provided to extend the diffusion of sustainable and quality timber constructions by art. 86 of the provincial town planning law of 2008 and by the tax breaks governed by the recent decree law no. 34/2020 in articles 119 and 121.

The former (PAT's Sustainable Building Bonus) are applicable to both renovation and new construction interventions, and can result in extensions of surface area or in the reduction of the construction tax[9]. The latter (Superbonuns 110%) involve specific energy retrofitting, static consolidation or seismic risk reduction interventions. The installation of photovoltaic panels and infrastructures to charge electric vehicles are part of the subsided works[10].

The Sustainable Urban Mobility Plan (PUMS) addresses energy transition issues through actions and policies related to local mobility and its relationship with the territory, and is coordinated with the other planning tools. The PUMS envisages a substantial package of cycling interventions, reorganizes the existing interchange car parks such as the one in the former Zuffo area (Area 4), and implements smart mobility strategies by identifying places where to install electric recharging stations.

In the framework of funds allocated by the National Recovery and Resilience Plan (PNRR) and within the vision of a more sustainable local transport model in 2022, the Municipality of Trento approves the preliminary project to build the new section of the city cycle path from Piedicastello to the public park in the Le Albere district. In addition, the municipality intends to transform the parking areas into mobility hubs, i.e., "in strategic places in the urban area where the most important facilities are concentrated, such as: exchange car parks, public transport lines, sharing services, electric cars and micro-mobility, micro activities to increase commercial places" [13].

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[8]https://www.comune.trento.it/Aree-tematiche/Ambiente-e-territorio/Urbanistica/Regolamenti-di-interesse-urbanistico/B24-Regolamento-per-la-diffusione-dell-edilizia-sostenibile
[9] http://www.urbanistica-dati.provincia.tn.it/cms_storage/urbanistica/gp2091_2021_allegato_edilizia_sostenibile.pdf
[10] https://www.efficienzaenergetica.enea.it/images/detrazioni/Normativa/ART._119_E_121.pdf

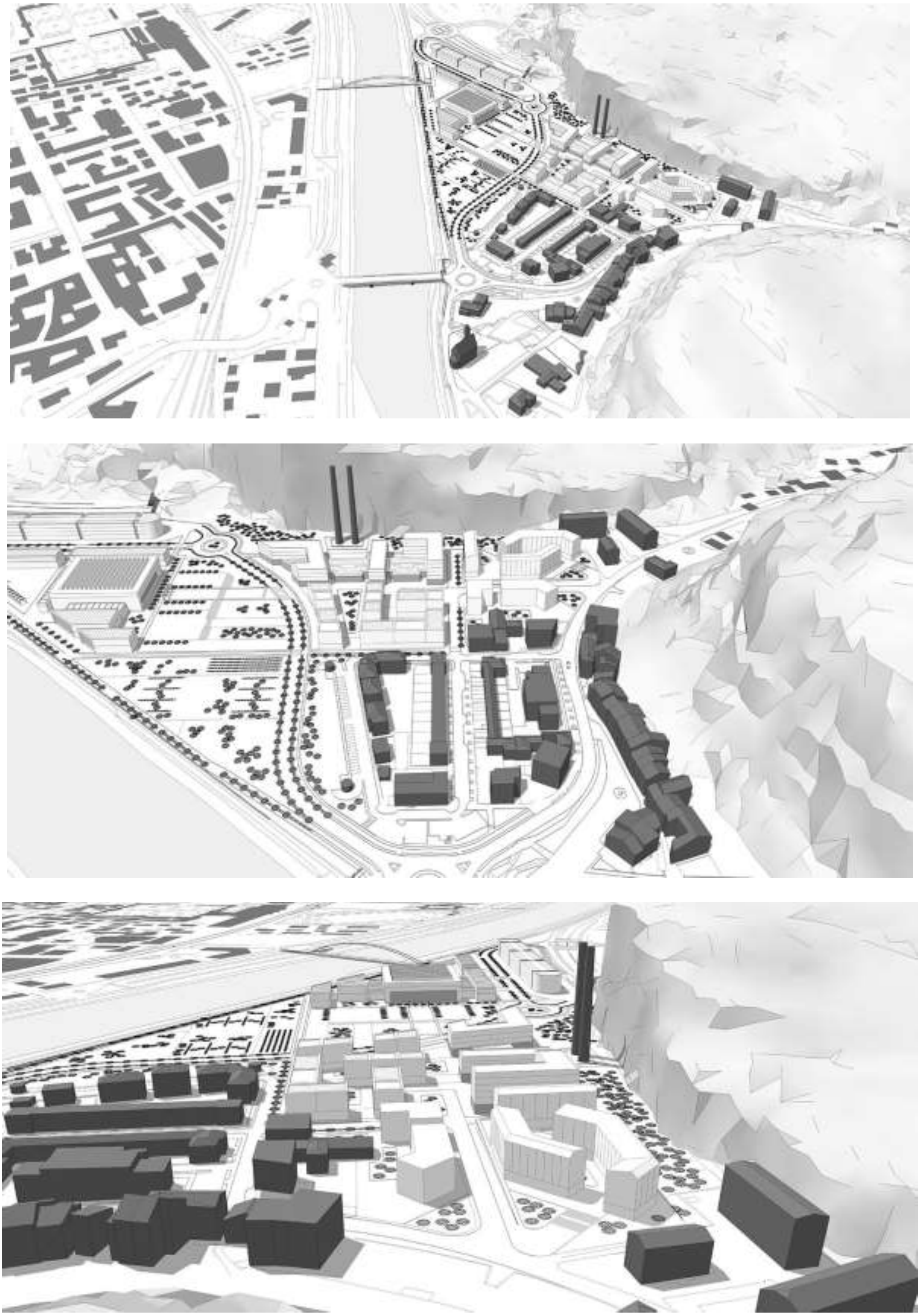

***Figure 4.** Visions for the Destra Adige area according to the "Destra Adige – Piedicastello" Master Plan by Patrimonio del Trentino Spa (Source:* https://www.patrimoniotn.it/property/riqualificazione-urbanistica-destra-adige-piedicastello*).*

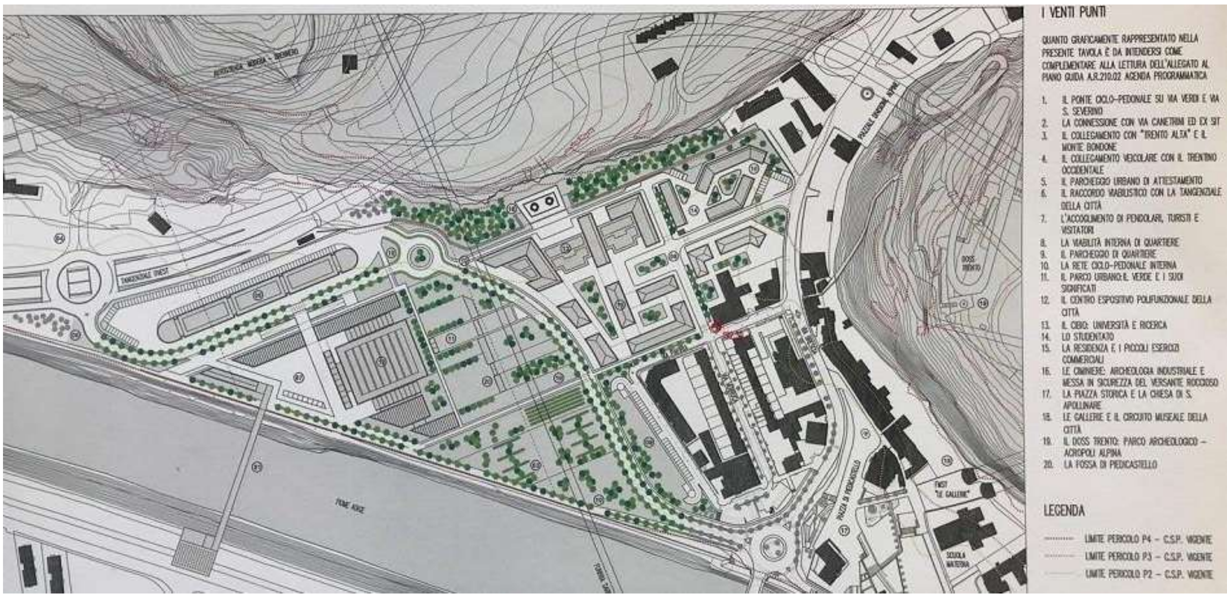

Figure 5. *Twenty points of "Destra Adige – Piedicastello" Master Plan by Patrimonio del Trentino Spa (Source:* https://www.patrimoniotn.it/property/riqualificazione-urbanistica-destra-adige-piedicastello)..

4.2 DESIGN PLAN

In Europe, the building sector is responsible for 36% of annual CO2 emissions, 40% of energy consumption, 50% of raw material extraction, 21% of drinking water consumption [14]. At the same time, this sector is also responsible for one third of the total waste produced; in Italy 41.3% of all special waste comes from the construction sector [15]. The situation is expected to worsen without swift and decisive actions. The real estate sector is a powerful driver of the global economy and also a crucial sector for the achievement of many of the UN SDGs. In this scenario, cities will play a crucial role if they transform themselves into CPCCs.

Could the city of TRENTO become a CPCC? Trentino, a region that is technologically advanced and accustomed to competing on the basis of innovation and sustainability, must necessarily move within a European vision of transition towards a circular economy, exploiting opportunities and promoting concrete initiatives.

The TRENTO demonstration project in the Piedicastello district represents an innovative test in order to:

- develop and test a new paradigm of "integrated circular CPCC design" adopting a multidisciplinary approach to (RE)DESIGN buildings using digital tools (BIM, Digital Twins) in a multi-stakeholder cooperation;
- apply integrated strategies, solutions and technologies that maximise energy efficiency, minimise greenhouse gas emissions and life cycle costs, optimise occupant well-being and ensure high architectural quality.

TRENTO demo case consists of two building interventions. The first one is the *Design of a New Construction* in Area 4. The second one is the *Design of an Existing Building Refurbishment* in Area 4.

SUSTAINABLE BUILDING (RE)DESIGN planning is a process that analyses *requirements* as well as *potentials and opportunities*, defines *architectural, environmental, social and economic objectives*, and identifies related *strategies and solutions* to achieve them.

4.2.1 ANALYSIS REQUIREMENTS AND POTENTIALITIES/OPPORTUNITIES

The start of an ecological and circular transition represents a highly relevant strategic input with the shift from the "need" for energy efficiency to the "opportunity" to (re)design building products at different scales using sustainable and/or circular economy materials, and Integrated Circular Design Solutions (ICDSs). The ICDSs that can be applied in the building sector today are collected in **Annex 9.1** “Catalogue of integrated circular design solutions” of this document.

All phases of a building's life cycle contribute significantly to current greenhouse gas emissions. For this reason, reducing the use of concrete and steel in the building sector contributes to lower material-related greenhouse gas emissions. Wood is an important renewable natural resource obtained from Italy's extensive forests and used for a wide variety of purposes, not only for the construction of buildings but also for panels, semi-finished products, and insulation. Wood is a local and circular raw material that has excellent mechanical properties and thermal insulation.

The massive forest cover testifies to the strong link between Trentino and its forests. In Trentino, forests currently cover an area of 392.000 hectares; this is this is 63% of the provincial territory. In terms of ownership, 76% of the forests are public. Due to the reduction of traditional activities related to mountain rural and pastoral practices and the sustainable management of the resources, the forest is constantly evolving. The use of the forest heritage is based on Forest Management Plans (FMPs), which are the tool for monitoring and managing forests and the mountain territory [16]. Spruce (*Picea abies*), (*Abies alba*), larch (*Larix Decidua*) and beech (*Fagus sylvatica*) are among the most widespread forest species. In Trentino, there are already various technologies and production chains linked to the use of these wooden species in the construction sector.

The Autonomous Province of Trento has launched a policy focused on sustainable forest management, paying attention to environmental protection, strengthening competitiveness and improving socio-economic conditions in the sector for some time.

With Provincial Law No. 16 of 27 August 1992, the PAT mandates the Trento Chamber of Commerce of developing timber markets and the valorisation of forest resources in the provincial district. In 1993 the Chamber of Commerce launches the 'Wood Project' aimed at the organisation of common local markets. The recent programme agreement between PAT and Chamber of Commerce, which took place in June 2020 for the period 2020-2023, identifies the Trentino wood sector as a sector to be valorised, in particular through specific actions aimed at "developing the Trentino wood market and promoting innovative forms of use and product qualification, also in relation to the adoption of certification systems" [17].

Today, Trentino is an important cluster in the wood industry. But, in Trentino there is also an extensive network for research into timber constructions and the energy requalification of buildings. A new solution called “Renew-Wall“ was recently developed for insulating buildings with Trentino wood. “Renew-Wall” is a newly developed and non-intrusive modular system for the retrofit of existing buildings, consisting mainly of an insulated wood-based panel already integrated with windows, shutters and VMC with heat recovery [18]. In addition, the city of Trento is one of the seven European cities involved in the “Build-in-Wood” project [19].

Furthermore, the ARCA system should not be forgotten in this context. ARCA is a rating system focused on timber construction, funded by the Autonomous Province of Trento in 2011. It has requirements to ensure the quality, durability, and sustainability of the constructions. The certification aims to guarantee to owners and developers the performances of the building and the quality of their investment, and to promote a sustainable construction way-of-think approach to all the stakeholders (designers, builders, suppliers) through measurable and comparable criteria.

The general REQUIREMENTS to be met and the POTENTIALITIES/OPPORTUNITIES are related mainly, but not exclusively, to the issues of sustainability and the culture of circularity. REQUIREMENTS are listed in **Table 1** and POTENTIALITIES/OPPORTUNITIES of both projects are listed in **Table 2**.

Table 1. *List of general requirements for the Design of the New Building and Renovation.*

NEW BUILDING	EXISTING BUILDING REFURBISHMENT
Be **innovative**	
Have a **timber frame**	Use mainly **wood-based solutions**
Be **energy positive**	Achieve **high energy performance**
Assure **high environmental comfort**	Assure **high environmental comfort**
Integrate **Nature-Based Solutions**	Be a **multifunctional** building intervention
Use **sustainable materials**	Be a **replicable** and **scalable** building intervention
Be a **smart building**	Be characterised by **speed of construction** and **possible disassembly**
Be a **climate responsive** building	Be **compatible with Superbonus** or its evolutions
Be **flexible** in adapting to future needs	
Be **reusable** or **recyclable**	
Be of **innovative architecture & BIPV**	
Be **inclusive**	
Have a **high architectural quality**	
Ensure **safety**	
Be **cheap**	

Table 2. *List of potentialities and opportunities.*

POTENTIALITY OF	OPPORTUNITY OF
Increasing the competitiveness of timber compared to “traditional” materials through the development of innovative solutions	Testing the creation of new sustainable supply chains that mainly use timber for both new construction and renovation
Connecting with the nearby energy geostructure	Providing seasonal thermal storage to the CPCC using disused road tunnels; reducing power needs, costs and emissions
Stimulating private property to join neighbourhood redevelopment with the creation of One Stop Shops	Becoming a neighbourhood model for innovation and sustainability
Reducing construction time and jobsite impacts (reducing dust and noise) for both new construction and refurbishment	Verifying the replicability potential of the building interventions
Contributing to the improvement of the quality of the indoor environment of buildings and the quality of the life of the citizens	Promoting the culture of circularity and CPCCs and creating awareness raising in the neighbourhood and community

4.2.2 PROCEDURE AND STAKEHOLDER INVOLVED

In order to face the great current and future challenges a mutual involvement of multiple actors is required (**Figure 6**). The creation of value for all those directly and indirectly involved in a project is essential for building a common purpose and approaching the complex issues affecting our planet. The importance of stakeholder engagement is recognized in promoting environmentally and socially responsible behaviours of companies from all sectors and of the community.

Figure 6. *Variety of actors involved in the sustainable building re(design).*
Source: ARV/NTNU/HABITECH.

SUSTAINABLE BUILDING (RE) DESIGN for CPCCs brings along the need to involve local stakeholders in order to collect needs and requirements, identify potential sources of conflict, strengthen the variety of design options, and improve decision-making and implementation processes.

Participatory design and stakeholder engagement practices are fundamental in situations involving the regeneration and redevelopment of buildings and urban spaces with criteria of environmental, social and economic sustainability in a circular economy perspective. The implementation of community activities and Living Labs focusing on "Social renovation" and "Energy transition" should not be missing in this context. They are being developed within the framework of WP3 - task 3.3.

The **GOALS of stakeholder engagement** are:

- TO COLLECT INFORMATION AND FEEDBACK to support strategic choices and decisions in the design process stages: Early Concept Design (ECD), Design Development (DD), Detailed Design (DeD);
- TO PROMOTE A CULTURE built on the importance of Stakeholders engagement in an integrated design process for CPCCs;
- TO DIRECTLY INVOLVE STAKEHOLDERS, COMMUNITY AND CITIZENS LIVING IN THE NEIGHBOURHOOD affected by the ARV project activities, in order to develop an integrated and neighbourhood-scale approach to building renovation, and in order to train them on the topics of energy transition, geothermal energy and energy communities.

The **STEPS of stakeholder engagement** are:

- IDENTIFYING and MAPPING of collaborative stakeholders to be involved in the activities of the design process;

- DEFINING and LISTING of the relevant issues to be addressed during the consultations (e.g. vision of the area project toward a CPCC in terms of strengths, weaknesses, opportunities, and threats; location of the building interventions and its relationship with the neighbourhood and the city; functions and end users; needs – requirements – performances, sizing, etc.);
- DEVELOPMENT OF THE ACTION PLAN in term of resources, initiatives of involvement (e.g. meetings, interviews, online questionnaire, forum, workshop, focus group, etc.), analysis and implementation of the results.

Stakeholder identification is the first step of stakeholder engagement. It identifies all those who can affect or are affected by the project, each with their own role and weight. In this context, the "internal" stakeholders are the organisations belonging to the ARV partnership involved in the Trento demo case (researchers and design team of the university and research unit, manufacturers, suppliers, etc.), while the "external" stakeholders are the owners, policy makers, end users, community, etc.). The identification of key collaborative persons is fundamental for working together, collaborating and maintaining productive relationships.

Stakeholder mapping (**Figure 7**) explores the relationships between actors as well as their links with the project. Its result is the actor-oriented map, a visual depiction of the key organizations and their relationships.

Stakeholders for the *Design of New Construction* and the *Design of Existing Building Refurbishment* of Trento demo case are listed and classified respectively in Tables which are reported in paragraphs 5.1.1, 5.2.1, 5.3.1 and 6.1.1, 6.2.1, 6.3.1 of this document. Please note that these tables and maps, (final product of a joint work with the partners HABITECH and EURACH working also in WP3) refer to the activities of the first year (2022) of the ARV project, and can be modified and integrated.

Figure 7. *Stakeholder mapping of the Trento demonstration project. Source: HABITECH.*

The **ACTION PLAN of stakeholder engagement** includes:

- LEVELS OF ENGAGEMENT that move from a more passive mode (1 and 2) to a more active mode (3), in particular:
  1) informing: bringing about knowledge and awareness raising
  2) consulting: asking and/or acquiring information

3) collaborating: cooperating and working together

- ENGAGEMENT TOOLS including direct on-site or remote interaction, internet, press, TV, etc.
- ENGAGEMENT METHODOLOGIES including meetings, public lectures, research, one-to-one interviews, online survey or forum, shared projects, joint initiatives or activities with other WPs, company visits, demo case visits, etc.
- PREPARATION OF INFORMATION MATERIAL regarding the ARV project and the demo case (e.g. presentations, summary of the project progress, etc.).

4.2.3 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL AND ECONOMIC GOALS

The built environment contributes to the establishment of communities, which must be SUSTAINABLE from architectural, environmental, social, and economic point of view to ensure a high quality of life for all. The Trento demonstration project intends to launch and test a collaborative design and creative space where researchers, architects, engineers, students, policy makers and manufactures work together to make ARV project vision a reality. In particular, the Trento demo case works towards implementation of a CPCC in the Trento city, focusing on new positive energy buildings and high energy efficiency refurbishment applying the EU Circular Economy Principles for Buildings Design.

The built environment is a major source of energy consumption throughout the life cycle of buildings. Buildings must be (re)designed to limit energy consumption in use, for example by using appropriate materials, and to produce and recycle energy. This means designing and constructing buildings optimising the 'anatomy' of the building non only to improve its performance, reduce energy consumption and employ innovative sources of renewable energy but also to achieve building envelop that are architecturally pleasing (new Bauhaus) and easy to implement.

The building sector is a major consumer of natural resources and contributor to waste. The process of constructing new buildings and the process of building renovations is producing waste. When buildings are demolished, most of the existing materials and components are lost. The same applies to renovations, which transform vast amounts of already extracted and treated materials into waste. Important environmental goals are: reduce the use of resources overall, significantly limit the use of non-renewable natural resources, emphasise the use and reuse of local materials, reduce the waste production during construction activities.

Positive energy buildings and NZEBs are an opportunity not only to save energy and reduce CO2 emissions, but also to improve the health and well-being of people who normally spend 90 per cent of their time inside buildings. Reducing emissions from buildings, particularly in the cities, can reduce pollution and improve air quality, benefiting the health of everyone living in cities.

The building sector is central to economic development. It is strategic that this sector increasingly takes on sustainable development as the key to change for the quality growth of our country's local communities. CPCCs can contribute significantly to increase of jobs to realise them as the demand for sustainable new construction and renovation grows. The life cycle of a building (from conception to construction, management and even renovation) impacts a wide range of people, and provides many opportunities for work.

Last but not least, goal of the Trento demonstration project is to educate and create awareness in all stakeholders involved. In order to bring the European Green Deal closer to people and to accelerate and achieve the transition towards CPCCs, it important to have the community, and in particular the citizens, on board to make sure this transition is accepted and feasible for all.

4.2.4 STRATEGIES AND SOLUTIONS

The basic idea introduced by the ARV project is to address integration, circularity, and simplicity in the processes of planning, design, construction, and use of CPPCs. The overall aim of the Trento demonstration project, for what concerns the WP4, is to demonstrate and validate attractive, resilient, and affordable strategies and solutions that will significantly speed up deep energy renovations and deployment of energy and climate measures in the construction and energy industries. The Trento demo case focuses on the strategies and solutions shown in **Table 3 and Table 4**.

Table 3. *List of strategies and solutions for the New Building.*

STRATEGIES AND SOLUTIONS FOR THE NEW BUILDING
Use a local and circular raw material for the structure (structural timber) and consider one or a combination of the following systems: post and beam construction, Cross Laminated Timber Panels (X-Lam), or framed wall
Produce more energy than the building consumes from renewable sources
Design building components to be long-lasting, easy to repair, reused, remanufactured, refurbished, and recycled
Integrate passive systems (ventilated facades, active thermal mass, natural ventilation) and active systems (photovoltaics, combination of mechanical ventilation and geothermal heat pumps also with connection to the energy geostructure) for energy saving and indoor living comfort
Include NBSs introducing green roof or green facades
Involve the installation of technology systems for monitoring the building performances
Design the optimized building according to specific characteristics of that particular site, to minimize extreme energy use and have a reduced impact on the natural environment (with particular attention to natural and mechanical ventilation concepts)
Design on the basis of a standard module to ensure adaptation to future needs (extensions or additions) and to facilitate construction features (transportability, etc.)
Possibility for the building to be reusable by changing its use, or to be relocated to another site, or be disassembled but with construction materials recyclable; have potential for future adaptation, re-use or deconstruction
Design with spatial quality and accessibility for persons with disabilities and senior citizens
Employ strategies and design measures for fire and seismic safety of the building
Minimize the disruption for citizens during the construction process, i.e., construction time, noise, dust, etc.
Provide comfortable indoor and outdoor conditions with spatial quality and accessibility for persons with disabilities and senior citizens
Convert the building envelope into electricity-producing surfaces with architectural and aesthetic considerations of the integration of BIPV/BAPV

Table 4. *List of strategies and solutions for the Renovation.*

STRATEGIES AND SOLUTIONS FOR THE EXISTING BUILDING REFURBISHMENT
Use a local and circular raw material for the structural framework and insulation
Zero disruption of building occupants (renovate while in use)
Use panels that provide architectural and energy (summer and winter) requalification, and environmental comfort; use panels that integrate high-efficiency windows, shutters and VMC with heat recovery
Use solutions with economies of scale capability
Not adversely affect the fire and seismic safety of buildings

5. DESIGN OF THE NEW CONSTRUCTION

5.1 EARLY CONCEPT DESIGN

The New Construction for the Trento demonstration project is an experimental service building (hereinafter referred to as the New Building) to be located in the parking lot called "ex-Zuffo" which is in Area 4 of the Piedicastello district.

Early Concept Design (ECD) refers to the first ideal representation of the New Building. Its objective is to define and present the main qualitative and functional characteristics of the building, highlighting its most significant aspects.

The final product of the ECD of the New Building is the result of a participatory design process. This chapter briefly describes the *procedures and stakeholders involved*, *the architectural, environmental, social, economic goals* and the *strategies and solutions* pursued.

5.1.1 PROCEDURE AND STAKEHOLDERS INVOLVED

EURAC and UNITN started the participatory design process for the New Building. Subsequently, the design process was developed with the collaboration of the other ARV partners which are POLITO, HABITECH and DOLOMITI Energia. Other stakeholders involved in the ECD phase were the Trento Municipality, the Users, and the Community of Piedicastello district (see **Table 5**).

Community of Piedicastello district and its neighbourhood committee were invited to the first public meeting with round table and discussion. In the first part of the meeting, the citizens listened to policy makers, experts and technicians who introduced the ARV project and the aims of the Trento demonstration project; in the second part, the participants were able to express their views and opinions (**Figure 8**).

Figure 8. *Public meeting, 24.06.2022. Photo: UNITN.*

Information, consultation, and collaboration among stakeholders took place through meetings (**Figure 9**). Participants, dates, locations, and topics discussed are listed in the "Table of Meetings with Stakeholders" (see **Annex 9.3.2**). The sharing of material concerning the concept design development took place through the transmission of attachments via email (i.e. working papers, flyers, etc.) and power point presentations. The outcomes of these meetings were reported in the local WP4 meetings. In addition, the use of an online survey for the involvement of End Users was important.

Figure 9. *Stakeholder meeting at the Trento Municipality, 20.09.2022. Photo: UNITN.*

All stakeholders contributed directly or indirectly to the development of the ECD of the New Building. The design activities dealt with the analysis of the context, the definition of function, form and construction system of the New Building.

EURACH mainly took care of the general coordination of the activities by assuming the role of facilitator. UNITN and POLITO took care of the technical-scientific part by involving the stakeholder key persons from the beginning. EURACH and HABITECH played an important role in the stakeholder engagement process by organising the public meeting, promoting and participating in other activities (i.e. survey online dissemination).

From the beginning, the political and regulatory role of the Trento Municipality was relevant. Council members and engineers of the “Land-use planning and private housing Department” and the “Mobility and Ecological Transition Department” collaborated on the location of the New Building in Area 4 and its introduction as a pilot project in the PUMS. After reiterating the interest in the New Building and recognising its importance in terms of scalability and implementation in other contexts, the Trento Municipality started the authorization process.

For the definition of the construction system, the role of HABITECH was very important, in particular the contribution of the local companies involved later in the DD and DeD phases.
DOLOMITI Energia contributed to the preliminary verification of specific aspects related to the function of the New Building.

Considering the importance of collecting the opinions of potential End Users, UNITN developed an online survey in order to verify the functional programme of the New Building (**Figure 10**). The questionnaire serves a dual purpose of:

- investigating the need/expectations of citizens who are owners or users of electric or hybrid vehicles on possible services that could improve the recharging and waiting times at dedicated stations;
- communicating and promoting the ARV project and the importance of citizens’ engagement in the same.

The short questionnaire was structured with “structure” questions to define the basic characteristics of the respondents (such as age group and where they live), “context” questions to introduce the reference scenario for the intent of the study, and “purpose” questions to answer the objectives of the survey. The questions are closed or semi-open, in some cases with the possibility of giving one or more answers, in other cases with the possibility of specifying the answer using one's own words (see **Annex 9.3.3**).

In order to contextualize the survey and also promote the ARV project, a short introduction was included in the questionnaire itself and in the text of the email with which the survey was disseminated. The questionnaire is anonymous and does not include questions which can potentially identify the respondent (e.g. name, gender, etc.). All responses to this survey were kept strictly confidential and the survey data were reported only in aggregate form or in a manner that does not allow individual responses to be identified. No individual response was disseminated or published.

The results of the online survey were presented and discussed during the stakeholder and local WP4 meetings. They essentially confirmed the initial hypotheses and provided some input for the further development of the early concept design. For further details, please refer to the “Summary Report of the online survey” (see **Annex 9.3.4**).

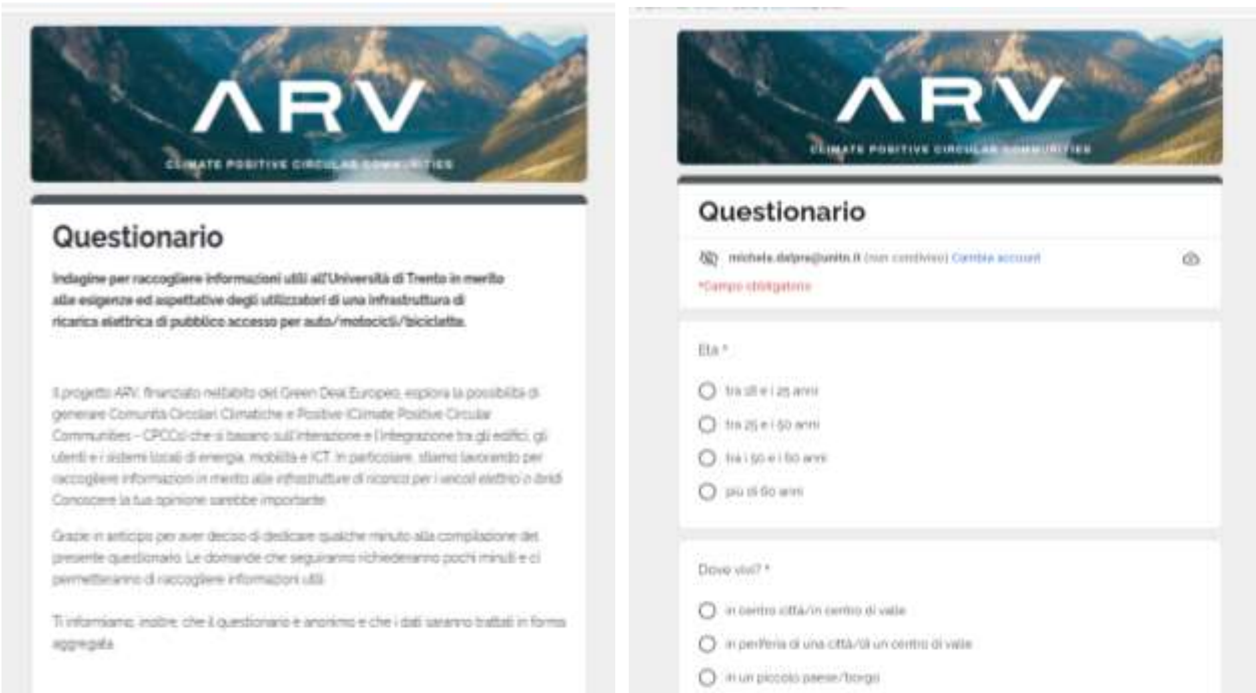

Figure 10. *Online survey for collecting information from End Users about the purpose of the new building. Source: UNITN.*

Another initiative organised by UNITN was to involve students of the course entitled *"Sustainable building and architecture"* of the Department of Civil, Environmental and Mechanical Engineering. The idea was to broaden the Community involvement by organizing a design workshop with a focus group of future design professionals in order to promote the ARV project and to collect ideas, visions and design proposals for the New Building.

This initiative, that is still ongoing at present, offers an opportunity for information/education, awareness-raising and participatory understanding of the new paradigm of ‘integrated circular design of CPCCs’, bringing the focus group of the student community closer to the concept of positive building (learning by doing). A total of 15 students are involved (**Figure 11**), that are working in small groups during the first semester of the academic year 2022/23 (from September 2022 to February 2022).

The expected results are a cultural reflection, a concrete application to a case study and the collection of proposals from young people who in the immediate future will be able to design by applying the new design paradigms promoted by the ARV project. The results will be presented and discussed during the stakeholder and local WP4 meetings of the DD of the New Building.

Figure 11. *Design workshop with the students of the course entitled "Sustainable building and architecture" of the University of Trento. Photo: UNITN.*

Table 5. *List of stakeholders of the Design of the New Building.*

	CATEGORIES	GROUPS	KEY PERSONS	LIFE CYCLE PHASES
INTERNAL ACTORS belonging to the ARV partnership	UNIVERSITY	UNITN (DICAM)	proff. R. Albatici, A. Frattari, M. Dalprà proff.M. Piazza, I. Giongo, proff.P.Baggio, A. Prada proff.G. Massari	Design (ECD, DD, DeD)
	UNIVERSITY	POLITO (DAD) POLITO (DISEG)	proff.G. Callegari, D. Bosia, phd student G. Ricciardi ing. G. Roccasalva arch. PhD L. Savio arch. P.Simeone prof. M Barla	Design (ECD, DD, DeD)
	RESEARCH UNIT	EURACH	dott. D. Vettorato	Design (ECD, DD, DeD)
	ENERGY AND ENVIRONMENT DISTRICT	HABITECH	dott. M. Curci	Design (ECD, DD, DeD) Production Construction
	MANUFACTURING COMPANY	HABITECH (ARMALAM)	ing. F. Ferrario	Design (ECD, DD, DeD) Production Construction
	ENERGY PROVIDER	DOLOMITI ENERGIA Spa	ing. N. Fruet	Design (ECD, DD, DeD) Use
EXTERNAL ACTORS not belonging to the	OWNER/LOCAL AUTHORITY	Municipatility of Trento	Policy makers council member M. Baggia council member E. Facchin ing. S. Fedrizzi ing. G. Franzoi	Design (ECD, DD, DeD) Construction Use
	COMMUNITY	Residents in Piedicastello district Citizen of Trento city	Representatives and/or small focus group - ing. C. Geat	Design (ECD, CD, DD) Use

		Students of University of Trento	Representatives and/or small focus group Sustainable building and architecture course aa 22/23	
	USERS	E–vehicle users Commuters	Focus group	Design (ECD, CD, DD) Use

5.1.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

After a number of unfortunate town-planning choices that have caused great damages that are still visible today, the intent of the ARV project in the city of Trento is to start a participatory process that will transform the Destra Adige - Piedicastello district into an incubator and demonstrator of a new way of thinking about local communities, oriented towards climate respect with a view to a circular economy and energy self-sufficiency, and through the development of simple and inexpensive solutions that can be rapidly replicated and exported to other districts and cities. To this end, it was decided to design an experimental wooden demonstration building that systematizes innovative design, construction, and plant engineering methods. The issue of positive energy building is studied to define design requirements that convey not only more efficient energy performance, but also a new culture for positive energy building design.

The basic idea behind this design process is to create a new **EV CHARGING HUB with INTEGRATED SERVICES** in an area that will take on a dual function in the near future, linked to commuting and tourist movements to and from the Trentino valleys, and that will become a "mobility hinge", also in expectation of increasing attention to the themes of railways, soft mobility and smart mobility according to the general objectives of the PUMS. Therefore, the functions of the area are:

- WAITING area for people stopping for medium to long periods for different reasons (e.g. electric vehicle recharging, commuting, car-pooling, work appointments or other) and for those who need space for short to medium term where they can carry out some activities, both recreational and work-related.
- TRANSIT area zone for people commuting or moving quickly for other reasons (work and tourism primarily), access to vehicle parking, access to sharing services (i.e. car-sharing), access to the city (i.e. tourists), access to logistics services (i.e. receiving shipments at hub lockers), etc.

5.1.3 STRATEGIES AND SOLUTIONS

The integrated design process with stakeholders defined the location of the New Building in Area 4, the definition of the functional programme, the preliminary sizing, the definition of the construction grid, the elaboration of schematic floor plans, sections and 3D views.

The location of the New Building is in ex Zuffo parking lot (**Figure 12**) owned by the Municipality of Trento. It will be located in the northern part (**Figures 13 and 14**), considered to be the most suitable and strategic in relation to the PUMS objectives. Contextually to the development of the building design of the New Building, the Municipality of Trento has undertaken to redefine the main axes of access and modal interchange of this parking area.

The activities proposed for the functional programme of the New Building and its surrounding outdoor space are divided into three macro-areas.

The first related to the VEHICLE includes the activities of *Recharge*, *Wash* and *Repair shop*.

The second area refers to the PERSON and consists of activities that are grouped in the categories called *Services, Trade* and *Other*. The *Services* category includes: info point, offices and meeting room (Management); relax, work and play (Relax); Bus, bike, scooter, Pedestrian and Taxi (Intermodal). The *Trade* category includes: bar, shelves, typical products, (Food) and basic products (Wear). The *Other* category concerns storage and systems.

The third area concerns COMPLEMENTARY FUNCTIONS such as green spaces and mobility.

Figure 12. *View of the ex Zuffo parking lot. Source: Google Earth*

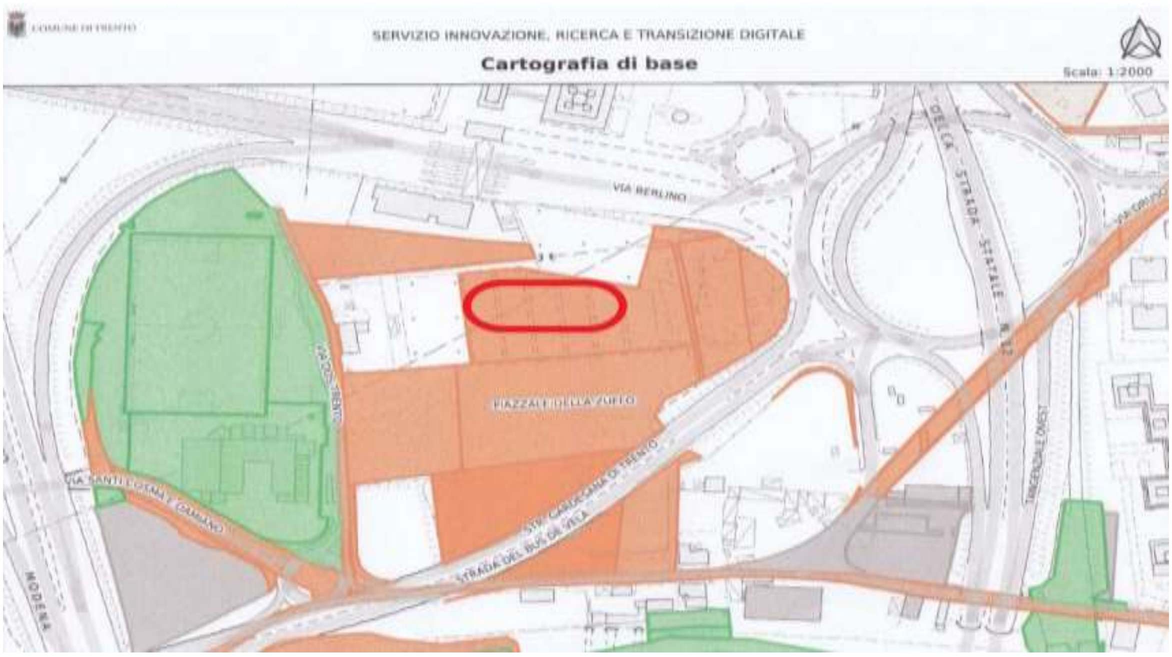

Figure 13. *Area designated for the location of the New Building (in red).*
Source: UNITN.

Figure 14. *Current state of the intervention area (in red. Source: Google Earth.*

Figure 15 depicts the interaction among the specific activities grouped into categories as follows:

1. Intermodal (I): bus, bicycle, scooter, taxi, pedestrian, sharing/rental, pooling, shuttle service, hub lockers;
2. Relax and work (R): rest, work, play, reading room, phone charging, smoking area, smart benches (e-lounge) to be placed inside the building (R(in)) or outside (R(out));
3. Vehicle (RLO): charging, washing and workshop;
4. Management (M): info point, offices, meeting room (with cloakroom, flipchart, video projector, printer) ticket machine for public transport or panels with QR codes, information panels with tips and points of interest;
5. Wear (W): essentials;
6. Food (F): shelves, counter, Trentino products, bar service/hot meals/ready meals also with possible equipped area (microwave, kettle, sink);
7. Other (A): storage, installations (electrical, fire prevention, heating, cooling, ACS, energy storage, controlled mechanical ventilation;
8. Complementary activities (C): possible
9. Toilets (WC).

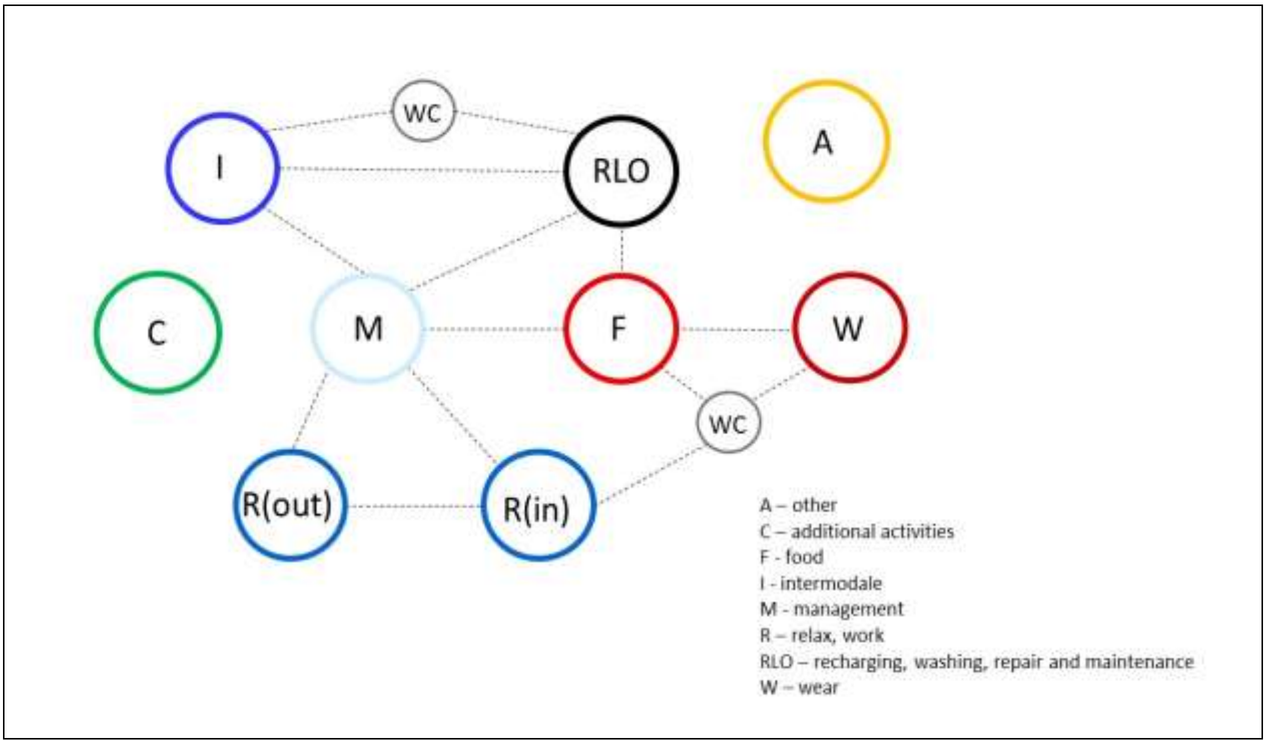

Figure 15. *Interactions among the activities of the New Building's functional programme.*

As the New Building is a demonstrator building, a simple solution was chosen for the shape, which could be combined with different façade element solutions to be monitored and proposed for future new constructions.

The building is designed on a square module with dimensions 3.60mx3.60m (60 cm being a useful dimension both in terms of usability of the space and furnishing) and with a load-bearing timber frame. Between one module and another there is a space of 20 cm that allows the insertion of vertical elements (pillars) that can have dimensions 20xL where L>=20cm. The module allows for floors with 3 different types of span: 3.6m - 7.20m - 10.80 m, depending on the type of new technology that will be used. The net floor area is approximately 155 square meters.

The building will have a rectangular plan (**Figure 16**) with short side 3.60mx2 = 7.20m (plus 3x0.20 for the structure) and long side approximately 3.60mx6 = 21.60m (plus 7x0.20 for the structure).

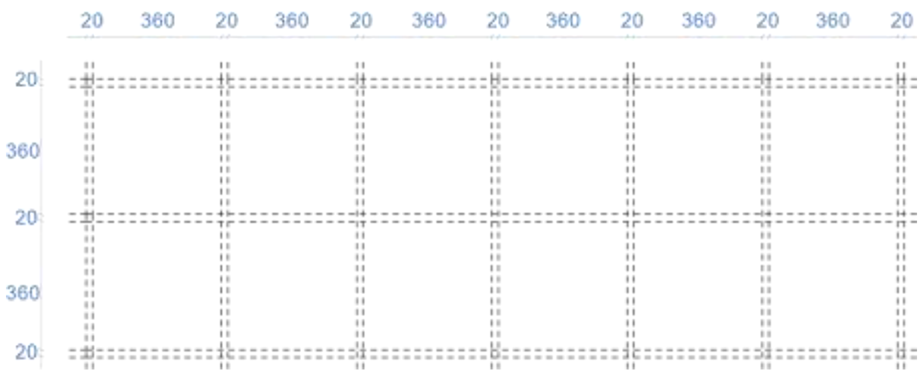

Figure 16. *Module and construction grid for the New Building.*

In elevation, the building will be **two storeys**, each 3m of effective height. Since the total height must be less than 8m as per building regulations, the roof will be flat or slightly sloping. A concrete basement is planned to be used as storage and plant room. The basement walls will also be used for testing the innovative geothermal probes proposed by POLITO in WP6. **Figure 17** shows the schematic sections and of the building.

The schematic functional plans of the New Building are shown in **Figure 18** while **Figure 19** and represents graphically the percentage distribution of the different functional areas.

The modularity in plan allows the available space to be increased if necessary (in plan in both directions but also in elevation), correlating the new parts to the existing structure and installations (thus allowing the scalability of the project and reproducibility in conditions with different requirements).

The load-bearing frame will consist of timber pillars, glulam beams, and innovative large-span wooden floors, inspectionable and easily replaceable St. Andrew's cross seismic dampers will be used.

The envelope will consist of prefabricated wooden walls hanging from the floors (which are protruding from the beams). To the south there will be six innovative prototype walls whose thermo-hygrometric performance will be monitored and compared: *green wall*, *super-insulated wall*, *cool wall*, *ventilated wall, BIPV wall* and *transparent BIPV wall*.

A simple conceptual mass design model was made to perform the initial analysis and design work required at this stage of the design process (**Figure 20**).

From the plant engineering point of view, the building will be equipped with:

1. Multi-source heat pump (aerothermal/geothermal/solar thermal) to exploit and compare the efficiency of the different sources
2. Solar thermal with drop pump connection (SAHP) and probably to cover the minimum demand for DHW
3. Sensible thermal storage (to exploit advanced control logic)
4. PV system (if alternative to BIPV)
5. PV storage batteries (if required)
6. Open control and regulation system (BAS) (useful for data collection but also for regulation and implementation of different strategies)
7. Dry heating system
8. VMC plant with thermodynamic recovery.

Passive heating and cooling techniques such as natural ventilation and envelope thermal inertia will also be implemented.

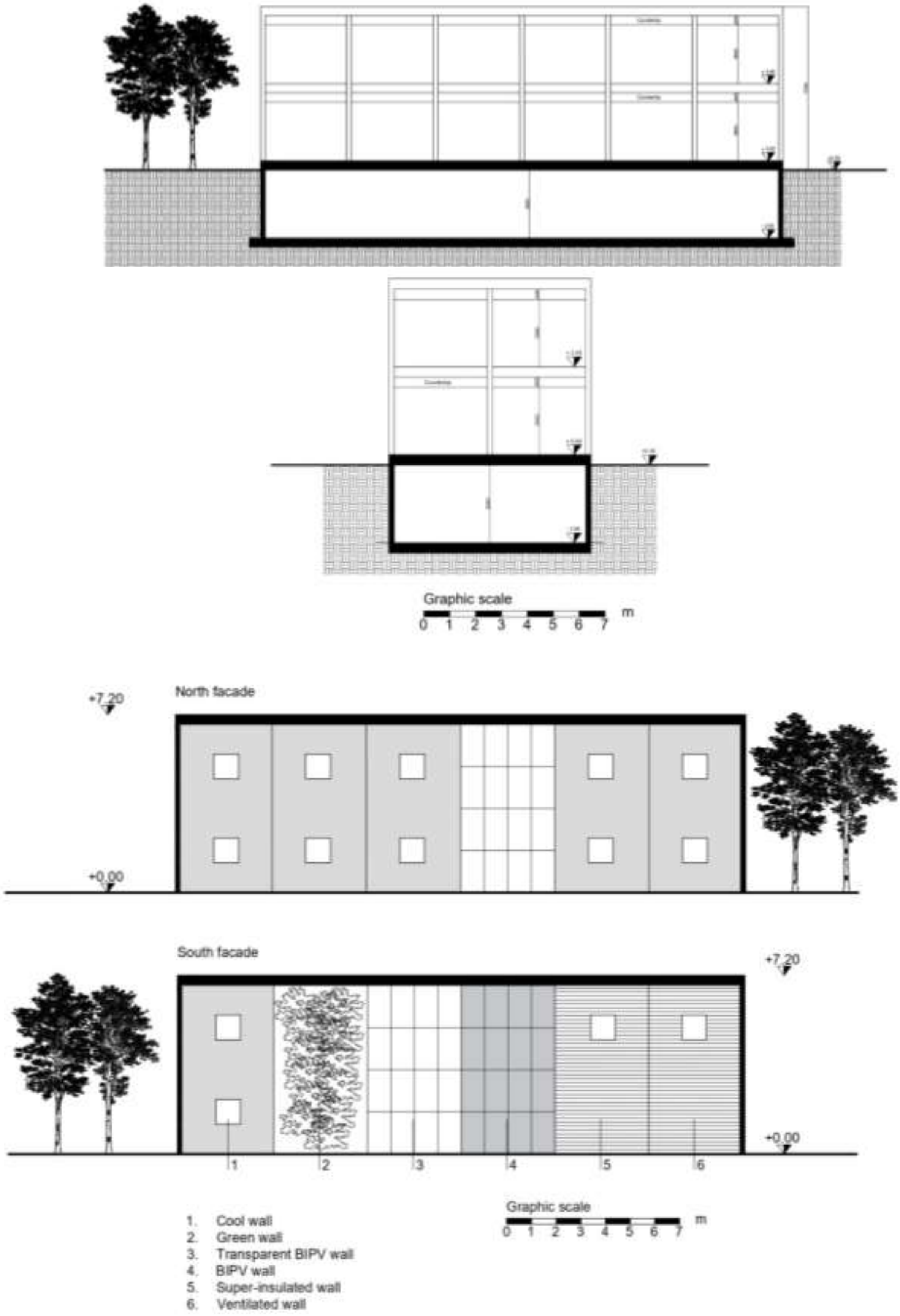

Figure 17. *Schematic sections and elevations of the New Building. Source: UNITN*

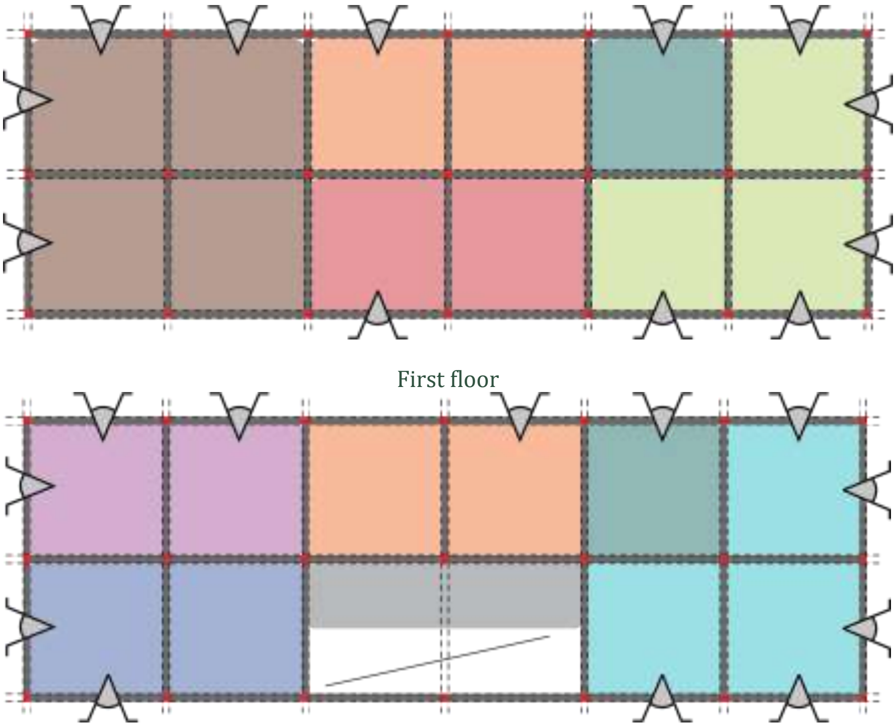

Figure 18. *Functional schematic plans of the New Building. Source: UNITN*

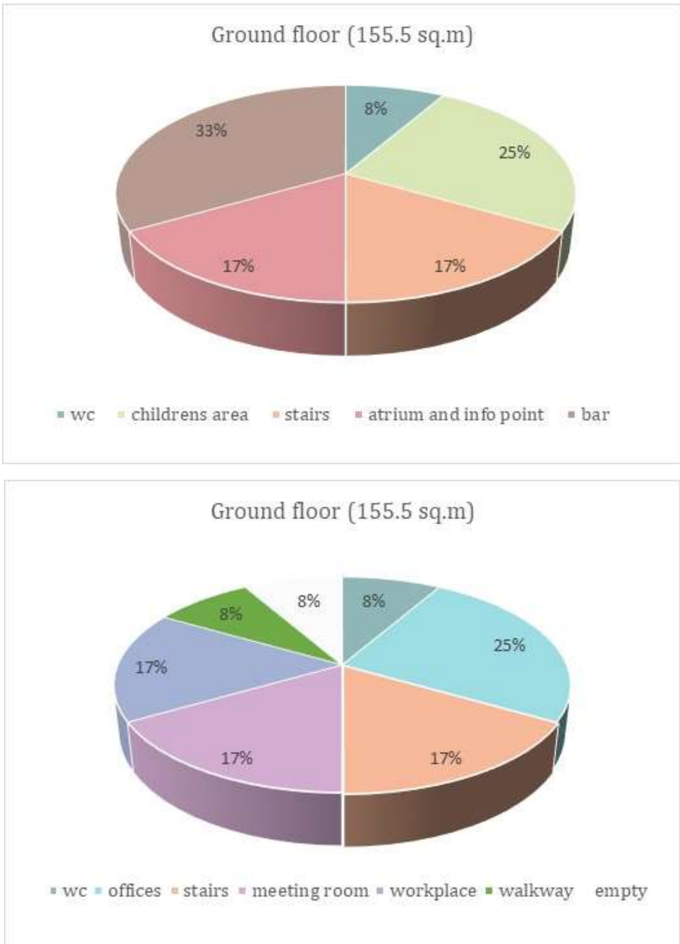

Figure 19. *Percentage distribution of the different functional areas for the New Building. Source: UNITN*

Figure 20. *3D views of the New Building model. Source: UNITN*

After defining the concept of the New Building, a preliminary cost estimate by applying a synthetic cost procedure has been done.

5.2 DESIGN DEVELOPMENT

5.2.1 PROCEDURE AND STAKEHOLDERS INVOLVED

5.2.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

5.2.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

5.3 DETAILED DESIGN

5.3.1 PROCEDURE AND STAKEHOLDERS INVOLVED

5.3.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

5.3.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

5.4 SUMMARY

5.4.1 ARCHITECTURAL QUALITIES

5.4.2 SOCIAL QUALITIES

5.4.3 ENVIRONMENTAL SUSTAINABILITY

5.4.4 ECONOMIC FRAMEWORK

Actions to be implemented in the next year

5.5 DESIGN REPLICABILITY AND TRANSFERABILITY IN THE URBAN AREA

5.5.1 OPPORTUNITIES

5.5.2 CHALLENGES

5.5.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

6. DESIGN OF EXISTING BUILDINGS REFURBISHMENT

6.1 EARLY CONCEPT DESIGN

6.1.1 PROCEDURE AND STAKEHOLDERS INVOLVED

6.1.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

6.1.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

6.2 DESIGN DEVELOPMENT

6.2.1 PROCEDURE AND STAKEHOLDERS INVOLVED

6.2.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

6.2.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

6.3 DETAILED DESIGN

6.3.1 PROCEDURE AND STAKEHOLDERS INVOLVED

6.3.2 ARCHITECTURAL, ENVIRONMENTAL, SOCIAL, ECONOMIC GOALS (WHAT, WHY, WHO, HOW)

6.3.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

6.4 SUMMARY

6.4.1 ARCHITECTURAL QUALITIES

6.4.2 SOCIAL QUALITIES

6.4.3 ENVIRONMENTAL SUSTAINABILITY

6.4.4 ECONOMIC FRAMEWORK

Actions to be implemented in the next year

6.5 DESIGN REPLICABILITY AND TRANSFERABILITY IN THE URBAN AREA

6.5.1 OPPORTUNITIES

6.5.2 CHALLENGES

6.5.3 STRATEGIES AND SOLUTIONS

Actions to be implemented in the next year

7. INNOVATIONS IN THE DESTRA ADIGE - PIEDICASTELLO DEMO

The innovations developed for the project in the Destra Adige Piedicastello are presented in this chapter.

INNOVATION #1:

A catalogue of Integrated Circular Design solutions for building refurbishment with 50% of energy reduction and positive energy new construction, mainly acting on: building envelopes with active (BAPV/BIPV) and passive elements, nature-based solutions integration, inform Industry 4.0 via digital surveys, comfort improvement (psychological, physiological).

It has been implemented in the ECD phase of the New Building. Particularly, the main factors it pertains to are Energy, Architectural quality, and Environmental sustainability.

The innovation is a catalogue of integrated circular and sustainable solutions for positive and low carbon footprint buildings which aims to be of help and support to all possible stakeholders (from designers to users), and especially to drive public administration and decision-makers to the proper choice of sustainable solutions for new buildings and refurbishment of existing ones, considering circular design practices integrated into Buildings 4.0 vision. Both physical solutions and digital ones have been considered, categorized as: Urban Green Infrastructure, Blue Infrastructure, Energy Systems, Shading devices, Building technologies, and Digital solutions. Each category is further divided in sub-categories, according to the type of solution considered. Each category answers to a specific climate-related challenge: Energy sustainability, Temperature regulation, Sustainable water management, Health and wellbeing, and synergies among them are highlighted as well.

For each solution, the catalogue provides a brief description, the challenges it responds to, the objectives it can achieve, the performances it can guarantee and the benefits, even if not strictly related to the challenges. Each solution refers to one or more case studies defined as best practices.

The performances of each solution constitute the due process to achieve the specific objective given in a design and planning procedure, driven by enabling processes of the built environment. As such, performances can be measured and controlled by practitioners. Designing through a climate sensitive approach relies on the understanding of the relationship between the built environment and urban climate and on the management of parameters and interactions among them. One of the main innovative aspects of the catalogue is the presence of information sheets on products, building systems and technologies, mainly related to companies in the local production fabric, which can contribute to the implementation of the proposed solutions.

The catalogue presents a range of possible physical and digital solutions that can be applied especially in a SUSTAINABLE BUILDING (RE)DESIGN process, in particular (but not only) in the ECD phase of new and existing buildings. Solutions are presented in general terms and real market products (particularly at a local/regional level) are listed. Depending on local environmental conditions and intended use of the building, pros and cons of each solution concerning environmental challenges are defined, with specific objectives and related performances. Especially designers and public administration technicians can refer to the catalogue so to guide their choice towards a local, circular and efficient (re)design and planning process.

In order to finalize this action, Habitech, in collaboration with the University of Trento, the Polytechnic of Turin and EURAC, has launched a consultation through a questionnaire available at the following link https://forms.office.com/r/vTLuiHr93T .

The consultation aims at identifying products, building systems and technologies, mainly related to local companies that can contribute to the implementation of the proposed solutions and that will be included in detailed information sheets within the Catalogue.

In order to promote the involvement of companies, a flyer was prepared (**Figure 21**) that briefly presents the catalogue and lists the possible advantages and opportunities for companies wishing to apply:

- local, national, and international visibility of your product/technology/system
- link to a European Green Deal project;
- promotion, information and training for the construction sector, public and private clients, end users;
- opportunity for synergies between building stakeholders and the world of research;
- active contribution to the challenge of the circular economy and integration into Building 4.0 processes.

The collected data will be analysed for research purposes by the ARV project team and may be made public to enrich the Catalogue information sheets.

Figure 21*. Flyer for the involvement of companies contributing to the implementation of catalogue solutions.*

INNOVATION #2:

Natural and mechanical ventilation concepts for climate responsive buildings.

It has been implemented in the ECD phase of the New Building. Particularly, the main factors it pertains to are Energy and Architectural quality.

The purpose of the study on Natural and Mechanical Ventilation concepts for climate responsive buildings is to offer an overview on IEQ conditions created by different ventilation types, defining pros and cons of natural ventilation techniques in buildings vs mechanical ones. A framework on scientific evidence of papers comparing NV and MV in terms of comfort and well-being has been provided, in a perspective of performant and sustainable buildings' design (e.g., nZEBs, nPEBs, climate responsive).

The main hypothesis is that ventilation is firstly aimed to provide IEQ, with energy savings as a very important additional aim. For this reason, the following research questions were explored:

1. Which differences are present between IEQ conditions guaranteed by NV and MV?
2. Which ventilation techniques are more suitable at different climates, seasonal and outdoor pollution conditions, according to both IEQ and energy perspectives?
3. Which ventilation techniques are more suitable with different building types and uses?
4. Which are the research gaps in terms of effects of NV and MV on the IEQ, depending on the type of building, the ventilation technique and the comfort domain considered?

The outcomes of the study can be useful for understanding the main research gaps in the field and to guide designers in the best choice to ensure comfort and well-being in nZEB and nPEB design, also with attention to proper ventilation of indoor spaces.

The outcomes of the study can be exploited by policymakers, in order to further expand and update ventilation standards and guidelines considering both energy consumption and indoor well-being. The development of such guidelines is fundamental for engineers, architects and planners, in order to help them in conscious and contemplated choices during the design process. In particular, the study can be applied during the ECD phase of the building (re)design in order to properly define the building shape and devices for ventilation and night cooling techniques towards energy saving and human well-being.

The results of the study were published in the paper entitled "Natural and Mechanical Ventilation Concepts for Indoor Comfort and Well-Being with a Sustainable Design Perspective:

A Systematic Review" in the issue n.12 of the scientific, peer-reviewed, open access journal Buildings (see **Annex 9.3.5**).

INNOVATION #3:

Architectural and aesthetic integration of BIPV/BAPV/PVT solutions; materials selection; integration between PV, Solar Thermal and CMV systems.

It has been implemented in the ECD phase of the New Building. Particularly, the main factors it pertains to are Energy and Architectural quality.

The strategic role of the energy sector in European decarbonisation is fundamental for achieving climate neutrality by 2050. The shift to energy communities has also been supported by new regulatory standards which in some cases also have implications for architecture. One example is the standard Photovoltaics in Buildings EN 50583:2016 which was the first to include the integrated photovoltaic module in a multi-functional construction component, in accordance with the Construction Products Regulation (EU) CPR 305/2011. This new interpretation has assisted with the move from PV to smart BIPV systems as innovative technological components contributing to tackling current decarbonisation challenges [2, 3]. These processes have stimulated the market through R&D to produce new generation smart materials which can generate electricity, extending the surface area of the building envelope used for this purpose. This approach has led to a change of interpretation in how building systems are incorporated into the architectural design, as shown in the case studies analysed in this paper.

The research group at the Politecnico di Torino Department of Architecture and Design analysed reports and scientific articles published by European research institutions in detail, and major online databases for sharing BIPV best practices were consulted; Interviews were also conducted, as a means for comparison and critical analysis, with BIPV innovation technology researchers from a number of

European organisations, such as the NEST[11] research lab in Zurich, SUPSI[12] and EPFL[13]. A comparison of the leading European producers of BIPV modules, such as SwissINSO, AGC Glass and Ertex Solar, has been made to complete the analytical framework. A summary of the sources consulted is presented in **Figure 22.**

	scientific papers	selected content
1	D'Ambrosio V., Losasso M., Tersigni E (2021) Towards the Energy Transition of the Building Stock with BIPV: Innovations, Gaps and Potential Steps for aWidespread Use of Multifunctional PV Components in the Building Envelope	Product customisation
2	Attoye D. E., Tabet Aoul K. A., Hassan A (2017) A Review on Building Integrated Photovoltaic Façade. Customization Potentials	BIPV façade applications
3	Pelle M., Lucchi E., Maturi L., Astigarraga A., Causone F., (2020) Coloured BIPV Technologies: Methodological and Experimental Asses¬sment for Architecturally Sensitive Areas	Product and manufacturer overview
4	Sánchez E., Izard L., (2015) Performance of photovoltaics in non-optimal orientations: An experimental study	PV façade benefits
5	Munari M. C., Roecker C., (2019) Criteria and policies to master the visual impact of solar systems in urban environments: The LESO-QSV method	Visual impact of PV system
6	Norwood, Z., Theoboldt, I., Archer, D.E. (2016) Step-by-step deep retrofit and building integrated façade/roof on a 'million program' house	case study of BIPV façade for retrofit

	reports	selected content
1	Zanetti I., Bonomo P., Frontini F., Saretta E., van den Donker M.N., Verberne G., Sinapis K, Folkerts W., Vossen F., (2017) Building Integrated Photovoltaics: Product overview for solar buildings skins. Status Report 2017	Customized products overview
2	Corti P., Bonomo P., Frontini F., (2020) Building Integrated Photovoltaics: a practical handbook for solar buildings. Status Report 2020	BIPV case studies
3	IEA SHC (2013) Designing Photovoltaics System for Architectural Integration. Criteria and guidelines for product and system developers, Task 41.A.3/2	Product and project overview
4	Kraubitz, T., Scheibstock, P., Guillen, G. (2018) Plus Energy Buildings and Districts, keystone papers 1 for GIZ's Sino-German Urbanisation Programme	case study of plus energy building with BIPV
5	IEA PVPS (2019) Coloured BIPV: Market, Research and Development, Task 15, Subtask E, 2019	PV Aesthetic features and technology

	interview	topic
1	Pietro Florio / *JRC, Scientific Research Project Officer*	the role of applied research in BIPV technological innovation
2	Alessandro Virtuani / *Senior researcher at EPFL & co-founder Officina del Sole*	the importance of BIPV for European decarbonisation challenges
3	Pierluigi Bonomo / *Researcher- Head of BIPV Advanced Building Skin Team at SUPSI*	new formal configurations interpreted by architecture
4	Enrico Ferramondo Marchesi / *innovation manager of living lab NEST, Zurigo*	collaboration between research, industry and architects to speed up the transfer of BIPV within the market and the architecture

database

1 solarchitecture.ch **2** bipv.ch **3** solaragentur.ch **4** bipv.eurac.edu/en

Figure 22. *Main analysed sources.*

As a result of the analysis, 78 BIPV integrated façades in Europe were identified and analysed, of which 67% related to the residential construction sector. First generation (c-Si), second generation (a-Si, CIGS, CIS, CdTe) and third generation (OPV, DSSC) PVs were all considered. It is relevant to show how – as a result of the technological innovation in PV aesthetics, which started in 2010 – 39.4% of the surveyed façades had adopted completely camouflaged solutions or coloured PV cells (**Figure 23**). These first results of the research project were presented within the framework of the international conference "CONF.ITECH 2022. Technological imagination in the green and digital transition" (Roma, 30/6 1-2/7, 2022). The scientific paper by Guido Callegari, Paolo Simeone, and Eleonora Merolla entitled "Photovoltaic breakthrough in architecture: integration and innovation best practice" will be included in the Proceedings to published by Springer International Publishing AG in the next few months.

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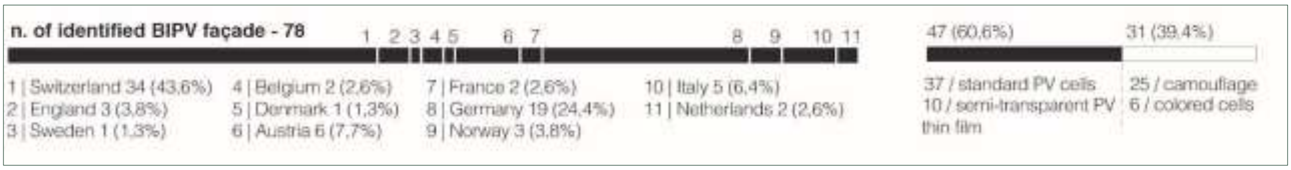

Figure 23. *Analysis of the current state-of-the-art of BIPV integrated façades in Europe. / Original graphics by Callegari G., Simeone P., Merolla E.*

The research group at the Politecnico di Torino Department of Architecture and Design ARV project is centred on developing and designing smart BIPV system building envelope components characterised by prefabrication, recyclability, and modularity.

In the context of the ARV project, these aspects are part of the ecosystem of the Autonomous Province of Trento, where the companies in the building sector are strongly oriented towards the development of industrialized products and off-site solutions for architecture, with particular reference to the engineered wood components sector. Therefore, the aim was to experiment, within the ARV project, with plant-systems integration in an industrialized building envelope system produced in a factory.

Incorporating a prefabricated envelope system and an industrialised product makes it possible to demonstrate the relationships between the various components, including the systems (PV, HVAC, etc.), the wall-window node, and the technologies for predictive monitoring, by analysing the design of the assembly-disassembly processes. Specifically, the innovation refers to a prefabricated PVT (solar photovoltaic thermal technology) module ready to be integrated into the building envelope as an active façade system.

The design of the prefabricated building solution guarantees efficient assembly/disassembly in external walls, easy maintenance, and possible integration of plant systems, thanks to fast and plug-in connections. At the same time, it guarantees air/wind tightness and water resistance, offering considerable adaptability to the various structural configurations of the façade. The PVT module is made using additive manufacturing processes, such as digital fabrication and thermoforming methods. Aesthetically, a unique coloured glass hides the solar technologies without filtering or blocking UV rays assuring both the solar and technological functions.

Preliminary energy analyses have been carried out by the Department of ENERGY (DENERG) of Politecnico di Torino, through numerical models, in order to evaluate the behaviour of PVT technologies. Several full-scale mock-ups of the module have been produced to analyse the technical solutions and start testing the physical module's behaviour.

8. BEST DESIGN PRACTICES AND CHALLENGES

Generally speaking, during the urban planning and the design stages, the experience may be either positive or negative. Both successes and critical steps or failures are considered sources of lessons learned.

The lessons learned in this first year of the ARV project with particular reference for the Trento demonstration project are summarised below. Please consider that at this stage of the research only the ECD phase concerning the New Construction has been implemented while the other phases as well as the Existing Building Refurbishment will be developed in the second year of the project. So, the following statement are preliminary and based on the experience occurred so far.

1) To **design not *for* people, but *with* people.** In the early stages of the design process it was important:
   i) to build a team including people from different departments and organizations with different interests, competencies and backgrounds providing regular meetings (also online) in order to discuss step by step the design implementation;
   ii) to develop a connection with all the possible stakeholders involved (including the end-user and the local population through citizen associations) with a democratic process, listening to their needs and taking into account their vision of the area also in connection to the history and to the perspectives (past and future);
   iii) to implement a social engagement with a Living Lab focusing on "Social renovation" and "Energy transition". In fact, the best solutions come when input derive from different perspectives.

2) To **introduce the use of KPIs.** The aim includes the setting targets (the desired level of performance) and the tracking progress against those targets. KPIs are an analytical basis for decision making and help focus attention on what matters most. The assessment of some indicators is often subjective and cannot be easily calculated. The use of shared KPIs allows to control all the design phases (from the ECD onward) and to guide the activities of all the actors involved especially considering the technical choices to be done.

3) To **integrate** as much as possible the different designer's competences between them in order to achieve the best solution balancing technical requirements with costs.

4) To **combine** different building solutions also in order to maximise energy coming from RES, considering local potentialities of the site regarding the environmental conditions such as wind and solar radiation. The idea is that there is not only one solution to be applied as the best one, but that several technologies can work together in synergy if duly managed by a BES.

9. ANNEXES

9.1 CATALOGUE OF INTEGRATED CIRCULAR DESIGN SOLUTIONS

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ANNEX

9.1 Catalogue of Integrated Circular Design (ICD) solutions

Catalogue of Integrated Circular Design (ICD) solutions

Authors: UNITN e POLITO

Index

1. Context of the catalogue

The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal and in line with the EU's commitment to global climate action under the Paris Agreement. All parts of society and economic sectors will play a role – from the power sector to industry, mobility, buildings, agriculture and forestry.

The construction sector has had a key role in contributing to climate change and currently accounts for 40 % of Europe's final energy consumption and 36 % of its CO2 emissions. The European **Green Deal for the construction sector**:

- calls for the sector's potential for energy savings and carbon footprint reduction to be unlocked, by the objective set out in the Energy Performance of Buildings Directive of achieving a highly energy-efficient and decarbonised building stock by 2050;
- stresses that making the energy consumption of buildings more efficient holds substantial potential for further reducing Europe's GHG emissions;
- considers, that the achievement of low-energy buildings, fully supplied by renewable energy, is a sine qua non for the Paris Agreement and an EU agenda for growth, local jobs and improved living conditions for citizens across Europe.

In addition, other plans at the EU level were developed in the European Green Deal, such as **the Circular Economy action plan** (2020) and **Climate Adaptation Strategy** (2021).

From the point of view of Built Environment and Construction industry, the Circular Economy Action Plan has promoted:

- sustainability performance of construction products, including the possible introduction of recycled content requirements for certain products;
- measures to improve the durability and adaptability of built assets;
- revision of material recovery targets set in EU legislation for construction and demolition waste and its material-specific fractions;
- promoting initiatives to reduce soil sealing, rehabilitate abandoned or contaminated brownfields and sustainable use of excavated soils.

The Circular Economy Action Plan contributes to the long-term EU climate neutrality vision for 2050, but at the same time, the EU wants to be a climate-resilient society, fully adapted to the unavoidable impacts of climate change. This means that by 2050, when we aim to have reached climate neutrality, we will have reinforced adaptive capacity and minimized vulnerability to climate impacts, in line with the Paris Agreement and the proposed European Climate Law.

The 'renovation wave' initiative, introduced under the European Green Deal could usefully not only focus on energy savings in buildings but also promote adaptation to the increasing frequency and intensity of various climate hazards. Consideration of climate change impacts is needed in designing urban infrastructure (e.g. sewerage systems) and built environments (homes and workspaces) to ensure their functionality in the future.

To reinforce these policies and to materialize the objectives has been created a **New European Bauhaus** initiative has to connect the European Green Deal to daily lives and living spaces. It calls on all Europeans to imagine and build together a sustainable and inclusive future that is beautiful for our eyes, minds, and souls. The initiative is:

- a bridge between the world of science and technology, art and culture;
- about leveraging our green and digital challenges to transform our lives for the better;
- an invitation to address complex societal problems together through co-creation.

The New European Bauhaus inspires a movement to facilitate and steer the transformation of our societies along three inseparable values:

- **sustainability, from climate goals to circularity, zero pollution, and biodiversity;**

- **aesthetics, quality of experience and style beyond functionality**;
- inclusion, from valuing diversity to securing accessibility and affordability.

The New European Bauhaus brings citizens, experts, businesses, and institutions together to reimagine sustainable living in Europe and beyond. In addition to creating a platform for experimentation and connection, the initiative supports positive change also by providing access to EU funding for beautiful, sustainable, and inclusive projects.

In this scenario are fundamental all the concepts and urban models developed and tested in the last years to transfer the policies into real action at urban, neighbourhood and building scales. Positive Energy Districts (PED), Sustainable Plus Energy Neighborhoods (SPEN) and Zero Emission Neighborhoods (ZEN) focus strongly on the interaction and integration between the buildings, the users, and the regional energy, mobility and ICT systems. Climate Positive Circular Communities (CPCC) concept proposed in this EU project, adds some characteristics beyond, also including socio-environmental aspects and highlighting circularity as a key aspect.

The present catalogue of integrated circular design solutions aims to collect and systematize the available design measures to respond to the effects of climate change and to reduce greenhouse gas emissions in built environment. At the same time, the catalogue explores the digital solutions that could support policymakers, architects, urban planners and technical practitioners in all the life cycle construction stages and the environmental challenges highlighted for the development of Climate Positive Circular Communities (CPCC).

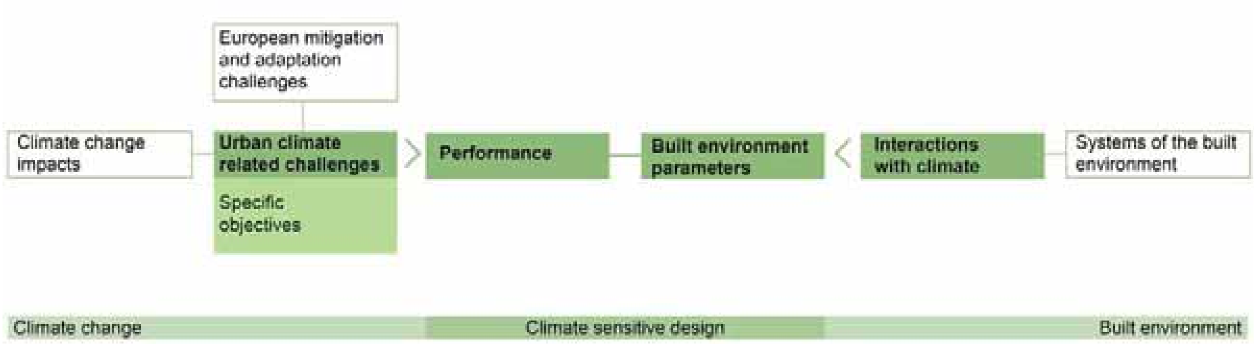
2. Climate-related challenges

In the current scenario of urbanization and urban population growth, cities need to move towards a better and healthier quality of urban life. The increase of built-up areas and energy demand have been exacerbating the causes and the impacts of climate change. On one hand, cities represent one of the major contributors to climate change and CO2 emissions; on the other hand, they are vulnerable to the impacts of climate change. Temperature increase and extreme events, such as floods, water scarcity and heat waves, are the cause of health risks as well as issues to services and infrastructures. The relationship between cities and climate change have been widely discussed by European and International policies, for example by the SGD 11 of the United Nations and by the European Urban Agenda.

To face such challenges, the built environment should not merely reduce the impacts of new developments, rather contribute to repairing human and natural ecosystems, by shifting from a less bad impact to a positive impact through regenerative design. In this view, strategies of mitigation (i.e. reducing greenhouse emissions) should be integrated with climate adaptation ones (i.e. capacity to recover and creation of a healthy baseline, to facilitate more liveable cities for people). As highlighted by the 2030 Agenda, energy issues of the built environment are connected to its environmental performance and to human centred health and wellbeing considerations. However, current practices lack a systemic approach capable of integrating several functions and issues, and are unable to tackle simultaneously different challenges. Thus, implementing a regenerative approach for urban transformations could constitute a good asset for this purpose, and improve the relationship between humans and the built environment, by creating a framework that considers building energy performances, environmental impacts, resilience to climate change and human needs (Raven et al., 2018).

Considering the main impacts of climate change in urban areas and the reports on the local situation, five main issues have been identified: Energy Sustainability (ES), Temperature Regulation (TR), sustainable Water Management (WM), inhabitant’s Health and Wellbeing (HW) and Transition to Circular System (TCS).

The proposed approach is based on *challenges* rather than objectives, allowing flexibility and continuous development of strategies and tactics as well as freedom in the choice of the specific solution. Each challenge is further developed by *specific objectives*. They identify the urban transformation actions that can be implemented to tackle the challenges, according to the location and conditions. The performances constitute the drivers to achieve the specific objectives, driven by enabling processes of the built environment. As such, performances can be measured and controlled by practitioners. Designing through a climate sensitive approach relies on the understanding of the relationship between the built environment and urban climate and on the management of parameters and interactions between them.



2.1 Energy sustainability

A great amount of energy in the EU is consumed by the built environment, for electric appliances, heating and cooling systems, causing around 50-60% of the total greenhouse gas emissions and consuming about 75% of global primary energy.
Regenerating the built environment constitutes a key action to limit greenhouse emissions and to contribute to climate change mitigation. The three main actions promoted by European policies in the built environment are: production of local energy from Renewable Energy Sources (RES), retrofitting the built environment to improve energy performances, and reducing emissions by energy saving (European Commission, 2018). Moreover, an important aspect for energy transition is to consider the interactions of the urban environment at the neighbourhood level, rather than the optimization of energy of the single building, as in the concepts of Positive Energy Districts PED (JPI Urban Europe) or Net-Zero Energy Districts (Saheb et al., 2019). The following objectives are necessary measures for the energy transition of the built environment: reduction of the energy demand for the operation of the building by energy efficiency; increase of energy produced locally from RES; reduction or offset of carbon emissions. Specifically, for urban transformations, energy efficiency can be achieved through passive technologies in the buildings, as well as through the use of efficient devices. In the urban environment, the most common RES is solar power, which relies on environmental conditions (i.e. solar radiation) and on the geometry of the built environment. Finally, carbon reduction is mainly addressed indirectly by reducing the need to cool or heat, and directly by strategies of carbon offset, such as reforestation.

2.2 Temperature regulation

The relationship between urban climate and humans is complex. Urban outdoor spaces usage is directly related to the outdoor thermal comfort (Nikolopoulou 2007). The outdoor thermal environment is facing three challenges: global warming, urban heat islands and heat waves. Urbanisation, and specifically

densification, led to the phenomenon of Urban Heat Island (UHI), which consists of higher temperatures in the urban areas compared to the surrounding rural ones. Its main causes rely on morphological and physical characteristics of the built environment, as well as anthropogenic factors such as traffic and cooling systems. Moreover, UHI is exacerbated by global warming and heat waves, being a risk for human health and comfort (Oberndorfer et al., 2007). Therefore, to address temperature regulation in the design practices, the focus should be both on reducing the UHI effect and improving local microclimate conditions.
The human body exchanges heat with the surrounding environment through convection, radiation, evaporation and conduction. To determine the heat transfer between the human body and the thermal environment, quantitative factors can be used related to the physical characteristics of the person (such as clothing and activity) as well as physical parameters of the environment. The main parameters to describe the urban thermal environment are humidity, thermal radiation, wind speed and air temperature. Thermal radiation in an open space is normally described through mean radiant temperature (Tmrt), which is the sum between long-wave and short-wave radiation. Short-wave radiation includes direct, diffuse and reflected solar radiation from the sun; long-wave is the radiation from the sky and solid surfaces, such as buildings, and it is commonly indicated by the surface temperature (Lai et al., 2019).

2.3 Sustainable water management

Integrated water quality and quantity management is becoming an important issue in recent years. Urbanisation and uncontrolled growth of soil sealing increased water demand as well as difficulties to manage stormwater. Moreover, the intensification of extreme rainfall events can be catastrophic to cities, damaging infrastructures and causing loss of lives. Hence, the traditional management of water, based on directing runoff to waterways through the sewer system, has shown difficulties to respond to recent phenomena. In the last years, European and national policies have been promoting diffuse systems of rainwater management which consider water as a resource and are based on localised and diffuse lamination, natural depuration, water reuse and infiltration in the soil (Charlesworth and Booth 2017). Water is therefore not quickly collected into pipes, but infiltrated and detented into surfaces on site. This approach contributes to maintaining hydrological balance as well as improves biodiversity in the urban environment.
Being based on the maintenance of hydraulic invariance, sustainable water management can be pursued through land use transformation, by integrating vegetation and pervious surfaces capable of infiltrating, retaining and purifying runoff (Vera et al., 2017). Such solutions, namely Sustainable Urban Drainage Systems (SUDS) aim at managing rainwater to reduce damages from flooding, to improve water quality, to protect the environment and health, to ensure stability of drainage systems (Booth and Colin, 2016). Giving equal emphasis on water quantity and quality, the specific objectives of the Sustainable Water Management (SWM) challenge are to decrease runoff volume, to reduce the risk of flooding, mitigate water scarcity, and improve water quality. SWM can play an important role in guaranteeing a more circular management of water streams in urban areas.

2.4 Health and wellbeing

Several scientists have clarified that climate change and global warming have been impacting human health, affecting morbidity and mortality, especially for urban citizens (Cedeño et al 2018). Actions are therefore needed to mitigate such impacts, guarantee safe and healthy living conditions, support healthier lifestyles and reduce exposure to stressors (Marselle et al., 2019). However, a shift from the "Healthy cities" towards the "Salutogenic cities" is driving the focus towards health promotion (Capolongo et al., 2018). According to the salutogenic orientation, the focus is directed towards health promotion (i.e maintaining health, strengthening health resources and establishing health-promoting environments) rather than towards health protection (i.e preventing potential health risks and diseases) (Rittel et al., 2016). In this framework, the health and wellbeing challenge, therefore, refers to actions aiming to experience good health and quality of life (Lindström & Eriksson, 2011; Maass et al. 2017). Specifically, urban regeneration strategies can improve social quality of life, livability and health, by making urban spaces more attractive (Taleghani et al., 2018). For this purpose, design practices, at any scale (city, neighbourhoods, buildings), should promote sociality, integration and inclusion as well as wellbeing, health and accessibility. In general, the aim is to promote actions ensuring safe and comfortable conditions, both from a physical and psychological point of view, and a sense of belonging. Healthy cities, as intended by the WHO, in line with the salutogenic principles, focus on the community as a whole rather than on single individuals (WHO 2012).

Cities, communities and neighbourhoods represent settings to improve comfort and quality of life (Biddle and Seymour, 2012), as they refer to identity, social entity, collective action. In particular, they represent: the mix between built environment and natural places shared by people; the collective identities or shared visions that define a sense of community; the social entities within people feeling integrated and that share a collective wellbeing; the resilience and pro-active forms of residents participating in the community life (Vaandrager and Kennedy, 2017). In this view, to tackle the challenge of health and wellbeing, a twofold attention should be carried on quality of life and on the quality of the urban environment.

2.5 Transition to circular system

Built Environment is characterized by many components that in the last years have contributed to increase the impacts anthropic activities on environment processes and on climate global and local dynamics. In particular construction sector in most industrialized countries, has consumed 50% of all materials (Herczeg et al., 2014), determining 36% of the total waste in European Union (Eurostat, 2021) contributing to the 39% of global energy related greenhouse gas emissions (IPCC, 2018) due to the its linear model, characterized by extraction, production, use, and discard of building materials. For example, concrete represents around the 8% of global CO_2 emissions and the second most consumed substance after the water (Scrivener, 2020).

Instead, the construction industry intends as a wide range (construction of buildings, infrastructures, streets, open air spaces) is called to urgent action to reduce the use of primary resources, to reduce waste production, to reduce energy consumption and related greenhouse gas emissions, in the perspective to shift from a linear system to a circular system.

Circular Economy concept was discussed by many authors and practitioners, yet from the second half of previous century. In the last years has gained a public attention thanks to the effort produced by Ellen MacArthur Foundation and by ARUP (2016), that have published a report on the Circular Economy in the Built Environment. As report by ARUP (2016) and adapted from Ellen Mac Arthur Foundation, the two main pillars of Circular Economy thinking are the combination of biological cycle and technical cycle to minimize systematic leakage and negative externalities through the application of six actions aiming to the transition to circular economy system. Regenerate, Share, Optimize, Loop, Virtualize, Exchange can be applied to products, buildings, neighborhoods, cities, regions, or even to entire economies. Virtualization and Exchange are actions that could benefit from the support of digitalization in order to overcome the lack of communication and coordination along the entire process to achieve a coherent implementation of circular strategy in Built Environment.

Digital transformation, as well as Circular Economy is one of the priority area for EU policies development (European Commission, 2021) until 2030. This goal enhances the investments not only for people and businesses but also for climate neutral, circular and resilient economy. As reported in the EU Circular Economy Action Plan (European Commission, 2020), innovation and digitalization can support the transition from linear to circular system, through tracking, tracing, and mapping for example. As reported by Çetin et al. (2021), there is a clear link among digital transformation and Circular Economy in the policy and practices environment in European context.

As argue Campell-Johnston et al. (2019) the implementation of challenges link to Circular Economy at city scale are scarce investigated and studied, as well as the involvement of monitoring systems. The main challenge for built environment to reduce its impacts in terms of natural resources consumption, energy consumption and greenhouse gas emissions is the transition to circular system. In this perspective, the main objectives necessary to achieve this goal are: circularity of infrastructures and buildings (De Filippi & Carbone, 2021) and circularity of products and materials (De Filippi & Carbone, 2021). The assessment of structures built and demolished or the quantification of abandoned structures in built environment are fundamentals to support the transition of infrastructures and buildings. The analysis of potential re-use and recycling of materials, the inventory of exterior buildings and infrastructures materials and the mapping of properties for demolition are key performances able to satisfy the transition to circular system of materials and products of Built Environment.

3. The built environment

The present paragraph focuses on the relationship between the climate-related challenges and the built environment. It relies on the definition of systems of interactions and *enabling processes*, which are properties of the urban components interacting with urban climate. Defining the enabling processes allows the definition of measurable *performances* to address the specific objectives through urban transformations. The built environment is seen with a multiscale perspective, defined by the interactions and dynamics between natural systems, inhabitants and urban components. Buildings, streets and open spaces are not individual objects, but the parts of a system, in which for example, the envelopes are the diaphragm between indoor and outdoor. As a matter of facts, the properties of the materials used for the building envelopes and outdoor spaces play a bifold role in the thermal response and environmental impact of the built environment: they affect the energy demand to guarantee indoor comfort, and they have an impact on the urban microclimate, affecting both outdoor and indoor comfort. The effectiveness of solutions on the climate-related challenges is different and depends on several factors, such as the location, the type of soil, and urban compactness (Garshasbi et al., 2020, Natanian and Auer, 2020). For this reason, the choice of the specific solutions depends on the area of study

3.1 Energy sustainability

Given the bifold role of the built environment, energy sustainability can be reached directly, through actions on the buildings aiming at reducing carbon emissions and energy consumption, as well as indirectly through actions in the urban environment improving the local microclimate and mitigating overheating. The latter will be explained in the Temperature Regulation challenge, therefore, it will not be considered in this section. The former depends on the materials used for the built environment and on the energy systems provided.
To reduce the energy demand of the building stock, both passive and active strategies can be adopted: the improvement of the building's thermal response, to limit the use of energy, and the production of energy from renewable energy sources. A series of norms and standards (e.g. Living Building Challenge, WELL) as well as research frameworks (e.g. Zero Energy Buildings, Zero Energy Neighbourhoods, Positive Energy Districts) have been developed to foster the reduction of energy demand both for new and retrofitted buildings. The thermal response of the building can be controlled by passive strategies using building design to collect sun's heat, limit heat loss, reducing the need for heating, and to improve indoor comfort by ventilation, reducing the need for cooling.
To limit the proposed solutions to urban surfaces, the production of renewable energy can be addressed by the use of solar and photovoltaic panels, producing thermal and electrical energy. Such solutions can be applied to existing surfaces (BAPV) as well as integrated in the buildings' envelopes (BIPV). The solar power

generation depends on the location and on the amount of exposed surfaces not shaded by surrounding elements.
In parallel to the Zero Energy objectives, the limitation of carbon emissions is envisaged, considering operational and embodied carbon emissions of the built environment. Indeed, standards and research frameworks (e.g. Carbon neutral, Low carbon) have been addressing the issue by extending the reduction of GHG emissions associated with operational use, raw material extraction, manufacturing and processing, transportation, and installation of materials. In this case, carbon emissions can be reduced by a responsible selection of carbon sequestering materials, and by offsetting associated emissions.

Specific objectives	Performances	Enabling processes	Example
Reduction of energy demand	Energy efficiency for cooling	Thermal response (Thermal transmittance, reduction of solar radiation, natural ventilation, air permeability, dissipation)	Trombe wall
	Energy efficiency for heating	Thermal response (direct solar radiation, reduction of heat loss, air tightness)	Wintergarden
Minimising carbon impact	Low carbon material use	Carbon sequestration	Insulation
	Greening		Urban forests
Energy production from RES	Energy from RES on site	Global solar irradiation	BIPV

3.2 Temperature regulation

The built environment can be categorised as four systems interacting with urban climate: urban geometry, vegetation, water bodies and surfaces. The physical parameters used to describe the thermal environment are air temperature, thermal radiation, wind speed and humidity. They are independent from each other, but they can be integrated to calculate equivalent temperature, which is a parameter used to evaluate outdoor thermal comfort. The Temperature Regulation challenge can be tackled by intervening on ventilation, shading, albedo, use of greening and evapotranspiration. Changing such characteristics can reduce surface and air temperature, improve outdoor thermal comfort and block solar radiation, thus reducing the UHI effect and improving local microclimate.

Urban geometry is the tridimensional shape and layout of the built environment and urban fabric. The effects of urban geometry on the thermal environment are the modification of radiative and convective heat exchange. The reduction of solar radiation, more long-wave radiation from the buildings, and less wind speed are the results of high and dense urban geometries. This parameter is normally defined by the sky view factor (SVF) for open spaces and blocks, and by the height-to-width ratio (H/W) and orientation for streets.

Green infrastructure, defined as the network of green spaces in the built environment, such as green walls, parks, trees along the streets, contributes to climate resilience, health and wellbeing of the inhabitants (Demuzere et al., 2014). In addition, vegetation in urban areas improves the quality of urban life.
The primary effects of vegetation on the urban thermal environment are block of radiation (shading), reduction of wind speed and air temperature. By reflection and absorption, trees can remove a great amount of short-wave solar radiation. Moreover, due to transpiration, vegetation reduces long-wave radiation, and therefore surface temperature. Trees increase the roughness of urban surface, reducing urban airflow. However, the reduction of airflow is different from the one caused by geometry, due to the porosity of trees. Vegetation reduces directly the temperature of the surrounding air by evapotranspiration (Oke 2002) and indirectly by shading, and it increases humidity by evapotranspiration. Such effects contribute to the improvement of thermal comfort.

Blue infrastructures, meant as the system covered and uncovered waterways in urban areas, contribute to outdoor thermal comfort. Water reduces the air temperature of the surrounding areas by evapotranspiration and increase of wind speed (Kleerekoper et al., 2012).

Urban surfaces influence UHI by absorbing solar heat (Santamouris, 2013). Their effect can be positive if the materials have high solar radiation reflectivity or if they are pervious. Surfaces with high albedo reflect solar radiation reducing surface temperature as well as air temperature. Despite the positive effect on surface and air temperature, many studies showed an increase of discomfort due to the reflection of solar radiation on the human body. The effects of pervious surfaces can be associated with the ones of green infrastructures, but with different degrees of effects.

Specific objectives	Performances	Enabling processes	Example
Improve local microclimate	Improve Outdoor Thermal Comfort (OTC)	Convection Radiation Evapotranspiration Conduction	Pocket gardens
	Shadow effect		Cool roofs
Mitigate UHI	Reduce surface temperature and air temperature (UHI intensity)		Trees along the streets

3.3 Sustainable water management

The measures related to the Sustainable Water Management challenge include hard constructions such as porous pavements and rainwater harvesting, and soft measures using nature-based solutions (e.g. green roofs, constructed wetlands, swales). The enabling processes of the water cycle, describing the behaviour of water entering the urban systems as precipitation, are conveyance, infiltration, detention, retention, evapotranspiration, and treatment (Langergraber et al 2021). The parameters influencing these processes are permeability, water storage capacity and greening. For example, the use of pervious surfaces re-establishes more natural water balances, reduces runoff peaks and volumes and facilitates infiltration, retention and evapotranspiration. The application of urban greening contributes to groundwater recharge through infiltration processes and to water holding capacity of natural land upstream of urban areas. Sustainable water management strategies can be fostered by using greenery, water storage and soil filtration, allowing temporary water retention, storage and reuse of rainwater, and improvement of water quality. To reduce runoff, Sustainable Urban Drainage Systems are measures implemented at different scales (i.e. surface water management train): prevention (land use planning), source control, site control and regional control (Woods Ballard et al. 2015)

The systems of the built environment interacting with the water streams are: green infrastructure, hard surfaces, blue infrastructures and devices (e.g. rainwater harvesting and water butts). To achieve the specific objectives related to the SWM challenge, the built environment should provide the following performances: water retention, water treatment and recovery and reuse. The performances are enabled by different physical, biological and chemical processes or by reusing and recovering water. Such processes to restore and maintain the water cycle are: conveyance (i.e. water transportation), infiltration (i.e water flow through the ground surface into soil), detention (i.e. temporary storage of precipitation), retention (i.e. permanent storage of precipitation), evapotranspiration (i.e. water transferred from the soil to the atmosphere by evaporation and plant transpiration). The processes for water treatment (change of physical and chemical properties), recovery and reuse are: sedimentation (i.e. settling and depositing suspended matter by gravity), filtration (i.e. passing a liquid through filter medium), uptake by plants (i.e. transfer of substances from the environment to plant), biodegradation (i.e. biochemical transformation of substances), photo-degradation (i.e. process of degradation of substances exposed to sunlight ultraviolet radiation), sorption (i.e. adsorption and absorption) and reuse (Langergraber et al 2021).

Specific objectives	Performances	Enabling processes	Example
Runoff mitigation	Water retention	Conveyance	Rainwater harvesting Bioswales
		Infiltration	Pervious pavement Infiltration strips
		Detention	Water squares Rainwater harvesting Intensive green roof
		Retention	Retention pond
		Evapotranspiration	Vegetated pavement Intensive green roof
Water scarcity mitigation	Water storage and reuse	Reuse	Water butt Green facade
Improve water quality	Water treatment	Sedimentation	Rain garden
		Filtration	Vegetated pavement Wetland

		Uptake by plants	Vegetated pavement Intensive green roof
		Biodegradation	Treatment wetland
		Photo-degradation	Wet retention pond

3.4 Health and wellbeing

As mentioned above, according to the salutogenic orientation and to the conceptual definition of community, urban transformations can address health and wellbeing of the inhabitants. The WHO recognizes the influences that indoor and outdoor living conditions have on public health (WHO): many physical characteristics of cities can play an important role on how people perceive the place and how people live the space. Firstly, neighbourhoods should be the places in which people identify with and for which they feel a sense of belonging. Similarly, the concept of sense of community, related to the experience rather than to the physical attributes or structure, is a significant factor for one's health (Mc Knight and Block 2010). In this regard, access to nature and places where to practise community life (e.g. community gardens, playgrounds) are associated with satisfaction. However, the effects that the solutions have on health might be different according to several conditions, such as dimension, condition of the green areas or satisfaction about the living environment. Secondly, communities represent collective identities (Vaandrager and Kennedy 2017), sharing an interest or sets of circumstances. Thirdly, neighbourhood cohesion defines the social entity of a neighbourhood and refers to the creation of collective wellbeing of a community and to the reduction of conflicts (Robinson 2005). The evidence, in general, is that people with stronger social connections tend to be stronger and healthier (Marmot et al. 2010). As social capital is essential for salutogenic communities, creating spaces for connections between individuals with different social identity is linked to wellbeing. Fourtly, community resilience is the ability of individuals and communities to cope with challenges and has a key role in health promotion. Pro-action, with its various forms of participation by individuals, brings people together and increases their role in taking decisions for their living environment.

In a salutogenic view, communities and neighbourhoods improve their health through generalised resistance resources (i.e. sense of belonging, sense of community, cohesion) to tackle the everyday stressors (Vaandrager and Kennerdy, 2017). To support communities' health and wellbeing, the built environment and public spaces can have a positive impact, through easy access to green space, community gardens, places where to meet and being active together. Moreover, walkability - meant as the intention to make roads and transport routes less stressful - contributes to health and wellbeing. The link between biodiversity and health (physical and mental) has been widely recognized (WHO & CBD, 2015, Marselle et al., 2019) and several practices have been exploring nature-based solutions and green and blue infrastructures to combine adaptation to climate change and human health. Such examples can also contribute to the provision of ecosystem services, such as air quality, and resilience to extreme events (Vaandrager and Kennerdy, 2017). Besides these practices, traditional risk reduction strategies remain important and can be addressed by providing shade and shelter in open areas.

Specific objectives	Performances	Enabling processes	Example
Improve comfort and life quality	Green space	Contact with nature	Green facades
Improve quality of the urban space	Space for socialisation	Sense of community	Pocket gardens
	Air quality	Risk reduction	Urban forests
	Walkability	Sense of belonging	Infiltration strips

The effectiveness of solutions on the climate-related challenges is different and depends on several factors, such as the location, the type of soil, and urban compactness (Garshasbi et al., 2020, Natanian and Auer, 2020). For this reason, the choice of the specific solutions depends on the area of study.

4. The solutions

Urban surfaces have a key role to tackle the climate-related challenges and they influence quality of life as well as environmental conditions (Croce and Vettorato, 2021). For example, soil sealing influences the microclimate conditions and the infiltration capacity, increasing surface temperature and run off. Moreover, artificial surfaces contribute to the reduction of green areas, limiting walkability and spaces for socialization. Given their role in contributing to climate adaptation and mitigation, urban surfaces have received increasing attention in the last years. In this view, strategies of desealing have been promoted in open spaces, as well as retrofitting buildings with green roofs. The contribution of urban surfaces is not only limited to addressing climate change, as they provide functions related to resilience and sustainability, such as habitats and biodiversity preservation, food security, and freshwater availability (Croce and Vettorato, 2021). However, most of the studies are mainly sectorial. For example, they focus on single solutions (e.g. Pisello, 2017) or on single purposes, such as mitigation (e.g. Taleghani et al., 2018). Some recent studies investigate scenarios combining adaptation strategies and mitigation techniques (e.g. Garshasbi et al., 2020), or integrating different challenges related to buildings' energy performances (e.g. Natanian and Auer, 2020). Moreover, other studies propose processes to assess an integrated approach through digital tools, such as Naboni et al.2019 and Mauree et al. 2019. However, such studies focus on the relationship between energy performances and outdoor temperatures, excluding the impacts of solutions on water management.

The catalogue of solutions proposed in this study aims to overcome such limitations, by highlighting which solutions are available and which climate-related benefits they provide. In this view, the suggested solutions consider the urban components as a diaphragm, giving attention to the twofold effects of urban components on the indoor and the outdoor environment.

As promoted by the SDGs and JPI, urban transformations should shift from mono-disciplinary perspectives to holistic approaches enhancing relationships between natural systems, built environment and inhabitants. Such a shift entails a network between several disciplines related to planning and design and interdisciplinary system thinking. To control an integrated approach, framing common goals is essential to develop climate positive circular communities, and parametric design methods can facilitate the optimization of solutions. Indeed, strategies of adaptation and mitigation can have incompatibilities due to different temporal and spatial scales, the involvement of different stakeholders, and the complexities in the measurement and assessment of adaptation policies. This could lead to conflicts or trade-offs that need to be coordinated by a common vision, for example the physical space requested by the implementation of nature-based solutions against the concept of densification. However, this conflict can be solved by the promotion of multifunctional surfaces. Moreover, many surface solutions for buildings and open spaces can strengthen the synergies between challenges. For example, nature-based solutions provide temperature reduction as well as carbon sequestration; passive technologies in the buildings improve indoor comfort, reducing energy needs. Recognizing the conflicts and synergies can facilitate the implementation of a holistic approach. For this purpose, the catalogue of solutions aims to highlight which solutions are available and which climate-related benefits they provide. Given the complexity of urban surfaces, in this study we present surface solutions to be applied to the external part of the envelopes and some outdoor solutions.

4.1 Classification of surfaces

The types of urban surfaces available for transformations are both on ground and buildings' envelopes. Ground surfaces include linear elements (e.g. streets) and open spaces (e.g. parking lots), while buildings' surfaces are divided between roofs, facades and additional tridimensional elements.

Type of surface	Classification
Envelopes	Roof
	Facade
	Add-on
Ground	Street
	Open space

Classification of the built environment surfaces

4.2 Categorization of solutions

The collected solutions have been categorised as follows: Urban Green Infrastructure, Blue Infrastructure, Energy Systems, Shading devices, Building technologies. Each category is further divided in sub-categories, according to the type of solution.

Urban Green Infrastructure (UGI)
UGI provides many ecosystem services (e.g. balancing water flows, providing thermal comfort), contributing to ecosystem resilience and bio-physical, social, psychological benefits (Demuzere et al., 2014). It constitutes an infrastructure of built systems and green spaces, including large-scale elements such as wetlands, forests, parks, and small-scale elements such as green roofs and green facades.

Blue Infrastructure (BI)
BI provides benefits in sustainable water management as well as in cooling, through evaporation. It includes: natural water surfaces, such as rivers and lakes; artificial surfaces, such as canals; techniques like spaying and water curtains, which can be applied to ground surfaces as well as to buildings (Croce and Vettorato, 2021).

Energy systems (ES)
ES include systems in urban areas locally generating energy from RES, to meet energy requirements (heating, cooling, electricity, hot water). Clean energy in built-up areas is mostly produced by active solar systems, applied in buildings' surfaces or on-ground, as well as by grid systems that connect multiple buildings.

Shading devices (S)
S include solutions to protect from direct solar radiation, adapting to the rise of temperature and reducing the buildings' energy needs. Shading devices solutions can be applied to buildings surfaces, as well as to open spaces.

Building Technologies (BT)
BT refer to the adaptive technologies, which rely on passive design to improve building energy efficiency and, indirectly, outdoor thermal regulation. These solutions include the techniques applied to buildings' envelopes to encourage natural ventilation and maximize direct solar gains.

Code	Category	Sub category
UGI	Urban Green Infrastructure	Wet Green-Building Productive Functional Recreative
BI	Blue Infrastructure	Devices Water surfaces Evaporative
ES	Energy systems	Solar active Grids
S	Shading devices	
BT	Building Technologies	Reflective materials Passive Technologies Innovative facades Pervious surfaces

Categorization of solutions

4.3 Types of solutions to implement on buildings' envelopes

The solutions suitable for the building envelopes are defined and categorized considering the above mentioned categories (described in 4.2) and the synergies of the climate-related challenges (section 3).

The solutions belonging to the UGI category can be integrated into the building envelope, both in vertical and horizontal elements. For example, green roofs can be applied to both flat and sloped roofs. According to the thickness of the growing medium, the green roof can be intensive, extensive and semi-intensive. Vertical greening systems can also be classified into living walls and green walls according to the growing techniques. Green elements of the buildings provide benefits both at the city and at the building scale, as they improve the thermal behaviour of the building and contribute to reducing temperature, mitigating the UHI effect, sustainable stormwater management and improving air quality. Moreover, by increasing the green spaces in the urban areas, they contribute to the health and wellbeing of the inhabitants and biodiversity.
BT include those materials or paintings that improve the building's behaviour, by reducing absorption of solar radiation or maintaining lower temperatures. Reflective materials, known as cool materials, have high solar reflectivity and infrared emissivity reducing surface temperature. Cool materials are generally applied to roofs to avoid glare issues through membranes, coating, paintings, tiles, but they can be used also in the facades. Cooling technologies, besides contributing to temperature regulation, contribute to the reduction of greenhouse gas emissions, by lowering the need of cooling. Moreover, passive technologies are part of BT solutions as they improve the building behaviour, for example by increasing the thermal mass of the wall. Finally, innovative facades technologies can be responsive and reactive to external conditions.

Belonging to ES, active solar systems (solar thermal and photovoltaics) can be applied to the surfaces of buildings, both on the roofs and on the facades. They can be either applied on the external surfaces or integrated as a cladding material.

Type of surface	**Category**	**Solutions**	**Climate-related challenge addressed**			
			ES	TR	SWM	HW
Roofs	UGI	Green roof	X	X	X	X
	BT	Cool roof	X	X		
	BT	Ventilated roof	X			
	ES	Solar thermal panels	X			
	ES	Yellow roof	X			
Facades	BT	Thermal insulation	X			
	UGI	Green wall	X	X	X	X
	UGI	Green facade	X	X	X	X
	BT	Cool wall	X	X		
	BT	Trombe wall	X			
	BT	Glass with solar control	X			
	BT	Adaptive skin	X			
	S	Sunshade	X			
	BT	Phase changing materials	X			
	BT	Ventilated facade	X			
	BT	Double skin	X			
	BT	Natural ventilation	X			
	BT	Night cooling	X			
	ES	BIPV/BAPV	X			
	ES	Solar panels	X			
Add-on	UGI	Productive façade system	X	X	X	X
	UGI	Vertical farming	X		X	X
	BT	Wintergarden	X			X

4.4 Types of solutions to implement on ground

The ground-based solutions are defined and categorized considering the categories described in section 4.2 and the synergies of the climate-related challenges in section 3.

As part of UGI, nature based solutions can be used in ground surfaces as recreational areas, such as pocket gardens, in public or private spaces, as linear elements along the streets, such as infiltration strips or tree lines. Some green spaces can be created for a specific function, such as wetlands or rain gardens, but they can be designed as multifunctional elements, creating spaces for socialisation. Urban greenery provides several functions to the urban areas: they create shade, contribute to temperature regulation through evapotranspiration, improve air quality, reduce greenhouse gases emissions and reduce runoff. Moreover, they provide social benefits contributing to health and wellbeing of the users and improve urban biodiversity.

Water solutions are divided between water surfaces, evaporative techniques and water devices. Water surfaces are natural water bodies (e.g. lakes, rivers) and artificial ones (e.g. fountains, artificial lakes). Evaporative techniques are mainly used to improve microclimate conditions, as through spraying and water curtains they improve outdoor thermal comfort. In addition, water devices, such as water storage systems, contribute to the management of the water cycle. Blue infrastructure solutions contribute to improving human thermal comfort through evapotranspiration and sustainable stormwater management. Moreover, as for green elements, water solutions also provide social benefits. The surface solutions using nature-based solutions to manage the water cycle are commonly referred as Sustainable Urban Drainage Systems (SUDS). They have been receiving more attention as, besides contributing to the water management objectives, they have benefits in carbon sequestration, urban cooling, human health and wellbeing (Charlesworth 2010).

BT such as cool materials as they generally include light colour layers applied on asphalt can be used to cover open spaces. Although solar reflectance reduces surface temperature, it can cause uncomfortable thermal conditions or glare issues. Pervious surfaces are widely used to contribute to the reduction of surface temperature through evaporation and to the reduction of water runoff. Moreover, by contributing to the mitigation of UHI, cool solutions potentially reduce directly and indirectly greenhouse emissions.

ES can be applied to open spaces, for example through the installation of PV pavements and roads. Moreover, urban furniture, such as acoustic barriers of the roads, street lighting or bus shelters can include photovoltaic technologies. The deployment of renewable energy systems in the cities is one of the key strategies to meet carbon neutrality.

Type of surface	Category	Solutions	Climate-related challenge addressed			
			ES	TR	SWM	HW
Open spaces	BT	Pervious pavements	X	X	X	
	BT	Cool pavements	X	X		
	UGI	Pocket gardens		X	X	X
	UGI	Bioretention areas		X	X	X
	UGI	Phytodepuration		X	X	

SOLUTIONS
ROOF

UGI

Green roof

Green roof is the top of all buildings in which different types of vegetation grow. It includes several layers as vegetation, substrate, filter layer, drainage layer, protection membrane, waterproof membrane, insulation, vapour barrier, a layer with a slope of 2% to drain the excessive rainwater and the slab. They can be classified as intensive green roof characterised by a wide variety of plants (shrubs, bushes and small trees) and a greater load on the roof structure; the extensive green roof characterised by limited plants variety (hardy, drought tolerant, succulents, herbs or grasses), less total weight and the limited access, usually just for maintenance.

Challenges	Objectives	Performances
Energy sustainability	Energy demand; Carbon impact; Energy produced from RES; Energy from RES on site; Low carbon material use	Greening; Energy efficiency
Temperature regulation	Local microclimate; UHI	Temperature surface/air; Outdoor thermal comfort; Shadow effect
Water management	Run off mitigation; Water scarsity; Water quality	Water retention; Water storage and reuse; Water treatment
Health and wellbeing	Comfort and life quality; Urban space quality	Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort; Biodiversity; Noise pollution; Lifespan; Food production; Thermal insulation

Regulations & Standards

UNI 11235

Strategies

(M) (A)

Scale of application

Building; Neighborhood; City

Space usage

Monofunctional
Multifunctional

S.D.G.

(P) 13.2, 13.3 (S) 11.0, 15.3

Disadvantages

Extra maintenance
Extra weight load

Energy consumption

Greening

The green roof system can decrease the carbon footprint through green roof layers, therefore can increase the energy saving. With appropriate plant and soil layers, different extensive GRs could improve the carbon sequestration rate from 4.77 kg C eq. $m^{-2} yr^{-1}$ to 7.11 kg C eq. $m^{-2} yr^{-1}$.

Case study: the extensive green roof of Berlin-Brandeburg Airport (Germany), has been chosen. The green roof composed of different plants such as sedum floriferum Weihenstephaner Gold, Sedum album and Allium schoenoprasum, was monitored for a full annual cycle. The results show that the green roof is a carbon sink on an annual basis with an uptake rate of – 313 g CO2 m^{-2}, equivalent to – 85 g C m^{-2} ***[1].***

Energy efficiency

The green roof system indirectly can reduce the building's energy consumption. Several studies show that all green roofs are more energy efficient than black roofs in all climates. Considering just the cfb zone, it is shown that the extensive green roof can reach 84% of energy efficiency in an insulated roof, while it reaches 100% with no insulation in the cooling season. During the heating season it reaches just 8% when the roof is insulated. For semi-intensive green roofs, the energy efficiency is just 7-8% either in the heating and cooling season and with an insulated roof. Finally, with an intensive green roof, the energy efficiency reaches just 6-10% either in the heating and cooling season and with an insulated roof ***[2].***

Temperature regulation

Temperature surface/air

One of the most important effects created by a green roof is the reduction of the surface temperature and the attenuation of temperature fluctuations, due to the plant shading, insulation guaranteed by the thickness of substrate and evapotranspiration that depends on the foliage's size.

Case study: the green roof of the Regional Council building located in Ancona (Italy, cfa zone), was monitored. A comparison of green roof and conventional roof has been conducted. The results show that for the green roof the heat flux is considerably reduced. The external surface temperature in July changes from 30.10°C to 24.99 °C (under foliage) and in August, it changes from 31.72 °C (reference roof) to 24.89°C (under foliage) ***[3].***

Outdoor thermal comfort

Several studies show that green roofs can highly improve the outdoor thermal comfort by reducing the albedo and increasing shadow effect and evapotranspiration. In addition, some other parameters such as the orientation, the wind speed, the humidity and solar radiation should be considered.

Case study: the requalification of the district of Turin (Italy) with the use of green-roof technologies, has been analysed. The results show that the OTC evaluated using air temperature increases with the presence of plants. The increase of 15% in green implies a decrease in land-surface temperature (LST) of 2.7 °C. Finally, there is a significant relationship between LST and the building coverage ratio (BCR) of 34%, and a negative correlation between LST and NDVI (–43%) ***[4].***

Shadow effect

The presence of foliage creates a shadow on the soil, which allows decreasing the incident solar irradiance, therefore reducing the temperature and the heat gain though the cover. The size of leaves is significant: benefits increase as the leaves increase.

Case study: the green roof of the Regional Council building located in Ancona (Italy, cfa zone), was monitored. A comparison of green roof and conventional roof has been conducted. It demonstrates the benefits of foliage in summertime. The results show that the horizontal month average global radiation in July is 252.76 W/m^2, while the radiation under foliage is 38.29 W/m^2, also in August the values are positive, hence the horizontal month average global radiation is 281.08 W/m^2 and the radiation under foliage is 29.87 W/m^2 ***[3].***

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Water management

Water retention

Green roofs can contribute to the reduction of stormwater runoff due to their capacity to retain water. The benefit of stormwater management depends on the roof age, slope, substrate thickness, composition, pore volume and degree of saturation, plant selection and type of drainage layer. According to several research, for the extensive green roofs, the minimum stormwater runoff reduction is 33% and the maximum is 81% (57% average). Concerning intensive green roofs, the average stormwater runoff retention is 79%, which represents a 22% higher than the water retention capacity of extensive green roofs. Probably, this difference is due to substrate depth ***[2].***

Water storage and reuse

The greywater can be collected by the drainage layer of the green roof and can be stored in a tank link to the secondary pipeline. This pipeline is connected to a deposit with filtering water and a pump to bring water to upper levels. This process is necessary, because the greywater could contain concentration of nutrients, solid particles, microbes, organic and inorganic pollutants.

Local greywater recycling can achieve potential water savings of 9%–46% within the household and could be used for many domestic uses such as for bathrooms, showers, laundries, washbasins and irrigation ***[2].***

Water treatment

According to several studies, it is demonstrated that the green roof improves the quality of water using its capability to reduce the amount of dust, pollutants and nutrients that would be sent to the sewer system and the receiving stream. The green roof can retain up to 92% of Cb, 97% Cu, 99% Pb, and 96% Zn. In addition, it's shown that the green roofs retain nutrients with an average retention of 80% NO_3 and 68% PO_4 ***[2].***

Health and wellbeing

Green space

Some studies show that urban green spaces, including green roofs, promote mental and physical health, providing psychological relaxation and stress alleviation. Health and well-being benefits derived from simply viewing a green space, even if not accessible ***[1].*** It's shown that green roofs could be used for increasing urban green space in cities and promoting landscape connectivity. In addition, they have been recognized by ecologists as opportunities to contribute to urban wildlife. Parameters such as the size, height, and design contribute to the types and numbers of species frequenting green roofs. The height could be more restrictive; for example, any taxa able to reach the top of a building could have difficulty getting down, or sometimes taller buildings experience increased exposure to wind and solar radiation, further limiting their value as habitat ***[5].***

Space for socialization

Several studies show that the green roofs attract people and try to connect each other for urban agriculture. People can use green roofs to produce different vegetables and make the society self-resilient for food production. In addition, the results also indicated that with proper selection of vegetable types except pepper plants and proper management in an extensive green roof can be helpful for more food production ***[6].***

Quality of air

It's shown that green roofs can reduce the high levels of air pollution produced by many human activities, which are harmful to human health.

Several studies show that the extensive green roof compared to a conventional roof, could have a higher average removal capacity of O_3 (1,96 g/m^2 /year about 20%), PM_{10} (1,47 g/m^2/year about 79%) and NO_2 (1,03 g/m^2/year about 29%), but also for SO_2 (0,41 g/m^2/year about 37%) and CO (0,41 g/m^2/year)***[2].***

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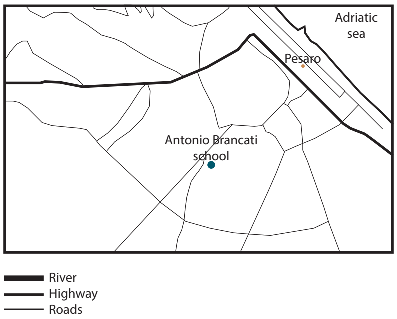
Green roof: best practice

Project name

"Antonio Brancati"
Middle School - School, college, University

Climate zone

Csb - Coastal Mediterranean,
Mild with cool, dry summer.



Construction year

2018

Location

Pesaro, Marche, Italy

Integrated system

Solar photovoltaic panels

Certification

LEED Platinum

Health & Comfort

The indoor comfort is guarantee by the mechanical filtered ventilation climate system that allows the air exchange of 5 volumes per hour; some thermal sensors that control and regulate the temperature and the several tests (made) enhance the acoustic comfort.

Energy consumption

Heating: 15.54 kWh/m²/year;
Hot water: 0.89 kWh/m²/year;
Cooling: 9.57 kWh/m²/year;
Ventilation: 18.84 kWh/m²/year;
Lighting: 15.58 kWh/m²/year;
Lift: 0.25 kWh/m²/year
Renewable energy production: 57,00 %

GHG Cradle to Grave

579,70 KgCO_2 /m²

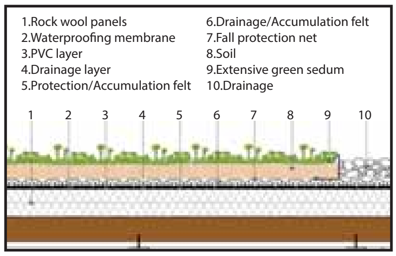
Building quality

Building flexibility
Comfort (visual, thermal, acoustic)

How it works

it's hard to define a standard green roof because the new technology developed different kind of new materials and several combinations. Typically, the layers that characterize and define the performances of the roof are: plants, substrate and drainage/storage layer.

The layers sequence is defined in order to the drainage/storage layer can collect the water from stormwater and from the plants and doesn't affect the slab. In addition, all the layers allow a better thermal insulation, solar absorption control and accumulation/release of moisture.



Description

In 2017, the city of Pesaro decided to reuse the old site replacing the three old army barracks built in 1950 with a new middle-school. The municipality launched a pilot project that follow some specific purposes as energy efficiency, sustainability, responsibility, circular economy and other social considerations. The project is successful, it is focused on the optimisation of circularity, the usage of sustainable building material and technologies, saving raw materials, product lifecycle, waste management, adaptability, durability, water efficiency, the creation of the best indoor environmental conditions for the students and teachers. The building structure is composed with reinforced concrete and timber structure for the roof to contribute at chieving low environmental impact. In addition, this first concrete example in mainstreaming circular practices is harmonious within the context creating a friendly new space for all the citizens, due to the tone-in-tone colours of the façade and the green roof. It is made of Mediterranean plants with low water need to moderate the impact of high temperatures, capture storm water, abate pollution and act as carbon sinks.
Source: https://www.construction21.org/case-studies/h/antonio-brancati-middle-school.html, | Photo credit: -

Cool roof

BIT

A cool roof is characterised by a coating with high solar reflectance and high thermal emissivity. This system can reduce the temperature of the external surface and the heat load caused by the solar irradiation, thanks to the high reflectance that permits the minimum absorption of solar radiation and the high level of emissivity. These features allow the surface to not overheat and to disperse energy by irradiation. The last important parameter is the surface attitude to become colder. The combination of all these parameters allows the cool roof system to work properly.

Challenges / Objectives / Performances

Energy sustainability
- Objectives: Energy demand; Carbon impact; Energy produced from RES
- Performances: Energy from RES on site; Low carbon material use; Greening; Energy efficiency

Temperature regulation
- Objectives: Local microclimate; UHI
- Performances: Temperature surface/air; Outdoor thermal comfort; Shadow effect

Water management
- Objectives: Run off mitigation; Water scarsity; Water quality
- Performances: Water retention; Water storage and reuse; Water treatment

Health and wellbeing
- Objectives: Comfort and life quality; Urban space quality
- Performances: Green space; Space for socialization; Air quality; Walkability

Other benefits
Indoor thermal comfort; Lifespan; Cooling costs; Easy to repair; Flexibility; Weather protection

Regulations & Standards

UNI EN ISO 13786, UNI 10375 and UNI 11442

Strategies

M A

Scale of application

Building; Neighborhood; City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 11.3 11.b
S 12.2 -

Disadvantages

Limited application
Susceptible to mold

Energy consumption

Low carbon material use

A cool roof can highly reduce the carbon footprint in more poorly insulated roofs in locations with high solar radiation throughout the year and high ambient temperatures.

Case study: a retrofit of a single storey in Palermo (Italy, Csa zone), was adopted. It is composed of a living room, a kitchen, a study and three bedrooms, with a total floor area of 100m^2. The cool paint adopted for the roof is a waterborne liquid with 0.84 initial solar reflectance, 0.90 thermal emittance and initial solar reflectance index of 106. The paint is made by polymer, solvent, filler, titanium dioxide pigment, zinc dioxide additive and plasticizer. The simulation results show that from electricity the CO_2 emissions factor is 0.4109 kgCO2/m^2/year and the CO_2 emissions saving is 0.96 kgCO2/m^2/year. Applying the LCA method, it has been shown that the production of polymer and pigment lifecycle phases are the main responsible for carbon impact ***[1].***

Energy efficiency

Several studies show that cool roofs considerably contribute to the reduction of energy demand for cooling and the peak power requirements. The efficiency of this solution depends on climate zone, orientation, and the albedo value.

Case study: the municipality building of Acharnes in Greece (csa zone), was adopted. The municipality seat was built in 1998 and contains offices and the department itself. It is composed of more floors and the roof is covered by grey cool tiles with an emissivity factor equal to 0.89. The building has oil fired boilers for heating, instead heat pumps are used for cooling. As expected, the results show that the total annual energy savings for cooling and heating is 20.1 MWh (about 8.9%), instead the total annual energy savings for cooling only is 22.2 MWh (about 17%)***[2].***

Temperature regulation

Temperature surface/air

Cool roofs can contribute to alleviating overheating/UHI in contexts with high solar radiation. To optimise the building performance, some parameters such as the values of albedo in between 0.6–0.7, air change rate of 2ACH, climate zone, orientation should be considered.

Case study: Open office area and three office rooms located on the top floor of a four-storey building in Brunel University (London, UK), was adopted. The roof is composed of 0.15m thick concrete slab with 0.04 m of insulation layer, a thin layer of asphalt and a layer of cool material. The offices have a central heating system and a natural ventilation system. The results show that the cool roof can reduce the surface temperature of 2°C in the middle of the day, and it can reduce the air temperature with an average of 2-3°C in the middle of the day. It's shown that if the insulation layer is increased, the cooling potential decreases because of the heat transfer reduction ***[3].***

Outdoor thermal comfort

The great system performance depends on the use of the building and the insulation adopted: if the insulation is thicker, the performance of a cool roof is reduced.

The case study: just a left side part of a building in Poitiers (France) belongs to Saint Elio district composed of 87 dwellings in four stories. The terrace roof is made of steel cladding, a layer of mineral wood, a layer of asphalt and a double layer elastomeric self-protection. The results show a significant reduction by more than 10°C of outside surface temperature. It's shown that the cool roof has a strong impact on the highest temperatures because of the thick layer of insulation. It means that during summertime, the cool roof guarantees a reduction of the heat island effect that allows to improve the thermal comfort outdoors ***[4].***

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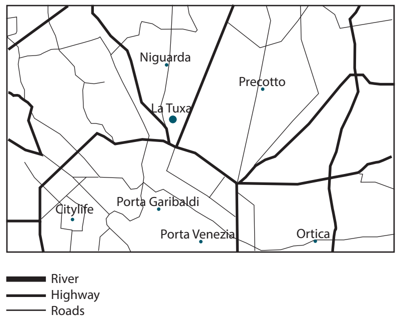
Cool roof: best practice



Project name

La Tuxa
Residential Building

Climate zone

Cfb - Subtropical highland climate

Construction year

2012

Location

Milan, Italy

Integrated system

Solar thermal panels
Sunshade

Certification

Klimahouse Gold
Cened A+

Health & Comfort

The high energy efficiency feature and the using of "cool roof" that prevents overheating in summer, greatly improving the quality of user's life and urban environment.

Primary energy

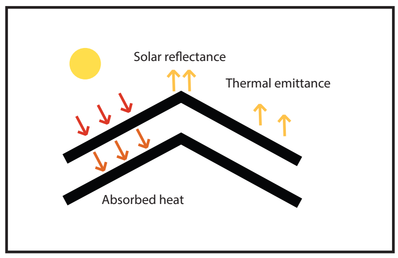
8,00 kWh/m²/year

Sustainability

The building is characterised with rock wool external coat, mechanical ventilation system, low temperature radiant panels, the production of DHW by solar panels (more than 50%), and a rainwater recovery system that will be used to irrigate the condominium outdoor garden and feed the toilet cisterns. All these elements make the building more sustainable. In addition, cradle-to-grave approach shows a carbon emission of 13,00 $KgCO_2/m^2$.

How it works

The cool material should follow the specific features described by the ASTM E 1980 norm. It defines the solar reflectance index (SRI) as the capability of a surface to not overheat. It considers the solar radiation and the emissivity, and it is expressed in %. If the coverage surface is white the solar radiation equals 0.8, the emissivity equals 0.9 and the SRI is 100%; if the coverage surface is black the solar radiation is 0.05, the emissivity is 0.9 and the SRI is 0%.
The best coverage has solar radiation higher than 0.8, emissivity higher than 0.9, consequently the SRI is higher than 100%. Using these values just a little portion across the slab and the other part is reflected and doesn't influence indoor thermal comfort.



Description

La Tuxa is located in Milano, between "Isola" and "Garibaldi", it is one of the first Italian examples of residential buildings having almost zero consumption. It was designed following the purposes of energy saving, energy efficiency, environmental sustainability and indoor thermal comfort. It is composed of six floors with a total of eleven medium-size apartments. The structure is made of reinforced concrete covered by the external coat. The windows and the doors are made of wood-aluminium with the transmittance value equal to 0.8 W/m2K. In addition, some other solutions were adopted to achieve high energy efficiency such as summer shading design with a system of slats external (raffstore), controlled mechanical ventilation with the 88% of heat recovery, and cool roof. The cool roof is made of a white bituminous membrane reflective layer called Derbibrite Nt produced by Derbigum. Its Solar Reflectance Index (Sri) equal to 100, allow it to obtain Leed credits for the reduction of island heat.
Source:https://www.construction21.org/case-studies/it/residential-building-la-tuxa.html,http://s3.amazonaws.com/europaconcorsi/project_documents/3469191/RIVISTA_PROGETTO_ENERGIA_76_-_SETTEMBRE_2012.pdf, | Photo credit: -

BIT

Ventilated roof

The ventilated roof systems are essentially two slabs delimiting a duct through which air flows. This air gap/air flow diminishes the heat transfer across the roof into the building. Ventilated roofs can be either a passive type, with stack effect driving the air flow, or an active type, with fan induced ventilation. In addition, according to the size of the duct, the flow through it could be laminar or turbulent. Typically, it is composed of roof covering, air gap, insulation, waterpro-of sheath and slab. If the system works properly the heat load is reduced by 30% and the users benefit of indoor comfort improved and of a significant energy saving.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produ-ced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor ther-mal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Air pollution · Cooling costs · Cooling effect · Const temperature · Mold - condensation

Regulations & Standards

UNI 9460, UNI 8178 and UNI 8627

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.2 12.0 S 11.0 -

Disadvantages

Reduce acoustic indoor comfort
Reduce height

Energy consumption

Low carbon material use

Ventilated roof is a good strategy to reduce the carbon footprint and to save energy. Some parameters that influence the performances are the thickness of air gap, material used and climate zone.

Case study: a detached single floor house located in Catalonia (Spain), was considered. It is characterised by rectangular geometry, ground floor area of 100m^2 with standard accessibility to the construction site. The more common typologies of roofs have been analysed, but the focus is on the ventilated roof. It is composed of slab with 3% of slope, mineral wool insulation layer, bitumen membrane with polyester felt reinforcement, cement mortar regularisation layer, and external ceramic flooring tiles pavement. The results show that, adopting the LCA method, the CO_2 emitted by a ventilated roof is equal to 86.61 CO_2/m^2. This value is lower compared to some other solutions such as green roof (143 -145 CO_2/m^2), grey roof (127-130 CO_2/m^2) ***[1].*** Another interesting case ***[3].***

Energy efficiency

Several studies show the ventilated roof is one of the most effective strategies to reduce energy consumption.

Case study: the building "Bent to the Sun" in The District of Tomorrow (TDoT) located on the European Science and Business Park Avantis in Heerlen/Aachen (in between the Netherlands and Germany), was adopted. The BIPV roof includes 24PV modules, which are placed in 4 segments of 6 modules each. Each segment has a different air gap or hasn't any air gap. The natural ventilation duct adopted is of 13cm with an inclination of 12.5cm. The results show that in the segment chosen, the annual energy performance is 1216 kWh in the non-ventilated situation and 1249 kWh for the ventilated. Comparing the two results, it's notable that the PV performance has a difference of 2.7% on a yearly basis on the same location ***[2].***

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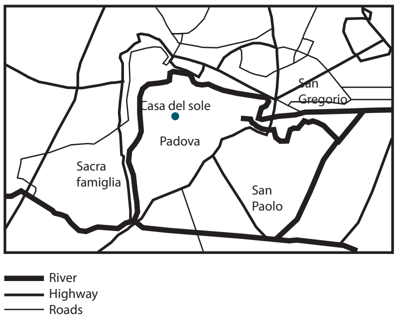
Ventilated roof: best practice

Project name

La casa del sole -
Terraced Individual
housing

Climate zone

Csa - Hot-summer Mediterranean climate



Construction year

2012

Location

Padua, Veneto, Italy

Integrated system

Solar photovoltaic panels
Solar thermal panels

Certification

Class B

Health & Comfort

the use of low temperature floor heating and the South-South/west exposure of windows to get warm in winter and cold in summer, greatly improve the quality of users' life.

Energy consumption

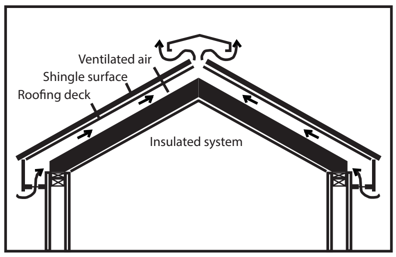
39,00 kWh/m²/year
Renewable energy production: 60,00%

Sustainability

The installation of 9m2 of vacuum solar panels on the roof that provide the 90% of the ACS and 18% of the heating and the photovoltaic installation that makes the dwelling self-sufficient, make the building more sustainable. In addition, the surplus of electricity produced at peak time make home a hub of electricity production.

How it works

The potential of this system is the natural air cavity that separates the roof covering from the underlying insulation layers. It allows the activation of ''upward convective motions'' which subtract most of the head loads that would be transmitted to the other layers. This system permits moisture to escape without compromising the thermal insulation power of the roof.



There are many different types of ventilated roof, it's possible to distinguish three possible solutions: insulated-ventilated roof with double air cavity, insulated-ventilated roof with ventilation of protective undercoat and insulated-ventilated roof on non-habitable attic with ventilation of the attic environment.

Description

The residence Casotto – Goffo, known as ''casa del sole'', is a makeover of the 90% of the structural part and the total renovation of plants. The compound is divided into two units: the first one is the house organised only on the ground floor; the second one is the apartment composed of three floors. To improve the performance some interventions are executed such as the installation of solar and photovoltaic panels on the roof, the renovation of structural parts with a new masonry, complete makeover of the wooden ventilated roof with an exposure to the south 30°. The ventilated roof is characterised by a galvanised sheet, air gap, insulation in wood fiber panels, supporting structure in fir wood and bitumen membranes. At the end of recovering, the house was tested with thermographic tests and blower test, and it's shown that its energy class changed from 260 kWh/m² to 39 kWh/m².

Source: https://www.construction21.org/case-studies/it/la-casa-del-sole-en.html, | Photo credit: -

ES

Solar thermal panels

A solar collector absorbs solar irradiation energy and converts it into thermal energy. The heat is transferred by its working fluid (air, oil or water) to the solar applications. Usually, the heat is used to either provide domestic hot water/heating, or to charge a thermal energy storage tank from which the heat can be drawn for use later. According to the position of storage, the system can be based on natural circulation that uses gravity force or forced circulation that needs some other devices to work properly. New technologies allow the solar thermal panels to be used in more several applications and to extend the limited energy efficiency.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Integration | Lifespan | Storage | Easy to repair | Flexibility | Weather protection

Regulations & Standards

UNI EN 12977, UNI 12975 and ISO 9806

Strategies

M A

Scale of application

Building | Neighborhood | City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.2 12.0
S 7.1 11.0

Disadvantages

High land-use
Weather-dependent

Energy consumption

Energy from RES on site

For 2030 projections, strong efforts should be made to find a coherent energy policy to carry on the extension of 2020 targets.

Case study: the solar thermal installations are presented along with produced energy and associated avoided carbon emissions. It has been shown that an installation of 1200 m^2 of solar thermal in Milan can produce 836 MWh_{th} of thermal energy. It's an uncredible result compared to other Italian cities such as Naples or Rome. In Milan, the solar thermal would show better performance due to the contemporary strong commitment at European level for district heating infrastructures which will benefit from solar thermal zero carbon heating supply ***[1].***

Low carbon material use

A cradle-to-grave LCA analysis are conducted to quantify the carbon emissions of solar thermal panels. Their environmental impact could be different according to the material used, the local climate and the typology of panels.

Case study: a LCA comparison of unglazed panels (composed by a strip of polypropylene, 313 mm in width and variable in length) and glazed panels (consists of an external case in aluminium which contains two sheets of rockwool insulation, a sheet of absorber in copper and a serpentine pipe in copper alloy). The results show that the GWP is 1670.92kg CO_2-eq for the glazed panels and 105.06 kg CO_2-eq for the unglazed panels. The panels were tested in three different locations (Rome, Madrid and Munich) with traditional and electric boilers, to evaluate the influence of local climate ***[2].***

Energy efficiency

Several studies show that the solar thermal panels strongly reduce the energy consumption for DHW production. It depends on their capability are the orientation, building volume and geometry, and climate zone.

Case study: one-floor apartment located in Košice (Slovakia, Dfb zone), was adopted. It is characterised by floor area of 53 m^2, heat load of 5 kW, and the specific annual energy supply equal to 163.585 W/m^3. Twelve combinations of solar thermal panels were analysed with software and were compared with real cases. The software results show that the energy demand for DHW is always 2040.65 kWh/y. Conversely, in real-time, this value is 725-792 kWh/y. Specifically, the best value for DHW energy supply was from a wood-fired boiler installation with 725.17 kWh/y ***[3].***

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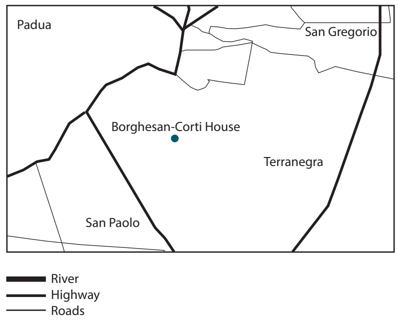
Solar thermal panels: best practice

Project name

Casa Borghesan-Corti
- Terraced Individual housing

Climate zone

Cfa - Humid subtropical climate



Construction year

2009

Location

Padua, Veneto, Italy

Integrated system

Solar photovoltaic

Certification

Class B+

Health & Comfort

The simple installation of Controlled Mechanical Ventilation and Heat Recovery which allows air exchange in 24 hours, combined the external thermal coating allow the building to be more comfortable for the users.

Primary energy

38.00 kWhpe/m²/year
Renewable energy production: 65.49 %

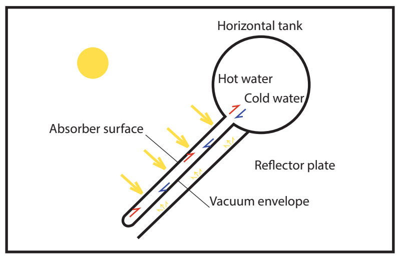
Sustainability

During the intervention the designers pay attention to some sustainable aspects. They reuse and recover all materials, the original artefacts. In addition, they used renewable and recycled material combined with some new material such as wood fiber and thermal plaster to protect and insulate the building.
GHG before use: 128,00 KgCO_2 /m²

How it works

The solar thermal panel can be divided into the not concentrating collectors where the collector area which intercepts solar radiation is the same as the absorber area (i.e. flat-plate collector) and concentrating collectors where the area intercepting solar radiation is greater, sometimes hundreds of times greater, than the absorber area (i.e. parabolic trough collector).

Typically, the system is composed by the collectors that capture the sun's energy by heating a fluid contained within reinforced glass pipes. The pump and controller ensure the transfer fluid is circulated between the collectors and the water cylinder efficiently.



Description

The original building was built in 1927 and shows all the typical features of the style of the twenties. Due to the high discomfort in wintertime and the over-consumption for heating, the house needs interventions. It was studying a specific approach to combine the restructuring and the energy efficiency. To pursue these aims the original structure of the roof was preserved but it was installed the controlled mechanical ventilation and heat recovery. In addition, pv panels and solar thermal panels were applied to satisfy the electricity demand and the hot water demand. To improve the management of water and to avoid the moisture problem an excavation perimeter of the house was done. In addition, to ensure the isolation a XPS panel of 12 cm was adopted for the underground part of masonry and a layer of wooden fiber was adopted for the front (without ornaments) and for the four an inner layer of wooden fiber combined with thermal plaster were used.

Source: https://www.construction21.org/case-studies/it/casa-borghesan-corti-casaclima-b-en.html, | Photo credit: -

ES

Yellow roof

The PV system is made by a group of solar modules that work together to produce electricity connected to a structure with inverters, charge regulators and batteries. PV solar technology can be used as a standalone system or as a grid-connected installation. PV technology converts light into electricity directly using solar cells without gas emissions or noise. Most of them are made with silicon because they have the most efficiency ranges 12-17% and these can be monocrystalline or polycrystalline. Other kinds of PV cells are thin film cells made from very thin layers of photosensitive materials placed on backing such as glass, steel or plastic.

Challenges	*Objectives*			*Performances*			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Easy to repair · Lifespan · Flexibility · Cooling costs · Weather protection · UV rays

Regulations & Standards

IEE , IEC and D.L. n.17 of 01/03/2022

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 12.0 13.0 · S 11.0 -

Disadvantages

Weather dependent
Lack of a system of energy storage

Energy consumption

Energy from RES on site

It's shown that the photovoltaic panels installed in zones with high solar radiance and with correct inclination angle, could produce enough energy to make the building self-sufficient.

Case study: elementary school of Serres located in Serres (Macedonia, cfa zone), was adopted. It is characterised by an insulated envelope, half openings with double glazing, half with single glazing and a metallic frame with no insulation. The building with these features presents a primary energy consumption of 250.7kWh/m^2 and energy performance rank of E. To improve the building performance small photovoltaic (PV) stations with 2,1 kWp power were installed on the roofs. The results show that PVs can reduce the 8.23% energy consumption ***[1].***

Low carbon material use

Several studies show that the accumulated primary energy consumption for the construction of the photovoltaic power plants ranges from 13,000 to 21,000 kWh/kWp. The life cycle CO_2 emission is 3.360 kg-CO_2/kWp for amorphous technology. The emission also depends on the type of pv panel: mono-crystalline or poly-crystalline. In order to define a general indicative value, two examples have been taken. Muneer et al. study a case in the UK and the results show that the GHG emission of a mono-crystalline pv is 44.0 g-CO_2/kWhe. On the opposite side Battisti and Corrado demonstrate that in Italy, the GHG emissions for a poly-crystalline panel is 26,4 g-CO_2/kWhe ***[2].***

Energy efficiency

Several studies show that photovoltaic panels strongly reduce energy consumption, if they are installed in some conditions such as in hot climates, with the correct orientation and inclination angle.

Case study: elementary school located in Polykastro (Greece, cfa zone), was adopted. The building presents a primary energy consumption of 628.5 kWh/m^2 and energy performance rank of G. Some passive measures as external thermal insulation, new windows and doors with double glazing and metallic insulated frame, and the installation of PVs. were adopted. The results show that, the reduction percentage of electricity consumption was 77,65% with a PV installed power equal to 5,0 kWp. In addition, the primary energy consumption was reduced to 92.07 kWh/m^2 and the new energy performance rank is B ***[1].***

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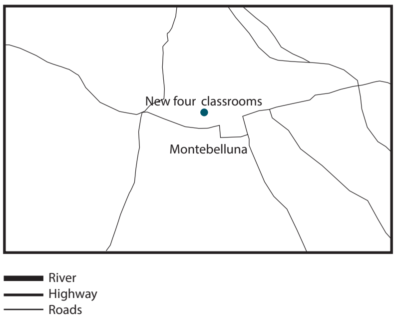
Yellow roof: best practice

Project name

New four classrooms (extension) – school, college, university

Climate zone

Cfa - Humid subtropical climate



Construction year

2007

Location

Montebelluna, Veneto, Italy

Integrated system

Thermal insulation coating
Venetian blinds

Certification

Class A

Health & Comfort

The simple control system for air quality and the South-South/west exposure of windows to get warm in winter and cold in summer, greatly improve the quality of users' life.

Energy consumption

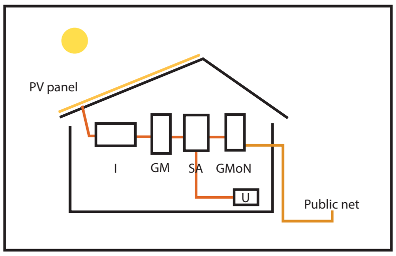
20,00 kWhpe/m^2/year
Renewable energy production: 115,00%

Sustainability

For a considerably reduction of energy consumption some strategies were adopted such as the XPS insulation, the air-to-air heat pumps, and solar panels. In addition, the direct sunlight gain provides about 46% of the heat demand. All these strategies make the building more sustainable and almost self-sufficient.

How it works

The PV cells of panels located on the roof capture the energy from the sunlight. This energy creates electrical charges that electricity to flow. This flow across the solar inverter that convert the direct current (DV) into alternating current (AC). The flow continues its path from invert to the generator that count the quantity of electricity generated and the part of this that is directed to the devices and plugs. The users use the amount of electricity generated that need, if the energy produced is more than aspect, it could be introduced in the grid connect and sold to the energy provider. Alternatively, it could be storage in batteries.
(I: inverter, GM: generator meter, SA: solar accumulator, GMoN: generator meter of net, U:users)



Description

The city of Montebelluna requested to build an extension composed of 4 new classrooms of a secondary school that will consume less energy for their operation. The structure of the building is composed of reinforced concrete columns and Predalles floor plates; in addition, all frames are made of wood with safety glass, cavity filled with argon gas and low emission surfaces. The project is focused on the reinforcement of structure, the indoor comfort using renewable energies, energy efficiency and the creation of a building with low energy consumption but high-quality climate, using low budget. The great advantage of this building are the switchboards that can detect both produce electricity from photovoltaics, both electrical consumptions to operate heat pumps, fans for ventilation and artificial lighting. Solar panels placed on the roof can provide the electricity for the lighting, ventilation (air exchange). The production of electricity is equivalent to 5400 kWh/year, while its consumption amounts to 4785 kWh/year. The building consumes very little energy, and it produces a surplus of 600 kWh of electricity per year.
Source: https://www.construction21.org/case-studies/it/nuova-costruzione-4-aule-scuola-media-ampliamento-en.html, | Photo credit: -

SOLUTIONS
FACADES

BIT

Thermal insulation

Thermal insulation is a flexible technology that could be collocated on the outer or inner wall, for new construction or for some retrofitting interventions. It can be a cavity wall insulation or an interlayer of the wall. Insulation products are classified into three groups – mineral fibre, cellular plastic, and plant/animal derived. The first category includes rock, slag and glass wool. The second category are oil-derived - rigid polyurethane, phenolic, expanded/ extruded polystyrene - available as loose fill, rigid sheets, and foam. The last category includes cellulose fibre, sheep wool, cotton, and flax, available as fibre, batts, or compressed board.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Flexibility · Noise pollution · Cooling costs · Fire resistant · Low-cost solution

Regulations & Standards

ISO 6781, ISO 9869-1
and ISO 9869-2

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P -
S 13.0

Disadvantages

Mold and condensation problems
Exposed to atmospheric agents

Energy consumption

Low carbon material use

Thermal insulation reduces energy consumption, consequently it reduces the buildings' environmental impact. In addition, the comparison between other building materials and thermal insulation shows that the environmental effect of thermal insulation is small.

Case study: fifteen insulating materials different in thickness, density and thermal conductivity have been tested using an exterior building envelope, in Ljubljana (Slovenia). The goal of the study was to compare the environmental impact of selected materials using the common 'cradle-to-gate' LCA method. The results show for an envelope of $400m^2$ and a thermal conductivity of 0,20 W/m^2K, wood-based, rook-based insulations, and cellulose recycled cause minimal environmental impact which range on average from 0.062 to 1.156 kg of CO2-eq. In contrast, thermal insulations with high carbon footprint, such as VIP and XPS, cause the higher environmental impact of 16.6 and 13.4 t CO2-eq, respectively ***[1].***

Energy efficiency

Studies show that the environmental effects of thermal insulation materials in comparison with other building materials are small, while the energy savings they produce are significantly high.

Case study: a virtual model of a two-storey residential single-house, located near the city of L'Aquila (Italy) was adopted. The model has the same buildings' characteristics as north-south orientation, geometry, internal gains, reinforced concrete with EPS insulation as bearing structure, and prefabricated wood-cement blocks with high thermal performance for the structure. The model has been studied in EnergyPlus and some simulations with several combinations of systems have been done. The results show that the best combination, made by air boiler and air handling unit, has an energy consumption of 974.7 kWh/y, that corresponds to 67% of energy saved. The worst-case scenario is the use of an air-to-water heat pump that consumes 4401.4 kWh/y ***[2].***

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Thermal insulation: best practice

Project name

Passivhaus Marlegno
- Terraced Individual housing

Climate zone

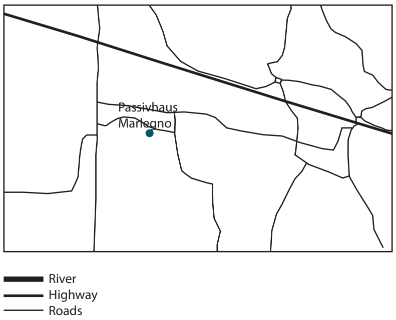
Csa - Hot-summer Mediterranean climate

Construction year

2015

Location

Bolgare, Lombardia, Italy



Integrated system

Solar photovoltaic

Primary energy

98,00 kWhpe/m² /year

Health & Comfort

The energy efficiency feature, the use of solar shade and thermal insulation that guarantee indoor thermal comfort, greatly improve the quality of users' life.

Environmental Quality

- indoor air quality and health
- comfort (visual, thermal, acoustics)
- renewable energies
- building end of life management
- energy efficiency

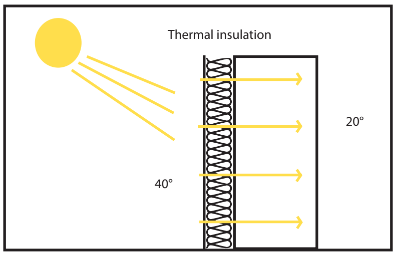
Sustainability

The entire house is made of sustainable materials. The innovative construction system called TAVEGO allows to assemble wooden walls and wooden beams without the use of adhesives. This methodology enhances to take full advantage of the ecological characteristics of a natural material such as wood, reducing carbon emissions and making the interior spaces healthier.

How it works

Thermal insulation is the method of preventing the transfer of thermal energy from one space to another. Typically, the heat flow has three different mechanisms of transmission - conduction, convection, radiation- and it changes from warmer to cooler areas until there is no longer a temperature difference. Most common insulation materials work by slowing conductive and convective heat flow.

It's known that every single material has its owner resistance to the heat flow, this value is called thermal resistance R-value. This value depends on the type of thickness, density, temperature, moisture of the layer. Actually, the commercial material with the highest thermal resistance is the expanded polystyrene (EPS).



Description

Passivhaus Marlegno is a single two-floor villa completely integrated into the urban surroundings. It was designed following the standards of Passivhaus Institut about high thermal insulation, air tightness, reduction of thermal bridges, high-performance windows, solar gains and VMC with heat recovery. The house is characterised by the load bearing walls and floor made of wooden boards assembled without glue; the buildings' stratigraphy has a U value of 0.083 W/m2k guaranteed by a natural stone wool coat with a thickness of 30 cm; the openings are carefully designed to acquire an appropriate solar gain in the winter and are adequately shielded with sunshade to prevent the overheating in summer period. In addition, an integrated home automation system controls the management of consumption, heating and cooling, lighting and solar shading.

Source: https://www.construction21.org/case-studies/it/passivhaus-marlegno-en.html | Photo credit: -

Green wall

UGI

Living walls can support several varieties of plant species growing along the vertical surface reaching higher areas and adapting to different types of buildings. Their systems are composed of pre-vegetated panels, vertical modules or planted blankets that are fixed vertically to a structural wall or frame. There are two main types of living walls: Continuous system and Modular system. The continuous system is composed of synthetic fabric, growing media, plants, and they are supported on a framework. The modular system is composed of containers which hold the growing media, regular irrigation system and fertilisation system that use gravity.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort, Biodiversity, Lifespan, Food production, Noise pollution, Artistic expression

Regulations & Standards

UNI 11235

Strategies

M A

Scale of application

Building Neighborhood City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.1 13.b
S 11.6 11.b

Disadvantages

Not easy to repair
Not lightweight system

Energy consumption

Greening

Several studies show that the green wall offers multiple benefits, one of the most important is its ability to capture the CO_2 emissions. This ability depends on the location, orientation, typology and thickness of the layers that compose the wall. *Case study*: 98m2 of green wall on a south-oriented building facade in Siena (Italy, cfa zone), was adopted. The herbaceous species selected for the CO_2 sequestration simulation are six species of perennial herbaceous plants - Sedum spurium, Salvia nemorosa, Rosmarinus officinalis, Geranium sanguineum, Carex brunnea and Fatsia japonica - and one perennial grass - Zoysia matrella -. The dynamic model results show that the entire wall can retain a carbon dioxide flow of 13.41–97.03 kg CO_2eq per year. Specifically, the S. Nemorosa was responsible for the highest CO_2 sequestration in terms of long -lasting accumulation, that is equal to 1640.27 kgCO_2eq. Generally, the simulations demonstrate that the best species in terms of CO2 accumulation is C. Brunnea, while the best species in terms of highest CO_2 retained is R. officinalis ***[1].***

Energy efficiency

Several studies show how important the presence of the green walls is in terms of energy performances. This ability depends on the orientation, the geometry, the typology of the wall as the thickness and the kind of layers.
Case study: a 3m x 3m house with the green wall (GW) on the south and west facades located in Puigverd de Lleida (Portugal, csa zone), was adopted. The element is characterised by a square pot made up of 3mm recycled polyethylene, 8cm of coconut fibre as substrate, 24 small plants and 4 micro irrigation tubes. The aim is to compare the energy performances of a GW, green façade and an uncovered façade. The results show that during the summer period, the GW can save energy in a range of 20%-60%, conversely the GF can save energy in a range of 5%-35%. During the wintertime, the energy saved by GW is in between 3% and 6%, conversely the GF can save at maximum 2% of energy ***[2].***

Temperature regulation

Temperature surface/air

Green walls can considerably reduce the UHI effect which leads to an increase of air temperature in urban areas up to 2°C–5°C compared to less populated areas. This result is influenced by the orientation of the wall, geometry, and typology and thickness of layers.
Case study: a south-west oriented 3 m x 3 m green wall prototype is installed in the headquarters of the IUAV University of Venice (Italy). The system is characterised by the presence of an aluminium structure, a PVC panel installed on it, and a vertical turf grass. The results show that when comparing bare wall and green wall the temperature difference during the day reaches values up to 16 °C, during the night, the temperature difference is about 6 °C. In addition, during cloudy days the surface temperature of the bare wall is higher than the green wall of 1 °C ***[3].***

Outdoor thermal comfort

Several studies show that due to density of foliage, the obstacles, the geometry, the orientation, typology of plants, and thickness of layers, green walls could improve the outdoor thermal comfort.
Case study: the central business district (CBD) in Melbourne (Australia) was selected. Just scenario D and E characterised by 50% of green walls and 100% of green walls were considered. The results show that in scenarios E/D the reduction of air temperature ranged between 6–10°C, and the relative humidity ranged between 0–1.8%. In addition, the PET index is between 33.2 and 59.0, it shows that the green walls could slightly improve the outdoor thermal comfort ***[4].***

Shadow effect

The foliage is characterised by leaf area index (LAI) that is the key parameter to define the foliar density and consequently the thermal behaviour of VGS. It depends on the typology of plants, the orientation building and the climate zone.
Case study: a steel modular existing double-skin greening system located near to Lleida (Spain, bsk zone), was adopted. It is composed of Glycine climber plants and its light transmission factor has the value in between 0.04 in July to 0.37 in April, during the season with the foliage fully developed. In addition, the transmission capacity of four different plant species is well adapted such as Ivy Honeysuckle, Virginia creeper and Clematis. The results show that the light transmission factor values of 0.15 for Virginia creeper, 0.18 for Honeysuckle, 0.14 for Clematis and 0.20 for Ivy plants ***[5].***

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Water management

Water retention
Several studies show that the green vertical system can greatly benefit the urban environment by delaying water peak flows. This capability depends on typology and thickness of system, orientation and material used.
Case study: GVs with expanded cork in the climatic chamber was used. Two tests were performed – fully confined tests and partially confined tests – using expanded cork agglomerates different in height, thickness, and density. The experiment was conducted with three kinds of density -standard, medium and high – and with four flushes hypnotised. The results of the second test show that in the first flush the medium density specimens retain 20 4 kg/m^3, but only 8.6 2 kg/m^3 in the following flushes. Generally, thinner specimens have smaller retention capacity than the thicker specimens ***[6].***

Water treatment
Several studies show that greening systems provide many benefits such as greywater treatment. This property depends on the typology and thickness of layers, the typology of plants, and the orientation of the façade.
Case study: a living wall located in Mannheim (Germany), was investigated. The south-oriented façade is characterised by a substrate container of 25 cm composed of polyethylene (PE) plate and a mixture of expanded clay aggregate (66.6%) and biochar (33.3%), and air gap of 5 cm. The foliage has the albedo equal to 0.3, with a transmittance index equal to 0.2 and the area density equal to 6 m2 /m. The simulation results show the greywater flow rate in the substrate is 75 L/d ***[7].***

Health and wellbeing

Green space
Several studies show that people benefit from the vertical greening system without consciously using it.
Case study: Quirónsalud Sagrado Corazón Hospital (QSCH) is located in Sevilla (Spain, csa zone). In 2012, a living wall of 40 m2, a felt system with pockets in which the plant root balls are inserted, was installed on the external façade facing the hall. Twenty-six pre-coded questions divided in 4 categories (personal data, attitude towards green elements, Self-Reported Psychological Well-Being Gai and 'contingent valuation') and the options for responses have been submitted to 555 people. From the interviews the following results have been obtained. When viewing the LW, 82% of participants feel happy and calm, 87.7% of participants feel more positive emotions or reactions, around 60% of them feel serenity or welfare and 31% happiness. Finally, 30% of the respondents showed negative (mainly allergies) or no reactions, and only 3.8% expressed indifference or negative feelings in all the items. 'Calm' and 'happiness' were the answers preferred, followed by 'pleasant' and 'stimulating' ***[8].***

Space for socialization
The green wall couldn't directly be used to create a net of relationship because of their not accessibility. However, it's interesting to investigate how the green wall associated with some other urban furniture can create a comfortable space where people can meet each other. This space can use the advantages related to the green wall and at the same time can promote the interactions. In addition, some art associations were founded to transform these green walls into real works of art.
Case study: Breathe O_2 living art installation was made in the USA in 2014. The installation is made up of more than 3500 annual, perennials and tropical plants with a large leaf-pattern that represent Michigan native trees. The installation is 22 feet tall and 150 feet large ***[9].***

Quality of air
Green wall is one of the best solutions that could help the improvement of air quality. Some plants, depending on their form and dimension, can capture the air pollutant and consume CO_2 to develop their vital function, and introduce O_2 in the air.
Case study: green walls can also contribute to air pollutants removal as much as 11,7%–40% of NO_2, and 42%–60% of PM_{10}, 40% O3, 3,5% SO_2, 1,34% CO and also 1,34% $PM_{2.5}$. ***[10].***

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Green wall: best practice

Project name

Fiordaliso shopping center – Commercial building

Climate zone

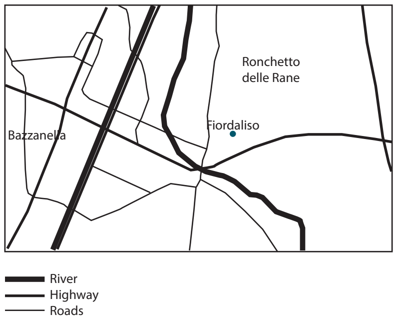
Cfa - Humid subtropical climate

Construction year

2012

Location

(Rozzano) Milano, Lombardia, Italy



Integrated system

Cool roof

Certification

BREEAM-In-Use given by BRE

Health & Comfort

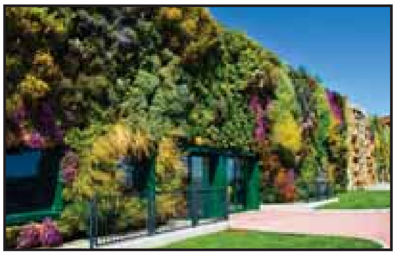
The building guarantees thermal, visual, and acoustic comfort. In addition, some "green cleaning" interventions have been adopted, to improve the accessibility for people with disability.

Energy consumption

-

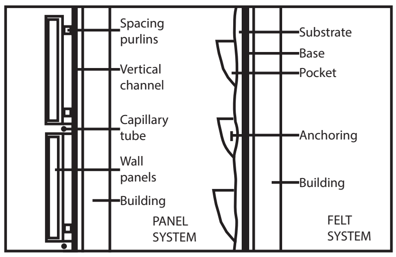
Sustainability

In this project, the cool roof and the green wall avoid the absorbance of solar radiation, consequently they are due to not overheat in summer. Conversely, in winter they avoid heat losses. In addition, the green elements with all the benefits connected, make the building more sustainable.



How it works

The green wall Living walls differ from green façades in being able to support vegetation that is rooted in an attached substrate to the wall itself, rather than being rooted at the base of the wall. The typical green wall is composed by a waterproof membrane against the façade to protect it, framework structure, layers of synthetic fabric with pockets filled with growing media and plants. Basically, each kind of medium-small plants compatible with local climate could be used. Another important aspect is the irrigation system.
The most efficient plant is the internal drip green wall irrigation watering system that re-captures and re-circulates water throughout the plants in the Green Wall. It pumps the water to the top and flows from plant to plant to the bottom, guaranteeing adequate quantity of water for all the wall. The green wall have a several quantity of configurations that using different technologies such as panel system, felt system, modular system.



Description

The green wall is an alternating combination of evergreen and flowering plants, which allows the viewer to follow the change of seasons consequently to see the chromatic metamorphosis, changing from bright green to white to intense red. With a surface of 1.262 square meters, the vertical garden is the largest living wall in the world (now in Italy). The wall is composed of 44.000 plants of 200 different species such as Festuca tenuifolia, Delosperma cooperi, Campanule, etc. The selection considered several factors such as the Milanese climate, the wall integration in the surrounding green, the resistance to the one-year test in the nursery, and the capability of the plants. The great water retention capacity of the bottom soil, which can hold water up to ten times its weight, it is possible to guarantee the vegetation an essential supply even at high temperatures, while micro-droplets, also present in agricultural crops, allow considerable savings. In addition, the green wall protects the building from solar radiation in summer and avoids heat losses in winter, therefore has a strong impact on the energetic balance. This element allows the reduction of CO2 emissions, improvement of air quality, improvement of visual impact, and it works as a noise barrier.
Source: https://una.city/ and https://www.youinit.it/progetti/, | Photo credit: -

UGI

Green facade

Green facades are a system in which climbing plants (one or two) or cascading groundcover growing up an existing vertical surface. Green facades are mainly rooted at the base of these structures, in the ground, in intermediate planters or even on rooftops. They can be anchored to existing walls or built as free-standing structures, usually cable and wire rope net system, metal mesh system and modular trellis panels. They are classified into two main categories: direct and indirect greening system. In addition, the indirect green façades function as "double skin façades", creating an air gap between the building surface and the vegetation.

Challenges	*Objectives*	*Performances*
Energy sustainability	Energy demand; Carbon impact; Energy produced from RES	Energy from RES on site; Low carbon material use; Greening; Energy efficiency
Temperature regulation	Local microclimate; UHI	Temperature surface/air; Outdoor thermal comfort; Shadow effect
Water management	Run off mitigation; Water scarsity; Water quality	Water retention; Water storage and reuse; Water treatment
Health and wellbeing	Comfort and life quality; Urban space quality	Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort · Biodiversity · Cooling effect · Air pollution · Noise pollution · Carbon sequestration

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.1 13.b
S 11.6 11.b

Disadvantages

More expensive
More intensive maintenance

Energy consumption

Low carbon material use

It's known that the green vertical systems play an important role in a sustainable urban environment, therefore the entire greening solution should be designed to pursue the sustainable aims.

Case study: the indirect green façade system with constructive un-vegetated technical solutions as PVC (GF_{PVC}), nylon cables (GF_N) and wood (GF_W), were compared. The experimental data of the green façade prototype characterised by a steel frame and Rhyncospermus Jasminoides vegetation and located at the University of Bari, were collected. The results of the carbon footprint of the green façade prototype (GF_S) show that only the GF_W has a low impact close to 20 kg CO_2 eq, followed by the GF_S with a GWP_{100} value equal to 32 kg CO_2 eq. Conversely the GF_{PVC} has the highest environmental impact equal to 50 kg CO_2 eq ***[1].***

Greening

It's known that the green facade is less complex, in terms of components and systems, compared to a green wall. Proportionally, the environmental impact is reduced by about 5%.

Case study: three experimental cubicles characterised by three different façade – green façade, green wall and bare wall - located in Puigverd (Spain, csa), were considered. The aim is to compare the potential environmental impacts of the three cubicles, using the LCA method. The results obtained by the study of manufacturing, operational and maintenance stages show that the green façade impact is 616,17 kg CO_2 eq. That is lower than the green wall impact equals to 646,18 kg CO_2 eq ***[2].***

Energy efficiency

Several studies show that green façade could help buildings to save energy, their foliage could create the shadow effect that in summer protects from the solar radiation and in winter provides thermal insulation.

Case study: a Boston ivy double-screen green facade located in Puigverd de Lleida (Spain, csa zone) was adopted. The aim is to understand how the changing of the foliage can reduce the energy consumption during the year, according to different orientations. The results show that, during cooling periods, the energy saving reaches up to 54% reductions in early summer and 30% during late summer when the foliage is degraded. On the other hand, during autumn and winter, the green facade leads to a 5.4% increase in the daily energy consumption for heating ***[3].***

Temperature regulation

Temperature surface/air

Green façade can be used in passive design of buildings to reduce the UHI effect. In addition, this system could offer several benefits such as the reduction of solar absorbance and of the heat load and the improvement of thermal insulation.

Case study: two experimental green façades located in Valenzano (Bari, Italy, csa zone) were tested. The aim is to evaluate the thermal effect of the two façade characterised by two kinds of plants: Pandorea jasminoides and Rhyncospermum jasminoides. The results show that during the summertime, the external air temperature measured on the south oriented green façades is around 1-2° on cloudy days and around 7-8° on sunny days. During the wintertime, the temperature of the green wall is in a range of 1-2° higher. lower than the respective temperatures of the uncovered wall up to 9.0 °C ***[4].***

Outdoor thermal comfort

Several studies show that a green façade could help to reduce the UHI effect and to improve the outdoor thermal comfort because of its low absorptivity and its thermal capacity.

Case study: green façade located in Madrid (Spain, Bsk zone), was adopted. The aim is to analyse the effects of these elements in the urban microclimate and to understand how the urban comfort could be improved. The results show that, adopting a green façade, the temperature decreases by 0.13°C, the wind speed decreases by 0.25 m/s and the relative humidity values generally can be increased during the summer and improve human comfort ***[5].***

Shadow effect

It's known that a well designed green vertical system can improve the indoor thermal comfort during the entire year. Naturally, the performance of the green façade depends on the orientation, the geometry, and the kind of vegetation.

Case study: four modular and south oriented trellises were prepared to accommodate a container garden in Puigverd de Lleida (Spain, Csa zone). The aim is to compare the growth of four different climbing – ivy, honeysuckle, virginia creeper and clematis -, as well as their ability to provide shadow. The results show that the plants best developed in height were ivy and honeysuckle, but they left some areas with lower density of foliage. For each plant the light transmission factor has been calculated for Ivy is 0.20, clematis 0.41, Honeysuckle 0.18 and Virginia creeper 0.15 ***[6].***

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Water management

Water retention
Several studies show that the green façades gave a strong water retention capability. This strength depends on different parameters such as the leaf area index, foliage profile, depth and typology of soil, evapotranspiration rate and drainage layer.
Case study: two vertical green façades were located on the south facing brick wall of a detached residential property in the UK. The first façade is fully foliated and the second one is predominantly twiggy, but both are about 3 m high, 0.5 m deep and 1.2 m wide, supported by wooden frames. The results show that, after 12 weeks of measurement and 27 events, the potential precipitation interception for the façades with distinct morphological features are different. For the fully-foliated façade the typical interception range is 54–94% and a delay of precipitation event of 30 min, conversely for the twiggy façade the interception range is 10–55% and the delay of precipitation event is about 15 min ***[7].***

Health and wellbeing

Green space
Several studies show that the physical and visual direct contact with greenery can highly decrease stress, violent behaviour, and fear. On the other hand they can increase the resistance to illness, patience and enhance public spaces, and add identity to a building.
Case study: 24 photographs of four different houses with various types of vegetation were created and a questionnaire was designed and submitted to 188 people in the UK. The multiple-choice answers were divided in 4 groups as Preference, Beauty, Affective Quality and Restoration. The results show that the houses with vegetation were more preferred. The most rated was ivy, followed by meadow, with Sedum, turf and brown vegetation. The same experiment was submitted again in the South-East of England. The results confirmed the classification obtained in the first experiment ***[8]***.

Quality of air
The usage of a vertical green façade could reduce the particulate matter capturing the air pollution and giving back oxygen. The main parameters that determine the amount of capturing are humidity, meteorological conditions, precipitation and the foliage density.
Case study: the experiment was carried out in Hanover (Germany). The aim is to determine the PM content on the leaf surface using the gravimetric method. The results show that in wintertime, the total amount of PM deposited on the leaves of Hedera helix varied between 161 ± 8 μg cm^{-2} and 158 ± 28 μg cm^{-2}. In addition, the comparison with other vegetation shows that hedera helix has the lowest capacity for PM_{10} capture that is equal to 0.1613 ± 0.0138 mg cm^{-2}, and for $PM_{2.5}$ capture that is equal to 0.1557 ± 0.0078 mg cm^{-2}***[9].***

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Green facade: best practice

Project name

Le Albere district – Residential, Commercial, educational buildings

Climate zone

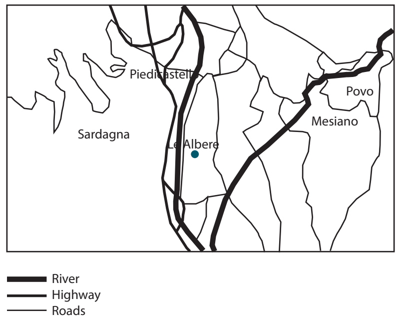
Cfb - Subtropical highland climate

Construction year

2014

Location

Trento, Trentino, Italy



Integrated system

Solar PV
Sunshade
Geothermal plant

Certification

Level B of CasaClima and LEED Gold

Health & Comfort

The natural shade effect helps to prevent overheating in summer and improve the quality of users' life.

Energy consumption

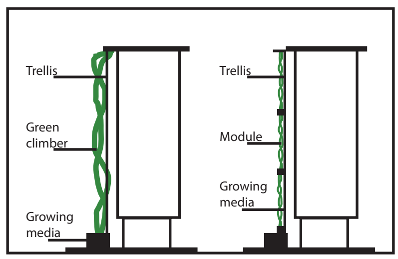
40-50 kWh/m^2/year
0,6 Megawatt/year

Sustainability

In this project, the most commonly used material is the wood. This material combined with the usage of some other natural-based solutions such as the green façade or the passive systems as the sunshade, create an eco-friendly and sustainable district.

How it works

They are classified into two main categories: direct and indirect greening systems. In the first system, common ivy is used due to the adhesive property that can allow the plants to be attached directly to the wall. In addition, the plant roots are either placed in the ground or in planter boxes. In the second system all types of plants could be used, due to the presence of the additional supporting structure systems. This component allows the plants to develop their growth along the wall. As in the first case, the rooting space is either placed in the ground or in planter boxes which may either be placed at the bottom of the façade or at multiple intervals along the wall. According to the height that they want to reach, vegetation and system are chosen. For example, Common ivy (Hedera helix) or three-leaved creepers (Parthenocissus) are used for self-bonders with a growing height up to 30 m. Using several types of system means creating different facades, specifically four types of facade vegetation can be discerned: Bonders, self-bonders using clinging roots.



Description

Le Albere district is on a surface of 11 hectares, and it is composed of 300 passive apartments, 30.000 square meters of offices, shops, squares, roads, pedestrian, and bicycle paths. The district is bordered on the south by the library and to the north by the natural science Museum. The aim of the project is to develop an eco-friendly, sustainable and high-efficient space using innovative strategies as the green facade. This natural solution is made by a structure consisting of steel elements in tension on which two types of ivy climb (one evergreen and one deciduous leaf). These elements are delimited by the planters containing the roots at the base and by a handrail at the top. The entire system acts as a parapet located close to the large-glazed window. These parapets solve the aesthetic problems and energetic problems partially. In addition, each apartment is equipped with photovoltaic systems and coloured roller blinds that allow the improvement of indoor thermal comfort, energy saving and adequate privacy.

Source: M. Marcantoni and M. L. Dinacci, LE ALBERE: il quartiere green di Renzo Piano, IASA Edizioni 2011, Trento, | Photo credit: -

Cool wall

BIT

The cool facade refers to exterior walls that reflect the infra-red portion of the sun's rays, keeping the exterior surface cooler and allowing less heat to be transferred into the building interior. The albedo stemming from the use of either light-coloured paints or "cool colours," and high thermal emittance. The exteriors of many buildings are painted by a variety of lighter and darker colours that use reflective "cool" pigments, regardless of the underlying material used in construction, other types of siding, may be pre-painted or pigmented in the factory. In most cases they use paints, but in few other cases synthetic waterproofing membranes are used.

Challenges / Objectives / Performances

Energy sustainability
- Objectives: Energy demand; Carbon impact; Energy produced from RES
- Performances: Energy from RES on site; Low carbon material use; Greening; Energy efficiency

Temperature regulation
- Objectives: Local microclimate; UHI
- Performances: Temperature surface/air; Outdoor thermal comfort; Shadow effect

Water management
- Objectives: Run off mitigation; Water scarsity; Water quality
- Performances: Water retention; Water storage and reuse; Water treatment

Health and wellbeing
- Objectives: Comfort and life quality; Urban space quality
- Performances: Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort, Flexibility, Cooling costs, Lifespan, Weather protection, Easy to repair

Regulations & Standards

ASHRAE 90.1 and ASHRAE 189.1

Strategies

M A

Scale of application

Building, Neighborhood, City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 11.0
S 13.2, 13.3

Disadvantages

Inadequate for colder climates
Get dirty easily

Energy consumption

Low carbon material use

Increasing in wall albedo means the energy saving and carbon footprint reduction. To implement this strategy, it's necessary to combine the cool wall with wall geometry, wall orientation, and climate.

Case study: three different buildings - new, older (for 1980 buildings), and oldest (for pre -1980 buildings) - located in California (USA, different climate zones), were evaluated. The prototypes were simulated with wood-frame walls and attic roof and concrete foundation. The simulations for the single-family home, medium and large office building, and stand-alone retail store were conducted. The results show that the cool walls can reduce annual pollutant (CO_2e, NOx, SO_2) emissions by −1.5 –24% in single-family homes, 0.3–3.8% in medium office buildings, and 0.0–10% in stand-alone retail stores ***[1]***.

Energy efficiency

It's known that the cool materials could improve the building energy performances and can reduce the cooling use up to 20%. The improvement depends on the climate zone and the insulation level.

Case study: the simulation is made on a 3-storey block in total located in three different cities Milan, Rome and Palermo (Italy, different climate zone). The building contains 6 apartments, each of them is characterised by a net floor area of 80.41 m^2, windows area of 10.50 m^2, internal height of 2.7 m and it is divided into two thermal zones: day and night. Two building envelope configurations were implemented: insulated and not insulated. The results show that the cooling savings is 1.5 kWh/m^2 for insulated buildings and 1.0 kWh/m^2 for the not insulated one, in Rome and Milan. In Palermo, cooling savings are around 2.0 kWh/m^2 for both configurations. For heating, the penalties are lower than 5% in Milan and Rome for both configurations, around 7%–9% in Palermo ***[2].***

Temperature regulation

Temperature surface/air

It is evident how the application of the innovative cool painting on the external surface of each wall combined with the right orientation, significantly reduces wall surface temperature.

Case study: a comparison between a fully instrumented test-room and a case scenario in Perugia (Italy), was considered. The test-room is characterised by the fenestration ratio of 0.41 due to the rectangular window in the South facade and a rectangular armoured door in the North façade. In addition, the cool painting among the facade consists of white non-organic painting, composed of potassium silicate and resin. The results show that the cool facade painting can reduce the external surface temperature up to 9.9 °C, 8.7 °C, 13.8 °C, and 11.4 °C for the South, North, East, and West wall, respectively ***[3].***

Outdoor thermal comfort

The inability to absorb the solar radiation of urban buildings, causes the UHI effect. Increasing the albedo of walls combined with the right urban canyon geometry, could be one of the best strategies.

Case study: a typical residential area with three storey terraced houses in London (UK), was analysed. The area includes street canyons with different orientations and a width of 16 m, and buildings altitude 10 m. The aim is to investigate the multiple impacts of reflective materials on outdoor thermal comfort. The results show that the increasing the façades reflectance reduces the Mean Radiant Temperature, and it improves the Physiological Equivalent Temperature up to 0.5 °C. Conversely, the reduction of the façade reflectance reduces the PET temperatures up to 1.6 °C, while the reduction in MRT is up to 3.3 °C. In the case of low reflectance of façade, the outdoor thermal comfort is improved ***[4].***

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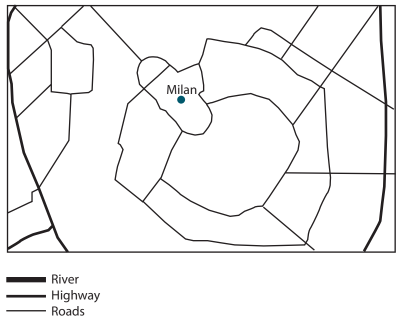
Cool wall: best practice

Project name

Residential isolated
tower building

Climate zone

Cfa - Humid subtropical climate



Construction year

2012 - 2016

Location

Milano, Lombardia, Italy

Integrated system

Thermal insulation

Energy needs

11% non-retrofitted case
5% retrofitted case

Temperature surface

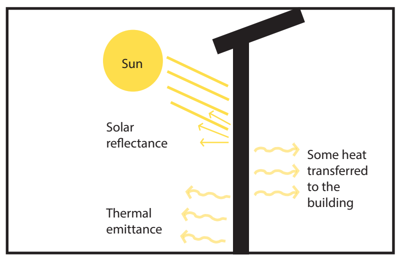
A white aged ETICS (insulation layer) can be 6 °C hotter than when new, considering a typical hot summer day in Milan.
With aging, for the non-insulated wall, the temperature surface changes from 32 °C to 38 °C, while for the wall with ETICS the variation is from 33 °C to 40 °C, implying an increase in the magnitude of thermal stress-strain cycles.

Energy efficiency

Difference in cooling load of 0.16 kWh m^{-2} y^{-1} for the insulated case and 0.08 kWh m^{-2} y^{-1} for the uninsulated case. A small reduction of the initial heating need, of 4% and 2% for the non-retrofitted and retrofitted buildings, respectively.

How it works

The wall is covered by a cool material that allows the building to not overheat. The cool material should have some specific features: in particular, the ASTM E 1980 norm defines the solar reflectance index (SRI) as the capability of a surface to not overheat. It considers the solar radiation and the emissivity and it is expressed in %. If the coverage surface is white the solar radiation equals 0.8, the emissivity equals 0.9 and the SRI is 100%; if the coverage surface is black the solar radiation is 0.05, the emissivity is 0.9 and the SRI is 0%. The best coverage has solar radiation higher than 0.8, emissivity higher than 0.9, consequently the SRI is higher than 100%. Compared to a ceiling that usually has a percentage of reflectance of 80% - 90%, the wall can reflect the solar radiation at maximum 60%.



Description

The principle of a cool wall was adopted to a façade of building in Milan, from April 2012 to April 2016. The purpose is to evaluate the solar reflectance and thermal emittance before and after aging of two finish coating natural exposed. Two standard finish coats beige and white with r_s equal to 0.46 and 0.75 respectively, have been selected from the market. It's shown that the finish coat lost in average 0.02-0.03 r_s, with different according to the exposure north-south. After 48 months, the losses were 0.08 for the white finish coat and 0.20 for the beige one. To determine the impact of weathering and soiling of cool walls on the building hygrothermal and energy performance, a ten-storey isolated tower building has been chosen. This is characterised by 30m of hight, and 20.3 m × 20.3 m in plan, with a total net floor area of 3307 m^2. Two cases have been studied: non retrofitted case and retrofitted case with a insulation layer.

Source: https://doi.org/10.1016/j.enbuild.2017.08.017 | Photo credit: -

Trombe wall

The Trombe walls are a type of technology derived by a combination of thermal mass and glazing elements to collect and store solar radiation. Trombe walls are made up of a material as bricks or concrete that are characterised by high thermal mass materials, usually coated with a dark colour paint to achieve higher solar absorptivity. In addition, the air cavity is necessary. It can be very narrow, just sufficient to allow air movement between the glazing and the wall or it can be large enough to be habitable. This system could be improved using double glazing with low-e coating or installing a solar thermal system on the effective emissivity surface.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort, Flexibility, Cooling effect, Noise pollution, Heat gain, Weather protection

Regulations & Standards

-

Strategies

M A

Scale of application

Building, Neighborhood, City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.0 S -
-

Disadvantages

Less natural daylight
Weather dependent

Energy consumption

Low carbon material use

Several studies show that the traditional Trombe wall is made up of materials such as concrete and aluminium framing, characterised by a strong environmental impact that could be easily reduced using different materials and thickness.

Case study: a Trombe wall in a solar residential building prototype in Ancona (Italy, cfa zone), was adopted. The Trombe wall system installed on the southern side, is made up of a 40 cm concrete with plaster, a single glazed window and external-aluminium frame. The aim is to calculate the carbon footprint using the LCA method. The results show that the Trombe wall as built has a carbon impact equal 1562.90 kg CO_2 eq. in pre-use phase, plus the contribution of use-phase that is 1061.40 kg CO_2 eq., totally the CO_2 emission is 2624.31 kg CO_2 eq. The experimental show that changing the material, the carbon footprint can be reduced up to a maximum equal to -1105.00 kg CO_2 eq. (-71%) for the pre-use phase, -576.00 kg CO_2 eq. (-54%) for the use phase and -1445.28 kg CO_2 eq. for the entire process ***[1].***

Energy efficiency

It's shown that the Trombe wall improves the energy demand, using its ability to capture the sun and use it for space heating partly or completely. The absorbance increases as the design of the wall is adequate, in terms of geometry, orientation, location and materials.

Case study: two single-family houses located in Lyon (France), were adopted. The two houses are characterised by an average elevation of 240 m, ten rooms, and just one of them has the Trombe wall. A comparison between the building with the Trombe wall and the building without one, was done. The results show that the Trombe wall could generate the saving of primary operating energy up to 21%, and it could save more proportionally to the thicker core layer of clay brick that is able to accumulate more solar ray's heat ***[2].***

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Trombe Wall: best practice

Project name

Residential two-storey
family house

Climate zone

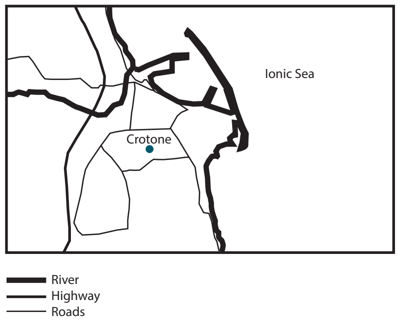
Csa - Hot-summer Mediterranean climate

Construction year

2022

Location

Crotone, Calabria, Italy



Carbon emission

The system allows to save 185 kg of emitted CO_2.

Certification

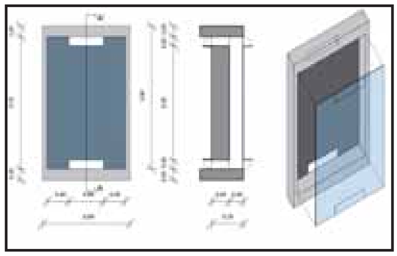
-

Payback time

The investment costs can be recovered in less than 6 years, independently from the electric energy inflation rate, assuming an air-conditioning system driven by an air-air heat pump.

Energy consumption

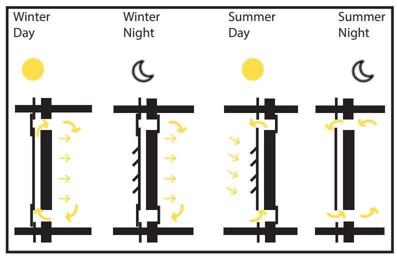
430 kWh (-10.5%) for heating
316 kWh (-9.5%) for cooling



How it works

Sunlight passes through the glass panel in front of the wall then the air in the gap between the wall and the glass is heated through conduction. Finally, the air can pass through the top vent into the home, heating the house via convection. At the same time, cold air is drawn in through the bottom vent to be heated by the sun and rise up again. This creates a cycle of warm air flow.

Throughout the day, the wall will continuously absorb heat, then at night when temperatures drop it will release the heat absorbed by the concrete wall, providing a comfortably warm internal space overnight.



Description

The residential two-storey family house is developed on two floors with an eight of 3 m each. The ground floor contains the hall, kitchen, living room, bathroom and the second floor contains 3 bedrooms and two bathrooms. The total floor area is 125 m^2 and South-facing vertical walls are available for hosting Trombe Walls. It is composed of, externally a double-pane system (with Ug of 2.471 W/m^2K and Uw of 2.013 W/m^2K) equipped with vents and internally by the existing dark-coloured painted external wall. In addition, the thermo-circulation between the air gap and the indoor environment is permitted by air vents. The entire system has modular features for an easy installation. Simulations were carried out to determine the heating and cooling energy needs of the building and the achieved thermal performances, both in winter and summer. To quantify the positive results the Trombe wall was compared with the same building not equipped with TWs.

Source: https://doi.org/10.1016/j.energy.2022.124798, | Photo credit: -

Glass with solar control

BIT

Solar control glass is an hi-product characterised by a special coating designed to reflect and filter the sun's rays, allowing natural daylight into the room, but without uncomfortable visual glare. The indoor space stays bright and much cooler than would be the case if normal glass were used. To render switchable solar control glazing, two types of materials are placed between two glass or plastic sheets. The first material is an electrochromic material and the second one is a thermotropic material such as hydrogels. Solar control is often specified for large-glazed areas, façades, conservatories, windows, skylights and roofs.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Glare · Cooling costs · Heat gain · Easy to repair · Daylight

Regulations & Standards

EN 1096 and EN 17074

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P -
S 11.0 13.0

Disadvantages

Overheating
Not suitable in cool climates

Energy consumption

Low carbon material use

Several studies show that solar control film could be economically advantageous and could reduce the carbon footprint to 2 times less the carbon emissions produced by a new window.

Case study: a typical office area located in Lisbon (Portugal, Csb zone), was considered. It is characterised by a floor area of 17 400 m^2, a glazing area of 1732 m^2, and three main areas - halls, security and conference rooms and office spaces -. The purpose is to assess the environmental impact of three different SCFs (solar control film) as retrofitting solutions and to compare these solutions with the replacement of the window with new one. The SCFs are different, for example SCF A is a reflective film with silver colour and a thickness of 0.050 mm as SCF B and C that are tinted-yellow and not coloured, respectively. The results show that the carbon footprint (CF) normalised per m^2 of floor area in a period of 40 years in average is 4.73 kgCO_2eq (SCF A ha an emission of 4.26 kgCO_2eq, SCF B has an emission of 5.20 kgCO_2eq, SCF C has an emission of 4.73 kgCO_2eq). In terms of the NW (new window), the carbon footprint is 35.93 kgCO_2eq/m^2/40 y, almost eight times higher than the average of the three films ***[1].***

Energy efficiency

The intelligent use of controlled EC glass and the orientation could optimise the comfort and reduce considerably the energy demand in existing buildings through retrofitting interventions.

Case study: three independent single-room blocks located in the Faculty of Arts and Humanities' building of University of Coimbra (Portugal, csb zone), were adopted. The test-cell models were based on the typical characteristics of school buildings dated of the 1950s, and they were characterised by square layout, exterior walls of 60cm thick and windows placed at 1m from the floor and centred on the façade. Single and double glass with static optical properties and double EC glass were considered in the simulations. The results show that by adopting EC glass, in the cooling season in the east façade the energy difference is 144.33 kWh, on the south façade is equal to 110.29 kWh and on the west façade is 209.02 kWh. Different values were carried out in the heating season: in the east façade the energy difference is 95.95 kWh, on the south façade is equal to 136.57 kWh and on the west façade is 152.08 kWh. ***[2].***

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Glass with solar control: best practice

Project name

The Sign

Climate zone

Cfb - Subtropical highland climate

Construction year

2021

Location

Milano, Lombardia, Italy

Integrated system

UTA
photovoltaic solar system

Certification

LEED 2009

Health & Comfort

The building is equipped with CO2 sensors for the detection of crowding and with automatic regulation valves of the room temperature to ensure adequate internal thermal comfort.

Building materials

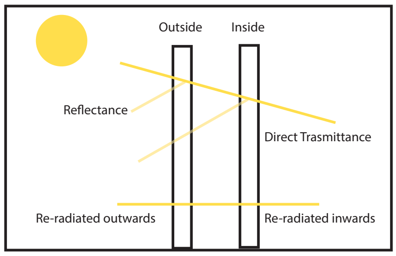
Regional materials, with a very low content of volatile organic compounds and wood from certified forest, were used in this project.

Sustainability

The usage of local material combined to the glass with solar control reduce the carbon emissions in the phase of transportation and in terms of energy consumption. These two strategies combined to other system allows to reduce the global environmental impact of the building.

How it works

Glass with solar control prevents a significant amount of sun's radiation thanks to three important features. The first one is the reflectance that is the proportion of solar radiation reflected into the atmosphere; the second feature is the direct, and the last is the absorptance. It is important to keep in mind that as the G Factor of the glazing is reduced, the visible reflection from the exterior of the glazing may increase and the glass can become tinted. Whilst there are many solar control-coatings available and the most popular is a 70/35 Solar control coating which reduces the G factor of the glass unit to 35% while maintaining the units light transmission at 70%. Solar control glass is not necessarily coloured or mirrored glass, although such finishes can be applied for aesthetic purposes if desired.



Description

The sign, located in the south-east area of Milan, is a building of the 1950s. The project transforms Vedani Foundry in a new business district. The innovative project is characterised by three buildings united by a strongly contemporary and captivating façade, a series of golden flaps that alternate with the transparencies of glass. Since external shielding is not provided, the glazed windows ensure the reduction of 70% of the solar irradiation accident. The selective toughened glass Energy 72/38 from AGC's Energy range of magnetronic coatings, ensures the maximum level of natural light inside buildings and the minimum amount of heat. This product offers an excellent selection and a totally neutral appearance and thanks to the possibility to be combined with other AGC products, it is an extremely versatile product able to guarantee maximum comfort.

Source: G. Dall'O, Green Buildings in Italy. The green certified projects in Italy, Edizione Ambiente, Milano 2021, https://thesignmilano.it/ and https://www.progettocmr.com/project/the-sign/ | Photo credit: -

BIT

Adaptive skin

The adaptive skin is a building envelope that could be internal or external, without distinction between walls and roof. The term "adaptive" refers to a system with interactive behaviour. It constantly changes towards changing environmental conditions to enhance indoor comfort, glare protection, light deflection, heat and energy management, Indoor Air Quality (IAQ) and to reduce the carbon emissions. New generations of envelopes are emerging dynamic, auto-reactive, responsive envelopes and kinetic characterised by different features, some types of facades may influence the performance of the load-bearing structure and its internal forces.

Challenges / Objectives / Performances

Energy sustainability
- Objectives: Energy demand; Carbon impact; Energy produced from RES
- Performances: Energy from RES on site; Low carbon material use; Greening; Energy efficiency

Temperature regulation
- Objectives: Local microclimate; UHI
- Performances: Temperature surface/air; Outdoor thermal comfort; Shadow effect

Water management
- Objectives: Run off mitigation; Water scarsity; Water quality
- Performances: Water retention; Water storage and reuse; Water treatment

Health and wellbeing
- Objectives: Comfort and life quality; Urban space quality
- Performances: Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort · Lifespan · Easy torepair · Glare · Privacy · Noise pollution

Regulations & Standards

UNI EN 13830

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 7.3
S 12.0, 13.0

Disadvantages

May negatively affect the view
Reduction of usable space

Energy consumption

Low carbon material use

Several studies show that using adequate strategies as adaptive skin, the carbon emission could be reduced by 50%-60%. Adaptive skin could be made of recycled material or with elements that could produce energy. The CO_2 saved depends on electricity mix, the façade orientation and the typology of the façade.

Case study: adaptive solar façade (ASF) at ETH house of natural resources living lab in Zurich (Switzerland), was adopted. The facade consists of 45 dynamic PV modules composed of PV module, actuator, and cantilever. The cradle-to-grave approach that contains the values of production, operation, and disposal of ASF, was used. The results show that this kind of ASF gives a final emission of 3037 kgCO_2-eq. Considering the energy savings produced by ASF the final emission decreases up to -8318 kgCO_2-eq. ***[1].***

Energy efficiency

Several studies show that the adaptive façade reduces solar gain and hence the energy consumption, with minimal reduction in visual comfort for users.

Case study: a building rectangular model located in a Cfb climatic zone, was used. The model contains six zones, in between a floor and external roof, with glazing north-south facades and west biomimetic façade. The simulations were performed assuming a different HVAC system that works in specific time slots and several functions. A comparison between the model with and without bioclimatic facade was performed. The results obtained show that, using a bioclimatic façade allows 46% of energy saving in the year. For the heating system the energy saved is 4,7 W/m2 and for the cooling system the energy saved is 19 W/m2. The simulations conducted across building types show that the Aged Care model can reduce energy up to 67.1% compared to the reference case, the Education type indicates a reduction of 42.6% compared with the original, and for Office study a 46.2% reduction is obtained ***[2].***

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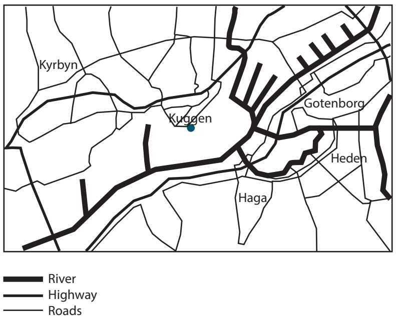
Adaptive skin : best practice



Project name

Kuggen –
office building

Climate zone

Cfb - Subtropical highland
climate

Construction year

2011

Location

Gothenburg, Sweden

Integrated system

Photovoltaic system,
Solar panels

Certification

Class A +

Health & Comfort

the indoor thermal comfort is enhanced by the variable diffusers that provide VAV ventilation and cooling as required. In addition, the occupancy sensors provide both ventilation and lighting, according to the quantity of occupants.

Energy consumption

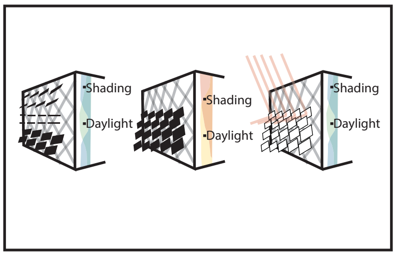
60 kWh/m²/year

Sustainability

Kuggen is characterised by innovative-adaptive technologies in terms of daylighting, heating/cooling, light and ventilation. In addition, the ceramic panels used in façade are made by a special technique that allows extending their use beyond the limits of our own civilization. They are so persistent that they can be reused.

How it works

The adaptive building skin can change its properties and flexibly control the different parameters, according to climatic conditions to ensure thermal comfort. The change can be obtained in many different ways as moving elements, introducing air flows, through PMC materials, etc. According to the materials and the technology used, the adaptive skin could be called as kinetic, kinematic, dynamic, convertible, transformable, performative, responsive. In general terms, the vast category could be divided into opaque facades, which are basically made of layers of solid materials, such as stone, precast panels, etc.; and glazed facades, as curtain walls or storefront facades, which basically constructed with transparent glazing elements and metal framing structures.



Description

Kuggen is the new building of Campus Lindholmend, designed by architect Gert Wingårdh. The purpose of the project is to create a kind of magnet that can attract students, businesspeople and the public and create an innovative meeting place for the community. It has a circular shape with saw-tooth edge that provides shading to the storey-below, six floors and the triangular windows daylight to follow the ceiling deep into the building. It hosts 192 conform office units surrounding open, flexible space, destined to scientists working within Chalmers University of Technology setting up their start-up firms. The entire building is covered by a permanent-glazed terracotta skin made of six different shades of red and one green. A movable mesh-like system of photovoltaic cells sunscreen provides additional shade as well as electricity as it moves around the outer surface.

Source: https://web.archive.org/, https://www.magicad.com/, https://www.designboom.com/, | Photo credit: -

Sunshade

Solar shading is an element of daylighting that can reduce glare and heat gain, by reflecting or blocking sunlight. The main design parameters, which alter the solar contribution, are the amount of wall area facing the sun, ratio of window/wall, wall orientation, etc. There is a wide variety of shading devices, basically divided into two categories: fixed (direction and path of the sun to optimise the effectiveness of shades need to be considered before the installation) and dynamic solar shades (they change throughout the day to respond to the sun's angle and strength). The common feature of both categories is the versatility of materials.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Glare · Cooling costs · Heat gain · Privacy · UV rays

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 7.3
S 11.b 13.3

Disadvantages

Unaesthetic
exposed to atmospheric agents

Energy consumption

Low carbon material use

A cradle-to-grave environmental LCA was used to define the environmental performance in terms of CO_2 emission of the shadings in their all life stages. The analysis shows that the choice of shading material could have a strong environmental impact.

Case study: one-story detached house model located in Seattle (Washington, USA) was adopted. The residential building is characterised by a total floor area of 130m2, a height of 3.2 m, and the total window to wall ratio was 18.87. The purpose is to assess the effect of various shading designs and materials such as wood, aluminium and PVC. The results show that the normalised global warming value is 3.02E-02 g CO2 eq for the aluminium shadings, 1.24E-02 g CO2 eq for the wood shadings and 3.27E-02 g CO2 eq for the PVC shadings. It's shown that, in all studies, wood elements have the best environmental, economic and overall behaviour ***[1].***

Energy efficiency

As several previous studies have found, automatic control of shading is essential to save energy and provide daylight benefits.

Case study: some simulations for one/two person office cubicles have been performed in Oslo (Norway). The main characteristics of the office cells are the 3x3 m façade with a U-value of 0.15 W/m^2 K. Six strategies were adopted and each one was analysed in two different ways: with a fixed slat angle and with a variable slat angle. From the eleven cases, plus the twelfth case with no shading used as reference, emerged that the energy demand could be reduced as large as 9% if the right shading strategy is chosen on the south-facing facade. On the other hand, it was found that improper use of shading systems on the north-facing will lead to an increase of the total energy demand of 10%. In addition, upgrading to four-pane glazing will always have a beneficial impact on the energy demand. It's notable a significant reduction of 20% with the replacement of two-pane glazing with four panes, and a reduction of 7% with the replacement of the three-pane window with a four-pane glazing unit ***[2].***

References

[1] H. Babaizadeh, N. Haghighi, S. Asadi, R. Broun and D. Riley***, Life cycle assessment of exterior window shadings in residential buildings in different climate zones,*** Building and Environment 90 (August 2015) Pages 168-177***, https://doi.org/10.1016/j.buildenv.2015.03.038***

[2] S. Grynning, B. Time, B. Matusiak, ***Solar shading control strategies in cold climates – Heating, cooling demand and daylight availability in office spaces,*** Solar Energy 107 (September 2014) 182-194, ***https://doi.org/10.1016/j.solener.2014.06.007***

Sunshade: best practice

Project name

BUM –
Biblioteca Universitaria
Mesiano

Climate zone

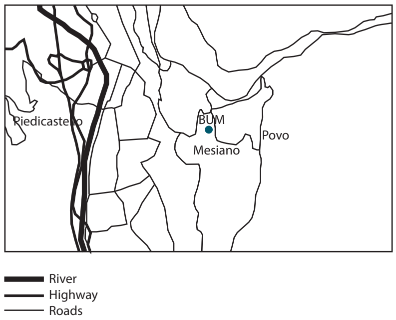
Cfb - Subtropical highland climate

Construction year

2021

Location

Trento, Trentino, Italy



Integrated system

Geothermal system

Certification

Class A +

Health & Comfort

The energy efficiency feature and the use of "solar shade" that prevents overheating in summer and heating in winter, greatly improving the quality of users' life.

Energy consumption

7.27 kWh/m^3 /year for heating
5.32 lWh/m^3 /year for cooling
1.48 kWh/m^3 /year for DHW

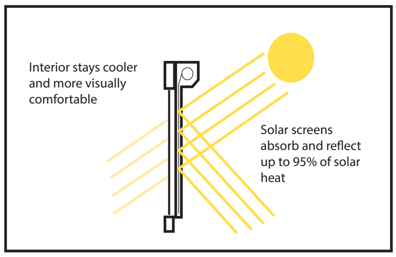
Sustainability

All the materials used make the building more sustainable, for example the furniture follows the CAM concept, dimerable led lamps, concrete is made of recycled aggregates with porphyry waste in a variable percentage between 75% - 80%, windows and floors with high thermal break guarantee of non-toxicity due to formaldehyde and heavy metal content and 180m^2 lamination tank that recovers water and is used for irrigation.

How it works

They block up to 97% of the heat and UV rays before the sun enters through the window. This system allows to dissipate or reflect bulk of the heat absorbed by the screen, and to control heat gain by rolling down exterior solar shades on hot days to block the heat and rolling the shade up when it isn't necessary. The choice of shading devices depends on several parameters. The key factor is the context compatibility, followed by the regulation of light, the right ventilation, durability, costs.

In addition, according to the compatibility with style and urban language some different solar shades could be used, as pull up and down and open inwards or outwards, in different shapes as venetian blinds, shutters, textile solutions.



Description

The BUM building has almost 1500 m^2 in 3 floors: one above ground, one basement and the underground for technical services. It is built with reinforced concrete structures with large-glazed openings that allow the 320 occupants to enjoy an excellent view as well as excellent thermal comfort. On sunny days the windows are covered by grey-textile shade devices that pull up and down according to the sun rays and the heat load. Interior comfort is guaranteed by the sunshades, the construction of oak wood floors and ceiling panels with sound-absorbing materials, underfloor heating, high-efficiency windows with acoustic cut, brightness control by sensors for measuring natural light and regulation of artificial light via dimerators that allow home automation self-regulation. In addition, the used colours as black, oak colour and grey, makes the rooms welcoming and suitable for concentration.

Source: https://www.biblioteca.unitn.it/929/ledificio & https://youtu.be/ZNdkW7P0Aqw, | Photo credit: -

Phase changing material

BIT

When the ambient temperature rises, the phase change materials absorb heat, therefore with an endothermic change from solid to liquid. As the ambient temperature drops again, the PCM will return to the solid state and give off the absorbed heat. PCMs can be divided into several subcategories based on their chemical composition: (i) organic compounds (paraffins/non-paraffins), (ii) inorganic compounds and (iii) inorganic eutectics mixtures. In addition, they could be incorporated into building envelope elements by immersion, micro or macro encapsulation, shape-stabilised PCMs, and form-stable PCM composites.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Reuse · Cooling costs · Heat gain · Fire resistant · Noise pollution

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 7.0

S 13.2 13.3

Disadvantages

Poor thermal conductivity
PCM performance is limited

Energy consumption

Low carbon material use

Several studies show the PCMs could reduce the carbon emission of the buildings. Typically, the carbon quantity depends on PCM thickness and surface area, local weather and position, and materials used.

Case study: a typical Australian home was simulated in Newcastle (Australia, cfa zone). The model is characterised by the floor area of 6 x 5 m with the height equal to 2.5 m, and two identical 2 x 1 m^2 windows in the southern part and in the northern. The aim is to calculate the environmental impact of six model modes. The simulation results show that using PCM the amount of CO_2 could decrease up to 4,917 kg/year by oil, 3073 kg/year by natural gas and 6146 kg/year by coal. The worst-case scenario is represented by the PCM positioned in the roof-wall of the building, when the amount of CO_2 emissions is 2433.2 kg. Globally, considering the entire building with a life span of 50 years, the total CO_2 reduction is about 264 tons, less than 1%, therefore, the carbon footprint would be negligible ***[1].*** Another interesting case ***[3].***

Energy efficiency

It's shown that the PMC technology could capture heat, create a real TES (thermal energy storage) and be a valid solution for heating and cooling. The PCM performance system depends on the temperature, thermal conductivity and density.

Case study: an energy simulation of an office with 4 m × 3 m × 2.8 m was chosen. The building is characterised by a solar collector that sends air into TES where it releases heat to PMC plates., facing south, 3 m^2 of windows. In addition, ventilation, infiltration, and temperature values have been set. The results show that, during the winter, using PMC plates, the energy saved is about 84 kWh, that is the 8% of the heat load accumulated by PCM storage. In summertime, the energy saved is approximately 58 kWh. Using PCM technology, approximately 142 kWh of energy could be saved in an office ***[2].*** Another interesting case ***[4].***

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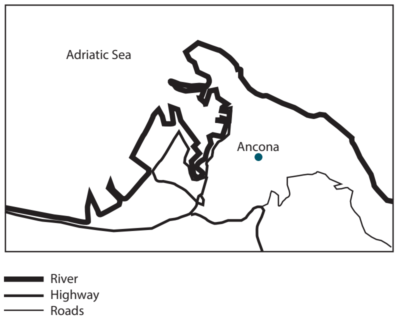
Phase changing material: best practice



Project name

A refrigerated container envelope with a PCM layer

Climate zone

Cfb - Subtropical highland climate

Construction year

2016

Location

Ancona, Marche, Italy

Integrated system

Thermal insulation

Heat peak transfer rate

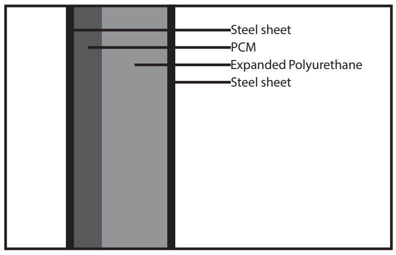
Reduction of 5.55% and 8.57% compared with the reference.

Surface temperature

Reduction of 1–2 °C compared with the reference container.

Energy consumption

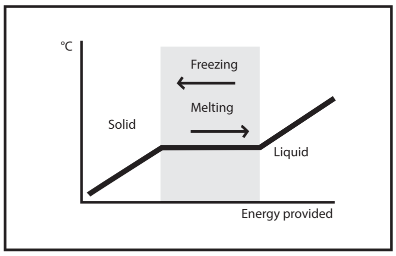
Total energy reduction of 20% and 4.7% respectively.



How it works

PCM are substances that absorb heat when on the external envelope surface the maximum incoming heat flux is present during the hot hours of the day. When the temperature decreases to the melting point, the latent heat stored by PCM is subsequently released. A phase displacement of heat flux is generated by this storage-release cycle. This process allows to reduce cooling peak load between the daytime and the night-time. These kinds of materials are suitable for several different applications, because of their melt and solidify specific temperature allow to control the temperature. This property improves the efficiency of the material, for this reason, compared to a conventional material, the PCM is used in a smaller amount.

There are several factors should be considered when selecting a phase change material such as high heat of fusion, high thermal conductivity, high specific heat and density, long term reliability during repeated cycling, and dependable freezing behaviour. In addition, there are several classes of phase change materials such as paraffin waxes, non-paraffin organics, and liquid-to-gas phase change materials.



Description

The energy performance of a reefer container enclosure using PCM was experimentally and numerically investigated in Ancona. The PCM material selected is rubitherm RT35HC paraffin wax, characterised by an average density of 770 kg/m^3, a latent heat of fusion of 220,000 J/kg, a fusion temperature of 35 °C and a volume expansion of 12%. Due to the nature of PCM (solid-liquid transition), it can only be used in containers or if encapsulated. The solution adopted are polyethylene panels with dimensions of 0.6 x 0.6 x 0.03 m) each of which is internally divided into 81 small square tanks. They were manually filled with the previously oven-melted (50 °C) paraffin wax. Finally, the packaging system was hermetically closed using a thin multilayer film. The outdoor and indoor analysis were conducted. For the indoor analysis experiment, a comparison of thermal behaviour of PCM-added prototype panel and the reference panel have been investigated. For the outdoor analysis, two identical cold rooms one of them fitted with a PCM external layer, have been chosen.

Source: https://doi.org/10.1016/j.enconman.2016.05.071, | Photo credit: -

Ventilated facade

A ventilated facade is an exterior building envelope system that could be installed on both new and existing buildings. It has a double function: it is practical and aesthetically attractive from an architectural point of view, and it moderates the exchange of heat and air. Typically, the ventilated façade comprises five main parts: base material, insulation, ventilation gap, sub-structure, and façade panel. The external layer could be made by porcelain stoneware, aluminium composite panels, fiber cement panels, high pressure laminate panels, linear slabs, glass panels. In addition, it could be combined with some other innovative solutions such as PCM.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort, Flexibility, Noise pollution, Mold, Thermal insulation, Easy to repair

Regulations & Standards

UNI 11018, UNI 8012, UNI EN 12152, UNI EN 12153, UNI EN 12179, UNI EN 13116

Strategies

M A

Scale of application

Building Neighborhood City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.0 S 12.2

Disadvantages

Low fire safety
Susceptible to corrosion

Energy consumption

Low carbon material use

Different studies show that ventilated facade could reduce the carbon footprint, save energy and guarantee indoor thermal comfort.

Case study: the "Polígono San Pablo" building, built in 1962, is located in Seville (Spain, csa zone). It is characterised by 4 floors, with two houses per floor, for a total of 8 houses composed by living-dining room, kitchen, laundry room, bathroom, toilet, four bedrooms, and distribution space. The aim is to compare the conventional façade made up external coating of granite slabs, ceramic bricks, busbar layer, insulation, double hollow brick partition, inner coating and the windows have aluminium frames; with the new prototype facade composed by external coating cladding, thermal insulation, ceramic bricks and all the layers of conventional façade. The results show that some features of the new façade have a strong impact on the CO_2 emission. Comparing the two façade, it's notable that the window frame emits 31.70 $kgCO_2/m^2$ less than the conventional one, for the exterior cladding difference is 19.40 $kgCO_2/m^2$, and for thermal insulation, the difference is 42.48 $kgCO_2/m^2$ ***[1].***

Energy efficiency

Several studies show that the ventilated façade can bring different benefits, the most important of them is the reduction of the energy building performance.

Case study: the comparison between an opaque ventilated (OVF) and an unventilated façade (UF) located in Catania (Italy, csa zone), using fluid-dynamic simulations. The unventilated element is made up of inner plaster, brick wall, cement mortar, insulation of rock wool. Conversely, the OVF is like the conventional one, with the addition of an air cavity, a layer of brick slabs and two openings placed at the bottom and the top of the facade to improve the chimney effect. The aim is to calculate the energy saving for different façades in different conditions.The results show that during the winter season the energy-saving (ES) achievable by the OVF is up to 20.0 for East /West façade under windy conditions, and up to 50.0% for the South façade under calm wind conditions. The situation changes in the summer season. The ES achieved by OVF is in the range from 40.0% to 50.0%, depending on the orienta***tion*** of the façade and the wind conditions ***[2].***

References

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Ventilated facade : best practice

Project name

Humanitas University
Campus

Climate zone

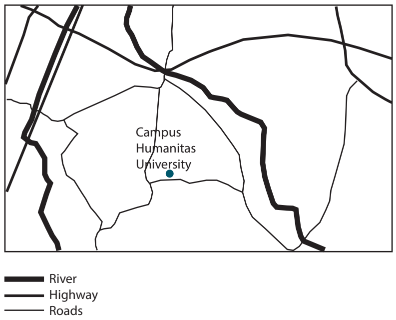
Cfb - Subtropical highland
climate

Construction year

2017

Location

Pieve Emanuele, Lombardia , Italy



Integrated system

Geothermal pump,
Solar thermal and
Photovoltaic panels

Certification

Class A2

GHG emissions

23,09 $KgCO_2/m^2$/year

Primary energy

103,95 $kWhpe/m^2$/year

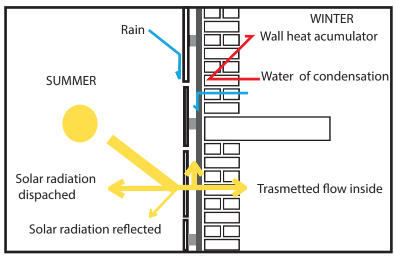
Sustainability

To pursue the sustainable goals some precautions have been adopted such as the installation of low energy LED lighting, photovoltaic and solar thermal panels in roof, shading system as venetian blind and brisee-soleil for internal shading, glazed façade with thermal cutout to improve energy efficiency, and natural lighting guaranteed by the right exposure and orientation of the building.

How it works

the air cavity in between the exterior cladding and the wall allows the air convective movement. This phenomenon is based on the difference between the internal and external temperature, therefore is a function of context, orientation, geometry, and exposure. The convective movement characterised the efficiency of the ventilated façade. It's show that in summertime the increasing of the temperature in the cavity generates a "chimney effect" that pushes the air upwards, thus reducing the wall's temperature facing the inside of the building.

During wintertime, the openings balance the wall's temperature and reduce the risk of moisture from condensation.



Description

The Campus Humanitas University is the new international university of medicine in Rozzano (Mi). The project is designed for 1000 students and consists of four buildings that will host teaching activities, a research unit, a multifunctional hub with a canteen and a library, and a student residence. The main buildings of the campus - didactics, hubs and research – are covered by a ventilated façade made up of stone panels fixed to the wall with punctual aluminium couplings. This kind of anchorage allows the panels to be detached from the main wall and create the air cavity. The new skin has been planned to ensure a proper insulation in terms of energy efficiency and protection against atmospheric agents. The local material used for finishes allows to the building to be able to save the part of the costs for transportation, as well as to ensure a direct relationship between the manufacturer and the supplier.

Source: https://www.construction21.org/case-studies/it/humanitas-university-campus-en.html | Photo credit: -

Double Skin

BIT

The double skin façade system typically is composed by two layers (typically glass) that allows airflow through the in-between space of 20 cm to 2 m. This layer increases thermal insulation, thermal efficiency and at the same time, reduces winds and sound. If the double-skin facade could be used an active way or as a passive system. A double-skin facade is a complex concept, commonly classified according to three parameters: type of ventilation, geometry of the cavity, and airflow path inside the cavity. Regarding geometry, double-skin facades can be divided into four distinct groups: box-window, shaft-box and multi-storey double-skin façade.

Challenges

Energy sustainability
Temperature regulation
Water management
Health and wellbeing

Objectives

Energy demand
Carbon impact
Energy produced from RES
Local microclimate
UHI
Run off mitigation
Water scarsity
Water quality
Comfort and life quality
Urban space quality

Performances

Energy from RES on site
Low carbon material use
Greening
Energy efficiency
Temperature surface/air
Outdoor thermal comfort
Shadow effect
Water retention
Water storage and reuse
Water treatment
Green space
Space for socialization
Air quality
Walkability

Other benefits

Indoor thermal comfort
Flexibility
Noise pollution
Cooling effects
Thermal insulation
Longer lifespan

Regulations & Standards

-

Strategies

M A

Scale of application

Building
Neighborhood
City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.0 S -

Disadvantages

Overheating issues
More weight to the structure

Energy consumption

Low carbon material use

Improvements to the façade, using the double skin façade, is one of the most effective strategies to reduce carbon footprint.

Case study: an office building type located in London (England), composed of nine floors, 9,590 m^2 and naturally ventilated, was adopted. The purpose of the study is to make a comparison between SSF (single skin façade) and the DSF (double skin façade) and to underline that the DSF can outweigh the GHG impacts. The results show that the best configuration made with a narrow cavity could save up to more than 2,500 of kg CO_2-eq over the service life, against the 1,000 of kg CO_2-eq saved using SSF. Pomponi et al. show that 67% of UK offices could be refurbished using DSF, therefore over 17 million MWh and 3.5 Mt CO_2-eq could be saved ***[1].***

Energy efficiency

It's known that a double skin façade could be used as a passive system to improve building energy efficiency and indoor thermal comfort.

Case study: a simplified double skin facade model located in central Spain was used for the study. The model is characterised by a double skin facade facing south of 3 m high and 6 m wide, and the air cavity that is extended the whole height of the model. Eight different cases were simulated with 29 facade configurations studied in different conditions as summer, winter, with cavity opened or closed, considering solar radiation or not, which is a total of 116 cases. The results show that in the winter scenario, the energy saving with solar radiation and vents closed, is 75,1% against the 52,3 % without solar radiation. In the summer scenario, the energy saving with solar radiation and vents opened is 4,0% against the 44,3 % without solar radiation and vents closed ***[2].***

References

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Double Skin: best practice

Project name

Renovation of the school gym – middle school "DANTE ALIGHIERI"

Climate zone

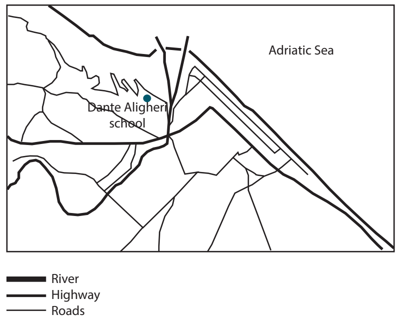
Csa - Hot-summer Mediterranean climate

Construction year

2010

Location

Gattoni, Marche, Italy

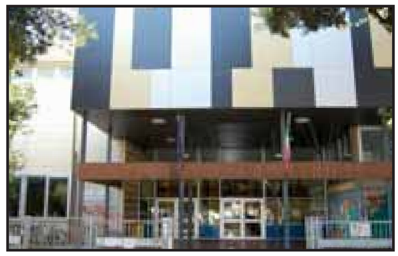


Integrated system

Solar panel
Photovoltaic panels

Certification

Class A +



GHG in use

7,00 $KgCO_2/m^2$/year

Primary energy

22,00 $kWhpe/m^2$/year

GHG Cradle to Grave

8,55 $KgCO_2/m^2$

Renewable energy

59,67 %

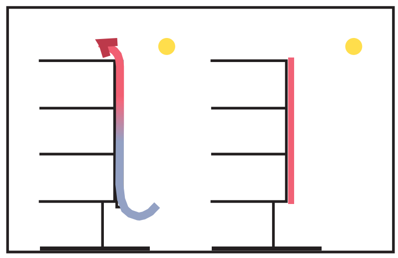
Sustainability

The method of dry construction and use of natural materials make the building more sustainable, and they allow to create a healthy space in which to live. In addition, the use of some materials as the rock wool of different densities, the ventilated wall panels and fibre cement allow to isolate the envelope and to save energy for heating during winter, and for cooling during the summer.

How it works

The double skin façade is usually made by a high resistance laminated glass, which usually covers the entire building and supported by metal brackets, it is connected to the building structure. The outer layer has a high incident solar radiation index that allows the glass temperature to increase and air heats up within the confined cavity due to the convective heat exchanges.

Due to the stack effect, the warm air becomes less dense and rises through the facade. The action of the wind on the building could create positive pressure at the bottom and negative pressure at the top outlet of the façade. This phenomenon depends on the geometry of the façade and on the location of the openings.



Description

The school "Dante Alighieri" has an area of 4.200 mq and it is divided into three volumes, the school for 560 pupils, the gym and the auditorium. The 60's building is characterised by the skeleton of a steel frame, and by heavy concrete panels as a sandwich. In 2010, some interventions were adopted to make suitable for seismic regulations and to provide an envelope that could reduce energy consumption in terms of heating and cooling demand. Practically, control of heat loss, ventilation control, noise control, comfort indoor and a shell of double skin façade panels are the most important strategies used. The shell is made of fibre cement panels that, during manufacturing, receives a unique surface treatment which makes them waterproof and resistant. The panels are characterised by slight colour variations that make the building more attractive. In addition, attention was paid not only on the finishes, but also on orientation, temperature, damp, direction of the dominant winds, summer sea breezes to make the building more efficient.

Source: https://www.construction21.org/case-studies/h/renovation-of-the-school-gym-middle-school-dante-alighieri.html | Photo credit: -

BIT

Natural ventilation

Natural ventilation is a passive strategy that utilises the natural power of wind to enter fresh air and spread it in buildings. It works using the pressure difference among rooms or between inside and outside, therefore it doesn't require energy. Typically, the occupants open windows and allow the entering or leaving of the air. According to the opening's orientation, the "chimney effect" could be generated. There are basically two kinds of natural ventilation: the first is wind-based ventilation, and the second is stack-effect. Nevertheless, the choice of ventilation system depends on several parameters such as geometry, orientation, exposure.

Challenges	*Objectives*	*Performances*
Energy sustainability	Energy demand; Carbon impact; Energy produced from RES	Energy from RES on site; Low carbon material use; Greening; Energy efficiency
Temperature regulation	Local microclimate; UHI	Temperature surface/air; Outdoor thermal comfort; Shadow effect
Water management	Run off mitigation; Water scarsity; Water quality	Water retention; Water storage and reuse; Water treatment
Health and wellbeing	Comfort and life quality; Urban space quality	Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort · Mold · Cooling costs · Flexibility · Noise pollution · Daylight

Regulations & Standards

EN 15242, ISO 12569 and EN 15251

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 13.0
S 7.1 7.a

Disadvantages

Weather dependent
Hard to control

Energy consumption

Low carbon material use

It is known that Natural Ventilation Systems (NVS) is one of the passive strategies to save up to 50% in CO_2 emissions, depending on the heating fuel used and the zone where the building is located.

Case study: a comparison between the school building models A.1 and B.1, in Andalusian region (Spain, different zones). The A.1 model is characterised by NVS with stacks and air admission on façade; an opposite case is represented by the B.1 model characterised by a mechanical ventilation system. The purpose of this study is to compare the CO_2 emission of NVS which has cross ventilation, stacks and automatic ventilation with MVS. The results show that, depending on the zone, MVS can produce more than a maximum of 49,80% of CO_2 emission in C4 zone (Jaen, Spain) zone to a minimum of 31,18% in A4 (Almeira, Spain), compared to the natural ventilation system. According to these results, the 5000 schools of Andalusia could reduce their emission by about 46,500 tons of CO_2 with the application of NVS. ***[1].*** Another interesting case ***[2].***

Energy efficiency

Several studies show that the natural ventilation system can improve up to 9.7% the building energy efficiency compared to a building without this kind of system.

Case study: a typical one-floor modular familiar dwelling located in the Polytechnic University of Valencia (Spain, Bsk zone). The building is composed of three rooms, a pergola at the entry and shadows in the windows. Three cases A, B, C are compared to determine the architectural solution that best improves the NV behaviour in the building. Case A has no lateral window, case B has right window in the east face and case C has left window in the east face. The results show that the best case that reduces up to 1.13 kWh/m^2 the energy consumption is the Case C. In addition, the global energy behaviour is approximately improved by 4.12% ***[2].*** Another interesting case ***[3].***

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[3] Babak Raji, Martin J. Tenpierik, Regina Bokel & Andy van den Dobbelsteen, ***Natural summer ventilation strategies for energy-saving in high-rise buildings: a case study in the Netherlands,*** International Journal of Ventilation, 19:1, 25-48, ***https://doi.org/10.1080/14733315.2018.1524210***

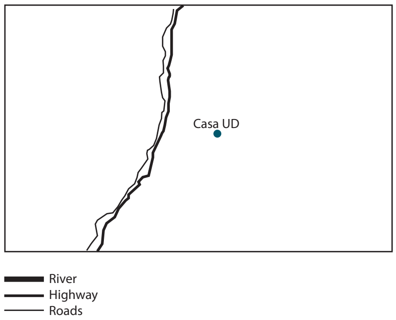
Natural ventilation: best practice

Project name

Casa UD

Climate zone

H - Highland Climate
(mountainous terrain)



Construction year

2017

Location

Chamois, Valle d'Aosta, Italy

Integrated system

Solar photovoltaic

Primary energy

11.74 kWhpe/m^2/y

Health & Comfort

The usage of natural ventilation systems allow the temperature and humidity to remain constant even with significant climatic variations on the outside. It improves the quality of the user's life.

Environmental Quality

- indoor air quality and health
- comfort (visual, thermal, acoustics)
- energy efficiency
- renewable energies
- integration in the land

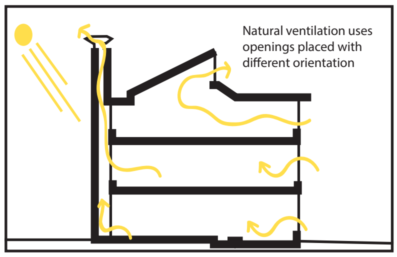
Sustainability

The right position of the openings allows the correct crossed air flow and the complete exchanging of air. The building is made sustainable using exclusively eco-design materials that don't contain toxic substances. The natural materials used, for example, are recycled cellular glass plates and sheep's wool for insulation, raw earth for plaster, stone for external covering, and so on.

How it works

Natural ventilation system is a highly effective, user-friendly, and passive way to make the house cooler without using energy. Each designer should combine the aesthetic feature of the window with its function. If the combinations of openings are accurately studied, the natural ventilation can change the entire volume of air, to remove each kind of odours, to allow a breeze to come through while removing the warm air.

In other words, it's an effective way to cool down a house during summertime. To improve this system it's necessary to introduce different openings in size and position along different façade.



Description

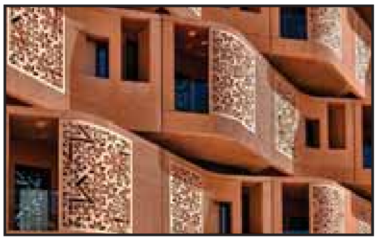
Casa UD is an almost zero-energy house built on the remains of an old dry-stone cottage of 1834. Due to the impossibility to easily reach the site, the load-bearing structure of the roof, walls and floors in prefabricated wood frame were assembled in 4 days using a helicopter. The house is composed of a kitchen, dining area and relax on the ground floor, the master bedroom and bathroom on the first floor and two bedrooms with mezzanine at the last. The entire house is developed on three floors. The innovative aspects of the project are basically the construction technique and the usage of local materials that reduced to a minimum the environmental impact, and the absence of the heating system. The presence of big glazed- windows along the south façade, combined with some different small openings on the East and West façade, ensure the passive contribution of the sun, ventilation, and natural lighting.

Source: https://www.construction21.org/case-studies/it/casa-ud-en.html | Photo credit: -

BIT

Nigth cooling

Night cooling, known also as night-purge ventilation or night flushing, is a passive technique that uses the building's thermal mass as a sink during the day as it absorbs heat gains from occupants and the sun. When evening temperatures drop, the building envelope is opened, allowing cool air to enter the building and dissipate the stored heat via convection. Night cooling can be used in a natural, mechanical, or mixed-mode ventilation approach. All approaches offer the potential to improve the internal condition and to avoid the overcooling and subsequent re-heating or thermal discomfort the following day.



Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Easy to repair · Cooling costs · Weather protection · Daylight · Mold and condensation

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P -

S 11.0
13.0

Disadvantages

Noise pollution
Air pollution

Energy consumption

Low carbon material use

Several studies show that the well-designed night cooling strategy could extremely decrease the carbon footprint. To follow this purpose, it's necessary to study accurately the orientation, the geometry, the position of windows and the climate zone.

Case study: newly built FOS/BOS school building in Erding (Germany), was adopted. It is composed of three blocks, the four-storey north building and three-storey south building connected with a fully glazed atrium that hosts various spaces including a lecture room, offices, IT room, laboratory, storeroom, toilet, common room, kitchen, etc. It was designed for 750 students according to Passive House standards. The results show that using night cooling the energy used for cooling is extremely reduced. The CO_2 equivalent emission was estimated for the energy consumption of the heating system and the electricity use. The results show that the CO_2 equivalent emission is 88.1 t/a, which is about one-third of the CO_2 emitted by standard school (281 t/a) ***[1].***

Energy efficiency

It's shown that the combination between natural or mechanical ventilation with thermal inertia, the energy consumption decreases drastically. Some other important parameters that influence the performances are geometry, windows ratio, orientation, climate zone and materials used.

Case study: An isolated office building with dimensions 16 m x 24 m x 18 m located in Bergamo (Italy), was adopted. It is composed of six floors; each floor is composed of twelve office rooms aligned on the northern and southern sides of the building. To achieve cross-ventilation, operable bottom-hung openings are added. The building is characterised by the presence of shading devices, by high thermal inertia and other setpoint parameters as Cp (pressure coefficient), ACHN, etc. The simulation in Energy Plus shows that for the Bergamo case, the energy saving (ES) is lower from 33.7% to 32.0% when the exposed thermal mass has a lower thermal inertia, since the heat stored in the thermal mass is reduced. Clearly for a given value of ACHN, the lower the night-averaged outdoor temperature the higher are the energy savings ***[2]***. Another interesting case is ***[3].***

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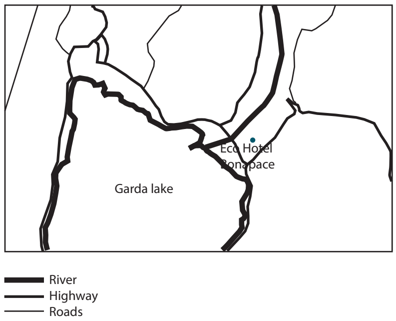
Night cooling: best practice



Project name

EcoHotel Bonapace

Climate zone

Cfb - Subtropical highland climate

Construction year

2012

Location

Nago Torbole ,Trento, Trentino, Italy

Integrated system

Geothermal system
Solar panels
Photovoltaic panels

Certification

CasaClima Climahotel Oro
Passivhaus
Arca Platinum

Health & Comfort

The building is equipped with a basic demotic system that controls the ventilation / heating or cooling systems/ external shading devices.

Energy consumption

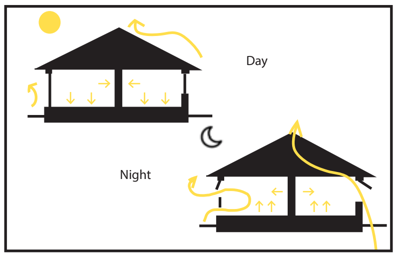
12 kWh/m^2 year,
7,42 kWh/m^2 year for heating system

Sustainability

The building is made of a new material developed in Trentino region made of cross-laminated wood panels with outstanding structural features (earthquake response, lightness, fireproofing resistance, etc.). The wood used respects the PEFC standard. The structure is covered externally by thick insulation layers made of recycled material. In addition, all the internal and external plaster-covers are made of natural components. Finally, the building is characterised by the green roof that helps to reduce the UHI effect.

How it works

During the day, the building is closed to prevent warm outside air from entering. The cool mass absorbs heat from occupants and other internal loads. Throughout the night, using pathways for wind ventilation, the thermal mass cools down. Using natural ventilation for the cooling also requires a relatively unobstructed interior to promote air flow. Because the "coolth" of night-purge ventilation is stored in thermal mass, it requires a building with large areas of exposed internal thermal mass. This means not obscuring floors with carpets and coverings, walls with cupboards and panels, or ceilings with acoustic tiles and drop-panels. The night purge is one of the cheaper and most efficient strategy, but this system has some limitations due to climate, security concerns, and usability factors.



Description

The Ecohotel Bonapace is a three-story building located 1 km far from Garda Lake, in northern Italy. To optimise the ratio between internal and external surface and the heating/cooling losses, the footprint shape is squared. The building is composed by a not heated reinforced concrete basement and three storeys in solid wood X-LAM panels. These floors contain the reception, bar and some other functions on the ground floor, the twenty rooms are spread on the other two floors. The roof contains the solarium zone, photovoltaic and thermal panels and the thermal power plant which contains the ventilation systems with heat recovery. The building is equipped with summer-winter air conditioning, great openings accurate designed for adequately ventilation and daylight. All the windows are made of triple glass with a U value of 0.703 and protected by shading devices. These elements allow the use of the night cooling approach, in order to improve the indoor thermal comfort and reduce the carbon footprint and energy consumption.
Source: https://passivhausitalia.com, https://www.politesi.polimi.it/bitstream/10589/109230/1/nearly%20Zero-Energy%20Buildings%20(nZEBs).pdf, | Photo credit: -

ES

BIPV / BAPV

The BIPV system (Building Integrated Photovoltaics) is one of the viable technologies to improve building energy performance and to reduce environmental effects by on-site electricity generation with solar energy. This system is composed of photovoltaic cells that are capable of being integrated into the building skins such as roof or façade. There are two basic commercial PV module technologies available on the market today: thick crystal products, as crystalline silicon-based (c-Si); and thin-film products, as amorphous-based silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS).

Challenges

Objectives

Performances

Energy sustainability

- Objectives: Energy demand; Carbon impact; Energy produced from RES
- Performances: Energy from RES on site; Low carbon material use; Greening; Energy efficiency

Temperature regulation

- Objectives: Local microclimate; UHI
- Performances: Temperature surface/air; Outdoor thermal comfort; Shadow effect

Water management

- Objectives: Run off mitigation; Water scarsity; Water quality
- Performances: Water retention; Water storage and reuse; Water treatment

Health and wellbeing

- Objectives: Comfort and life quality; Urban space quality
- Performances: Green space; Space for socialization; Air quality; Walkability

Other benefits

Reuse; Thermal insulation; Flexibility; Noise pollution; Safety; Weather protection

Regulations & Standards

EN 50583-1, UNI 8290-1/2

Strategies

M A

Scale of application

Building; Neighborhood; City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 12.0, 13.0
S 11.0

Disadvantages

Slow development
Weather dependent

Energy consumption

Energy from RES in site

The retrofit with BIPV represents an opportunity for improving both the energy efficiency by producing energy on site, and the architectural view. *Case study*: a building of a social house district in Catania (Italy, Csa zone) designed by K. Tange in the 1970s and realised by IACP. To approach a NZEB, some retrofit strategies were adopted s. Three kinds of PV panels as Monocrystalline Silicon (c-Si), Copper indium gallium selenide (CGIS) and Amorphous Silicon (a-Si) were tested virtually in three different locations (Catania, Milano and Roma). The results suggest that the best solution is c-Si modules with an average annual energy efficiency in between 12.5% and 13.5%, cover surface of 55% and annual electricity consumption of 3250 kWh, where the cooling demand is predominant ***[1].***

Low carbon material use

The BIPV system is composed of a significant technical component that is responsible for the strong impact on the CO_2 emissions.
Case study: BIPV installation in a car shelter and in a skylight with a total capacity of 20 kW, were installed at Patras Science Park, in Peloponnese (Greece, csa zone).The system includes skylights and a car shelter consisting of 22 and 66 panels, respectively. The poly-crystalline technology is encapsulated in the frameless PV with a surface of 2.22 m and weighting 44.4 kg. The purpose is to quantify and analyse the environmental impacts using the LCA (cradle-to-grave) method. The results show that the BIPV system consumes 6.46 g CO_2 per kWh for carbon cycle emissions ***[2].***

Energy efficiency

It's notable that an integrated photovoltaic panel on the façade is essential to reduce energy consumption and provide indoor thermal comfort.
Case study: a typical residential building of the 70's located in Neuchâtel (Switzerland), is composed of eleven-stories, 52 apartments and 5,263 m^2 of living floor area. Three strategies were adopted: ''Conservation" (S1), ''Renovation" (S2), and ''Transformation" (S3). For all scenarios monocrystalline (sc-Si) technology of cells with an efficiency of 14% have been used. The target for the housing is 38 kWh/m^2/year. This value is achieved by all scenarios, corresponding to a 53% saving on the heating demand. It means that the strategies produce respectively 75 (S1), 128 (S2) and 174 (S3) MWh/year ***[3].*** Another interesting case ***[4].***

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BIPV/BAPV: best practice

Project name

Smart Lab

Climate zone

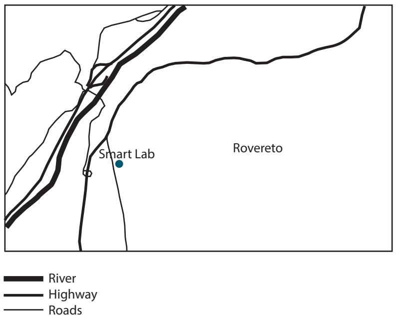
Cfb - Subtropical highland climate

Construction year

2013

Location

Rovereto Trentino, Italy



Integrated system

Thermal insulation

Certification

LEED Silver

Health & Comfort

The usage of BIPV as "solar shade" or combined with a ventilated façade prevents overheating in summer and heating in winter, greatly improving the quality of users' life.

Energy consumption

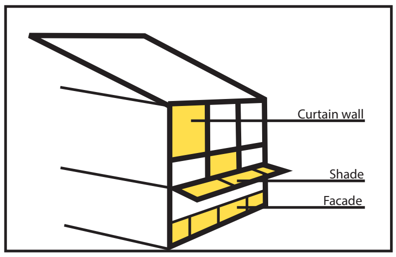
9,072 kWh per year

Sustainability

It was estimated that the BIPV system can provide more than 30% of the building's electricity demand and can guarantee an effective thermal insulation. This system combined with the usage of recycled materials, the high quality of the technical-constructive strategies, are some of the measures adopted in Smart Lab with the prospect of green building and energy efficiency.

How it works

Basically, they work as the PV panels but the photovoltaic could be integrated on the façade as shade, on the balcony, as curtain wall or as a wall. The BIPV system typically is composed by several components as PV modules, a charge controller to regulate the power into and out of the battery storage, and a power storage system that transform the utility grid in utility-interactive systems or, several batteries in stand-alone systems. In addition, the power conversion equipment is installed, and it include an inverter to convert the PV modules' DC output to AC compatible with the utility grid, a backup power supplies, and appropriate support and mounting hardware, wiring, and safety disconnects. It's necessary to highlight that panels efficiency decreases with the increase of transparency. The transparency male the PV not able to capture and convert sunlight into electricity.



Description

The Smart Lab is a sociocultural meeting place for young people and associations managed by Cooperativa Sociale Smart Onlus. It is composed of two floors; on the ground floor there is a coworking space and a conference room; on the first floor there is a chillout corner, bookcrossing, internet point, etc. The façade has a strong visual impact that increases the architectural value of a building and its bearing structure is composed of metal uprights and crosspieces hiding the junction boxes and the cabling system. It is characterised by the BIPV plant that consists of 90 thin-film photovoltaic modules ProSol TF+ integrated to a ventilated façade system on the south facade of Smart Lab. The modules compose a semi-transparent layer made of micro-amorphous silicon cells, able to control the solar gain and to create an eco-friendly and aesthetically appealing surface, hiding the existing facade made of glazed and opaque.

Source: L. Maturi and J. Adami, Building Integrated Photovoltaic (BIPV) in trentino Alto Adige, Springer Nature, Switzerland 2018. |
Photo credit: -

ES

Solar panels

Building integrated solar thermal collectors (BIST) convert the sun's rays into thermal energy, in which the heat is conveyed into the air, liquid, or both. These kinds of systems are mainly used to produce low-temperature heat, for sanitary hot water and space heating support. The main feature is the total integration of the panels into the façade, playing a double role: aesthetic and functional. It fits easily into the architectural design framework and guarantees a high degree of design freedom and realisation optimization compared to conventional, off-the-shelf panels. It's possible because of the wide range of flexible size and height ratios.

Challenges — *Objectives* — *Performances*

Challenges	*Objectives*	*Performances*
Energy sustainability	Energy demand; Carbon impact; Energy produced from RES	Energy from RES on site; Low carbon material use; Greening; Energy efficiency
Temperature regulation	Local microclimate; UHI	Temperature surface/air; Outdoor thermal comfort; Shadow effect
Water management	Run off mitigation; Water scarsity; Water quality	Water retention; Water storage and reuse; Water treatment
Health and wellbeing	Comfort and life quality; Urban space quality	Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort; Flexibility; Thermal insulation; Daylighting; Privacy; Noise pollution

Regulations & Standards

EN 50583-1 and UNI 8290-1/2

Strategies

M A

Scale of application

Building; Neighborhood; City

Space usage

Monofunctional
Multifunctional

S.D.G.

P: 12.0, 13.0
S: 11.0, -

Disadvantages

Slow development
Weather dependent

Energy consumption

Energy from RES on site

Several studies show that the solar panels can produce energy and satisfy the DHW demand, according to the location, geometry, materials used and climatic zone.

Case study: typical multi-storey building located in Cagliari (Italy, zone), was adopted. It is made up of five floors, balconies, and opaque walls. Using software simulation, the solar radiation was investigated. Consequently, 22 flat plate collectors on the south facade and 22 evacuated-tube solar collectors as active shading elements on the East-West facade, were placed. The results show that the panels could produce 100% of energy when the system is used for DHW only, and more than 60% when it is used also for space heating ***[1].***

Low carbon material use

The architectural integration of the solar system could increase the carbon footprint, accordinf to the geometry, the climate zone and typology of materials used.

Case study : the analysis of simulations of olar thermal façade (BSTF) in an Italian residential unit was illustrated. The unit is characterised by an area of 40m^2, facing south, daily DHW consumption equal to 200l/day. It was constructed with two distinct typologies of solar collectors, in the first they consist of a flat plate model (FPC), while in the second configuration they are an evacuated tube model (ETC). The results show that comparing the two systems,the value of greenhouse gases emitted during the production is equal to 1074 Kg CO_2 eq for the FPC and equal to 917 Kg CO_2 eq for the ETC system ***[2].***

Energy efficiency

Several studies show that the solar collector is one of the most effective strategies to save energy. Their production depends mostly on the climate zone and the orientation, and the materials used.

Case study : the analysis of air-based Flat-Plate solar thermal Collector (FPC) prototype for an office-use space, was discussed. It is made up of an air channel, a back plate in aluminium sheet, and a steel absorber plate covered by black varnish. The results show that, in terms of energy savings, the highest energy saving is obtained in Naples with 9.1 MWh/y for the S-E oriented BISTS façade. Conversely, the lowest value is achieved by Freiburg with 4.5 MWh/y. In addition, considering the passive effects only, maximum savings equal to 7.5, 5.5 and 4.0 kWh/m^2/y are achieved in Freiburg, Naples and Almeria, respectively ***[3].***

References

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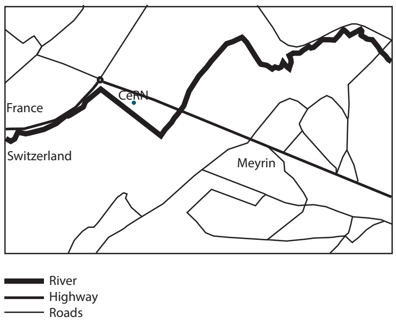
[3] R. Agathokleous, G. Barone, A. Buonomano , C. Forzano, S.A. Kalogirou, A. Palombo, ***Building façade integrated solar thermal collectors for air heating: experimentation, modelling and applications,*** Applied Energy 239 (1 April 2019) Pages 658-679***, https://doi.org/10.1016/j.apenergy.2019.01.020***

Solar panels: best practice



Project name

CeRN building

Climate zone

Cfb - Subtropical highland climate

Construction year

2007

Location

Bursins, Ginevra, Switzerland

Integrated system

Roof solar collectors

Certification

Minergie eco building

Health & Comfort

The volumetry as well as the orientation of the openings reflects the specificities of this site and they can capture natural light and allow a correct natural ventilation to improve the quality of user's life.

Energy consumption

11 MJ/m²/y
Solar energy covers 40% of the heating demand

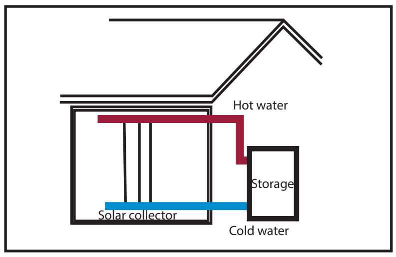
Sustainability

The eco-friendly building is characterised by the of minimum grey energy content, the orientation and design of the building allows a good passive solar gain and natural lighting. In addition, the choice of materials aims to minimize environmental impacts, to use local resources and to limit transport and embodied energy. The main used materials are wood and concrete.

How it works

Typically, the system is composed by the collectors that capture the sun's energy by heating a fluid contained within reinforced glass pipes. The pump and controller ensure the transfer fluid is circulated between the collectors and the water cylinder efficiently. A system control panel regulates the pump, providing information on the system's performance and highlighting any issues.

The heat captured by the solar thermal collectors is pumped to a coil in the water cylinder. A solar thermal water cylinder has a dedicated coil that allows the heat from the collectors to be transferred as efficiently as possible.



Description

The competition organised between 1999-2000, have been won by a studio based in Lausanne. This office presented a project that can combine the sustainable development with particular sensitivity and strong technical interests. From the combination of socio-cultural issues related to the insertion of the building in the site and its operation for users, environmental aspects and economic constraints, the project has been realised. The CeRN building includes garages for vehicles, large storage spaces, technical rooms, as well as administrative premises. It's characterized by the south façade covered by thermal solar collectors for a solar façade surface of 590 m², solar fraction of 97%, energy output of 288000 kWh/year obtained using 236x86x0.5 cm modules. In addition, a wood fired boiler installation covers heat needs from November to March, while solar thermal is sufficient to cover those for the rest of the year. The panels covered with a selective coating, can be installed without glass cover. The solar radiance reaches the absorber surface without being absorbed or reflected by a glass, therefore the effect of slope and azimuth are minimised.
Source: https://www.osti.gov/etdeweb/servlets/purl/20948273#page=389, | Photo credit: -

SOLUTIONS
ADD-ON

Productive façade system

Productive facades (PFs), as flexible and multi-functional systems integrating photovoltaic (PV) and vertical farming (VF) systems, could contribute to transforming buildings and communities from consumers to producers. The positive aspect of this solution is that it can benefit from all the advantages of the PV system and vertical farming system at the same time.

Challenges	Objectives	Performances
Energy sustainability	Energy demand; Carbon impact; Energy produced from RES	Energy from RES on site; Low carbon material use; Greening; Energy efficiency
Temperature regulation	Local microclimate; UHI	Temperature surface/air; Outdoor thermal comfort; Shadow effect
Water management	Run off mitigation; Water scarsity; Water quality	Water retention; Water storage and reuse; Water treatment
Health and wellbeing	Comfort and life quality; Urban space quality	Green space; Space for socialization; Air quality; Walkability

Other benefits

Food production · Security/Safety · Reduce Heat gain · Flexibility · Indoor thermal and visual comfort · Biodiversity

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 2.0 12.0 · S 13.0 15.0

Disadvantages

High maintenance costs
Suitable only in some place and for some plants

Energy consumption

Energy Sustainability RES on site

Productive façade system is one of the most complex solutions that can improve food production and energy efficiency. This capability mostly depends on the façade orientation, the quantity, typology and surface of modules installed.
Case study: an existing HDB public housing building in Singapore (Af zone) was considered.
Some façade arrangements for Window Facades (WF) and Balcony Facades (BF) were adopted. The PV cells of 2.8 m high, 1.8 m wide and 1.8 m deep were combined with different plants, to create four different scenarios. The results show that for a typical 4-room HDB unit with total façade dimension of 20 m in length, the total electricity generated by the shading PV modules could be as high as 1860 kWh (40% of the average annual electricity consumption). The electricity generated by the PV shading device represents between 40% (SBF) and 46% (SWF and EBF) of the electricity generated by the same PV module type and surface located on a rooftop without obstruction ***[1].***

Greening

Productive façade system is one of the most complex solutions that can improve the energy efficiency and can improve the food production. This capability mostly depends on the façade orientation and the type of crops.
Case study: an existing HDB public housing buildings in Singapore (Af zone), was considered.
Some façade arrangements for WF and BF were adopted. The PV cells of 2.8 m high, 1.8 m wide and 1.8 m deep were combined with different plants, to create four different scenarios. The results show that a façade of 20 m could enable each household to produce an estimated 35 to 66 kg of leafy vegetables. The number of products represents 55–103% of the average leafy vegetable's consumption of a 4-member household in Singapore (ca. 16 kg per year) ***[1].***

Temperature regulation

Temperature surface/air

Productive facades are optimised for food production and electricity generation. Moreover, similarly to green walls, they have several environmental benefits such as reducing external surface temperature and air temperature ***[2]***. However, specific tests in this regard have not been conducted yet.

References

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[2] Tablada, Abel, and Vesna Kosorić. ***"Vertical farming on facades: transforming building skins for urban food security."*** Rethinking Building Skins. Woodhead Publishing, 2022. 285-311.

[3] Ling, Tzen-Ying, and Yi-Chang Chiang. ***"Well-being, health and urban coherence-advancing vertical greening approach toward resilience: A design practice consideration."*** Journal of cleaner production 182 (2018): 187-197.

Water management

Water storage and reuse

The productive facades are integrated with rainwater collection systems ensuring self-sufficiency. For example, the prototype developed by Tablada et al. (2022) collects, filters and stores rainwater from the roof and from the surroundings. The irrigation of the crops uses the electricity produced by the PV modules ***[2].***

Health and wellbeing

Green space

Productive facades are experimentations to answer questions about food and energy production in densely urbanised areas. The practice of self-food production has positive effects and inhabitants' health and wellbeing, and improves their quality of life ***[3]***. Moreover, the system is developed to improve public awareness and acceptance towards the use of Renewable Energy Sources in the facades.

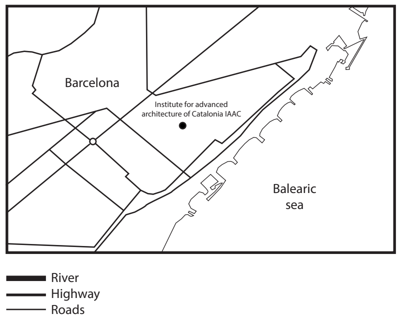
Productive façade system: best practice

Project name

3D printed ceramic green wall

Climate zone

Csa - Hot-summer Mediterranean climate



Construction year

2018

Location

Prototype developed at Institute for advanced architecture of Catalonia IAAC, Barcelona, Spain

Responsive design

Computational design softwares were used to optimise topological variability of the pots for the growth of the plant species and to generate energy, through the parameters of height and opening angle. The system also needs to be adapted to the local conditions and to the plants used in terms of light and wind. Moreover, extreme heat, humidity and rain can affect the health of the plants and the biophotovoltaic system.

Pysical interface

The wall provides real-time information on energy generation through an immersive visualisation tool.

Applications

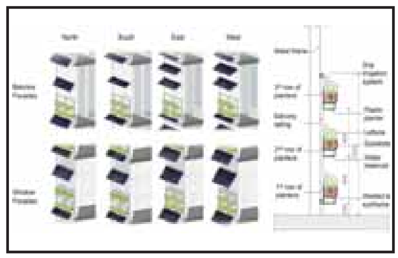
The system can be implemented in public spaces, building skins, building rooftops and interior of buildings.

Energy system

The system is self-sufficient and activates the irrigation system and the sensors.

How it works

The productive facade systems have been developed by Tablada et al. (2018) through a prototype built at the National University of Singapore. The system integrates PV modules as shading devices and vertical farming on balconies. Applied to existing walls, the system produces energy and food for the inhabitants, as well as indoor visual and thermal comfort. Other applications combining food and energy production are currently under development, such as the 3d printed ceramic walls.



Description

The 3D printed ceramic green wall is a prototype developed at the Institute for advanced architecture of catalonia IAAC. The wall system relies on a biophotovoltaic system (PBV) using the natural process of photosynthesis to produce energy. Through the energy from light, the plants consume carbon dioxide and water, and convert it into organic compounds. The latter contains bacteria releasing byproducts with electrons which can be collected as electricity using an electrode. The collection system was developed by Wey et al. (2015) at Cambridge. The types of plants used in the Barcelona prototype are native edible plants common in the Mediterranean climates for outdoor, and tropical low maintenance plants for indoor. The clay for the wall system was in stoneware which is suitable for printability, robust and absorbs low levels of water. Geometry and patterns were studied to optimise production, increase resistance and a good balance between stability and weight. The system has been standardised to allow installation into a secondary support structure and easy maintenance.

Source: http://papers.cumincad.org/data/works/att/ecaade2020_456.pdf; https://iaac.net/project/cgv-cyber-green-voltaics/; https://iaac.net/iaac-at-the-smart-city-expo-world-congress/, | Photo credit: IAAC

UGI

Vertical farm

Vertical farming consists in a system of productive vegetation. It system often incorporates controlled-environment agriculture to optimize plant growth, and soilless farming techniques such as hydroponics, aquaponics, and aeroponics. The main advantages of this system are the minimal land use and the improvement of local flora and fauna. The key role is played by the site because the treatment system applied requires access to water, access to housing within the city to minimize the distance between staff and visitors, and a complex pipeline system. For these reasons, house vertical farming systems include buildings, containers, tunnels, etc.

Challenges / *Objectives* / *Performances*

Energy sustainability
- Objectives: Energy demand; Carbon impact; Energy produced from RES
- Performances: Energy from RES on site; Low carbon material use; Greening; Energy efficiency

Temperature regulation
- Objectives: Local microclimate; UHI
- Performances: Temperature surface/air; Outdoor thermal comfort; Shadow effect

Water management
- Objectives: Run off mitigation; Water scarsity; Water quality
- Performances: Water retention; Water storage and reuse; Water treatment

Health and wellbeing
- Objectives: Comfort and life quality; Urban space quality
- Performances: Green space; Space for socialization; Air quality; Walkability

Other benefits

Indoor thermal comfort; Flexibility; Cooling effects; Food production; Privacy; Daylight

Regulations & Standards

-

Strategies

(M) (A)

Scale of application

Building; Neighborhood; City

Space usage

Monofunctional
Multifunctional

S.D.G.

(P) 2.0 - 3.0; 11.0 - 12.0
(S) 13.0; 15.0

Disadvantages

Suitable only in some place
Suitable only for some kind of plants

Energy consumption

Low carbon material use

Several studies show that building integrated agriculture could be adopted to reduce the CO_2 emission. This solution allows to reduce the impact of transportation, energy, and water use.

Case study: the simulation of three different building-integrated hydroponic urban farms (farms 2,3,4) located in Lisbon (Portugal, csa zone) was adopted. These models are compared with the baseline case that consists of the current situation in Portugal. Tomato was selected as a crop, as Portugal is the 15th largest tomato producer worldwide (FAOSTAT, 2012). The other farms are different in construction properties, WWRs and climate control levels. The results show that the carbon footprint related to energy use, water use, and transportation is extremely high in urban farm 4 with 1.319 kg CO_2 eq/kg, followed by Urban farm 1 with 0.974 kg CO_2 eq/kg, urban farm 3 with 0.500 CO_2 eq/kg and urban farm 2 with 0.300 kg CO_2 eq/kg. All the farms are more sustainable than the baseline case whose carbon footprint is 1.042 kg CO_2 eq/kg ***[1].***

References

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[3] WEBSITE - Grow It York, ***https://growityork.org/*** Access 27/10/2022

Water management

Water storage and reuse

Several studies show that the vertical farm could cause problems related to conventional agriculture such as the high and inefficient use of water and land, high concentrations of nutrients and pesticides in runoff, and soil degradation.

Case study: a comparison between hydroponics and conventional lettuce production in Yuma (Arizona, USA, BWh zone) was conducted. The hydroponics production is placed in a greenhouse of 815mq where temperature, supplemental artificial lighting, and water circulation pumps were controlled. Using data available from the National Agricultural Statistics Service (NASS), conventional lettuce production has a water demand of 250 ± 25 L/kg/y. The results show that hydroponic lettuce production uses 20 ± 3.8 L/kg/y of water. Comparing the two-situation, it emerged that the hydroponics system is more convenient in terms of water usage ***[2].*** Another interesting casa is ***[1].***

Health and wellbeing

Space for socialization

"Grow It York" - a vertical, community farm at the heart of a vibrant container park in the city.

It's the name of an indoor urban community interest company that re-use shipping containers for local business in Piccadilly, York. They use an aeroponic strategy of growing crops as pea shoots, microgreens, and herbs, indoor without soil and pesticides and with less water. The farm was built to investigate the environmental positive impacts of healthy and bio food, but also to create a big community. The farm is open to the public that can visit containers and test the foods ***[3].***

Quality of air

Several studies show that the rooftop farm could strongly reduce the air pollution, because of the green components located above the ground level.

Case study: Brooklyn Grange Rooftop Farm in New York City (USA, zone) was considered. It is characterised by 40,000 square feet of vegetable and herb located on the roof of a seven-story building. Some sensors detected the PM2.5 concentration at street level and on the top of the building (at 26m above ground). The results show that the rooftop farm can reduce in average 7-33% of PM2.5. In addition, the quantity of heavy metal and pollution that can reach the roof farm is considerably less than the pollution received at street level fields ***[4].***

Vertical farm: best practice

Project name

Plantagon World Food Building

Climate zone

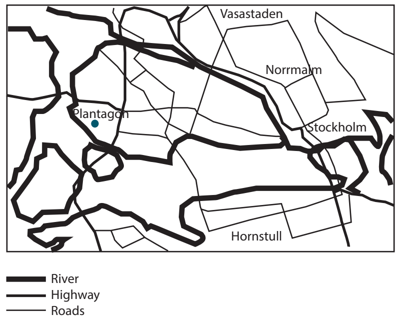
Cfb - Subtropical highland climate

Construction year

2020

Location

Linköping, Sweden



Integrated system

Biogas plant

Certification

Swedish-American Chamber of Commerce Deloitte Green Award

Water saved

13,000,000 gallons of water annually

CO_2 saved

1100 tons of CO_2 emissions

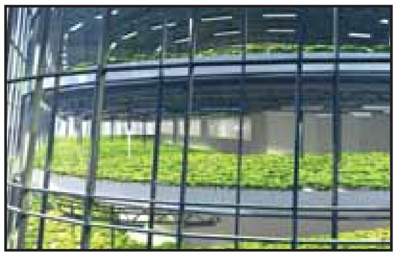
Sustainability

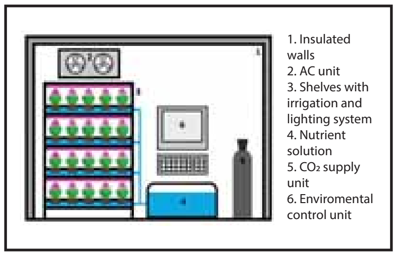
The purpose is to build a system with the smallest environmental impact and the biggest food production, using the least amount of land and water. In addition, this system could have a low impact in terms of transportation and fertilisation, and a bigger impact in terms of sociable sustainability.

How it works

Vertical farming is a complex system in which some kind of crops grow on top of each other in a controlled environmental. The plants usually cultivated are lettuce, chard, cabbage, rocket, kale and collard greens. The system is composed by multi-levels production shelves where plants are placed. Each shelf includes an irrigation and lighting system. Vertical farm doesn't use the traditional sunlight, consequently the farms' growing cycles aren't determined by seasonal variations in temperature and sunlight. They use the own light source for year-round photosynthesis through energy-efficient LED lights.

The irrigation system supplies water rich with nutrients directly to the plant's root. These systems are designed in a closed circuit, thus reducing water waste. In addition, the entire process with the temperature and ventilation systems are controlled by automatic systems control. Often use artificial intelligence or robots to assist in harvesting.





Description

The Plantagon World Food Building located in Sweden, was designed as a vertical agriculture urban farm. The tower is characterised by 16-storey buildings of which two-thirds are allocated offices, local restaurants, and a market for selling vegetables and fruit, and the other third will include an indoor farm. In the greenhouse space, food grows using hydroponic farming – a method that involves submerging crops in nutrient-rich water. The production of approximately 550 tons of vegetables is possible by using a southern-sloped glass facade that allows the maximum amount of sun to pass into the farming areas. In addition, this building works symbiotically with its neighbourhood. The waste from the greenhouse is sent to the biogas plant located in the neighbourhood for composting, which will finally deliver energy that enables the plantation to operate. The recycling of resources usually regarded as waste is key to making sustainable and eco-friendly urban farming.

Source: https://doi.org/10.3390/resources10110109, https://www.dezeen.com/ , https://www.agritecture.com/ and http://www.verticalfarms.com.au/advantagesvertical-farming, | Photo credit: -

Winter garden

Wintergardens are flexible spaces usually made of glass or with transparent plastic materials integrated or leaning against a building. The main advantages of this solution are collecting and conserving the light and heat of the sun and feeling of contact with nature. It can be used as garden, lab, living room, etc. in addition it could be built as a building adhering to an existing house, but it also can be isolated or embedded. To design a wintergarden, it's necessary to consider some elements as the orientation that better guarantees the maximization of the solar rays and the proper.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort, Flexibility, Noise pollution, Food production, Artistic expression, Daylight

Regulations & Standards

TUE – DPR 380/2001 and Local low Trento 4/3/2008 n. 1

Strategies

M A

Scale of application

Building, Neighborhood, City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 11.b 15.a
S 13.0 -

Disadvantages

Low thermal insulation
Wet weather

Energy consumption

Low carbon material use

The greenhouse could have a strong carbon footprint if they aren't accurately designed. The typology of greenhouses and the materials used, play an important role.

Case study: unheated greenhouse tomato production in a typical farm located in Cukas region (Albania, zone), was adopted. The aim is to calculate the cradle-to-farm gate environmental performance, commonly used in agricultural LCAs studies. Some phases were considered such as seedlings, fertilisers, pesticides, fuel, etc. The results show that carbon impact for 1 ha has a global warming potential of 2660.4 kg CO_2-eq and the particulate matter formation is of 7.99 kg $PM_{2.5}$ eq/ha ***[1].***

Energy efficiency

It's shown that the greenhouse could help to reduce the energy efficiency of the building, according to the choice of some parameters such as orientation, climate zone, and the materials used.

Case study: two apartments of a typical three-story building in Sweden (zone), have been chosen. The 'middle apartment' is on the second floor and its space heating demand is about 61 kWh/(m^2yr). The 'corner apartment' is on the third (last) floor with four and its space heating demand is about 119 kWh/(m^2yr). The winter garden solution (S1) characterised by single clear glazed window, as passive design measure was adopted. The results show that the winter garden reduces the space heating demand by 30% in the middle apartment, and 18% in the corner apartment. In addition, the winter garden enhances thermal comfort without extra heating or cooling in living space ***[2].***

Health and wellbeing

Green space

It's shown that there is a connection between green space and mental health. Several studies show that people who live in green urban areas feel less mental distress, less anxiety and depression. Comparing residents close to the green area to residents far from the green area, some differences have been shown. People that live in a greener area present better mental health and volunteer for sustainable improvement. In addition, new technologies allow the little green space as the greenhouse that could host different activities to improve the well-being such as the morning meditation, relating with the plants, and earthing. All these kinds of activities could reduce the stress and the anxiety mood ***[3].***

Space for socialization

Some projects have been designed to transform the greenhouses in space for socialisation and education such as the *Community Gardens* of Enrich Group and *Paspartù* project in Sicily. The team from Virginia Tech University, designed a socio-environmental garden that allows people to cultivate crops and interpersonal relationships. It's a greenhouse that looks like a traditional meeting room that contains an herb garden. The project purpose is to create a bridge between different generations and communities, to combine physical activity and mental benefits ***[4].***

Quality of air

The quality of air depends on several parameters such as the typology of crops, the position of the greenhouse, the orientation, the climate zone and the periods of the year.

Case study: a rooftop greenhouse laboratory (i-RTG Lab) located at Institute of Environmental Science and Technology (ICTA-UAB) at Bellaterra on the campus of the Universitat Autònoma de Barcelona (Catalonia, Spain, csa zone), has been chosen. The tomato production in the greenhouse was used for daily i-RTG indoor and outdoor aerobiological monitoring and testing or air quality. The results show that the pollen grains and fungal spores depend on the period, in particular the highest pollen grains were registered in the period from February to April with a total of 4924 pollen grains/m3. The highest fungal spores were registered in the same period and with an amount of 295,038 fungal spores/m^3 ***[5].***

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[4] WEBSITE - Cabin public gardens can be hubs for healthy food and socializing, ***https://en.futuroprossimo.it*** Access 26/10/2022

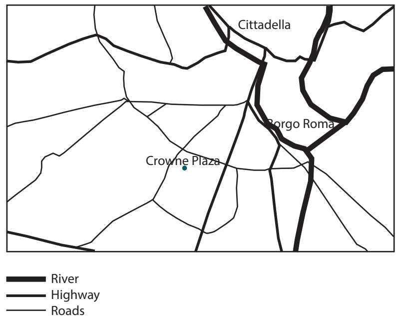
Winter garden: best practice

Project name

Crowne Plaza Hotel
Verona

Climate zone

Cfb - Subtropical highland
climate



Construction year

2016

Location

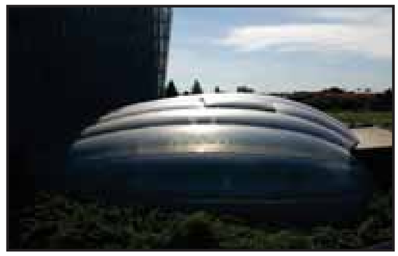
Verona, Veneto, Italy

Integrated system

Heating/cooling system
Lighting system

Certification

-



Health & Comfort

The presence of all the systems combined with some other services as the wi-fi, the special lighting and the presence of all devices for hosting an event, enhance the comfort users.

Energy consumption

-

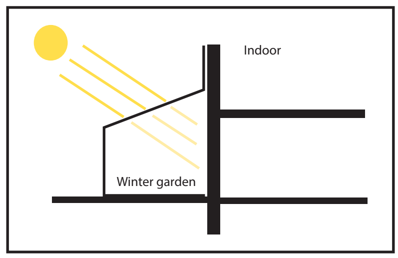
Sustainability

The winter garden is usually oriented to the south to be affected by more solar radiation, it allows to warm the space and reduce the heating system consumption in the wintertime. In addition, it can improve the sociable sustainability and create a new friendship net.

How it works

The winter garden consists in a house's extension that creates a connection between the surroundings and the house. It is a new room characterised by the presence of indoor plants such as winter flowering clematis, pansies, coronilla, hellebores, camellia, ilex, cornus, sarcococca, etc. The plants need a lot of sunlight, for this reason the winter gardens are characterised by big openings usually made of high-performance glazed windows or plastic materials.

Another advantage of windows is to create the condition for natural ventilation to avoid humidity and mold problems. The main positive aspect of this solution is that could be host the garden for the entire year and at the same could host many different activities.



Description

The Crowne Plaza winter garden is directly link to the hotel and it is characterised by tropical plants, floor area of 600m2, and by a combination of natural and artificial lighting. This structure consists of seven transversal arches hinge-connected to the concrete foundations. All arches have different shapes to generate the volume of an incomplete egg. The seven arches are connected with 11 longitudinal profiles, which are curved, bending, and stiff, and that run above the arches as well as connecting all arches to the technical installation building. The steel profiles also act as bearing profiles for the Ethylene tetrafluoroethylene (ETFE) cushions, always used for botanical gardens, zoos, etc. The winter garden cushions were replaced with new trile layers materials with g value of 0.24, to enhance the thermal comfort. The external layer is made by silver, conversely the inner one has a star's patterns.

Source: file:///C:/Users/Amministratore/Desktop/B978-1-78242-233-4.00021-8.pdf, wintergardenverona.it and https://www.macotechnology.com/, | Photo credit: -

SOLUTIONS

OPEN SPACES

Pervious pavement

BIT

Permeable paving surfaces allow water to pass through them into the soil and filter pollutants from stormwater. Pervious pavements are made of open-joint bricks that maintain voids between them, through which water can infiltrate. Pavers with as grass-concrete pavers, open-cell concrete blocks, or blocks laid in open patterns, allow room for plants to grow between them and rainwater to penetrate the soil. Semi-pervious paving materials such as wood chips, shells, gravel or stone aggregate allow rainwater to infiltrate but cannot support heavy loads. In addition, they could be used for roads, paths, parking lots, and residential sidewalks.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Biodiversity · Flexibility · Integration · Safety · Artistic expression · Cooling effects

Regulations & Standards

Legge Prov. 4/03/ 2008, n. 1, art.97
Decreto11/01/2017 – CAM 2.2.3

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 6.3, 6.4
S 11.0, 13.0

Disadvantages

No buffering capacity
Clogged with sediment

Energy consumption

Low carbon material use

Several studies show that the pavement LCA could be influenced by the analysis period, the discount rate and the design life.

Case study: the improvement project of HWY 4 Kennedy Hill Safety Improvements, located on Vancouver Island (British Columbia, zone), was considered. This highway is characterised by a length of 1.5 km, two 3.6-m lanes and it is alongside an important spawning habitat and the largest freshwater body on Vancouver Island. Four pavements have been tested, of which 2 open graded friction course (OGFC) and 2 hot-mixed asphalt (HMA), different in lifespan and thickness. The results show that, using the LCA method, the most quantity of carbon emissions are produced by the OGFC pavement with a lifespan of 20 years and a thickness of 20mm, with a footprint of 3217 $MgCO_2$-eq. Conversely, the least impacting floor is HMA pavement with 30 years of life design and 210mm of thickness, with a footprint of 2695 $MgCO_2$-eq. ***[1].***

Temperature regulation

Temperature surface/air

SThe temperature surface for permeable pavements strongly depends on the availability of moisture of the surface layer and on the climate zone.

Case study: a comparison of three pavements typology located in the suburbs of Guangzhou (China, zone) was conducted. The permeable paving materials including ceramic permeable brick (CB) and open-graded permeable concrete (PC) made of a single-size aggregate, and the slump of the fresh permeable concrete is zero. A dense concrete (DC) with a water-cement ratio of 0.40 and an aggregate-cement ratio of 3:1 , it was used as a reference. The results show that the surface temperature of CB in wet conditions is 10 °C lower after sprinkling compared to 5 °C for PC in wet conditions ***[2].***

Outdoor thermal comfort

Several studies show that the UTCI factor could be influenced by a lot of different parameters such as relative humidity, air humidity, orientation, wind speed, and shade effect. It's shown that the most important parameters are radiant temperature and air temperature.

Case study: the wetting optimization of a double-layer porous pavement during an extreme heat wave CFD model located in Zurich (Switzerland, zone), was considered. The model is composed of the top finer layer of low porosity (10%) porous pavement material and thickness of 7.5 cm, while the bottom 7.5 cm of the pavement consists of a coarser layer, higher porosity (30%). The pedestrian thermal comfort is evaluated by the UTCI, which is calculated using local values for air temperature, relative humidity, wind speed and mean radiant temperature. The results show that with high wetting fluxes, the reduction in the UTCI remains at 2°C during a large part of the afternoon. Finally, it reaches above 1°C even during the second day with a wetting flux of 3.5 mm/h ***[3].***

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Water management

Water retention

One the most important index to evaluate the infiltration of the water to the soil, is the SIR – soil infiltration rate. Generally, higher SIR means larger permeable areas.

Case study: eight permeable parking lots located in Rimini (Italy, cfa zone), have been investigated. These sites have different features. The site 1 has a capacity for 50 cars and it consists of CGPs with a mixture of sand (70%), soil (30%), and 40% grass. Site 2 has a total capacity of 30 cars and it is composed of honeycomb plastic grids (PG) filled with a mixture of soil. Site 3 is a park area for 80 cars and it is a CGPs filled with a mixture of gravel and sand. Site 4 has a surface of 750 m^2 composed of concrete grids filled with gravel. Site 5 is a PG paver with 95% open surface filled with soil. Site 6 with a total surface of 1950 m^2 and it is composed of 10% of sand. Sites 7 and 8 were CGPs with 40% of voids and a 22 cm thick drainage layer between the surface layer and the subgrade. The results show that the worst scenario is represented by site 6 with 11% of voids and 123mm/h permeability value. Conversely, Sites 3 and 4 are characterised by the highest average SIR of 10 574 and 20 137 mm/h, respectively ***[4].***

Water treatment

Several studies show that the permeable pavement can highly improve the quality of water using their capacity to capture heavy metals.

Case study: the lab-scale test bed has been tested. It consists of a plexiglas container of 59 x 459 x 41cm with a circular outlet in the centre of the bottom, a total volume of 143.000cm^3, and three layers – wear layer, bedding layer and sub-base layer. The concentrated chemical elements have been used to prepare synthetic stormwater, specifically 5–15 mg/L of dissolved Cu using Cu (SO)4, and 6–15 mg/L of Zn using Zn(CH3COO)2 2H2O). The results show that the Cu removal rate is higher than the Zn removal rate. It's shown that the Cu removal rate is in a range of 85% to 92%, different from 65% to 82% that consist of the Zn removal rate ***[5].***

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Pervious pavements: best practice

Project name

SUDS - Sustainable Urban Drainage Systems

Climate zone

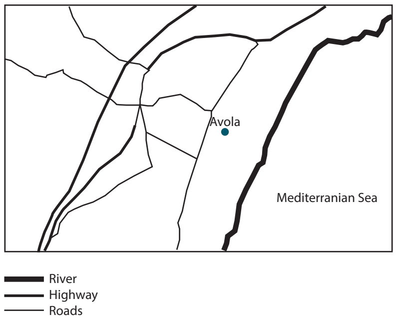
Csa - Hot - summer Mediterranean climate

Construction year

2017

Location

Avola, Sicilia, Italy

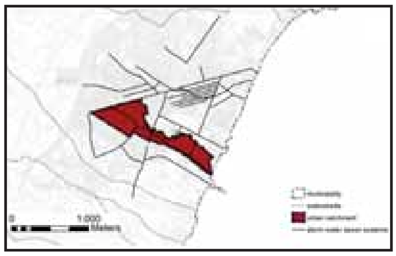


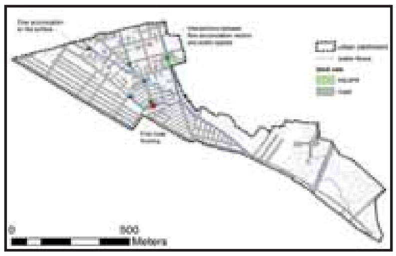
Pervious material

Manning's roughness coefficient n=0.015
Thickness 150 mm
Permeability 300 mm/h
Storage height 300 mm

Surface run-off

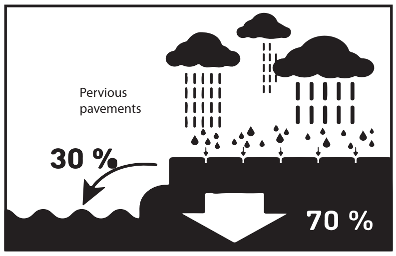
19.46 mm in 2 years
28.86 mm in 5 years
34.26 mm in 10 years





How it works

Permeable paving is made from porous stones. When it rains, the water seeps into the stone and drains into the ground. The water percolates, such as it would in a coffee pot, through the paving into a layer of gravel that acts as a natural filter, cleansing the water of any pollutants. Sometime permeable pavers are not exactly permeable. In fact, rainwater does not filter through the pavers, but they have gaps between them that allow water to pass through to the various layers underneath. In both cases, the clean water can conduce to the reservoir when it could be storage.



Description

The case study area is located in Avola, and it is characterised by the almost uniform morphology, with an elevation varying from 45 m to 10 m above sea level and an average slope value of about 3%. The site has a size of 39.5 ha and includes an urban fabric composed by different building types. To evaluate the appropriate strategies, hydrologic - hydraulic analysis, using simulation and modelling tools, have been conducted. A comparison between two types of SUDS measures, permeable pavements and green roofs have been investigated. The permeable pavements are in existing public spaces, and they include 150 units of 15 m^2. Conversely, the green roof was located in a portion of a private building. It is characterised by roughness coefficient (n=0.1 s/m1/3), surface slope (2.5%), thickness (87.5 mm), porosity (0.5), drainage mat thickness (3 mm). In addition, it covers just 20% of the surface.

Source: https://doi.org/10.1016/j.ecoser.2017.04.015, | Photo credit: -

Cool pavement

BIT

Cool pavement is a surface that reduce surface temperatures and the amount of heat absorbed by using cool materials. These materials increase albedo, thereby reflecting shortwave radiation out of the atmosphere. Pavement reflectance is enhanced by using reflective aggregate, reflective or clear binder or reflective surface coating. These materials could be used for new structures or for the existing ones. Cool pavements could be used for low-traffic areas, such as side-walks, trails, parking lots and streets. In addition, it could be combined with permeable pavements, modified mixed and vegetated pavements, to increase the albedo.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Indoor thermal comfort · Flexibility · Noise pollution · Safety · Artistic expression · Lighting costs

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P -
S 11.0, 13.0

Disadvantages

Brightness
Difficult installation

Energy consumption

Low carbon material use

Cool pavements are also responsible for decreasing the energy demand and Global Warming Potential during their lifespan. Their performance depends on emissivity factor, albedo, climate zone and context.

Case study: the in-field experimental investigation of five paving fields in University of Perugia (Italy), was conducted. The five pavements consist of a conventional asphalt (AR), a light-colored concrete (CR) and two different versions of the presented resin binder with and without TiO_2 (RTB and RB, respectively). The just white grains (GR) were considered as reference. A cradle-to-gate assessment was performed for a time frame of 100 years. The results show that the best solution with lower carbon emissions is the AR with 0.672 kgCO_2eq, followed by the RB with 0.967 kgCO_2eq. The worst case is represented by CR with 2.716 kgCO_2eq. ***[1].***

Energy efficiency

The application of high albedo pavements increases the solar gains transmitted into the building unit, consequently the energy demands reduce.

Case study: a high-density residential neighbourhood located in Thessaloniki (Greece, csa zone), was considered. The site extends to 40 000 m^2 and contains six blocks of residential buildings and open spaces that involve street canyons and courtyards of irregular shape. Some scenarios have been simulated as the base case (BC), with ground surfaces covered by conventional asphalt and concrete pavements, the design cool materials scenario (Des.CM-) that include cool asphalt (albedo 0.40) and cool concrete pavements (albedo 0.70). Finally, the cool materials scenario (Aged.CM-Aged): the high albedo asphalt and pavements have lost their initial reflectivity by 40% and 15% respectively. The results show that comparing the Des. CM with the BC scenarios, the energy saving for cooling is -0.5% and for heating is 0.8%. Different results are obtained comparing the Aged. CM-Aged with the BC the energy saving for cooling is 0.0% and for heating is 0.7% ***[2].***

Temperature regulation

Temperature surface/air

Several studies show that high solar reflectivity and high infrared emissivity could reduce the convection of heat from pavement to the atmosphere, consequently they decrease the air temperature.

Case study: simulations of high-density residential district in Thessaloniki (Greece, csa zone), were conducted. Four different scenarios – A, B, C, D - were analysed. They are case A that represents the current situation, case B consists in cool asphalt and concrete pavements, having design albedo values of 0.40 and 0.70 respectively; case C corresponding to a first ageing scenario, and case D corresponding to a second, less optimistic ageing scenario. The results show that the best case is case B with a surface temperature reduction of 5.0 °C–7.0 °C and 6.0 °C–9.0 °C for the all the exposed parts of the asphalt streets and pavements respectively ***[3].***

Outdoor thermal comfort

The universal thermal climate index (UTCI) is one of the best parameters that could be used to evaluate the thermal comfort in open space.

Case study: a comparison of the actual scenario and cool pavements scenario in ZIP district of Padua (Italy), was conducted. Its development started in 1946 and now it covers an area of over 11 km^2, It hosts more than 1300 industries, and it has a regular urban geometry composed of large road axes for the transit of vehicles. The Cool Pavement Scenario (CPS) has an extension of 73,200 m^2 and it is composed of whitetopping, pervious concrete, colored asphalt and permeable interlocking concrete blocks. The results show that the colored asphalt with an albedo of 0.27, produced a reduction of UTCI up to 0.3 °C ***[4].***

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Cool pavements: best practice

Project name

Flaminio district

Climate zone

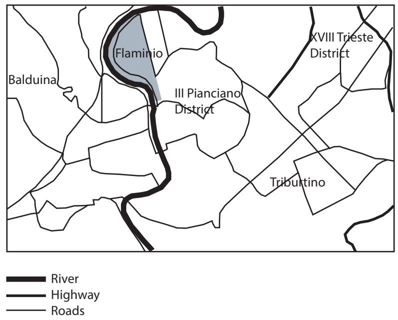
Csa - Hot - summer Mediterranean climate

Construction year

2017

Location

Rome, Lazio, italy

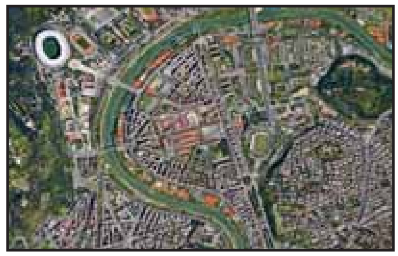


Cool material

Thickness asphalt of 0.01 m,
Density of 1500 kg/m^3,
Thermal capacity of 6.50 kJ/khK,
Thermal conductivity of 0.50 W/mK

Air temperature

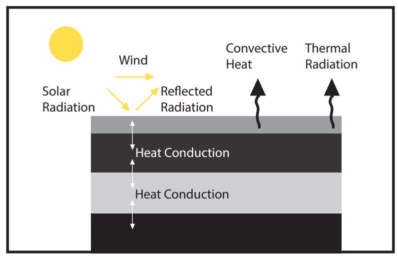
The 3D has been recreated and using ENVI-met some simulations have been conducted. The results show that, by increasing the asphalt albedo from 0.11 to 0.40 – 0.65 the air temperature decreases up to 1°C – 3°C.



How it works

The roofs and pavements that cover around 60% of a city and absorb 80% of sunlight, are among the biggest contributors to the UHI. To evaluate how "cool" a specific material is, it's necessary to measure solar reflectance or albedo, thermal emittance, and solar reflectance index. The most important is the solar reflectance, therefore the percentage of solar energy reflected by the surface. It is determined for the surface temperature; it's shown that how changing only albedo can significantly alter surface temperatures. Conventional paving materials such as asphalt and concrete have solar reflectance of 5% to 40%, which means they absorb 95% to 60% of energy. In alternative, cool-coloured coatings that reflect about 50% of sunlight could be used.

Another important factor is the time. All materials that are exposed to the atmosphere and use, change the solar reflectance of pavement over time. For example, as cement concrete pavement ages it tends to get darker with tire and grease stains, for these reasons the solar reflectance index changes from 30-50% to 20-35%. Conversely, the asphalt concrete lightens because of more aggregate is exposed through wear, for these reasons the solar reflectance index changes from 5% to 10-20%.



Description

The Flaminio district is an area of about 0.218 km^2. It is located in the north of the city and north-west of the Tiber River. It is characterised by the presence of historical buildings, condominiums about 70's, sheds for industrial use and some modern buildings. The area of 735000 m^2 is characterised by vegetation along the streets and around the river. An albometer was used to evaluate the solar surface reflectance. The results show that the roof consists of bituminous materials and measure an albedo of 0.10, the wall albedo in a range of 0.21 and 0.85, and the asphalt has an albedo of 0.11. It's shown that the high albedo that allows the low absorption of solar radiation and high infrared emission, could mitigate the UHI effects.

Source: https://doi.org/10.1016/j.egypro.2017.04.027, | Photo credit: -

Pocket garden

UGI

Pocket or garden parks are publicly accessible and compact green areas around and between buildings. They could be vegetated by ornamental trees, grass, other types of plants - perennial, annual plants, herbaceous – combined with outdoor furniture and decorations. Because of its size it usually does not provide opportunities for great physical activities, but the area is designed for playing, for relaxing, meeting friends, and some other outdoor activities. Pocket gardens provide opportunities for people to create small but important public spaces left in their own neighbourhoods.

Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits: Biodiversity, Food production, Heat gain, Privacy, Indoor thermal comfort, Flexibility

Regulations & Standards

-

Strategies

M A

Scale of application

Building Neighborhood City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 11.0 15.0 S 6.0 13.0

Disadvantages

Increased maintenance
Limited plant sizes

Temperature regulation

Temperature surface/air
The temperature air could change according to the presence of the pocket garden, specifically it depends on the typology of plants, soil and area's size.
Case study: 11 pocket gardens located in Victoria (Australia), were analysed. These eleven areas contain 655 plants of 122 species across 80 genera divided in 1 × 1 m quadrats along transects placed every 5 m across the garden. All gardens had a minimum of eight 1 × 1 m quadrats, and proportionally a 1 × 1 m quadrat was added for every additional 500 m2 for gardens. It's showed that the daily temperatures are in between 22.2 - 23.2 °C at the garden scale and 21.2 to 26.1 °C at the plot scale. The temperature variability values ranged from 22.4 to 31.9 at the garden scale and 19.8 to 35.4 at the plot scale. In addition, temperature CV is lower in gardens with higher impervious surfaces surrounding them (garden-scale temperatures), and mean temperatures were lower in larger gardens ***[1].***

Outdoor thermal comfort
Trees used in pocket areas could help to increase the outdoor thermal comfort proportionally to their quantity and typology.
Case study: two most intense main street of Erzurum (Turkey, dfb zone), was choose. Two different scenarios were applied. The first one was prepared by adding a deciduous tree species on the street, differently second scenario includes parking area with deciduous trees. Both streets are in the same direction and are positioned as a continuation of each other. The results show that the first street has the SVF value low, while in the second street the SVF value is higher. In addition, the index of agreement (d) for street 1 is 0.91 and 0.99 for winter and summer, respectively. The index of agreement (d) for street 2 is 0.88 and 0.99 for winter and summer, respectively ***[2].***

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Water management

Water retention

Pocket gardens can provide important benefits of stormwater runoff mitigation in comparison to other land uses, due to their soil amending practices and composting activities.

Case study: 529 gardens located in New York City (USA, cfa zone), have been studied. They are 83 % green space, 16 % paved, and 1 % bare, and they cover about 49 ha of land. The results show a higher percentage of water absorbed during the 3.8 cm rain event than during the 12.7 cm rain event across methods. Specifically, for each storm level respectively, about 2.3 mm and about 4.1 cm of water would become runoff for each square inch of the garden ***[3].***

Water treatment

According to the typology of plants and the position of green area, the property of the soil and the nutrients change.

Case study: two suburban lots, two semi urban lots and two urban lots located in Leipzig (Germany,), were selected. A total of 36 plots, i.e. six vacant plots, 12 medium- intensity plots and 12 high-intensity plots with a total area of 0.75 ha in allotment estates, and 6 adjacent community gardens, were used. These allotment estates host up to 22% of all shrubs and small trees of the built-up area of Leipzig. The results show that water content was significantly influenced by the vegetation patch type ($p = 0.0038$). Edible areas showed the highest values for soil water content, while lawn showed the lowest values. The location of gardens in the city had a significant effect on soil pH ($p = 0.019$) and a marginally significant effect on soil water content ($p = 0.055$) in allotment gardens. In both cases the highest values were found in semi-urban gardens, the lowest values in suburban gardens ***[7].***

Health and wellbeing

Green space

Several studies show that pocket garden could improve green space and it brings all the benefits related to the green component.

Case study: 20 gardens have been studied between 2015 and 2018 during the summer seasons in California Central Coast region. The gardens studied are 405–8134 m2 in size, 2–39 years in age, and are surrounded by a mix of natural, agricultural, open green space, etc. They have been selected because they were all managed in an allotment style where households cultivate individual plots within the garden or because well supported by local. They represent an important resource because they serve between 5 and 92 different gardeners who garden for a wide variety of reasons including food production but also quality family time, and social cohesion. In addition, some survey questionnaires show that gardeners represent a diverse range of family sizes, education and salary levels ***[4]***.

Space for socialization

Different proposals have been brought forward to use urban tree pits on sidewalks as bioretention areas. Improving on this concept, a recent study has shown that bioretention areas can be effectively used as suspended pavement systems for sidewalks, roadways and parking areas.

Case study: bioretention areas have been installed in suspended pavement systems in Knoxville, Tennessee. It was monitored for 27 months showing a runoff reduction between 88% and 99% ***[5].***

Walkability

Several studies show that pocket gardens also called community gardens increase the neighborhood walkability and it improves health behaviours, including increased PA (physical activity) as well as it reduces depressive symptoms. Accessibility is key to increasing gardening in older adults. Gardening has an array of positives influences on many aspects of older adult life, including physical, nutritional, social, and psychological outcomes. In addition, it has been shown that walking, gardening, and yard work are some of the most popular forms of physical activity in older adults. A secondary analysis of the LIFE-P study, which examined 70–89-year-old adults at risk for mobility disability, determined that those who lived in less compact neighborhoods spent more time performing heavy gardening compared with those in more compact ***[6].***

(2017) pages887–897, ***https://doi.org/10.1007/s10460-017-9782-z***

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Pocket garden: best practice

Project name

Municipal community gardens in the metropolitan area of Milano. Assessment and planning criteria

Climate zone

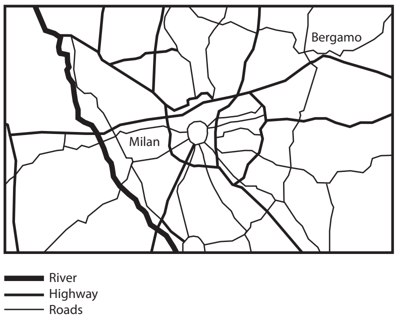
Cfb - Temperate oceanic climate or subtropical highland climate

Construction year

2016

Location

Milan, Lombardia, italy

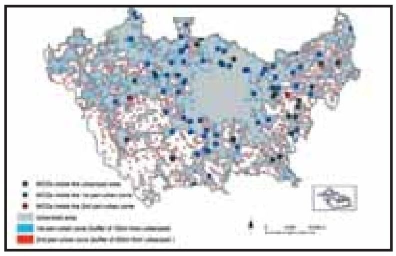


Health and well-being

Most MCGs are surrounded by a prevalent urbanized landscape, while the MCGs in agricultural areas are quite distant from the city of Milano. This confirms the role that the MCGs have to allow, in an urban environment, easy access to and contact with nature.

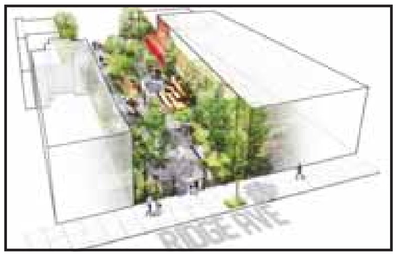
Space for socialization

This data confirm that the municipality usually locate MCGs near urbanized areas in order to ensure a better accessibility, as should be for all social services.



How it works

Pocket gardens are a kind of public gardens which haven't been included in the original project of an urban design, but they have been created subsequently on the basis of the initiative of free citizens, or as a result of a choice from the public administration. Pocket gardens are created within already existing blocks, for this reason the most peculiar characteristic is to be able to "slip" usually in undeveloped vacant lots, lots of demolished buildings or abandoned spaces. According to the context, the pocket garden contains typology of plants, urban furniture and some other accessory.



Description

The study area is made by the municipalities of the Città metropolitana di Milano that includes a total of 133 municipalities and an area of about 1400 square km (55%agricultural, 36% urban, 8% forest and semi natural, 1% wetlands and water bodies). The analysis includes the definition and quantification of MCGs. The process is composed of several steps: the study area definition and identification and quantification is made by several steps: analysis of the municipality land use plans, analysis of the official web sites of the133 municipalities, digitization of the MCGs areas, ground control through direct survey of the digitized MCGs areas and creation of a GIS database of the MCGs areas. The purpose of the study is to requalify the marginal and urban fringe areas, for improving environmental and life quality in urban and suburban degraded areas. In this sense MCGs represent an urban and social service to improve through decisions supported by careful planning of interventions.

Source: https://dx.doi.org/10.4081/jae.2016.509, | Photo credit: -

UGI

Bioretention area

Bioretention is a technique to reduce and filter peak stormwater runoff thanks to a system of layered organic and inorganic materials. Bioretention cells consist in shallow depressions where runoff is collected: thanks to sand bad water is slowed down and distributed evenly along the ponding area, which consists of a filter media layer, such as mulch, and topped with dense ground cover. Properly designed cells remove suspended solids, metals, and nutrients, and can retain an inch or more of rainfall. Stored water can then exfiltrate slowly, over a period of days, into the underlying soil.

Challenges	*Objectives*			*Performances*			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Biodiversity | Noise pollution | Flexibility | Storage | Artistic expression | Easy to repair

Regulations & Standards

-

Strategies

M A

Scale of application

Building | Neighborhood | City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 6.0 11.0 S 13.0 15.0

Disadvantages

Requires landscaping and management
Not suitable for areas with steep slope

Temperature regulation

Temperature surface/air

Several studies show that bioretention areas have the ability to reduce the temperature of thermally charged stormwater runoff received from an asphalt surface.

Case study: bioretention site located at the Community Center parking lot in Blacksburg (Virginia), was adopted. Its facility was designed as a retrofit to treat the entire 0.73 ha asphalt parking lot. It is 27 m long, 3.7 m wide, and 1.3 m deep and it is filled with CU-Structural Soil composed of approximately 80% crushed stone and 20% clay loam soil held together with hydrogel. The results show that bioretention facility reduced thermal energy in average of 8.8°C. The average influent temperature for the 10 runs was 34.0°C, while the average effluent temperature was 25.2°C ***[5].***

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Water management

Water retention

The capability of bioretention areas to retain stormwater depends on design: for example, smooth inlet systems may lead to more flow through the structure and thus potentially better retention. Likewise, the presence and configuration of underdrain systems can also limit the retention characteristics of retention cells.

Case study: a bioretention cell located in Cleveland (Ohio, dfa zone), was analysed. It is composed of a sandy substrate amended with compost and an aggregate base layer designed for stormwater storage was monitored, collecting runoff from transportation surfaces, rooftops, and sidewalks. Collected data was used to calibrate a hydrological model of the cell. The results show that the mean soil water content increased by ~8% with respect to the case without the retention cell. ***[1].***

Water treatment

Bioretention has proved a great efficiency (70%) in absorbing toxic water contaminants such as naphthalene and suspended solids in runoff waters. Recent proposals have demonstrated a potential use in denitrification of waters using wood chips as filter media while other studies indicate a reduced mass flow of contaminants in cells with increased soil organic matter (SOM).

Case study: concentration and mass flux of contaminants (Na, Cr, Ni, Cu, Zn, Cd, Pb) were measured in soil samples from street tree pits used as bioretention areas in Montreal, Canada. Tree pits with higher SOM reduced the mass flux of contaminants more than tree pits with lower SOM. The estimated water flux in the open part of the tree pit changed from 6.15 to 1.64 mm week−1 from the less permeable units to the more permeable ones ***[2].***

Health and wellbeing

Green space

Bioretention facilities incorporate patches of urban green spaces, proved to positively affect mental health and wellbeing, while reducing the content of toxic pollutants that reach groundwaters.

Case study: a recent survey investigating their role on landscape aesthetics proved low perceived impact, as only 1 in 3 interviewees recognized the difference with conventional gardens. The same study showed a high degree of favour towards its function and concept ***[3]***.

Walkability

Different proposals have been brought forward to use urban tree pits on sidewalks as bioretention areas. Improving on this concept, a recent study has shown that bioretention areas can be effectively used as suspended pavement systems for sidewalks, roadways and parking areas.

Case study: bioretention areas have been installed in suspended pavement systems in Knoxville, Tennessee. It was monitored for 27 months showing a runoff reduction between 88% and 99% ***[4].***

Bioretention area: best practice

Project name

A public square in Ostia Lido

Climate zone

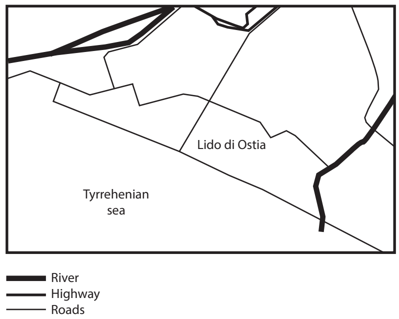
Csa - Hot-summer Mediterranean climate

Construction year

2019

Location

Rome, Lazio, italy

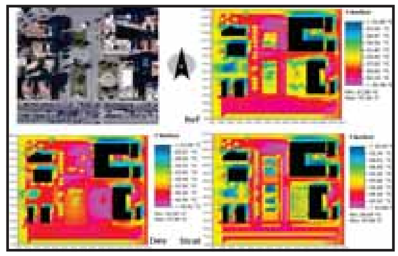


Runoff

The results obtained through the SCS Curve number method show a significant reduction of the runoff in the Strat scenario, confirming the effectiveness of the adopted strategies also under this point of view. Specifically, it is for Ref, 67.11 mm; for Dev, 90.84 mm and for Strat, 42.21 mm.

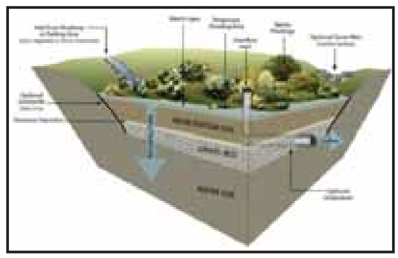
Temperature

In Ref, temperatures on the sidewalks are similar to Dev, but much lower Tsurf are visible in the squares (32-34°C) as well as slightly lower Tmr, equal to 66°C. Strat displays even lower Tsurf, 28-35°C in the green squares, while the water ponds reach even lower temperatures. Tmr is lower especially in the squares (64°C, and as low as 42°C close to the trees), where trees are present.



How it works

Bioretention “cells” are landscaped depressions or shallow basins filled with sandy soil, topped with a thick layer of mulch, and planted with dense vegetation. They are used to slow and treat on-site stormwater runoff. Stormwater runoff slowly percolates through the system where it is treated by a number of physical, chemical and biological processes; some of the water is also taken up by the plants and the other part is allowed to infiltrate native soils. The main objectives of this solution are to provide water quality treatment removing suspended solids, metals, and nutrients, to increase groundwater recharge and to reduce peak discharge rates.



Description

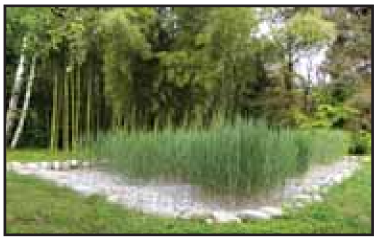
Sustainable Urban Drainage Systems (SUDS) are flood mitigation strategies specifically designed to benefit on urban microclimate and outdoor thermal comfort. The area is 140x140 m wide, mainly composed of urban paving and asphalt roads and sidewalks. In addition, three green areas with not irrigated soil and plants such as palm trees, are present. A case study urban area where some different scenarios for the future were modelled, was adopted. This scenario was compared with the reference case study modelled on ENVI-met. In the same case study and scenarios, runoff was calculated. The scenarios were three: “Ref” scenario as reference; “Strat” scenario: green, irrigated areas with trees and permeable paving for the parking lots and water ponds in the green areas. Finally, a “Dev” scenario characterised by impermeable paving.

Source: DOI: 10.1088/1742-6596/1343/1/012023, | Photo credit: -

Phytodepuration

UGI

Phytodepuration is a natural treatment technique inspired of natural paludal ecosystems, that reproduces artificially the natural purification process in a controlled environment. Practically, they are artificial little deep basins, often filled with inert material and fed with aquatic plants (macrophytes). The macrophytes can be floating, flooded or emerging. The systems can have superficial or sub-superficial streams, in addition, the sub-superficial stream can be horizontally or vertically oriented. Superficial streams can support all the types of macrophytes, on the other hand the sub superficial can just support the emerging macrophytes.



Challenges	Objectives			Performances			
Energy sustainability	Energy demand	Carbon impact	Energy produced from RES	Energy from RES on site	Low carbon material use	Greening	Energy efficiency
Temperature regulation	Local microclimate	UHI		Temperature surface/air	Outdoor thermal comfort	Shadow effect	
Water management	Run off mitigation	Water scarsity	Water quality	Water retention	Water storage and reuse	Water treatment	
Health and wellbeing	Comfort and life quality	Urban space quality		Green space	Space for socialization	Air quality	Walkability

Other benefits

Biodiversity · Security/Safety · Food production · Flexibility · Easy to repair · Artistic expression

Regulations & Standards

-

Strategies

M A

Scale of application

Building · Neighborhood · City

Space usage

Monofunctional
Multifunctional

S.D.G.

P 6.0, 11.0
S 13.0, 14.0

Disadvantages

Accumulation of pollutant in edible plants
Maintenance costs
Some place/just for some plants

Temperature regulation

Temperature surface/air
Several studies show that phytodepuration system could help to reduce the temperature according to its shape, the plants chose and the location.
Case study: the infinity green located in Wrocław (Poland), was adopted. The structure with the dimensions of 1000 × 360 × 500 cm and the distance between shelves of about 51 cm, consists of seven levels of horizontal plywood frames that are joined by steel masts. It is 120 m2 of growing area, that includes 120 plant species and varieties of 63 genera were used, with the most numerous species and varieties of the genera Sedum (13), Geranium (9), Campanula (5) and Dianthus and Festuca. The results show that during the colder days, the temperatures significantly decrease up to 2–3 °C less ***[1].***

Water management

Water treatment
It's shown that phytodepuration is one the most efficient solution to treat the water and guarantee the water quality
Case study: vast abandoned areas of former industrial plants located in Turin (Italy, Cfa zone), was used. According to Italian laws, a part of the ex- industrial areas was allocated to green infrastructures, however, the restoration of the green areas was confronted with the problem of soil contamination. The surface of the experimental plot was about 0.1 ha, and the selected species for the experiment are from Populus, Salix. and Robinia genera. The results show that the Zn root uptake was constant over the two years for Poplar and Salix clones, between 6% and 17% of the total uptake of the plant. Robinia genotypes, instead, stored higher amounts of metals in roots using biennial coppicing (up to the 23% of the total), mostly due to the higher root biomass developed under this management. In addition, the decreasing of Zn was significant for all clones at the end of the experiment, and, on average, Poplar clones reduced Zn by 28%, Salix by 36%, and Robinia 26%.
Another interesting case is ***[2], [3].***

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Synonimous and other strategies: https://doi.org/10.3390/ijerph18105215

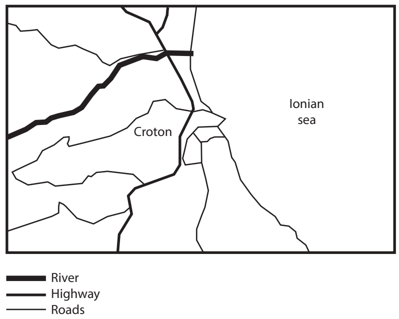
Phytodepuration: best practice

Project name

Effectiveness of in situ application of an Integrated Phytoremediation System (IPS) by adding a selected blend of rhizosphere microbes to heavily multi-contaminated soils

Climate zone

Csa - Hot-summer Mediterranean climate



Construction year

2017

Location

Crotone, Calabria, italy

Arsenic

The percentage reduction of As in average is 61%. The Eucalyptus rhizosphere microbes system provided the best results with a total percentage reduction of 63%.

Cadmium

The percentage of Cd content in soil increase of 25% and 38% in plots cultivated with A. saligna and E. camaldulensis, respectively. In particular, the Eucalyptus rhizosphere microbes system provided the best results with a total percentage reduction of 56%.

Lead

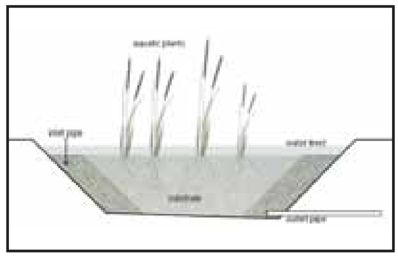
The percentage reduction of Pb has an average value of 52%. Acacia saligna highlighted a strong ability to uptake Pb from rhizosphere soil and increases the efficiency of 14%.

Zinc

The removal of Zn from soil showed the highest values of percentage reduction in both Acacia and Eucalyptus with an average value of 83%.

How it works

Phytodepuration system is made of artificial little deep basins, often filled with inert material and fed with aquatic plants (macrophytes). The soil consists in a single complex system of biological competition towards the bacteria, that has the active role in mechanical and chemical filtration. The soil's microfauna degrades the organic load of the wastewater turning it into nutrients for the plant species in the system. Finally, the vegetation reproduces the natural purification processes bringing oxygen in deep through the roots and absorbing nutrients from the soil.



Description

The former Zn smelter "Pertusola Sud" property located in Crotone (Calabria, Italy) was adopted. The full site is about 50 ha divided in different working sectors, but the investigation is focused on 5 ha called "Area Sottoprodotti" (By-products Area). It has been shown that the soil was heavily contaminated by PTEs (mainly, As, Cd, Pb and Zn), especially top soil (0–1 m) with the presence of clay layers. In the site five ecologically homogeneous areas were identified. Area A is an open scrub vegetation of shallow damp sandy soil. and area B is a wet zone. On the other hand, areas C and D host annual and perennial communities. Bare soil is the distinctive trait of area E. In addition, areas A and B are characterized by Acacia saligna (Labill.) H.KL. Wendl (subzone A e B) and Eucalyptus camaldulensis Dehnh (subzone C e D). They were chosen for their phytoremediation capacity and for their capacity to quickly produce high amounts of biomass and absorb and accumulate contaminants.

Source: https://doi.org/10.1016/j.ecoleng.2016.11.051, | Photo credit: -

4.5 Types of digital solutions

The digital solutions reported in this catalogue are a synthesis of the main Industry 4.0 technologies that could support all the life cycles stages in construction process of the Built Environment. In particular, all the digital solutions have been assessed on the ability to respond to the climate-related challenges. In addition, it has been evaluated the other benefits, the possible uses in the life cycle construction process and the possible integration with other digital technologies to satisfy one or more climate objectives.

In this section it has been added a challenge related to the transition to circular system, to analyse the role of digital solutions in a more holistic and coherent way to climate change, in order to respond to the objectives of circular infrastructures and buildings and circular materials and products.

The assessment of structures built and demolished or the quantification of abandoned structures in built environment are fundamentals to support the transition of infrastructures and buildings. The analysis of potential re-use and recycling of materials, the inventory of exterior buildings and infrastructures materials and the mapping of properties for demolition are key performances able to satisfy the transition to circular system of materials and products of Built Environment.

Solutions	Climate related challenge addressed				
	ES	TR	SWM	HW	CE
Additive Manufacturing/Robot manufacturing					
Artificial Intelligence (AI)	X	X	X	X	X
Big Data and Analytics (BDA)					
Blockchain Technology (BCT)	X				X
Building Information Modelling (BIM)	X	X	X	X	X
Digital Platform					
Digital Twin	X	X	X	X	X
Geographic Information Systems (GIS)	X	X	X	X	X
Material passport					
Internet of Things (IoT)	X	X	X	X	X
Augmented Reality (AR) and Virtual Reality (VR)					

5. Towards an integrated framework for Climate Positive Circular Communities

The present catalogue has been collected, systematise and categorized some possible measures that can respond to different challenges such as energy sustainability, temperature regulation, water management, health and wellbeing. These measures could respond at different scale (building, neighbourhood or city) both for mitigation and adaptation strategies for climate change in Built Environment. In addition, it has been underlined for each measure the benefits not only from the environmental point of view but also from social point of view. Some measures could insert in the range of Nature Based Solution and Blue Infrastructures and they are able to absorb the CO2 emissions already present in the atmosphere while reducing the production of new emissions (zero net carbon emissions). This approach is in line with the principle of climate positive, that consists in implementing additional measures in order to create an environmental benefit.

At the same time, digital solutions that can support the transition to circular system complete the catalogue to increase the efficiency and effectiveness of measures to reduce the greenhouse gas emissions and increase the benefits (less carbon emission, less water consumption and less waste consumption).

The benefits of a holistic and simultaneous strategy could lead to a reduction in the cost of emissions that affect urban climates and can also avoid maladjustment measures by providing support in the realization of other sustainable development goals.

DIGITAL SOLUTIONS

Artificial Intelligence (AI)

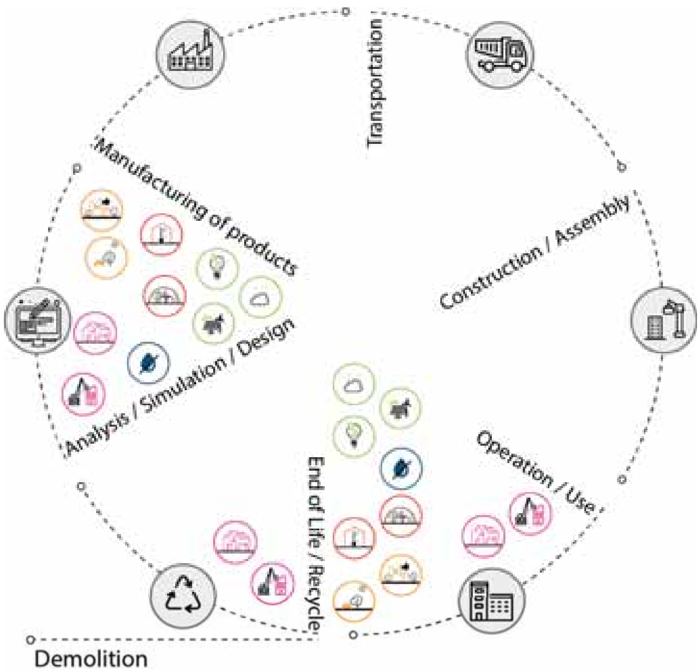
Many definitions of AI exist. At a basic level, AI refers to *"the ability of a computer or machine to mimic the capabilities of the human mind"* (IBM, 2020).The use of AI in city management relates to the collection, interpretation and analysis of data in support of policy-related decision-making and planning. AI can exert far-reaching impacts in numerous application areas, and several of these are critical for city management and urban development, including local government, health, safety, mobility and energy.
Progress in combining AI with other digital technologies (Big Data, Internet of Things (IoT), Cloud and telecommunications infrastructure) making possible full interconnectivity is driving the development of smart-cities, aiming to make the most of such technologies to increase the quality of life and wellbeing of citizens.

Challenges	*Objectives*		
Energy sustainability	Energy efficiency	Carbon impact	Energy produced from RES
Temperature regulation	Local microclimate	UHI	
Water management	Runoff mitigation	Water scarcity	Water quality
Health and wellbeing	Comfort and life quality	Urban space quality	
Transition to circular system	Circular Infrastructures and buildings	Circular Materials and products	

Other benefits

- time reduction
- increase of efficiency
- increase of effectiveness
- better governance
- better data management
- real time monitoring

AI uses in construction life cycle of Challenges



Strategies

M A

Scale of application

Building · Neighborhood · City

Potential linkages with other DTs

IoT · BD · BIM · GIS · DT · Blockchain · AM/ RM · MPassport · AR / VR · Digital Platform · AI

S.D.G.

6.4 · 11.3 · 11.b · 13.1 · 13.2

Disadvantages

+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Energy sustainability

AI has a great potential to improve the level of energy sustainability in Built Environment. Focusing on the energy performance and energy consumption, [1] have investigated the application of field measurement, computer modelling (AI) and survey to improve energy performance as well as thermal comfort using new system utilizing "big data" and AI in extreme hot regions, finding that energy cosnumed in the west facing apartment was higher than 20%. In addition, [2] have underlined the possible application of AI techniques (such as machine learning) to energy forecasting, air quality, occupancy strategy for built environment.

Temperature regulation

AI techniques have showed benefits to detect UHI pehnomenon that is intersting the built environment in the last years. [3] have investigated the impacts of surface UHI and land surface temperature with the application of landsat images and machine learning algorithms to identify urban growth, land surface temperature and UHI distribution patterns in several city directions. Thorugh this study, researchers have demonstrated the infleunce of built-up areas to land surface temperature and surface urban heat island and in the future this findings could support the increase of built environment thermal comfort.

Water Management

Built environment around the world is threatened by the water scarcity induced by the effects of climate change. In this scenario, water leakage in existing water distribution channel have exacerbate water scarcity problem in urban areas. To check and control water leakage in cities lies in operating Real-Time sensors Networks with Machine Learning [4]. While Real-Time Sensor Network monitors workflow in realt time, machine learning model will be able to predict and anomaly, and can accurately detect the same in the water distribution network.

Health and Wellbeing

Various studies have conducted to assess the indoor environmental quality, in particular with the attention to building and human interaction using AI technologies. Breeze Technologies startup wants [5] to fight the air pollution urban problem through the use of data-drive, AI-supported environmental intelligence that creates actionable insights based on sensor data. One of the most recent application of Breeze technologies is in Vilnius. Equipped with the rich air quality data provided by sensors, planning offices are already making progress toward improving happiness and health outcomes in the city.

Transition to circular system

AI characteristics offer a number of opportunities to favour the transition of built environment from linear to circular system. [6] have reported the application of AI into 3 main stage of life construction cycle. Firstly, the AI can support the design optimisation, through data driven approaches (such as neural network) to provide advanced solution for for the generation of multiple design alternatives considering some parameters (e.g. carbon footprint). Secondly, AI techniques provide capabilities to predict defects in systems and resource needs in building. Finally, AI techniques are also useful for end-use phase activities, for example to predict the amount of recyclable, reusable and waste materials generated from deconstruction and demolition projects.

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AI: best practice

Project name

FaSA (Façade Service Applicatie)

Year

2018, ongoing

Location

Nieuwegein, The Netherlands

Transition to circular economy

Sensors, drones and artificial intelligence are used for this. These measurements are automatically brought together, analyzed and result in strategic management of facade maintenance.
This application not only maps the current state of buildings, but also predicts future maintenance using smart algorithms. In addition, according to the facade industry, this technology makes it possible to determine the value of real estate more accurately over a longer period of time. This is important for the reuse of products and raw materials in a circular economy.

Other uses and digital applications

The corporations involved in the development of FaSA see the application as a way to increase the affordability of housing because of lower maintenance costs.

Description

How nice it would be if the maintenance of a building has already been done before a problem arises in a building. Now this usually happens periodically and often only when there are already problems. FaSA enables maintenance right on time.
Inspectors conduct periodic inspections. This is time-consuming, especially for large real estate projects, and is a subjective assessment of the condition of the building. There is a need for objective information to achieve better strategic management and maintenance of buildings. This is possible through digitization of maintenance inspections. With smart algorithms it is then possible to predict future maintenance. The maintenance is then done exactly on time. And that has advantages:

• Lower maintenance costs
• Higher residual value
• Fewer health complaints

Source: https://facadeserviceapplicatie.nl/

Blockchain Technology (BCT)

The concept is based on a distributed peer-to-peer system that is cryptographically secured, enabling transparent value transactions without needing central authorities and intermediaries such as banks and government agencies.
IBM defines five disruptive elements of BCT: transparency, immutability, security, consensus and smart contracts.
Hunhevicz and Hall (2020), identified twenty-four potential use cases of BCT in the BE, which include: using smart contracts to automate transactions between external actors, tracking supply chain logistics, timestamping changes in BIM models, recording the ownership of assets, maintaining material passports, and automating building maintenance based on IoT interactions.

Challenges / *Objectives*

Energy sustainability: Energy efficiency; Carbon impact; Energy produced from RES

Temperature regulation: Local microclimate; UHI

Water management: Runoff mitigation; Water scarcity; Water quality

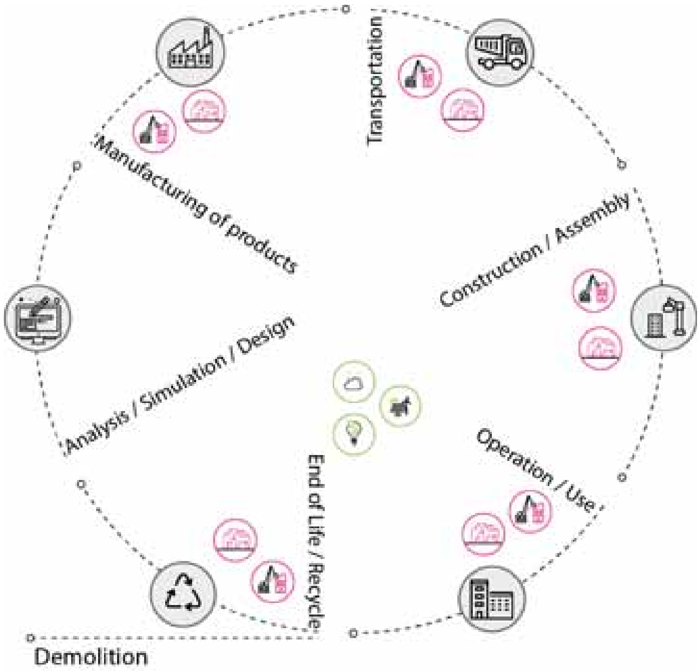
Health and wellbeing: Comfort and life quality; Urban space quality

Transition to circular system: Circular Infrastructures and buildings; Circular Materials and products

Other benefits

- time reduction
- increase of efficiency
- increase of effectiveness
- better governance
- better data management
- real time monitoring

BCT uses in construction life cycle of Challenges



Strategies

M A

Scale of application

Building Neighborhood City

Potential linkages with other DTs

IoT BD AI GIS DT
BIM AM / RM MPassport AR / VR Digital Platform
Blockchain

S.D.G.

6.4	11.3	13.1
	11.b	13.2

Disadvantages

+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Energy sustainability

BCT can support safe peer-to-peer trading networks. This attribute enable BCT to adapt to local renewable energy exchange, in which intermittency is a big obstacle. As reported by [1], BCT could avoid this issue and support local communities to increase safety, transparency and cost-efficient energy trading. For example, Pando enhance users to buy and receive local renewable energy within their neighborhoods through a mobile app.

Transition to circular system

As reported by [2], BCT will increase the development of circular economy paradigm in built environment in the next years. In particular in the construction process characterized by circular economy approach, BCT can enable the material passport systems [3], because it offers transparency and reliability of data flows accross the supply chain network, from extraction until end-of-use phase, and further in subsequent use.

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BCT: best practice

Project name

Circularise (Start-up) - City of Amsterdam

Year

2020

Location

Amsterdam, Netherlands

Transition to circular system

As part of the Amsterdam Circular Strategy, the City has set clear targets to halve the use of new raw materials by 2030 and to become a fully circular city by 2050. These targets bring challenges to the table when it comes to managing MKI-data (environmental costs calculation, focusing on CO_2 emissions) from their construction procurement. The Start-up in Residency program outlines how Circularise partnered with the City of Amsterdam to increase traceability and transparency throughout their construction procurement process.
During this project Circularise joins forces with a concrete product company and a company that recycles workwear into polymer infrastructure elements. Circularise's software solution ensures that both of these materials are traced end-to-end throughout the supply chain and that information can be shared without risking sensitive data. This supports the goal of the City of Amsterdam to create a standard for gathering procurement environmental impact insights from the upstream supply chain, without compromising confidential data of anyone involved.

Other uses and digital applications

Others applications of the BCT made by Circularise start up have focused on other manufacturing sector, such as automotive, for example with the porject for Porsche company in order to enable the access to reliable information, to understand the environmental impact of products making the information useful for the consumer.

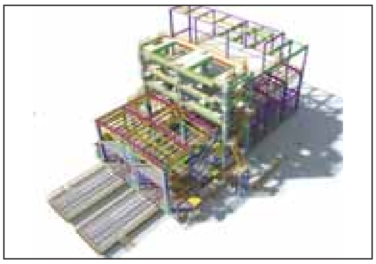
Description

End-to-end Supply Chain Traceability holds the key to overcoming major challenges that society faces in the areas of Circular Economy, Environmental Pollution, Carbon Emissions. But the race to Sustainability is held back by concerns around trust, privacy and confidentiality, as the available material data is often not accessible, proprietary or incomplete.
Circularise enables supply chain actors to share sensitive data without risking privacy and confidentiality.
To improve Resource Use, Verify Provenance, Conduct Carbon Footprint and Impact Assessments to unlock the potential of Circular Economy business models and to drive worldwide adoption.

Source: https://www.circularise.com/company and https://www.circularise.com/video/case-study-city-of-amsterdam

Building Information Modelling (BIM)

BIM has had a big diffusion in the last 10 years of the Architecture, Enrgineering and Construction sectors (AECs) supporting various purposes such as design, design visualisation, design optimisation, cost estimation, construction planning, maintenance and facility management and containing relevant information about buildings geometry, material properties and quantities of elements (Çetin et al., 2021).
BIM represents a core technology for transferring the idea of Industry 4.0 in the AECs (Begic & Galic, 2021). It has an important tool for the bidirectional coordination among physical and virtual domains (Maskuriy et al., 2019). Various subsets of BIM can be referred to as dimensions, where 3D is the object model, 4D is time, 5D is cost, 6D is operation, 7D is sustainability, and 8D is safety.



Challenges

Energy sustainability

Temperature regulation

Water management

Health and wellbeing

Transition to circular system

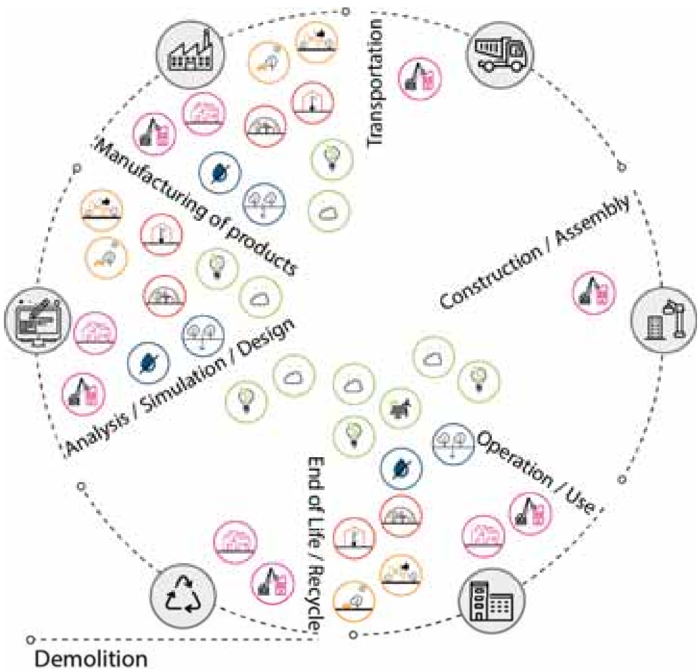
Objectives

- Energy efficiency
- Carbon impact
- Energy produced from RES
- Local microclimate
- UHI
- Runoff mitigation
- Water scarcity
- Water quality
- Comfort and life quality
- Urban space quality
- Circular Infrastructures and buildings
- Circular Materials and products

Other benefits

- time reduction
- increase of efficiency
- increase of effectiveness
- better governance
- better data management
- real time monitoring

BIM uses in construction life cycle of Challenges



Strategies

M A

Scale of application

Building
Neighborhood
City

S.D.G.

6.4
11.3
11.b
13.1
13.2

Disadvantages

+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Potential linkages with other DTs

IoT
BD
AI
GIS
DT
Blockchain
AM/ RM
MPassport
AR / VR
Digital Platform
BIM

Energy sustainability

BIM can be a valid support tool to green building approach in line with the energy sustainability challenge. In particular all of the three stages in construction process could be covered by the benefits of its use. As argue by [1] during the design phase, BIM with the integration of Life Cycle Assessment methods could promote the selection of sustainbale materials and sustainbaility performances to reduce carbon emissions. During the construction phase [2], BIM can support the simulation not only of the impacts on sorrouding environment but also the prediction of construction processes and risks.

Water Management

Water scarcity and water efficiency are objectives that BIM analysis could support. In particular [4] have investigated the potential of BIM to assessing rainwater harvesting potential in urban areas where BIM could feed the model development in Infraworks thourgh information about some building parameters such as household size, roofing materials and roofing size. Water efficiency, is the main goal of the study of [5], in order to compare different BIM tools to assess the applicability Revit Green Project Template (RGPT), Autodesk Green Building Studio (GBS) and automated GBI assessment tool (AGBIA) with the use of Dynamo.

Transition to circular system

[8] argue that BIM is fundamental to the technological development of circular economy strategies in construction sector and in built environment to reduce resource consumption and waste creation. [9] used material information extracted from BIM to accurate estimation of recoverability and recyclability of a construction and demolition waste. [8] sustain that BIM contribute to a reconstructured 3D model to establish a deconstruction waste management system. More efficient construction and demolition waste could be achieved through BIM combined with a system dynamic simulation to minimise waste production generation from change orders [8].

Temperature regulation

BIM could provide a model and information to support urban microclimate analysis to understand the outdoor comfort. For example, as reported by [3] through plug-ins could be possible to access to BIM information, extract subsets of object information, update BIM parameters, and execute performance simulations by Grasshopper platform. Three plug-ins enabled the use of validated simulation engines of Radiance, EnergyPlus, and OpenFOAM for microclimate variables of wind analysis, solar accessibility, energy use.

Health and Wellbeing

In the last years BIM has gained a lot of attention also to understand indoor and outdoor human comfort. Studies [6,7] were developed on the application of BIM to analyze some health parameters in indoor environment to calculate some indicators such as thermal comfort, volatile organic compound (VOC), formaldehyde concentration, thermal zoning and controls, daylight factor, sound insulation, indoor ambient noise level, room acoustics, security, safe access, outside space, views of nature, sedentary lifestyles and illuminance levels.

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BIM: best practice

Project name

Data-driven Landscape design with LIM®
From Building Information Modelling (BIM)
to Landscape Information Modelling (LIM®)

Year

2019

Location

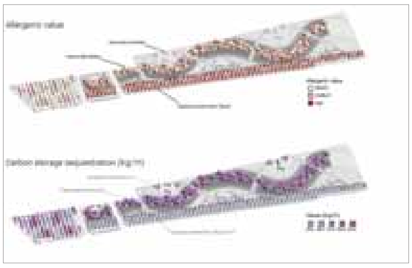
Milan, Italy

Water management

The combination of BIM with other open sources data and the integration with GIS has developed the possibility to assess different design scenarios in Built and Natural Environment in order to understand the water performance of open air spaces. In particular the LIM® project based on BIM technology is able to calculate the water demand (Daily total amount of water requested for trees growth [l / d]), the total annual benefits (sum of values relating to the ecosystem services generated annually [€ / Yr]), and the avoided runoff (amount of carbon sequestration interpreted as CO_2-Eq. [Kg / Yr]). These metrics could contribute to calculate some parameters related to the urban project development from building scale to district scale.

Health and Wellbeing

LIM® system has some potentials in terms of health and wellbeing for outdoor comfort. In particular the system can calculate some parameters related to the quality of air and the green space. For example, air quality can be measured to to quantify carbon dioxide sequestration (amount of carbon sequestration interpreted as CO_2-Eq. [Kg / Yr]), oxigen production (amount of Oxygen (O_2) annually produced by the photosynthetic process [Kg / Yr]). For green space, the system allow to calculate some parameters related to the level of permeability, such as biotope area factor, normalized difference moisture index, green space factor and normalized difference vegetation index.



Other uses and digital applications

By combining the application of BIM, GIS and visualization tools on a database specially developed for this purpose collecting LAND knowledge on the field and validated calculation procedures, it allows to quantify environmental parameters, simulate green growth, and impacts by providing spatial inputs and visualizations, and build a sustainability pre-assessment to support design decisions, approval processes and future maintenance. In addition with other metrics, LIM® is able to get some information during the design process about tree, such as total canopy cover (total area of the project covered by trees canopies [squared meters]), trees characteristics (trees' species types, agronomic characteristics, species number ratios in project), time (visualition of plants and parameters growth. time to ultimate height and growing speed rate. Maintenance frequency) and allergenic values (indicates whether the trees produce potentially allergenic pollen [absent / low / medium / high]).

Description

The LIM® Landscape Information Modelling service through the use of nature-based solution and a data driven approach, offers, in addition to the common data that can be extracted from the BIM modelling software, information that quantifies the environmental and partly socio-economic performance of the landscape project.
With the inclusion in the BIM methodology of the eighth dimension, or 8D environmental dimesion, LAND, through the LIM®, wants to revolutionize the way it designs urban landscapes by measuring the impact on air quality, the management of water resources and soil conditions to improve the well-being of the people living in those places and monitor their sustainability.
The work of the multidisciplinary team of LAND, which is translated and coded in a digitalized language applicable to the LIM® methodology, provides both a design proposal that can be easily managed from its initial phases, and a control and analysis of the existing situation, foreseeing the possibility of hypothesising but also to calculate and estimate the positive effect of the landscape project on economic, environmental and social sustainability issues, allowing continuous monitoring of nature's dynamism.

Source: https://www.landsrl.com/limlandscape-information-modelling

Digital Twin (DT)

The first conceptualization of Digital Twin has been made by Michael Grieves in 2003, in the product life cycle management field, where a set of virtual information can describe a potential or real physical manufactured product from micro scale to macro level. More recently Batty (2018), introduce the concept of "Mirror representation" to describe the capacity of Digital Twin to reproduce the physical counterpart into virtual world.
Cities can be reproduced in digital world through data and information collected from the real world about different topics and shape such as transportation, buildings, energy to improve the level of governance and increase the participation of citizens in the design and decision making processes.

Challenges

Objectives

Energy sustainability
- Energy efficiency
- Carbon impact
- Energy produced from RES

Temperature regulation
- Local microclimate
- UHI

Water management
- Runoff mitigation
- Water scarcity
- Water quality

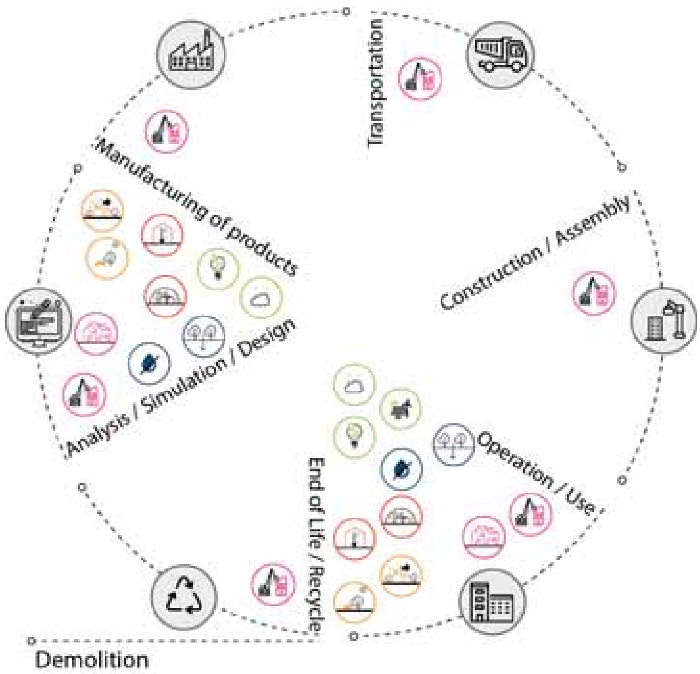
Health and wellbeing
- Comfort and life quality
- Urban space quality

Transition to circular system
- Circular Infrastructures and buildings
- Circular Materials and products

Other benefits

- time reduction
- increase of efficiency
- increase of effectiveness
- better governance
- better data management
- real time monitoring

DT uses in construction life cycle of Challenges



Strategies

M A

Scale of application

Building
Neighborhood
City

Potential linkages with other DTs

BIM
BD
AI
GIS
IoT
Blockchain
AM/RM
MPassport
AR / VR
Digital Platform
DT

S.D.G.

6.4
11.3
11.b
13.1
13.2

Disadvantages

+ Contribution to global warming
+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Energy sustainability

Digital Twin technology could be applied for different objectives of Energy Consumption challenge. As reported by [1], Digital Twin for Positive Energy District (PED) can accelerate the transition towards a more sustainable society. In Digital Twin platform, other enabling technologies such as sensors, can measure and collect some information related to temperature, moisture, energy consumption, renewable energy production, carbon footprint, CO_2 emissions from building scale to district. Few case studies are involved in recent years considering Energy Consumption challenge, for example in Helsinki, Zurich and Dundalk.

Temperature regulation

Local Microclimate parameters are assessed in Zurich and Helsinki Digital Twin as reported by [2] focusing in particular on the simulation of future climate scenarios in built environment considering the study of shadows, solar radiation, sunshine hours and ventilation analysis.
In addition some research projects were involved in the last years to study and manage the Urban Heat Island phenomenon, for example Cooling Singapore is a multi-disciplinary research project dedicated to developing solutions to address the urban heat challenge in Singapore, as well as the research conducted by [3] for Qingdao city.

Water Management

The Urban Digital Twin of Dublin has focsued on the development of risk modelling [2] to understand which are the areas at risk in the built environment and to support the local decision making process to avoid these risks.
Some researches have proposed the objectives of water management to intelligent green building to manage waste water and rain water harvesting and re utilization [4] during operational phase, while [5] have proposed a Green Metrics and Digital Twins for Sustainability Planning and Governance of Smart Buildings and Cities to optimize rainwater drainage to avoid soil contamination.

Health and Wellbeing

There aren't specific application of Digital Twin for the Health and Wellbeing but instead that, Virtual Singapore simulate and model heat and noise map to support local decision making. In addition, Dublin, Zurich and Helsinki can simulate the exposure to pollutants of local inhabitants [2] while Herrenberg has experimented Mobility and traffic simulations for awareness-raising on anthropogenic pollution issues [6].

Transition to circular system

[1] proposed that Digital Twin Technology applied to Positive Energy Districts model can ensure also the transition of Built Environment to Circular System. In addition, [7] have explored the potential of Digital Twin to extend the service life of building elements through predictive maintenance, to enable the reuse at the building's demolition phase and to remanufacturing of construction waste or to support design reuse. The project "Digital Twin for Circularity" of the Digital Twin Cities Centre underline the potential of this tool to mark property for demolition, to make an inventory of exterior and interior materials, to store information for future buildings and to analyze the re-use and recycled potential of materials.

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DT: best practice

Project name

Kalasatama digital twins
pilot project

Year

2019

Location

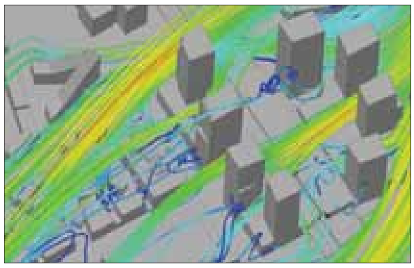
Helsinki, Finland

Energy consumption

The city of Helsinki has developed other dynamic 3D city models, named Energy Atlas platform, that have contribute to simulate energy information, such as information on the energy leakages of buildings, and to educate property owners and citizens about more energy-efficient consumption and carbon neutral behaviour.

Temperature regulation

The Digital Twin for Kalasatama District has used to design, test and build things digitally firts before the real development. In this way, some analysis related micro climate conditions has been developed. Wind simulation, wind speed and wind direction were investigated through Ladybug Tols plug-in of Rhinoceros parametric software. Simulations have been made for each month for the reference period (1990). Wind simulations were made using the CityGML city information model and importing it into ANSYS Discovery Live which is capable of performing accurate calculations of air flow behavior with various objects.
In addition solar hour analysis and a shadow analysis were carried out simulate micro-climate conditions.



Other uses and digital applications

The Digital Twin for the Smart District of Kalasatama have been implemented in other uses such as Smart City (traffic and transportation), City Planning (Project Management, Building and Infrastrcture Design), Services & Workflow (Business, Innovations & Products), Project Planning (Building permission, decision making and web services) and Comunication and Interaction (City Marketing, Tourism and Navigation).
The applications used beyond the analysis for the Energy Consumption and Temperature regulation are measurements and tracking (airflow, noise, visibility, floods and shadows), sensor data (IoT), data integration (big data, open data etc.), Co-operation platforms (feedback, participatory processes) and Simulations (Virtual Reality and Augmented Reality).

Description

The digital twins in the Kalasatama project in Helsinki offer high quality 3D city models as open data to all operators. The project team hopes that these city model platforms will promote diverse product development, research, teaching and innovation.
The general objective of the project was to produce high quality digital twin city models of the Kalasatama area and to share the models as open data. The models serve as a platform for designing, testing, applying and servicing the entire lifecycle of the built environment. The progress of the project was divided into five intermediate objectives. The general objective of producing the models was the first. The sharing of the 3D city models as open data was the second objective in the project. The third objective was focused on cooperation with the main partner, the Smart Kalasatama project. The fourth objective was to try out the latest ways to model, test and utilize 3D city models. The fifth objective was to promote the exploitation of digital twins in city processes and service production

Source: https://www.hel.fi/static/liitteet-2019/Kaupunginkanslia/Helsinki3D_Kalasatama_Digital_Twins.pdf | Photo credit: -

Geographic Information System (GIS)

A geographic information system (GIS) is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to a map, integrating location data (where things are) with all types of descriptive information (what things are like there). This provides a foundation for mapping and analysis that is used in science and almost every industry. GIS helps users understand patterns, relationships, and geographic context. The benefits include improved communication and efficiency as well as better management and decision making. Some examples of its applications include cadastral management, disaster monitoring, infrastructure maintenance, and regional planning" (Wang et al., 2019). GIS is also used with BIM for urban data management, energy-efficient building and urban design, optimising the climate requirements of buildings, and tracking supply chain and material flows.

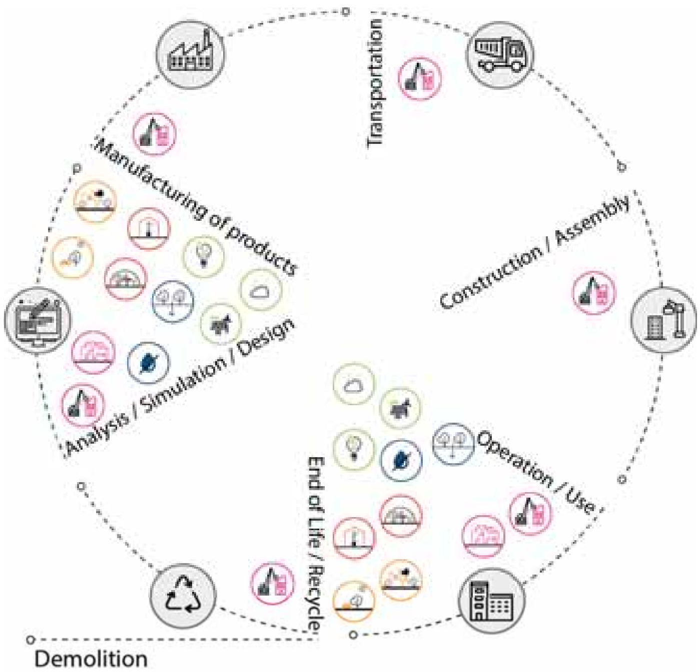
Challenges / Objectives

Challenges	Objectives		
Energy sustainability	Energy efficiency	Carbon impact	Energy produced from RES
Temperature regulation	Local microclimate	UHI	
Water management	Runoff mitigation	Water scarcity	Water quality
Health and wellbeing	Comfort and life quality	Urban space quality	
Transition to circular system	Circular Infrastructures and buildings	Circular Materials and products	

Other benefits

- time reduction
- increase of efficiency
- increase of effectiveness
- better governance
- better data management
- real time monitoring

GIS uses in construction life cycle of Challenges



Strategies

M A

Scale of application

Building | Neighborhood | City

Potential linkages with other DTs

IoT, BD, AI, BIM, DT, Blockchain, AM/RM, MPassport, AR/VR, Digital Platform, GIS

S.D.G.

6.4 | 11.3, 11.b | 13.1, 13.2

Disadvantages

+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Energy sustainability

GIS can support all the objectives of Energy Sustainability challenge, related to energy efficiency, carbon impact and energy produced by renewable energy systems. In particular [1], have developed a urban energy modelling and energy efficiency scenario based on GIS technology for the city of Turin. They have evaluated the energy performance of existing residential buildings using the energy performance certificate database and have identified the more effective retrofitting interventions by applying an urban-scale energy model. They have measured a significant energy and carbon saving for space heating.

Water Management

Runoff mitigation is one of the main objectives that local administration wants to achieve to adapt built environment to the increase of urban flood events caused by extreme precipitation. [3] have tested a GIS based simulation to understand the variations of flood regulation under different high-intensive urban development scenarios. The analyses were carried out utilizing SWMM (Storm Water Management Model) which is open-source flood inundation simulation approach with the help of GIS in a more qualitative manner. results indicate that expanding built form scenarios increase the flood venerability for city functions.

Transition to circular system

In the last years GIS has gained some attention in the transition of Built Environment to Circular system to identify, map and manage the resoruces embedded in building stocks for future reuse or recycling [5]. GIS is also used to support urban mining and industrial symbiosis, from one hand to identify, calculate, and map material stocks in cities and from the other hand to develop a GIS-based supply chain model for industrial symbiosis based on recycled concrete aggregate.

Temperature regulation

At city and neighborhood scale, GIS plays a key role to support urban planning and urban design decision making process to adapt built environment to the effects of climate change. [2], have assessed the influence of green spaces and Green Mark commercial buildings on Singapore's temperature distribution using non exhaustive factors related to energy consumption and efficiency. In addition the case study have examined the effectiveness of green spaces and commercial buildings in reducing the rate of temperature change. All of these operations were carried out with GIS to promote the goals of urban polcies to mitigate urban heat island phenomenon.

Health and Wellbeing

[4] underline the potential of GIS tool to support the analysis of indicators identified to develop a framework for Air Quality Management Zones. This research was applied to Antwerp and Gdansk, GIS tool support the calculation and mapping of each indicators involved manage the built environment from the point of view of quality of air. Indicators selected and calculated with GIS are compactenes, building height, street pattern, density, gross floor area ratio, street canyon density, height variability, percentage of high vegetation cover, residential and commercial function, vulnerable groups to air pollution and cycling infrastrctures, urban parks, and open air facilities.

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GIS: best practice

Project name

Sustainable urban model to new distrcit development with ArcGis Urban

Year

2021, ongoing

Location

Uppsala, Sweden

Energy Sustainability

The new 3D sustainbale development model for new district in Uppsala has supported the development of new district with transit oriented development able to led the community to carbon neutral city goal. From the transportation point of view, the platform developed with GIS support recharge points for buses powered by renewable energy and biofuel produced from local food waste. New bike lanes and a two-story bike-parking garage next to the train station encourage people to leave their cars at home.

Health and Wellbeing

The new 3D sustainbale development model for new district in Uppsala has supported the development of new district taking into account the outdoor comfort principles and the management of existing natural resources that were not disrupt by the new development but integrated in the open air spaces, such for example the existing trees.

Other uses and digital applications

Others applications of the new 3D sustainable model of the city of Uppsala were related to transportation and citizen's participation in the planning process of the new city district.
The new platform has supported the analysis and design of the rail network and new tramway form the spine of the new city district, matching a growing pattern of urban planning called transit-oriented development that reinforces the value of denser urban pedestrian-oriented areas centered around public transit, and having strong cycling connections.
City technicians were surprised by the very interest of people in the 3D sustainable model. Planners and architects are conducting public consultations according to planning law. The city is at the proposal stage now, and during the spring of 2021, the first detailed planning will take place, which will require another rigorous set of revisions.

Description

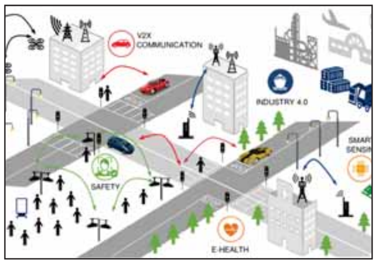
Uppsala city planners set out to create a southeastern city district, through the adoption of data-driven and model-centric approach of geodesign powered by a geographic information system (GIS).
City technicians have tested out cutting-edge techniques and work to find new solutions for becoming more sustainable. The innovative project was developed with the support of two universities in Uppsala, through a close connection with the academic community where we can explore creative and innovative approaches that include new actors and ways to have a smaller climate footprint.

Source: https://www.esri.com/about/newsroom/blog/uppsala-sustainable-development/

Internet of Things (IoT)

As reported by Li et al. (2014), Internet of Things (IoT) can *"enables information gathering, storing and transmitting be available for things equipped with the tags or sensors".* Different researchers argue that IoT is constitute by sensors layer able to detect and collect information from physical environment, by network layer for processing and transmitting data acquired by sensors and by application layer that constitute the final field (e.g., transportation, energy etc.) for decision making processes.

IoT has contributed to expand the Smart City paradigm in the last years, in order to support city operations with minimal human interventions. Some key components that can differ from each city are smart energy grids, smart communities, smart healthcare and smart transportation.



Challenges

Energy sustainability

Temperature regulation

Water management

Health and wellbeing

Transition to circular system

Objectives

Energy efficiency · Carbon impact · Energy produced from RES

Local microclimate · UHI

Runoff mitigation · Water scarcity · Water quality

Comfort and life quality · Urban space quality

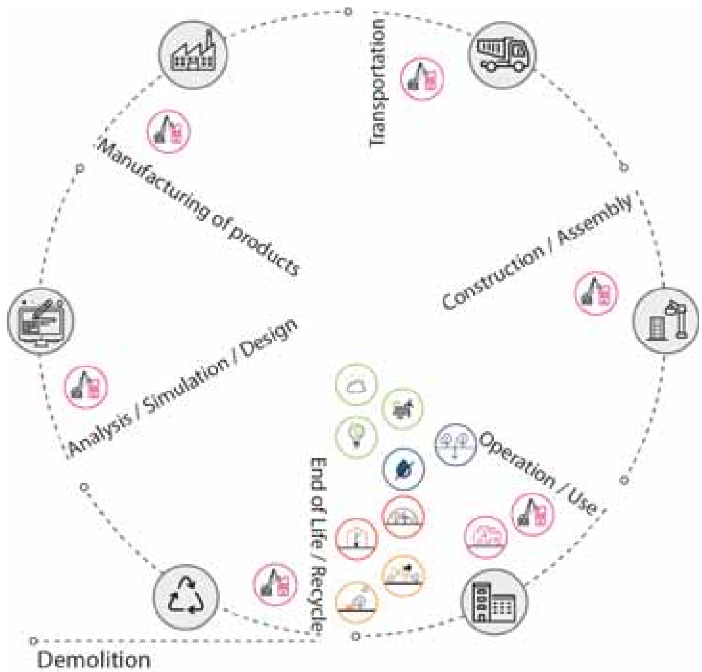
Circular Infrastructures and buildings · Circular Materials and products

Other benefits

time reduction · increase of efficiency · increase of effectiveness

better governance · better data management · real time monitoring

IoT uses in construction life cycle of Challenges



Strategies

M · A

Scale of application

Building · Neighborhood · City

Potential linkages with other DTs

BIM · BD · AI · GIS · DT

Blockchain · AM/ RM · Digital Platform

IoT

S.D.G.

6.4 · 11.3 · 11.b · 13.1 · 13.2

Disadvantages

+ Contribution to global warming
+ long implementation process
+ high level of complexity
+ engagement of different disciplines and competences

Energy sustainability

IoT technology could be applied for different objectives of Energy Sustainbaility challenge. We can find IoT in different scale, at building scale Smart Metering and Environment Monitoring have increased knowledge on how buildings perform [1] and also Building Energy Managment System (BEMS) used a network of sensors in all the environments [1]. The IoT is one of the main key technologies to enable Smart City concept towards the needs of improve energy efficiency of various city components, such as applications in smart Grids, Smart Homes, Smart Street Lights and Smart Parking [2]

Temperature regulation

Urban Heat Island effect could be also studied through the application of IoT in temperature monitoring and development of prediction system [3]. 3M'Air project aims to explore the potential of participatory citizen measures using low-cost sensors in order to improve the local knowledge of air quality and temperature and then bridge the gap between individual exposure and regional measurements [4]

Water management

An example of IoT applied in Built Environment to support the Water Management challenge is Polder Roof [5], where sensors can contribute to measures and regulates the rain-water collected on the rooftop in a green roof system.

Health and wellbeing

There are some case studies that used IoT in smart buildings to monitor the indoor environment. Interact [6] is a system that collects data and information from IoT sensors incorporated in lighting systems and provides some information to support the sustainable building operations. The Edge smart office Building [7] use the IoT benefits to increase the health and wellbeing of indoor environment by controlling heating, ventilation and space conditioning systems.

Transition to circular system

[8] have explored the potential of IoT for the physical and digital traceability of building elements in different construction lifecycle step. This potential was enhanced with the integration of RFID. [9] explore the use of IoT embedded in construction materials of distributed manufacturing of modular homes in which information flow is collected thorugh each life cycle step.

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IoT: best practice

Project name

Polder Roof®+ Smartroof 2.0

Year

2018

Location

Amsterdam

Water Management

The aim of the start-up Metro Polder is to make cities future-proof, by applying smart water management. Think of reusing rainwater or for cooling cities to combat heat stress.
The blue-green roofs conceptualized and realized by Metro Polder are equipped with a buffer system, an internet-connected valve and an online dashboard. The valves sensors and rain radars control the water level and discharge real-time. This smart connection enables dynamic water storage. A proven effective technology that has been implemented in projects in several locations worldwide, including the Netherlands, Guatemala, United States, France and the United Kingdom.

Temperature regulation

The aim of Smart Roof 2.0 research is to investigate the effect of water availability on actual evaporation (Ea) and the distribution of energy between the latent heat flux (LE) and the sensible heat flux (H) in a rooftop environment in Amsterdam, the Netherlands. Researchers have compared the water and energy balance of conventional green roofs and (blue-)green roofs equipped with a novel water storage and a passive capillary irrigation system. Research group have measured actual evaportation on-site using sensitive custom build weighing lysimeters integrated in the green roof over one year. We provide quantitative insights and practical modeling procedures to assess the success of different roof types in evaporating and storing rainwater and potentially cooling the air to mitigate the UHI phenomenon.

Other uses and digital applications

Other uses of smart green-blu roof could be meet in other pilot project realized by Metro Polder such as B. Bylon also built in Amsterdam. B. Bylon is an edible roof terrace, or Roof Park, on office concept B. Amsterdam is an impressive 1500m^2 park. It is the first of its kind and extremely versatile. On the roof you will find a water feature, two pétanque courts, a large vegetable garden, fruit trees and a chicken coop. There is an out-door seating are as well as covered office spaces with hammocks for meetings; you will even find two decorative Trabant cars on this roof.

Description

On the Marineterrein in Amsterdam, the roof of one of the buildings used to conduct detailed research into the evaporation of blue-green roofs. The effects of different substrate thicknesses and water buffering are compared with each other. Results of this research show that water availability is a condition for enhanced cooling and biodiversity on green roofs. In practice, the PolderRoof worked so well that the air conditioners for the poorly insulated top floor were not necessary during the hot summer of 2018.

Source: https://metropolder.com/projecten/smartroof-2-0-2/

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Glossary of Terms

BT	Building Technologies
BI	Blue Infrastructure
BIPV/BAPV	Building-Integrated Photovoltaics /Building Applied Photovoltaics
CO2	Carbon Dioxide
CPCC	Climate Positive Circular Communities
ES	Energy Sustainability
ES	Energy systems
EU	European Union
GHG	GreenHouse Gases
H/W	height-to-width ratio
HW	Health and wellbeing
PED	Positive Energy Districts
RES	Renewable Energy Sources
S	Shading devices
SPEN	Sustainable Plus Energy Neighborhoods
SUDS	Sustainable Urban Drainage Systems
SVF	sky view factor
SWM	Sustainable Water Management
TCS	Transition to Circular System
TR	Temperature Regulation
UGI	Urban Green Infrastructure
ZEN	Zero Emission Neighborhoods

Legend icons & symbols

Challenges

- Energy sustainability
- Temperature regulation
- Water management
- Health and wellbeing
- Transition to digital system

Objectives

- Energy demand
- Carbon impact
- Energy produced from RES
- Local microclimate
- UHI
- Run off mitigation
- Water scarsity
- Water quality
- Comfort and life quality
- Urban space quality
- Infrastructure and buildings
- Materials and Products

Performances

- Energy from RES on site
- Low carbon material use
- Greening
- Energy efficiency
- Temperature surface/air
- Outdoor thermal comfort
- Shadow effect
- Water retention
- Water storage and reuse
- Water treatment
- Green space
- Space for socialization
- Air quality
- Walkability

Other benefits

- Artistic expression
- Biodiversity
- Cooling costs
- Cooling effect
- Const temperature
- Easy to repair
- Fire resistant
- Flexibility
- Food production
- Glare
- Heat gain
- Indoor thermal comfort
- Integration
- Lifespan/Reuse
- Lighting costs
- Mold and condensation
- Noise pollution
- Privacy
- Storage
- Thermal insulation
- UV rays
- Weather protection

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ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

ANNEX

9.2 Natural and mechanical ventilation in climate responsive and net-positive energy buildings

Natural and mechanical ventilation in climate responsive and net-positive energy buildings

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Index

1. Climate responsive and net-positive energy buildings: definitions

In the framework of research and practice within the field of building design, the aim of **responsive architecture** is to make the buildings able to adapt their shape, color, form or character (by means of actuators) using sensors' measurements of environmental conditions. In this way, responsive technologies such as control systems, sensors and actuators can be used to improve buildings' energy performance. This technique is distinguished from other forms of interactive building design, since smart and responsive technologies are embodied in building's fabric core elements, thus allowing, for instance, to connect the shape of the facility to the environment where it is located [1]–[6]. In practice, climatic responsive design uses weather data (e.g., wind, sun, humidity and rainfall) to create a building structure reflecting the weather conditions of the peculiar area where the building is located [7]. Some examples of applied climate responsive architecture are reported in Figures Figure 1 -Figure 2Figure 3.

Net-positive energy buildings (nPEBs) can be defined as ones that, on annual average, produce more renewable energy than they import from external sources. As Hu (2016) highlights "this is achieved using a combination of small power generators and low-energy building techniques, such as passive solar building design, insulation and careful site selection and placement" [8], [9]. In practice, many technologies and principles of net-zero energy buildings (nZEBs) are followed, with new district/network and alternative energy resources (instead than renewable) perspectives. Several techniques can be used to maximize the energy production and minimize the energy consumption in nPEB and nZEB, including: improved levels of building insulation, high performance glazing, daylight, efficient HVAC (Heating, Ventilation and Air Conditioning) systems (e.g. heat pumps and exhaust energy recovery), high efficiency lighting and control, natural ventilation and thermal regulation through thermal mass [8], [10], [11]. Examples of buildings exploiting these solutions are reported in Figure 4 and Figure 5.

Figure 1: "Ecobulevar de Vallecas" in Madrid (Spain). Built from recycled plants and materials, the building is able to lower the temperature by up to 10 °C by mimicking a greenhouse system [7], [12]

Figure 2: "Caixaforum Vertical Garden" in Madrid (Spain). 250 species of plants grow on a 460 square meters vertical garden, contributing in creating indoor and outdoor thermal comfort conditions [7], [13]

Figure 3: "Abu Dhabi Central Market" (United Arab Emirates, UAE). Resembling the traditional Islamic art of coffered roofs, the covering is able to adapt to different sunlight conditions, with natural cooling when allowed by outside conditions [7], [14]

Figure 4: "Sustainable Energy Fund Office Building" in Schnecksville (Pennsylvania, USA). The building orientation and windows' design allows to take advantage from shade, sun and daylight, minimizing the loss of energy. It also uses a roof photovoltaic array. It is planned to generate 130 % of the required energy [15]

Figure 5: "2226" in Lustenau (Austria). The office building does not use energy sources different than internal gains or solar gains, being able to always maintain a temperature comprised between 22 °C and 26 °C by means of construction techniques, night cooling by means of natural ventilation, proper use of thermal mass and sensors' support [10], [11], [16]

2. Natural ventilation principles in climate responsive and energy positive buildings

By definition, **natural ventilation** (**NV**) relies on natural forces. For this reason, it is considered one as one of the main techniques to lower buildings' energy consumption [17]. Moreover, NV was observed to significantly enlarge the acceptable range of indoor thermal comfort, with respect to mechanical ventilation (MV) systems [18]. This led to the modification of ASHRAE Standard 55 [19], which introduced adaptive model for naturally ventilated buildings, beside the steady state *PMV-PPD* model from Fanger [20]. This allowed the possibility to accept an increase of indoor temperature when outdoor temperature is higher. Moreover, it was observed that NV also led to benefits related with symptoms associated with Sick Building Syndrome, satisfaction with the environment, productivity and job satisfaction [17], [21].
For these reasons, it is clear that NV techniques are worth to be analyzed in the framework of climate responsive and net positive energy buildings For instance, eleven glass towers will be incorporated in Masdar Headquarters in Abu Dhabi, in order to achieve carbon neutrality firstly, and even energy generation later (Figure 6 -Figure 7Figure 8) [22], [23].
The natural forces used by NV are of two types: (1) wind coming from the outdoor environment and (2) buoyancy forces formed by gradients of temperature inside building [17]. Efficiency of NV depends on building's architectural and location characteristics, such as spacing and arrangements, building orientation, landscaping and size of openings [24].
Following subsections explore different techniques of NV, grouped according to the driving forces they exploit. Examples of real buildings using the techniques are also included. Main purposes NV can be used for and some guidelines to be consulted for developing NV in buildings are also listed.
It is important to highlight that more than one technique (and driving force) can be used in the same building.

Figure 6: Rendering of Masdar Headquarters in Abu Dhabi (UAE) [23]

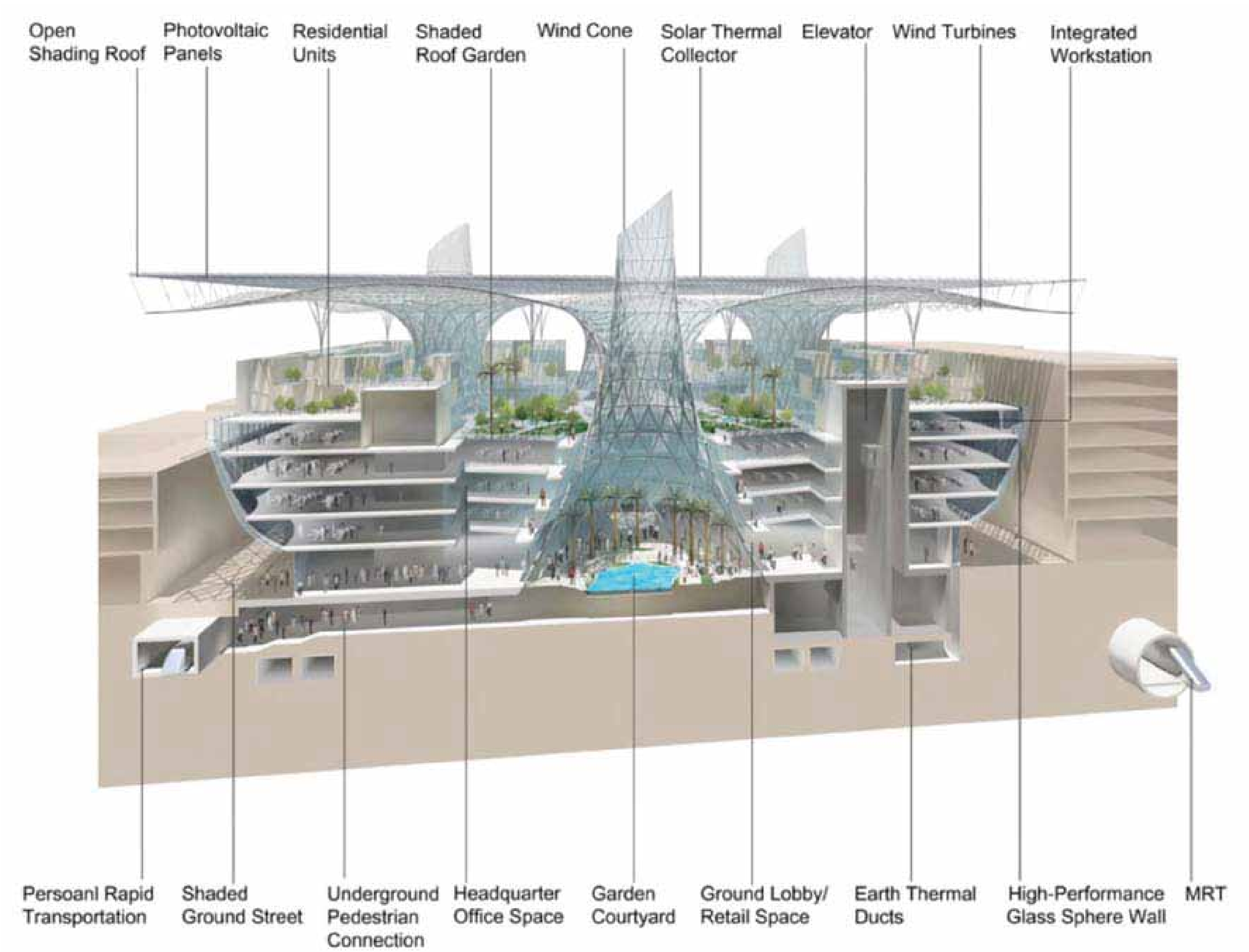

Figure 7: Section of Masdar Headquarter (Abu Dhabi, UAE) with different sustainability strategies, including wind towers [23]

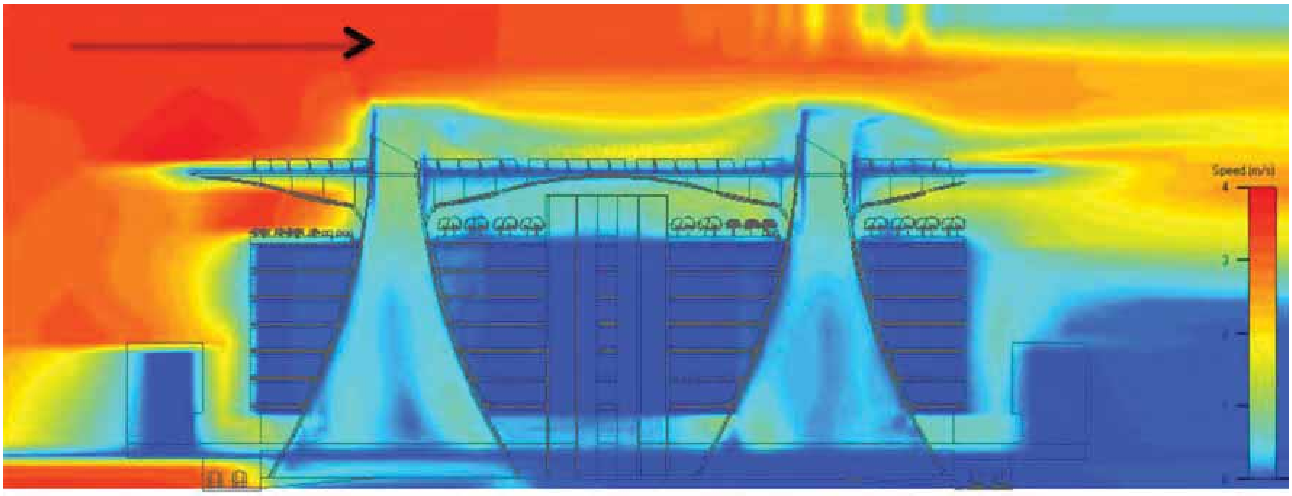

Figure 8: Section of Masdar Headquarters (Abu Dhabi, UAE) - natural ventilation through wind towers: Computational Fluid Dynamics [23]

2.1 Wind induced natural ventilation

This NV technique is driven by a difference of pressure between the windward and the leeward side of a building, resulting in an air movement due to the pressure gradient (Figure 9) [24]–[30]. It is important to remark that architectonic solutions for wind induced NV (listed below) can also be exploited for buoyancy driven NV, even if some further attentions might be needed (i.e. windows or openings at different heights to take advantage of convection).

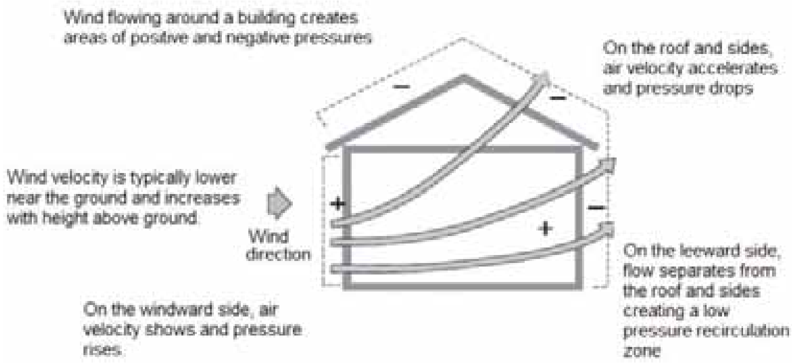

Figure 9: Mechanism of wind induced natural ventilation [24]

2.1.1 Fenestration: single-sided ventilation

This type of NV is produced through one or more openings on the same side (wall) of an enclosed indoor space. Ventilation is mainly driven by turbulence. It is the most simple technique, but low ventilation rates and airflow depth penetration are induced. The ventilation rate can be increased by stack effect if more than one opening at different heights are present [24]–[30].

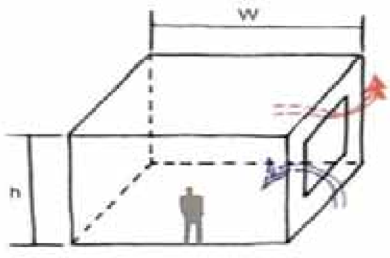

Figure 10: Single-sided ventilation [24]

Figure 11: Bauhaus (Dessau-Roßlau) – lined up windows operated by one unique joint actuator [25]

2.1.2 Fenestration: cross ventilation

This NV technique is driven by airflow entering an indoor space from an opening on one side (windward wall), and leaving from another side (leeward wall). Consistent airflow and deep air penetration can be achieved. An additional buoyancy effect can be produced if intake and outtake openings are located at different heights. Nevertheless, uncomfortable drafts might be produced by inappropriate windows' design [24]–[30].

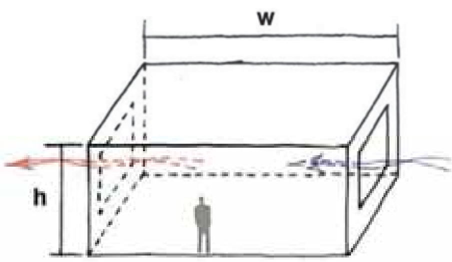

Figure 12: Cross ventilation [24]

2.1.3 Wind tower / Wind catcher

Being located next to the roof or as separate structures, they are designed to cool and circulate air by means of prevailing summer winds. Having several openings on different sides, they can work as inlets and outlets at the same time. They can be used together with wind scoops (see Paragraph 2.1.6), with the latter working as inlets. More air flow can be produced collecting and extracting air at higher levels [24]–[30].

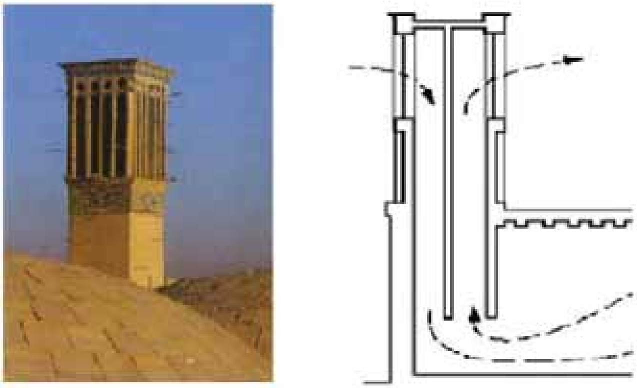

Figure 13: Wind tower [24]

Figure 14: Yazd (Iran) – traditional wind towers [25]

2.1.4 Wing walls

Wing walls are used to increase efficiency of NV, especially with single-sided NV and on sites with variable direction and/or low velocity of external wind. Constructive elements are used to increase the pressure gradient between inflow and outflow of air [24]–[30].

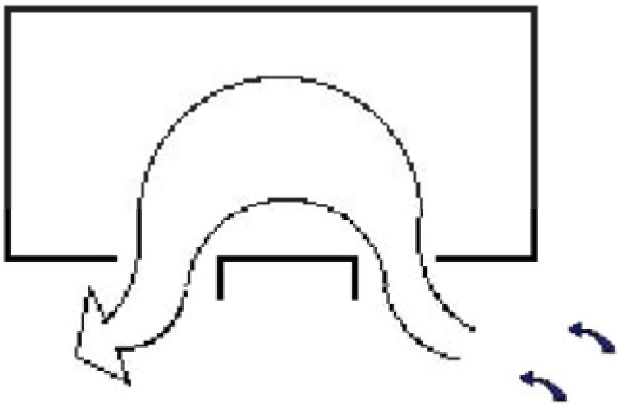

Figure 15: Wing walls [24]

2.1.5 Deflection by edges

This constructive technique is also used to improve the air-change, by means of deflection of the prevailing wind direction [24]–[30].

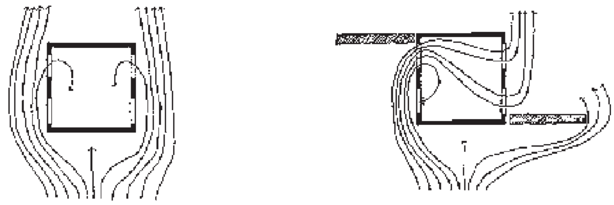

Figure 16: Example of a 90° deflection obtained by edges [24]

2.1.6 Wind cowls / Scoops

This architectural element is thought to catch a higher pressure air from roof top, carrying it below. This allows warm air to escape again from a higher opening. The effectiveness of the scoop depends on the opening angle (with an angle higher than 30° it starts to be ineffective). They can also be placed in the landscape outside of the building, with air being conducted via embedded ducts [24]–[30].

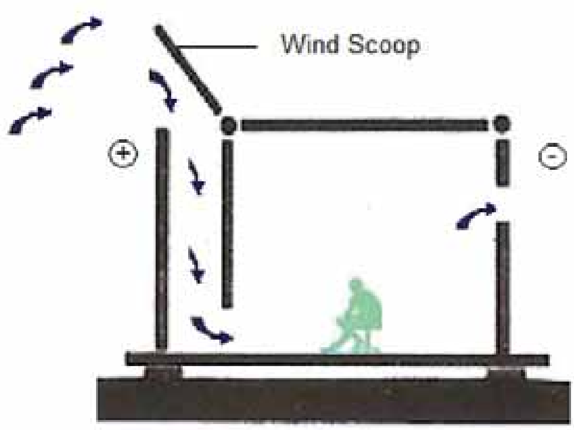

Figure 17: Wind scoop [24]

Figure 18: Wind cowls able to move with the wind changing direction in a beer brewing of Kent (England) [25]

Figure 19: Wind cowls enhancing NV in Nottingham Jubilee Campus (England) [25]

2.1.7 Rotating wind cowl, turbine ventilators, exhaust cowls, roof vents, roof cowls

These elements are used to enhance wind-driven ventilation. In order to improve the interaction with the external wind, they can be installed on the roof [24]–[30].

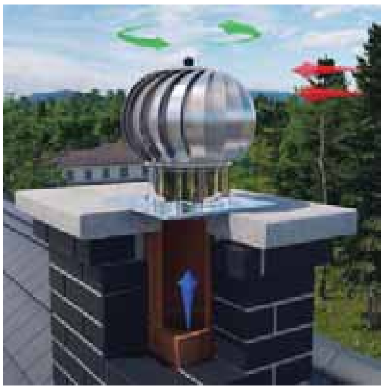

Figure 20: A roof chimney cowl, designed to increase and stabilize the draft of the chimney and the smoke ducts *[31]*

2.1.8 Ventilation openings in the façade

These elements are designed with the sole scope of being inlets and outlets for ventilation. In order to support a sufficient pressure drop, their size needs to be adequately designed. They can also be coupled with local suppliers or extractors [24]–[30].

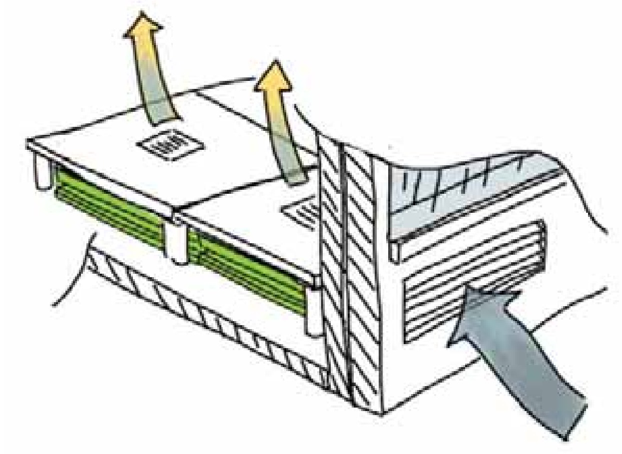

Figure 21: Ventilation openings in the façade [24]

Figure 22: Harm A. Weber Academic Center at Judson University in Elgin (Illinois, USA) – ventilation exhaust device on the roof [25]

2.1.9 Embedded ducts, ventilation chambers

These elements are defined as spaces within buildings, with the primary scope of collecting, transporting and distributing ventilation air [24]–[30].

2.2 Buoyancy driven natural ventilation

This technique of NV is driven by temperature gradient, which produces an upward airflow due to thermal buoyancy (Figure 23) [24]–[26], [28]–[30].

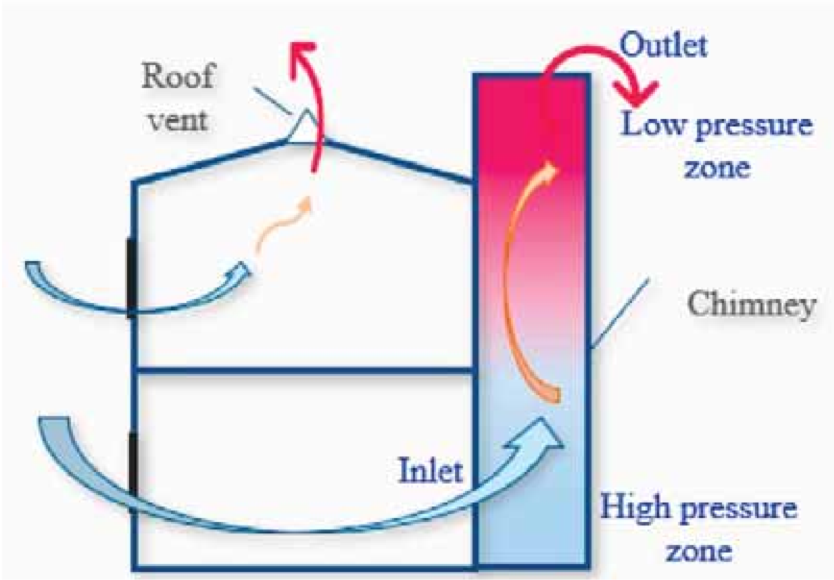

Figure 23: Stack ventilation [26]

2.2.1 Stack ventilation

With stack ventilation technique, cold air enters from lower openings in the envelope. Being heated inside the building, and thus becoming less dense, it leaves the building from openings high up in the envelope. With this technique, the heat removed from indoor environments is proportional to height difference between inlets and outlets [24]–[26], [28]–[30].

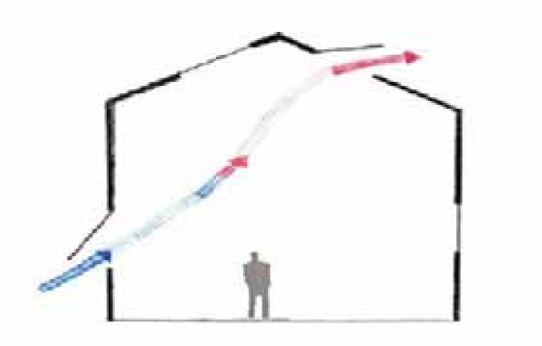

Figure 24: Mechanism of buoyancy driven natural ventilation [24]

Figure 25: Openings on opposite sides and at different heights of a space, allowing cross and stack ventilation [32]

2.2.2 Double skin façade (Vent-skin walls)

An additional second glazed envelope is added on the outside, creating a remarkable gradient of temperature, forcing the air to migrate upwards, being released by vents at the top. Automated vents in the inner skin allow indoor air to migrate from inside to the façade. Greenhouse effect can be used to pre-heat air during winter, but may constitute a drawback during summer. This design element can also be exploited for more advanced energy performance and daylight use [24]–[26], [28]–[30].

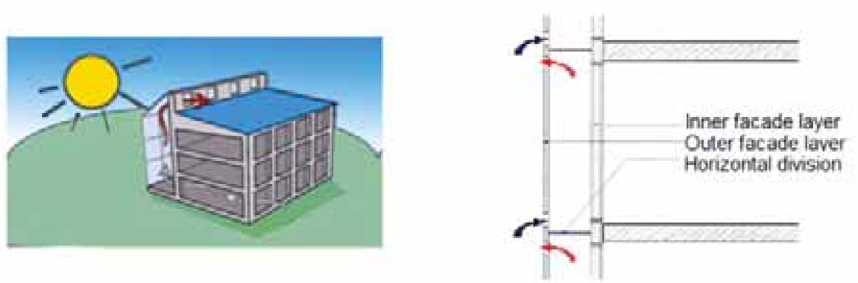

Figure 26: Mechanism of buoyancy driven natural ventilation in a double skin façade [24]

Figure 27: GSW building in Berlin (Germany) – cross ventilation is facilitated by the double glass façade providing a stack [25]

2.2.3 Trombe wall

Trombe wall is similar to a double-skin façade, but heat is also absorbed by the black-painted exterior surface of the more internal massive wall [33].

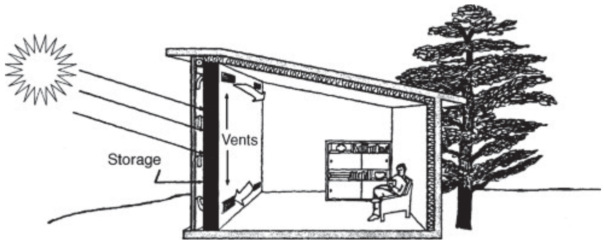

Figure 28: Trombe wall [33]

Figure 29: Trombe wall in Vivienda Trombe (Odeillo, France) [34]

2.2.4 Solar (thermal) chimney / Roof solar chimney

Chimneys are used to enhance the stack ventilation effect, used as a way out for air exhaust. The stack pressures can be increased by using incorporated glass elements (solar chimneys). Care needs to be taken in the design, e.g. chimney outlet needs to be located in a negative wind pressure zone (obtained by roof profile design). An extra fan can be incorporated for air extraction [24]–[26], [28]–[30].

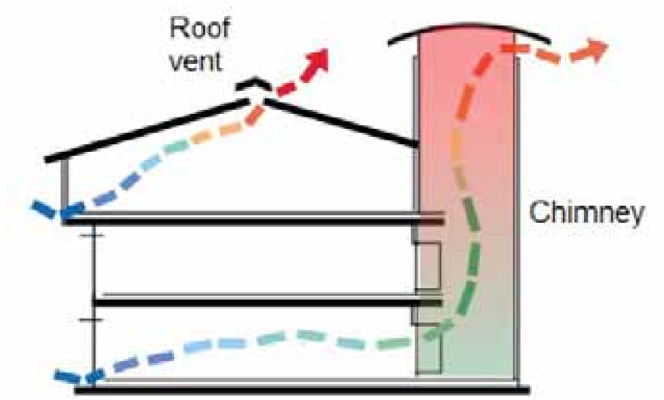

Figure 30: Chimney for NV [24]

Figure 31: McEwen Graduate Study & Research Building in York University (Toronto, Ontario, Canada) – a solar chimney for facilitating NV [35]

2.2.5 Solar façades (e.g. unglazed transpired solar façade and glazed transpired solar façade)

Solar façades are active façades designed in order to interact with solar radiation, exploiting it for heating, lighting or ventilation. Opaque façades absorb and reflect the incident solar radiation, without being able to directly transfer it inside the building. The scheme of a transpired solar collector is reported in Figure 32 [36].

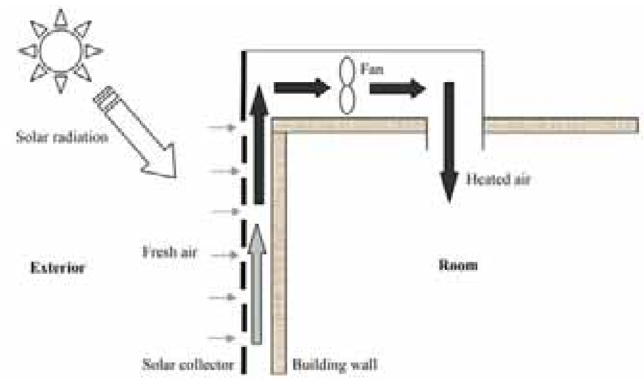

Figure 32: A scheme of a building integrated solar thermal system, such as the unglazed transpired solar collector [36]

2.2.6 Atrium

It is a variant of the chimney principles. In fact, air can be drawn out from both building sides to a central point for extraction. Also in this case, particular care needs to be taken with the positioning of outlet vents. This design element can also be used for more advanced daylight exploitation [24]–[26], [28]–[30].

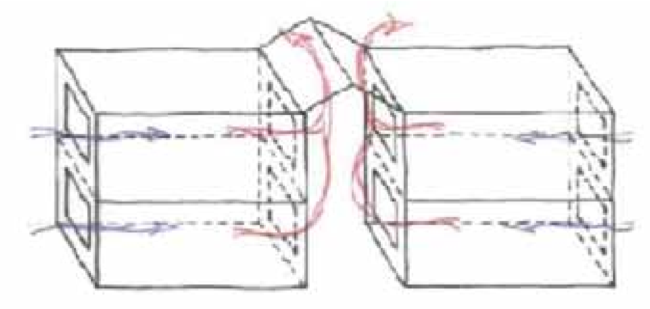

Figure 33: A NV strategy obtained by means of an internal atrium [24]

2.3 Main ways to exploit natural ventilation

NV can be used for different purposes, concerning the regulation of indoor environmental conditions. Main ways to exploit NV are listed here below.

2.3.1 Air-change

One first and intuitive purpose of NV is air-change. Thus, NV can be exploited for enhancing the Indoor Air Quality (IAQ) conditions, with CO_2, pollutants and pathogens removal. The effectiveness of removal depends on NV efficiency and, of course, on outdoor conditions [37], [38].

2.3.2 Thermal regulation

Thermal regulation is the process of variating internal thermal conditions by means heat removal (cooling). This process depends on external environmental conditions, and is therefore dependent on the climate area and the season. As previously introduced, it was observed that the use of NV enlarges the temperature range of satisfaction inside building, thus allowing to develop adaptive model [18], [37], [39].

2.3.3 Night cooling

It is a particular way of thermal regulation, which consists in using NV (e.g., opening windows) during colder hours of the day (during night) for cooling the indoor environment. This technique can be coupled with the use of massive materials for improving thermal inertia of buildings and shifting the indoor heating later during daytime. Home automation systems (i.e., automated windows opening, automated shadings) can also be exploited for properly regulating indoor conditions depending on daytime and/or outdoor conditions [40]–[43].

2.4 Standards and guidelines for NV

- Theory and measurement of NV, application to design, strength and weaknesses of techniques of NV, mathematical modeling and computational fluid dynamics (CFD): *D. Etheridge, Natural ventilation of buildings: theory, measurement and design. John Wiley & Sons.* [28]
- Potential, appropriate use dimensioning, barriers' overcome of NV: *S. Alvarez, E. Dascalaki, G. Guarracino, E. Maldonado, S. Sciuto, and L. Vandaele, Natural ventilation in buildings. A design handbook. James & James, 1998.* [29]
- Reference book for designing low carbon/low energy buildings using NV, with example case studies: *U. Passe and F. Battaglia, Designing spaces for natural ventilation - An architect's guide. Routledge.* [25]
- Guideline on hybrid and passive cooling techniques for building (Italian language): *M. Grosso, Il raffrescamento passivo degli edifici in zone a clima temperato, Second. Maggioli Editore.* [30]
- Environmental design guideline containing NV recommendations applicable worldwide: *CIBSE, 'TM40: Health and wellbeing in building services'. Chartered Institution of Building Services Engineers (CIBSE), 2019. [Online]. Available: https://www.cibse.org/Knowledge/CIBSETM/TM40-2019-Health-Issues-and-Wellbeing-in-Building-Services#Exec%20summary (https://www.cibse.org/Knowledge/CIBSE-TM/TM40-2019-Health-Issues-and-Wellbeing-in-BuildingServices#Exec%20summary)* [44]

3. Mechanical ventilation principles in climate responsive energy positive buildings

Mechanical ventilation (**MV**) uses a powered induced airflow by means of a mechanical external source of power. For this reason, MV has the clear advantage to have the possibility to be perfectly regulated (airflow, volume, velocity, temperature), regardless of outdoor conditions. Thus, the performance of MV system is constant and perfectly predictable, and units of air treatment can be incorporated, remarkably improving IAQ conditions [45]–[47]. Main disadvantages are dealing with the running cost of MV systems, as they require electric energy to function. Moreover, mechanical systems for ventilation can lead to noise due to the functioning of plants. Lack of control (fixed air flow, not self-regulating) is also a disadvantage, as the air flow is fixed and not self-regulated [45]. Moreover, disadvantages dealing with the loss of contact with the outside environment might be associated with the use of MV systems instead of windows, even if this is depends on the typology of view, area or landscape [48]–[54].

The disadvantage of the larger amount of consumed energy can be partially overcome by the use of heat recovery units, leading to passive houses applications of MV techniques [55]–[57]. An example of a heat recovery unit is reported in Figure 34.

A quick overview of the functioning of a heat recovery ventilation (HRV) plant, especially when coupled with a heat pump, is reported in following Subsection. Finally, a list of standards and guidelines for MV and heat recovery units is reported.

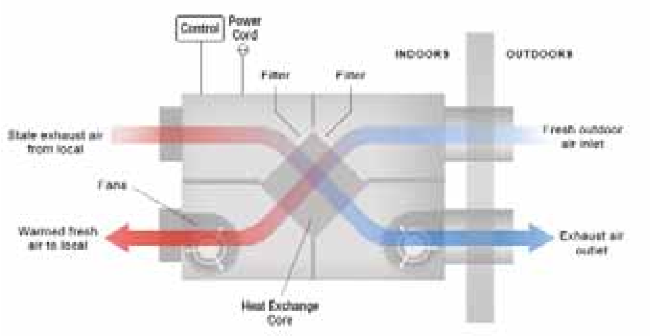

Figure 34: Scheme of a heat recovery unit [58]

3.1 Overview of Heat Recovery Ventilation (HRV) functioning

A HRV system is aimed at the exploitation of expelled exhausts to pre-heat or pre-cool the inlet air before it enters the room or air treatment units. It is normally composed of channels for exhaust and fresh air, a core unit and blower fans. It can generally improve the building energy efficiency by recovering between 60 and 95 % of heat in exhaust air. Several heat exchangers technologies are available for HRV, differentiating for the constructive point of view, as well as the air-flow inside them (parallel or counter-flow) [59]. Some examples of typical heat exchangers are [59]–[62]:

- **Fixed plate heat exchangers**, the most commonly used, with streams of cold and hot air passing through adjacent spaces between plates
- **Heat pipes**, transferring heat from between the two streams by means of a multi-phase process (evaporator-condenser)
- **Rotary thermal wheels**, mechanical exchangers with a porous metallic wheel alternatively in contact with cold or hot stream
- **Run-around**, hybrid systems using a mix of previous technologies to deliver heat between two distant air streams.

As heat pumps can be particularly efficiency and need electrical energy instead of fossil fuel to work, they are particularly interesting to be used in HVAC plants, when related with climate responsive energy positive buildings. In fact, they could cover most of global heating needs, remarkably reducing the CO_2 emissions [63]–[65]. Moreover, they can be inverted acting both for heating and cooling the environment. Performance of heat pumps is normally measured using the Coefficient of Performance (COP), defined as the heat transferred from low temperature to high temperature source divided by the work required [66]. A brief summary of heat pumps types of working technologies is here provided [67]–[69]:

- **Air source**, using outside air as heat source, being relatively easy to install, but being more performant in mild weathers than in cold ones; modern air source heat pumps are more performant, allowing to achieve COPs comparable to ones of ground source heat pumps
- **Ground source** (**geothermal**), drawing heat from soil or groundwater, which (at a certain depth) maintains a relatively constant temperature for all the year (Figure 36)
- **Water source**, taking heat from a water source, which needs to be large enough not to freeze and not to affect wildlife
- **Exhaust air**, transferring heat from exhausts of a MV system to intake air or a water circuit
- **Solar assisted**, with a solar panel used as low-temperature heat source feeding the evaporator
- **Absorption**, which uses thermal energy (natural gas, steam solar-heated water or air, geothermal-heated water, …); this system is more complex than compression heat pumps, requiring larger units
- **Hybrid**, drawing heat from different sources depending on temperature present outside.

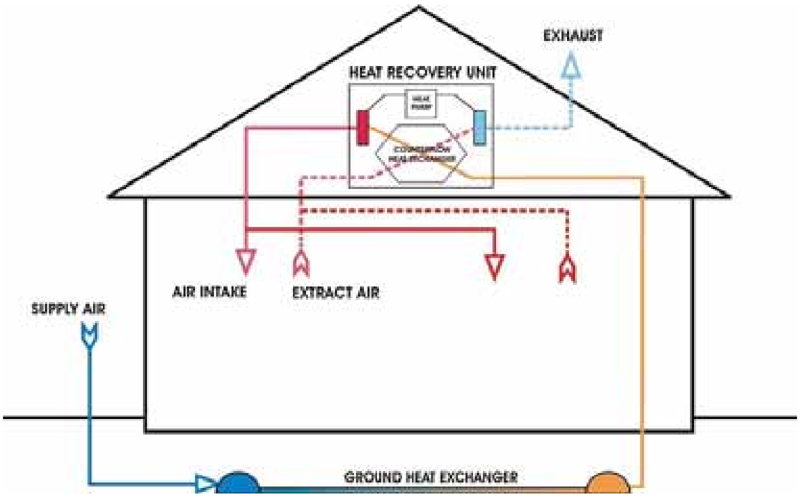

Figure 35: Scheme of a HRV system [70]

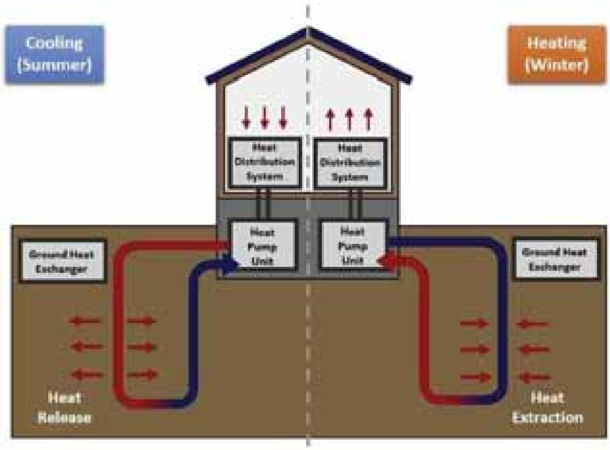

Figure 36: Scheme of a ground source heat pump in cooling and heating mode [71]

3.2 Standards and guidelines for MV

- Basic principles and data used in the HVAC industry: *ASHRAE, ASHRAE Handbook - Fundamentals. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2021.* [72]
- Standard for plants' classification, minimal requirements of plants and indoor environments: *UNI 10339 - Air-conditioning systems for thermal comfort in buildings - General, classification and requirements - Offer, order and supply specifications*. [46]
- Handbooks and manuals on domestic ventilation:
  HRAI, *Residential Mechanical Ventilation - National (SAR-R4)*. The Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI), 2010. Available: https://www.hrai.ca/technical-manual/residential-mechanical-ventilation---national--sar-r4- [73]
  R. Edwards, Handbook of Domestic Ventilation. London: Taylor & Francis, 2005. Available: https://doi.org/10.4324/9780080454580 [74]
  P. H. Raymer, Residential Ventilation Handbook, 2nd ed. Home Ventilation Management, 2017. [75]
- Overview on main building heat recovery technologies: A. Mardiana-Idayu and S. B. Riffat, 'Review on heat recovery technologies for building applications', *Renewable and Sustainable Energy Reviews*, vol. 16, no. 2, pp. 1241–1255, Feb. 2012, doi: 10.1016/j.rser.2011.09.026. [59]

- Guidelines on heat pumps:
  ASHRAE, 'Applied Heat Pump and Heat Recovery System', ASHRAE. https://www.ashrae.org/advertising/handbook-advertising/systems/applied-heat-pump-and-heat-recovery-systems [76]
  'Domestic Heat Pumps - A best Practice Guide'. Available: https://mcscertified.com/wp-content/uploads/2020/07/Heat-Pump-Guide.pdf [69]

4. Hybrid ventilation principles in climate responsive energy positive buildings

As introduced in Section 2, NV has the advantages of reducing the carbon footprint of buildings, while also improving some comfort elements, such as ones dealing with users' willingness of control and access to the outside/nature. On the other hand, MV (Section 3) is a "safer" technique, as it permits to have more controllable IAQ and thermo-hygrometric conditions, also allowing for filtering pollutants and better removing pathogens. A compromise between the two methodologies is **hybrid ventilation** (**HV**), or **mixed-mode ventilation** (**MMV**) [77]–[82]. In fact, the primary purpose of HV can be defined as "to provide acceptable indoor environment and thermal comfort […] using different features of these systems at different times of the day or season of the year". Therefore "Hybrid ventilation buildings, or mixed mode buildings, represent the buildings that have the capability of running the natural ventilation and mechanical ventilation concurrently or switching between these two modes during the building operation" [83]. In this way, the greatest advantages of ambient conditions can be exploited at any time. Moreover, an automatic intelligent control can allow to switch from one mode to the other when needed [84], [85]. The main principles of HV are reported in Figure 37.
Thus, the alternation of MV and NV could save up to 75 % of the energy use [80], while guaranteeing proper IAQ conditions. For this reason, this solution is particularly interesting for climate responsive and energy positive buildings.

Further information on HV technique can be found, for instance, on:

- *Principles of Hybrid Ventilation*. *Aalborg (Denmark): Aalborg University, Hybrid Ventilation Centre. Available: https://iea-ebc.org/Data/publications/EBC_Annex_35_Principles_of_H_V.pdf* [84]
- *Annex 35 - Hybrid Ventilation in New and Retrofitted Office Buildings. Hybrid Ventilation in New and Retrofitted Office Buildings. Available: https://www.iea-ebc.org/Data/publications/EBC_Annex_35_tsr.pdf* [81]

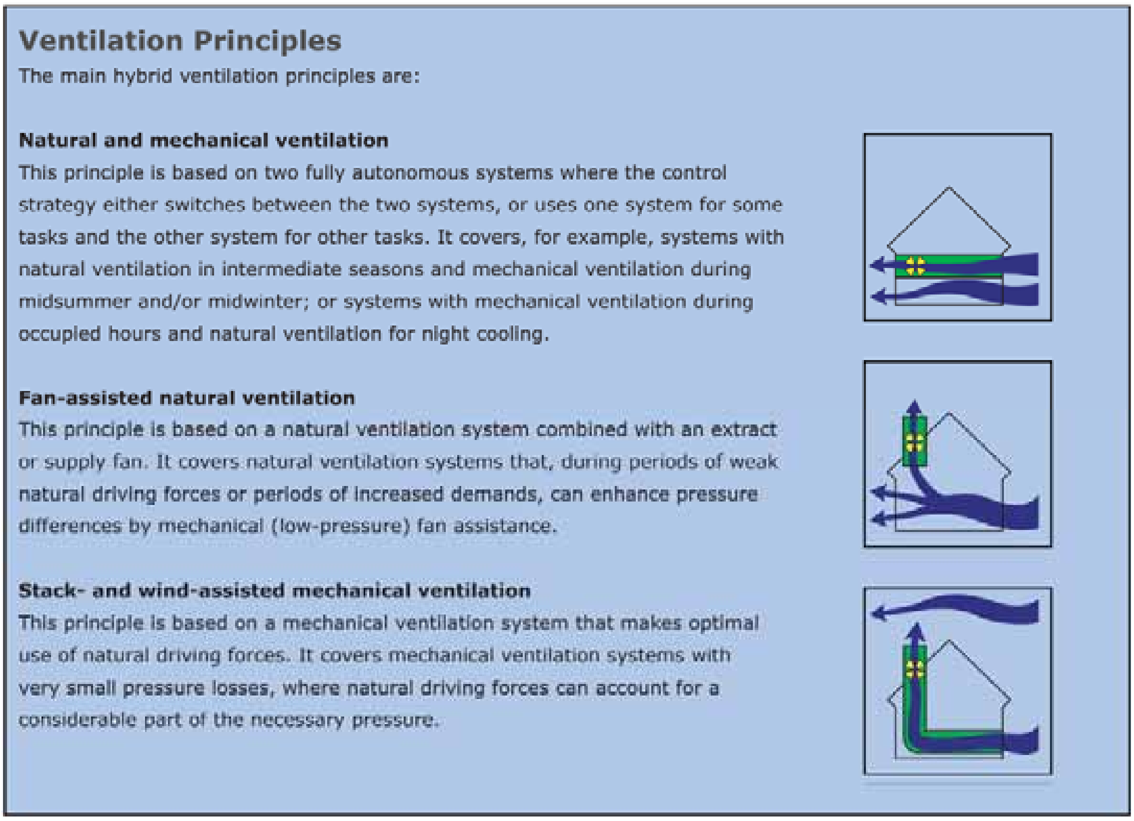

Figure 37: Examples of HV principles [84]

5. Natural, mechanical and hybrid ventilation with a double perspective, focusing on both energy consumption and indoor well-being

Given these premises, it is clear that the concept of ventilation is fundamental, when dealing with both climate responsive and nPEBs. In fact, NV can remarkably reduce the carbon footprint, which is a clear requisite of both these forms of energy-efficient architecture [86], [87]. Climate responsive principles can be observed in traditional buildings such as vernacular architecture in Nepal, which have been using natural ventilation for years, in order to adapt to climate conditions and improve comfort of occupants [88]. Nevertheless, as previously stated, MV allows for a better regulation of IAQ and thermal conditions. In fact, building design cannot overlook indoor comfort. Good environmental quality is also fundamental for work and performance, as well as for energy consumption. In fact, energy implications may derive from actions taken from occupants to improve their uncomfortable conditions [89], [90]. As Chenari et al. [91] points out, it is not possible to choose one ventilation solution relying on energy savings criteria, if indoor comfort cannot be met. In fact, ventilation is fundamental to provide a health and comfortable indoor condition, avoiding illnesses and complaints present in 40 % of cases [92]. Also, COVID-19 pandemic highlighted the importance of ventilation in buildings, with controversial opinions about the preferred use of MV [10], [93]–[97]. In fact, NV re-gained interest because of its utility to manage infection control in buildings [37], [98] and because of the preference of nature-connected environments by people [50]–[54]. For instance, window presence and window opening were found to possibly positively cross-influence the mental well-being of occupants during COVID-19 lockdown in London, as positive perceived soundscapes were found associated with psychological well-being, as well as with natural sounds and view of vegetation [48], [49]. On one hand, in the field of building resilience to climate change, within the next decade indoor spaces might terminate to fulfil adaptive comfort model [99]. Moreover, global warming will probably provoke an higher number overheating hours in warm areas, but the shifting of climate conditions might cause a higher use of NV in cold or mild climates [79]. On the other hand, even though open windows cannot be a proper solution when poor outdoor air quality, too warm conditions or too low wind are present, other future Indoor Environmental Quality (IEQ) issues might be created by totally avoiding NV. This solution would also create a situation relying on a totally dependence on HVAC systems, with large emissions and energy demand. For this reason, new regulatory criteria on overall IEQ in buildings are necessary, not to worsen the global climate emergency and future health problems [10].

For all these reasons, the careful study of ventilation with both an energy saving and IEQ perspective is fundamental. Both the two criteria need to be considered when designing climate responsive and net-positive energy buildings. In this section, a systematic literature review on studies analyzing an indoor comfort and/or well-being comparison between NV and MV is presented. The aim is to offer an overview aiming as a guideline for choice of best solution of NV, MV or HV in the design of nPEB or climate responsive buildings.

5.1. Methodology

A process of systematic review was used [100] on the Web of Science database [101]. A search using AND/OR Boolean operators [102] (Figure 38) was performed in order to identify all the studies concerning a comparison of NV and MV in terms of indoor comfort and well-being. A total number of 94 papers was found. A first screening process was applied considering only English-written studies and limiting the research areas to the following: 1. *Construction Building Technology*; 2. *Engineering Civil*; 3. *Engineering Environmental*; 4. *Green Sustainable Science Technology*; 5. *Environmental Sciences*; 6. *Public Environmental Occupational Health*; 7. *Environmental Studies*; 8. *Architecture*; 9. *Thermodynamics*; 10. *Engineering Mechanical*; 11. *Infectious Diseases*; 12. *Regional Urban Planning*; 13. *Urban Studies*. All types of documents (articles, proceedings papers, review articles and book chapters) were considered, obtaining a total number of 80 papers. A second screening process consisted in titles and abstracts reading, with the rejection of all the papers which topic was not in compliance with a comparison of natural and mechanical ventilation related with occupants' comfort and/or well-being. This screening allowed to obtain 69 papers for full reading. After the reading process, five additional papers were discarded, with a final number of 63 studies considered. Figure 39 reports the details about the screening process, and the number of studies obtained after each phase.

Resulting studies were categorized according to the comfort field considered (thermo-hygrometric, visual, IAQ, acoustic and multi-domain approach), as well as the type of ventilation recommended ("NV", "MV", "HV or both HV and NV", "no clear preference between MV and NV/HV"). Papers are presented here below grouped according to this last categorization. The type of paper (journal paper, journal review, conference proceedings), the type of indoor environment (residential, educational, working, …) and the climate or geographical area considered were also highlighted. When specified, the type of NV ("thermal regulation", "air-change" or "night cooling") was also highlighted.

Finally, statistical data about papers are presented, highlighting the number of studies per publication year, geographical area, research field and other types of categorization.

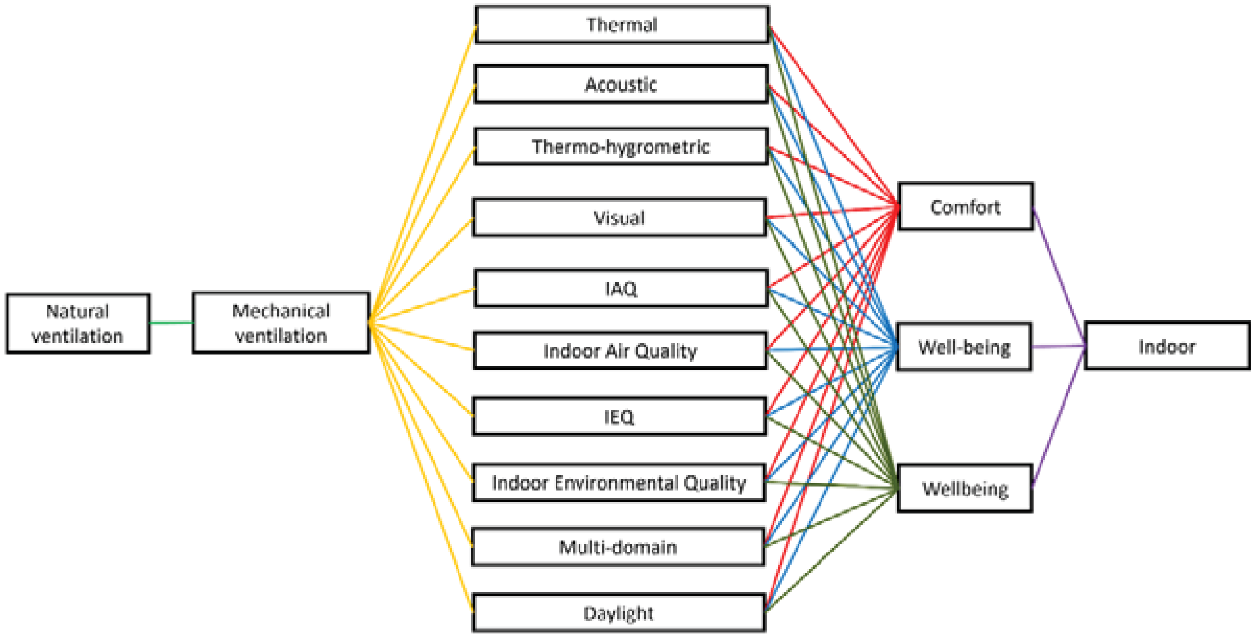

Figure 38: Boolean research string used for a first search of papers on the Web of Science database. Linking lines represent "AND" operator, while "OR" operator was used for keywords on the same column in the scheme

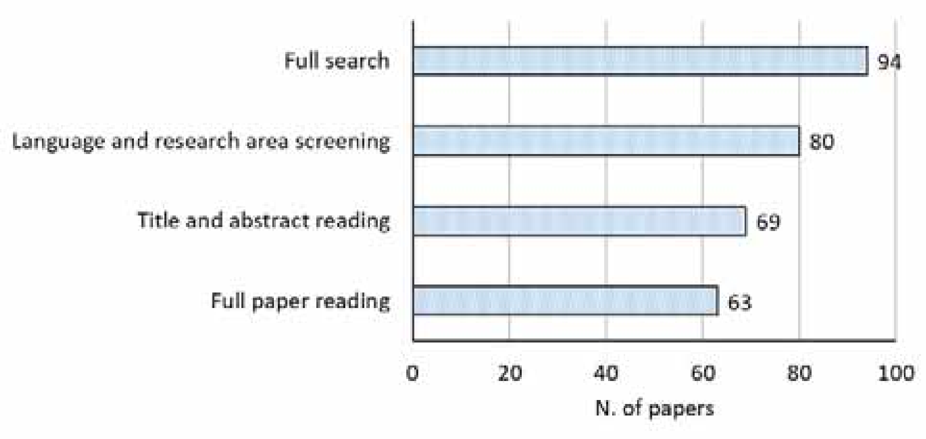

Figure 39: Details about the screening process applied and number of results after each phase

5.2. Results

5.2.1. Studies suggesting the use of NV

A Slovenian study of 2007 [103] analyzed comfort in three working buildings (two with MV and one with NV). It used surveys performed during normal activities of work, in the cold season. Thermal measurements of the environments were taken simultaneously. Health problems and health status of occupants were also surveyed. Deviations between predicted and subjective evaluations were noticed, with possible influence of psychological factors. Moreover, in mechanically ventilated buildings, a higher dissatisfaction with thermal and air quality environment was present. On the other hand, neutral condition was expressed by a higher percentage of occupants in the naturally ventilated building than in the two other buildings.

In a review by Omer (2008) [104], a description of several low-energy buildings design solutions was performed, also highlighting implications of dense urban building nature on consumption of energy and climate change. It was highlighted how maintaining thermal comfort in buildings by means of low-energy and passive techniques is one effective way to save energy, and therefore maximum share of natural energy should be used. For these reasons, new technologies like louvers for distribution of light, insulation, MV operations and simple passive cooling can help in fulfilling this target, with a combination of well-known technologies like shading, glazing, NV and insulation and other advanced solutions such as dynamic insulation, roof pond and evaporative water jacket. Moreover, the need of mechanical cooling and heating could be reduced designing buildings taking into account the climate of the area (climatic design). Using the proper building and urban design, the deterioration of environmental quality after urban densification could be minimized. For instance, thermal comfort could be maintained in arid regions by means of wind towers. Moreover, CO_2 emissions are also increased by poor design or control of passive ventilation systems (i.e., too high inflow), besides than too strong use of MV. Discomfort and draught are caused by too high outdoor air, while poor IAQ is caused by little inflow. For these reasons, proper design of NV solutions (single-sided ventilation, cross-flow ventilation, mixed-flow ventilation or other solutions like solar-induced ventilation) need to take into account the following buildings' factors and characteristics: ceiling height, space exposed thermal mass and building materials (e.g. for night cooling), depth of space in relation with ventilation openings, heat gain, building location in relation with sources of pollution (such as traffic noise and air pollution). Also, geographic location, exposure to sun, wind and rain (including effect of buildings themselves on them), building height and form, need to be taken into account. In this framework, CFD can help with problems in the design of air movement in rooms and airflow control.

In 2008, Stavrakakis et al. [105] performed a test-chamber and numerical (CFD) examination of natural cross-ventilation with non-symmetrical openings. In a test-chamber in rural Greece, velocity and temperature measurements were recorded during noon and afternoon in the hot season, while a weather station provided data about external weather conditions. Thermal comfort (thermal regulation perspective) was studied by means of both PMV and adaptive models. The study started from the idea that NV can help in saving energy, but needs to be properly designed based on airflow detailed understandings (pressure differences due to wind and buoyancy). It was highlighted that experimental measurements agreed quite well with all turbulence models, pointing out that well-mixed conditions can be provided by openings' locations which are not symmetrical. This can minimize local air draughts and temperature differences, avoiding unsatisfactory thermal environment even close to obstacles like pieces of furniture.

A CFD modeling to investigate the comfort performance of stack effect (buoyancy) and two driving forces-wind ventilation in a double-skin-façade university building (Figure 40) in Mediterranean climate (Eugene, Oregon), was studied by Azarbayjani (2013) [106]. The study highlighted that heat can be effectively drawn out by means of cool night air through top openings and that acceptable thermal comfort conditions can be provided by NV in the building with double-skin-façade. Moreover, air extraction can be obtained using the convective forces in the cavity, but air movement within the room should be promoted in order to release heat in excess. Finally, the climate analysis showed that, in summer or shoulder seasons, NV was made possible by orientation of building, which considered the prevailing winds. Therefore, comfort was studied with a thermo-hygrometric perspective and NV for night cooling and thermal regulation was considered.

Figure 40: Double-skin façade of the university building considered by Azarbayjani study [106]

A review on existing studies supporting NV efficiency and architectural designs and solutions to maximize the efficacy of NV in buildings in tropical (hot and humid) climates was performed by Aflaki et al. (2015) [107]. The paper points out how high humidity and temperature might provoke occupants to use MV in tropical climates. Nevertheless, the authors state that, with passive techniques such as NV, smaller operational cost and better IAQ and thermal comfort have been shown by many researches. Review results showed that future constructions should exploit design strategies such as window-to-wall ratio, orientation of buildings, position and size of openings, façade elements, balconies' form and ventilation shafts in order to optimize NV. Moreover, further studies on louvered windows' shape (for night ventilation), vernacular elements and apertures' forms could be needed.

The importance of design elements such as façades, orientation and structure in non-residential buildings in warm climates was pointed out by Annan & Nehme in 2016 [108], assessing the effect of cross and single-sided ventilation by windows and skylights openings that can be used for cooling the building with a thermal regulation perspective.

Da Graça & Linden (2016) [79] developed a list of 10 open questions about design of NV in non-domestic environments, from building, neighborhood and urban point of view. The authors linked the answers to the proposed questions with current literature, in order to identify the scientific gaps and provide designers with proper suggestions. It was pointed out how NV benefits of the preference of most people, who are also characterized by a higher thermal tolerance when rooms are naturally ventilated and openings can be controlled by users. Nevertheless, NV is still rare in non-domestic and modern buildings, but its usage could make the energy consumption decrease. Recent design solutions with the massive use large glazed walls have driven to the misunderstanding that NV and natural light compete. Nevertheless, the two systems can benefit from similar constructive techniques (i.e., high widows, high floor to ceiling height, operable skylights, both have a small penetration depth when windows are located on the same side, ...). Moreover, direct sunlight on large glazed façades can lead to both overheating and glare. Thus, both systems could benefit of a return to smaller window to wall ratios, climate adaptive building shells and use of external shadings. NV can possibly be applied with an outside temperature range from 10 °C to 25 °C. For this reason, climate change will rise the number of hours of overheating in non-commercial buildings, but, in cold and mild climates, will also lead to an expansion of hours of open windows. Innovative approaches (e.g., night cooling with thermal massive or phase-change materials equipped buildings, controls avoiding overheating during the warmest hours) may be useful for a NV use expansion. Moreover, coupling with external shadings, responsive glazing and ceiling fans to move air could be necessary. Modern mobility solutions (i.e., electric cars and bikes) will improve the urban environment in terms of particles and noise pollution. Thus, NV will further benefit.

Reasons of unpopularity of NV (with respect to air-conditioning or HV) in Green-rated offices of New Zealand were investigated by Rasheed et al. (2017) [109] by means of: (1) revision of criteria of thermal comfort in NZ Green Star [110], [111] rating tool; (2) online questionnaires of workers' perception of thermal comfort in the city of Auckland (most populated and with high number of modern office buildings; oceanic subtropical climate); (3) building experts' interviews. The following conclusions were listed: (1) NV was not encouraged by NZ Green Star IEQ thermal comfort criteria. (2) No preference of NV over MV and HV was observed among workers. (3) Among thermal comfort factors, the highest impact on workers' performance was noticed to be by temperature control and temperature extremity. (4) NV could be promoted by a better support to adaptive criteria from NZ Green Star IEQ thermal comfort criteria. This would possibly imply a preference change of accustomed workers. In this way, thermally comfortable Green offices would be achievable. (5) NV negative implications on productivity are still under debate. Therefore, energy inefficient buildings should not be built on those basis. (6) Other IEQ aspects connected to NV (i.e., lighting and noise) should be deepened by further studies.

In 2019, Mukhtar et al. [112] performed a review on strategies of passive design and building optimization potential in underground buildings. It was stated that incorporating passive systems in underground buildings is fundamental to mitigate the carbon impact. In this sense, IEQ level could be improved by including passive design strategies and optimization approach in building performance simulations. Moreover, the energy consumption could be decreased by adopting natural and soil ventilation (Figure 41: Earth to air heat exchanger (EATHE). Nevertheless, factors like geological features, physiological and psychological issues, construction typologies and ventilation system should be taken into account for the proper design of underground buildings. In this framework, thermal comfort improvement and reduction of the energy consumption could be fostered by passive design technologies specifically associated with underground buildings.

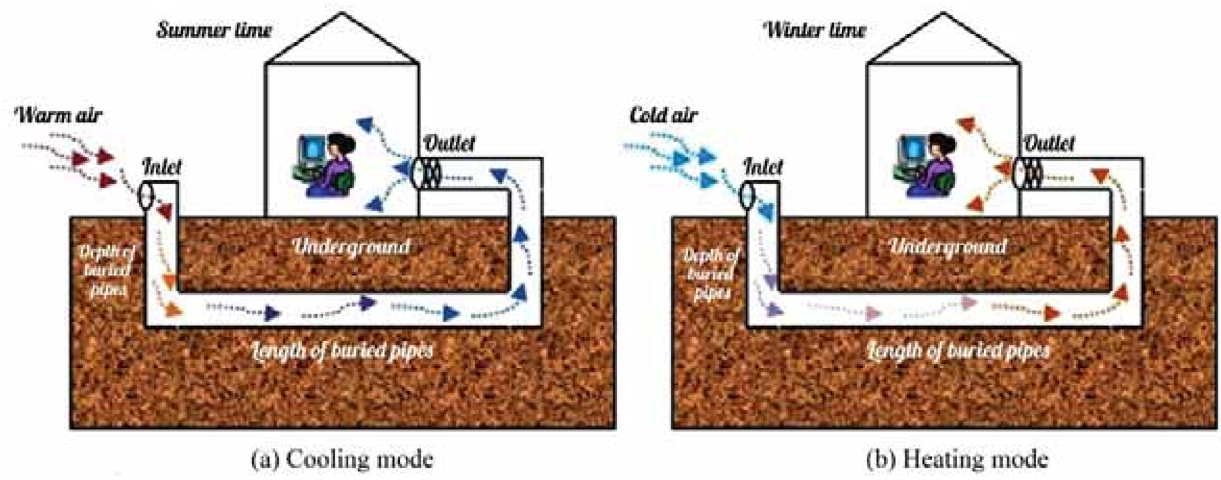

Figure 41: Earth to air heat exchanger (EATHE), reproduced from [112], [113]

Maas et al. (2019) [114] studied a 60 seats capacity seminar room of University of Luxembourg (a Seventies building with no major retrofitting). The MV system was switched on and off for periods of some weeks each. After each period, measurements of final energy consumption and of indoor climate (by both physical measurements and questionnaires) were performed. The building was not air-tight and manually operable windows were present. The research led to the following conclusions: (1) When the system was "on", light measurable benefits in the CO_2 concentrations were present, and it was not perceived by the occupants. (2) Primary energy consumption of the building was clearly higher when the system was “on”, due to fans' electric demand. (3) There was no relationship between the climate perceived and the perceived percentage of dissatisfied. (4) Advantages can be achieved in older buildings' seminar rooms, by shutting down or semi-automatic user-controlled modus by low-cost retrofitting.

A literature study on the influence of openings of façades and geometry of balconies on perception of occupants and NV performance, comparing design characteristics and geometries, was performed by Izadyar et al. in 2020 [115]. The paper started from the idea that NV could be used on its full potential, in particular in medium- and high- rise buildings. In this framework, airflow could be guided by balconies into the indoor environment, reducing the need of MV and improving the comfort conditions. Not enough studies were performed on the exploitation of balconies for NV. More studies, comprising both experiments (like Post-occupancy Evaluation) and simulations, should be made. Most of the studies present in the literature, have been performed in cooling dominant warm/hot climates. Nevertheless, climate change should drive the research expand also to heating-dominant areas. Design process impact of passive elements was not sufficiently explored, with indoor comfort and health factors being mainly considered in previous studies. More post-occupancy evaluation studies should be made, in order to link NV design and perception of occupants: this would allow to better investigate the façade openings' design effect on occupants.

In 2020, two other studies from Izadyar et al. [116], [117] analysed the performance of single-sided NV and related thermal comfort of a living room depending on depth (fixed length over depth size, L/D) and opening scale of a balcony, in a high-rise residential building in Brisbane (Australia). CFD simulations were performed after measurements’ validation, assessing the mean Indoor Air Velocity (IAV), the Indoor Air Distribution (IAD), and the PMV. Nine depth scenarios and five openings were considered. The following aspects were highlighted in [116]: (1) NV could decrease energy consumption and GHG emissions with respect to MV. (2) Depth and openings of balconies have an impact on IAD and IAV and indoor temperature. (3) Shallowest balconies give a weak IAD, and small openings give acceptable IAV indoor. (4) Further research to study the influence of geometry on indoor comfort and indoor temperature and air velocity distribution are necessary. Moreover, these additional points were pointed out in [117]: (1) Balconies could enhance NV, reducing dependence on MV in climates with cooling dominance. (2) The opening size and the depth scale influence IAD, IAV and thermal comfort. In fact, a small opening could reduce exterior air acting like a nozzle in transferring the recirculation farther in the room. Larger openings were seen to create extended cold areas close to the opening. (3) Smaller depth (less than 2 m) gave not stable and not uniform IAD, with deeper balconies being more performant on the point of view of thermal condition and IAV. In terms of thermal conditions, it was noticed that the best solution had a L/D of 35 % and opening size of 1.1 m. (4) Orientation of buildings influence the balcony's depth impact on mean IAV. Further studies are necessary to assess the proper depth with other orientations.

Yadeta et al. (2022) [118] performed a field survey (questionnaires, indoor and outdoor air temperature, humidity and air speed) in 104 naturally ventilated residential buildings in Jimma (South-West Ethiopia, warm-temperate climate), during the dry season (from 1st of February to 31st of May 2020). A neutral temperature of 20.4 °C and a wide comfort range (14.6 - 26.3 °C) were found. This suggested that, in developing countries like Ethiopia, thermal comfort can be achieved by NV, with occupants using natural adaptive means, allowing to save energy for MV, if compared with areas with narrower ranges. Moreover, it was highlighted how further studies on energy consumption from heating and cooling in the households would be necessary is these countries.

Mba et al. (2022) [119] investigated the NV effect of orientation of 60 primary schools buildings in the city of Enugu (Nigeria, hot-humid tropical climate). The paper firstly stated the fact that, in developing countries, educational buildings rely on NV in order to save energy. It was found out that the efficiency of ventilation depends on the orientation: inlet window planes perpendicular to the wind direction are recommended.

Moreover, inlet and outlet dimensions and positioning have an impact. Additionally, the authors stated that shading devices and corridors to promote the use of NV also during rainy and windy days should be used, and encouraged architectural solutions to couple wind and stack effect ventilation.

5.2.2. Studies suggesting the use of MV

A review by Braham (2000) [120] focused on independently published information on low-energy office buildings performance data about the ventilation and fabric energy storage strategies available, in the temperate maritime climate of the UK. The work started from the idea that not many studies about annual energy associated with NV and MV coupled with fabric thermal storage were published. The review concluded that, when including effective fabric energy storage with the integration of efficient heat recovery (using hollow-core slabs), low-energy MV systems can provide better comfort all over the year (with summer cooling included) and lower energy consumption than NV. Moreover, less maintenance is necessary. In temperate marine climates, it was shown that minimal supplementary demand and consumption of heating and cooling are needed.

A paper by Sultan (2007) [121] estimated the effects of outdoor PM (particulate matter) mortality and morbidity effects on the Singapore population under various buildings and conditions of ventilation and filtration. The study concluded that nationwide adoption of NV in residential buildings was associated with higher morbidity cases and mortality. Moreover, MV and filtration from current NV in schools was associated with less asthma cases. Additionally, better filtration in workplaces was associated with lower morbidity cases and mortality.

A study by Khaleghi et al. (2011) [122] provided a direct monitoring of IAQ (volatile organic compounds - VOCs and ultrafine particles, respirable-fibre concentrations), ventilation rates (air changes per hour) and acoustical conditions (times of reverberation and levels of noise) in study rooms located in selected "non-green" and "green" university campus buildings (Vancouver, Canada). Then, the two aspects of IAQ and acoustic comfort were considered, with an air-change point of view. The goal was to quantify these IEQ aspects, determining their relationship with design of building and windows' status and assessing the effects for systems of ventilation, especially in buildings considered as "green". The measurements were taken both in buildings with MV (mixed-flow and/or displacement) and NV. NV produced lower total sound-pressure and low-frequency noise, as well as lower fibre concentrations, but also lower rates of ventilation and higher ultrafine-particulates. Direct association between noise level and IAQ was observed with MV. It was concluded that a generally better IAQ can be provided by MV, even if poorly designed systems can produce noise issues. Higher noise levels was produced with higher ventilation rate by windows' openings. Finally, the use of MV with careful attention to noise, was suggested for optimum building design.

Guo et al. (2018) [123] used reduced-scale model, full-scale numerical simulation and similarity analysis to evaluate performance of buoyancy-driven ventilation in a large space building (ocean park) with a large glass ceiling. An investigation of conditions of thermal comfort was performed numerically. It was concluded that in a similar type of building (with a large glass ceiling), buoyancy-driven ventilation alone is not enough to ensure thermal comfort conditions, when high ambient temperature is present. Therefore, MV is needed in similar environments.

Measurements of indoor and outdoor particle number, as well as concentration of CO_2, were performed by Stabile et al. (2019) [124] in a school of Cassino (Central Italy). Pre-retrofit (different procedures of manual airing) and post-retrofit (CO_2-based controlled ventilation, with a set-point of 1000 ppm) solutions were considered. It was highlighted that, for highly crowded buildings like schools, MV is necessary. Moreover, evaluating the air quality just by means of CO_2 concentration constitutes an over-simplified approach, since other pollutants are present. The study concluded that: (1) With longer airing period, significantly lower CO_2

was present, but more sub-micron particles infiltrated from outside and no reduction of PM_{10} generated indoor were observed. (2) MV produced improvements on all the measured pollutants and on energy savings. The reduction of PM_{10} particles was caused by the higher rates of air exchange, giving better dilution effects. Moreover, the lower energy consumption was due to the presence of a heat recovery unit after retrofit. (3) Further analysis dealing with other pollutants (e.g., NOx), as well as thermal comfort and performance of children are necessary.

Zender-Świercz (2020) [125] performed an analysis of indoor air parameters of a Polish (moderate climate zone, low temperatures in winter and high temperatures in summer) office equipped with a façade ventilation device. Measurements of indoor and outdoor temperature, indoor and outdoor humidity, indoor CO_2 concentration were performed. The monitoring lasted twenty-six weeks during the fall-winter-spring period. Three different periods with different unit settings for the supply/exhaust cycle (2 min, 4 min and 10 min) were analyzed. In was pointed out how, with thermal insulation and new sealed windows, buildings only exploiting NV can undergo to lack of infiltration and insufficient air exchange. Moreover, due to a lack of place and architectural requirements, MV cannot be always installed. Temperature was observed to be in the range of 20 - 22 °C despite the absence of a heater in the device. PMV calculations showed that building categories B or C (PN EN 7730 [126] categorization) were maintained. Local draught risks with long air supply/exhaust cycle, when users stands in the air stream axis, were also noticed. Exhaust heat recovery and electric heater were recommended to decrease the possibility of local discomfort. Finally, low RH values (27 - 43 %) suggested to recommend air humidification.

A numerical energy efficiency assessment and an IAQ assessment were performed by Mareș et al. (2021) [127] in a single-family thermally insulated house in Cluj (Romania). The house was also equipped with low-transmittance windows and an efficient boiler. Since the substitution of old wooden framed windows with double glazed PVC windows, even if giving better thermal performances, might create air sealing issues, an evaluation of a controlled MV remedial system mitigating IAQ problems was performed. The mitigation solution considered was a decentralized MV with heat recovery coupled with a sub-slab depressurization system to reduce the radon concentration. This system gave a reduction in the radon average concentration from 425 to 70 Bq/m^3, also guaranteeing a CO_2 concentration around 760 ppm and thermal comfort (temperature around 21 °C). Compared to NV solution, this system gave an energy reduction of 86 %. It was therefore concluded that, when thermally retrofitting a building, there is the need to perform a balance between IAQ and energy consumption, allowing to find a remediation solution for poor IAQ.

Liao et al. (2021) [128] used an online questionnaire survey on the type of ventilation and the associated subjective sleep quality among 517 people in Danish dwellings, during winter 2020 (before COVID). The following information was asked: type of ventilation of bedroom, respondents' behavior on bedroom airing, information on bedroom environment, building location and surroundings, information on sleep disturbance by noise, stuffy air and thermal environment. Pittsburgh Sleep Quality Index (PSQI) was used to assess the sleep quality. An average reduced sleep quality was reported (median PSQI > 5). Noise, thermal discomfort and stuffy air were found to be related with less subjective quality of sleep. The presence of MV reduced the disturbance by “too cool” conditions and stuffy air while sleeping (Figure 42). The presence of carpets and the absence of MV seemed to cause sleep disturbance due to stuffy air. A more frequent opening of windows was detected among people who reported disturbed sleep by "too warm" or stuffy air conditions. On the other hand, no association between airing behaviors and PSQI was observed. Finally, it was specified that this study presented qualitative results and associations during the heating season: therefore, they need to be validated with field measurements and repeated during non-heating season to be generalized.

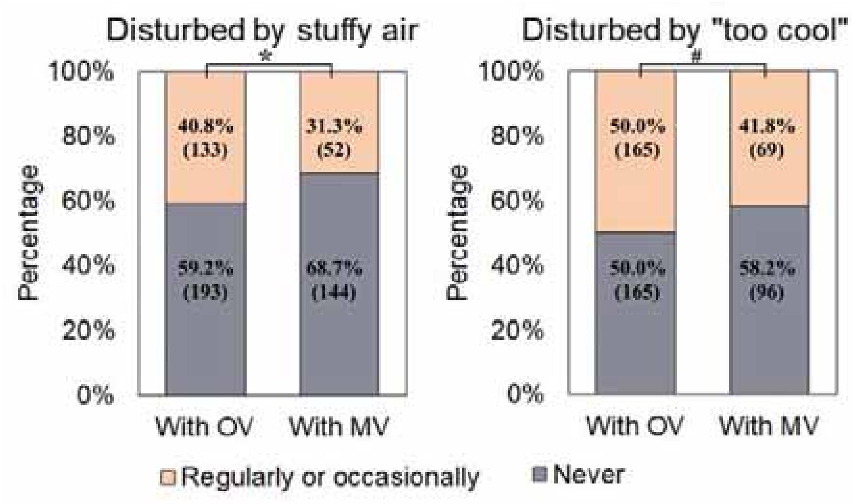

Figure 42: Percentage of people disturbed ("regularly or occasionally" and "never") by stuffy air or "too cool" conditions during sleep. Results for mechanical ventilation (MV) and other ventilation (OV) are differentiated. Reproduced from Liao et al. (2021) [128]

A review by Ding et al. (2022) [129] analyzed the ventilation strategies and IAQ conditions of classrooms, in order to study the capacity and further improvements in minimizing the presence of infectious aerosols. The following aspects were highlighted: (1) NV and mixing mechanical ventilation are mainly used in schools, but these systems are not fully effective in dealing with short-range and long-range airborne transmissions. (2) Current literature and standards lack of knowledge dealing with design and rates to ensure safety from airborne transmittable pathogens. There is still uncertainty about patterns of air distribution and rates of ventilation. There is still a main focus on perceived air quality, CO_2 concentration and energy savings on standards, and many schools even fail to meet the current air-change requirements. Therefore, there are several reports of problems dealing with comfort, IAQ, performance or health. (3) New ways of ventilation are needed in classrooms, moving the design from comfort- to health-based. Personalized ventilation can potentially protect from short-range generated aerosols, with a simultaneous IAQ improvement, compensating existing ventilation regimes. (4) Before applying these new methods in classrooms, there is the need of more studies, also considering the types and activities of occupants. (5) IAQ changes have the potential to influence the other IEQ factors, which interact together into giving occupants' comfort and health. This aspect needs to be considered when updating ventilation systems, with a holistic approach both ensuring health and IAQ in schools.

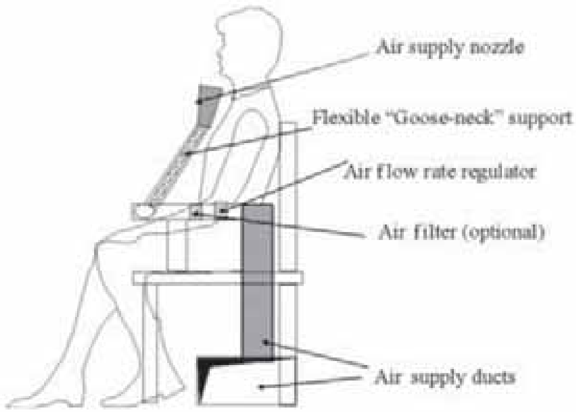

Figure 43: A chair-based system of personalized ventilation, reproduced from [129], [130].

5.2.3. Studies suggesting the use of HV or both NV and HV

The first paper recommending the exploitation of HV was written by Mathews et al. in 1994 [77]. The study validated and proposed a procedure to verify efficiency of load predictions of programs for thermal analysis to be used at the design stage to assess comfort regulating methods. The research involved 36 buildings in various climate conditions for 46 case studies. The article highlights how the study of NV, MV, passive performance and building's structural and evaporative cooling are necessary in the thermal and energy efficient design of buildings. Mechanical cooling techniques should be used only when these systems cannot provide with the desired thermal comfort. Moreover, by combining passive and mechanical cooling and various strategies of control, energy use and system size can be reduced by more of the 60 %.

Brager & Baker (2009) [78] performed a web-based survey in 12 buildings with mixed mode ventilation (with operable windows), compared with a database of over 43000 responses provided in 370 buildings, available at Center for the Built Environment (CBE). Thermal comfort, acoustics, air quality, cleanliness, lighting, office furnishing, spatial layout, maintenance and overall satisfaction were investigated. The following aspects were highlighted: (1) Hybrid approach consists in the use of some types of MV and/or cooling, combined with NV. (2) Most buildings in the CBE database (89 %) did not respect thermal comfort standards, with thermal environment satisfaction expressed by only 59 % of occupants on average. Too low air movement and lack of control were seen to be the main drivers of dissatisfaction. (3) Especially in terms of air quality and thermal comfort, HV buildings were found to perform extremely better than the benchmark buildings. On a scale from “-3” (very dissatisfied) to “+3” (very satisfied), mixed-mode buildings' thermal satisfaction was 0.94 points higher than in benchmark buildings. Additionally, air quality satisfaction was even larger (1.43 points higher). (4) In MMV buildings, a relationship was observed between air quality and thermal satisfaction and age of buildings (higher in most recent buildings) and climate (higher in moderate climates). (5) Causal mechanisms explaining trends in satisfaction would require more studies. Nevertheless, comments and previous research suggest people preferring operable windows because of a better personal control or the environment, fresh air perceived, major air movement and outdoor connection. The advantage of MMV buildings is that they offer these benefits and also high thermal control by mechanical devices. (6) Best performance buildings were observed to be the ones with MV only (no air-cooled systems) and radiant cooling. On the other hand, problems with the window interlock in changeover systems were associated with the lowest performance. The co-existence of NV and MV being able to work well together, with occupants able to ignore automated controls if desired or needed, was therefore pointed out. Moreover, occupants' comments indicated that MV - NV relationship does not always work as it was expected, having windows shut more than necessary.

Perino (2009) [131] performed an investigation about performance of buoyancy driven single-sided NV for IAQ management. This was done by means of measurements' series in a test lab (controlled environment) at the Aalborg University. Moreover, numerical models were used to assess different control strategies’ effects, as well as thermal and IAQ conditions. The following aspects were pointed out: (1) Innovative NV systems, integrating NV devices like motorized louvers and windows with MV, seem to be more welcomed by occupants. (2) Single-sided ventilation driven by buoyancy is effective, being able to guarantee good air-change rates, allowing to control IAQ and temperature; (3) Models can be used for control strategies optimization, to obtain adequate IAQ and indoor comfort. Thus, NV with thermal regulation and air-change perspectives was considered.

In a University building in mild oceanic climate (La Rochelle, France) a comparison of NV and MV strategies was performed by Dhalluin & Limam (2014) [132]. In particular, in two adjacent classrooms, a comparison of four ventilation modes was performed: (1) NV on a single room side; (2) NV with a systems of control of air-temperature and presence-based window control ("Self Opening and Shading System" = SOS), with 22 °C and 500 lx as summer setpoints and 21 °C and 500 lx as winter setpoints. (3) HV of 250 m^3h^{-1} associated with NV (manual windows only); (4) HV of 250 m^3h^{-1} associated with NV (SOS). A 40 % efficiency heat exchanger and a hot water battery made to supply a minimum of 20 °C air temperature in winter were present. Ambient parameters were measured and comfort questionnaires administered to teachers and students during hot and cold season in 2010. The following aspects were highlighted: (1) In many classrooms, poor ventilation leading to poor discomfort, learning performance and health risks is often present. (2) NV provided satisfactory IEQ, comfort and consumption of energy when well controlled. In this sense, the best compromise between energy demand and satisfactory learning was provided by SOS-NV. (3) When extreme conditions were present (i.e., very humid, cold or hot climate, or noisy outdoor conditions), no adequate energy savings and thermal comfort conditions could be provided. Therefore, HV might be necessary. Still, in environments where occupation density is lower (e.g., family houses), this would probably provide too many heat losses due to the too high amount of fresh air. Nevertheless, it would be easier to install than a MV system and would be associated with a good perception of occupants. (4) Good IEQ, comfort conditions and energy savings were guaranteed in summer by SOS system. During the whole year, this system provided good air-change rate and CO_2 conditions, even if particulate was slightly higher than with MV (because of the absence of filters). By means of windows, shadings control and night cooling action, SOS ensured a refreshment of 2 °C in summer, as well as meeting the setpoints in terms of lighting and air temperature levels. Best IAQ and thermal sensation were also met with this system. The drawback was a higher heat loss and necessity of backup electric heating in winter. Moreover, during the cold season, occupants often switched to manual modes in order to contrast colder draughts. (5) NV only (the most common in educational French buildings), despite being the most energy efficient, provides the lowest IEQ due to low air-change rate. Besides, this strategy provides the best acoustic and thermal sensation conditions, also saving the 85 % of electric energy. (6) Mixed modes, even if providing the most satisfactory IEQ due to lowest CO_2 concentration, provoked lowest comfort conditions and energy savings. Therefore, the lowest IAQ perception was given despite the best IAQ conditions in terms of CO_2 and particle concentration. (7) Overall IEQ conditions were generally "satisfactory" and "quite satisfactory", meeting French standards in both subjective and objective approach. (8) Consistency between sensation scores and the parameters measured was observed ("slightly cold" in cold season and "slightly warm" in hot season), as well as in the odor perception ("low odor in winter and "quite good" in summer). Therefore, World Health Organization (WHO) recommendations were fulfilled. (9) Acoustic perception was also "quite good" for all modes. Nevertheless, warm sensations seemed to be better tolerated with SOS system. The intermittent noise generated by this system was also better tolerated than the continuous one by MV. (10) Indoor environment was seen to provide a higher satisfaction in winter, despite a better footprint classification in summer. (11) Air velocity, lighting level and relative humidity (RH) subjective evaluations were observed to be homogeneous for all the ventilation types in both seasons, due to low sensitivity by occupants concerning these parameters' variations, which generally met standards' requirements. (12) Subjective approach did not suggest to use MV, despite the higher air-change rate. A multi-criteria approach is then justified.

In 2015, Montgomery et al. [133] investigated the IAQ of an office space in Vancouver (Canada), designed to be operated with both the ventilation types. TVOCs (total volatile organic compounds), CO_2 and PM in the space, with both NV and MV, were measured. It was observed that pollutants' concentration was more variable when using NV. Nevertheless, the concentration was still below thresholds from standards. On the other hand, higher control of pollutants' level was ensured by MV. NV air exchange rate was correlated with the TVOC concentration, while MV was not. $PM_{2.5}$ indoor-outdoor ratios were noticed to be 0.87 and 0.5 for NV and MV, respectively. Efficacy of NV also depends on indoor materials (VOC emission), outdoor pollution, period of the year (occupancy) and outdoor air velocity. In general, use of HV instead of NV would allow to save energy, while ensuring to meet IAQ needs. Moreover, these systems would benefit from occupancy control, sensors to detect differences of pressure on the envelope, PM and regional meteorological data, better occupants-building control interaction to optimize strategies of control. It was finally highlighted that investigations on sites with other systems of ventilation, outdoor air quality and types of building would be worth of interest.

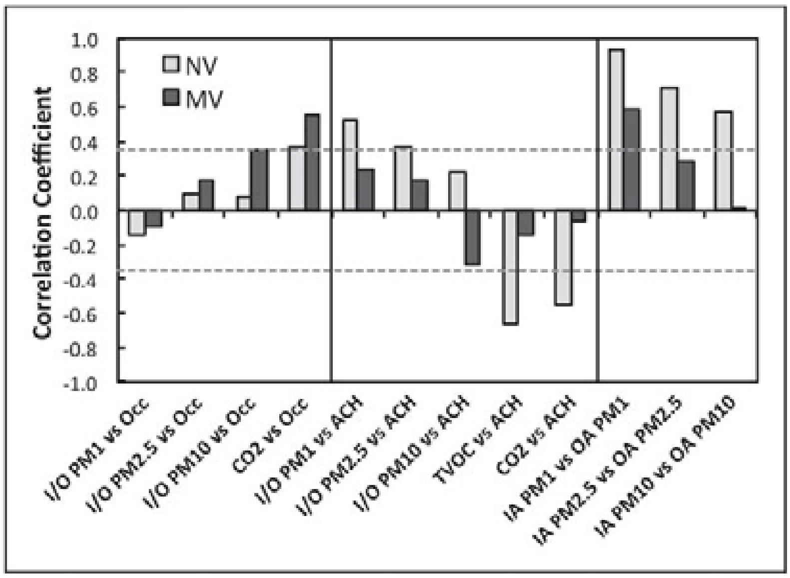

Figure 44: The correlation coefficient of Pearson between pairs of variables, 95 % confidence level indicated by dashed lines. Reproduced from Montgomery et al. (2015) [133].

In 2015, Daghigh [134] published a review about ventilation and thermal comfort in classrooms, residential and office buildings of Malaysia and the area nearby. It was firstly mentioned how, in order to obtain good IAQ levels, adequate ventilation system is necessary. On the other hand, too large amount of energy can be wasted by unnecessary ventilation. Moreover, energy efficiency can also enhance occupants' thermal comfort. On the other hand, NV could increase humidity levels and affect comfort in hot and humid climates. For this reason, MV and air conditioning use is broad in tropical climates. In this framework, the review concluded that, in hot-humid climates, the range of thermal comfort is wider than what is indicated in international standards, and that healthy IAQ and adequate ventilation strongly influence indoor thermal comfort sensation. In tropical climates, IAQ and thermal comfort could be improved (and energy consumption decreased) if more studies in the field would be performed. Findings could be exploited to modify building energy audits in order to obtain more energy efficiency. In the future, ventilation technologies and thermal comfort could be coupled with active and passive strategies and renewable energies. This would help overcoming building energy issues in hot-humid areas.

In 2016, a review by Salcido et al. (2016) [80] analyzed literature of 1996-2006 in order to understand the HV usage in offices, in terms of objectives, progresses fulfilled and challenges for the future. It was firstly stated that HV has been efficiently used to guarantee good indoor environment, since the alternation of MV and NV could save 75 % of the energy use, while 40 % of the energy could be saved by the optimization of windows' schedules. The following conclusions were listed: (1) Air quality, thermal comfort and consumption of energy are significantly influenced by occupancy and people behavior. (2) The design of HV systems by simulations is over-simplified in terms of occupants' behavior, and more advanced algorithms are needed. (3) In the future, HV should be optimized by proper design of layout of the building (internal and external), taking into account the direction and speed of the wind, and using the proper insulation, glazing, façade design and shadings. This would allow to minimize the use of MV cooling energy. (4) In order to improve the cooling systems' efficiency, better understanding of proper HV strategies depending on the climatic areas are necessary in the future. (5) Potentially higher energy savings can be obtained by users' education about thermal conditions and behaviors expected.

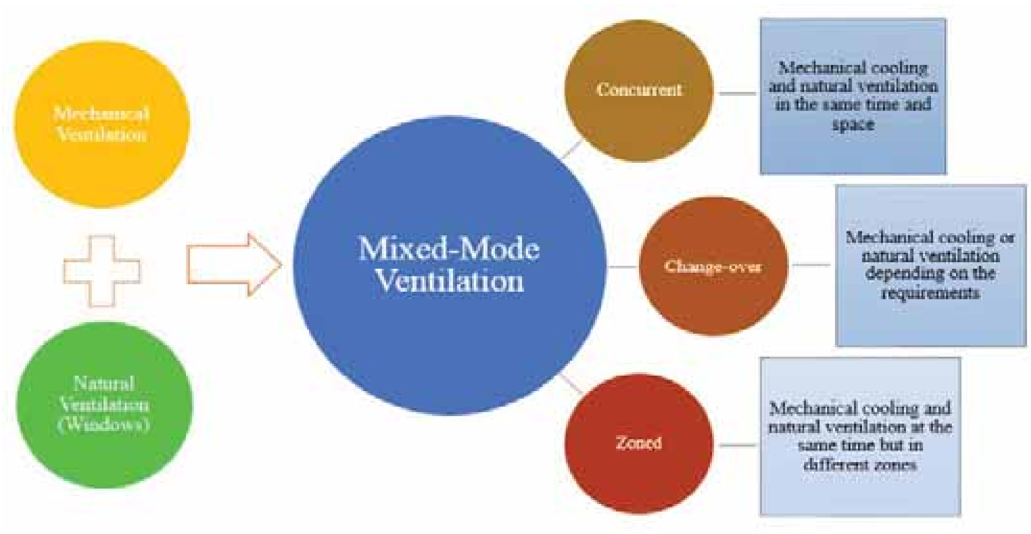

Figure 45: Types of HV systems, reproduced from Salcido et al. (2016) [80]

A review of standards, regulation, reports and scientific studies on energy efficient methodologies for ventilation, considering also occupants' behavior influence on energy use and correlation of ventilation with productivity and health, was published by Chenari et al. [91] in 2016. It was firstly highlighted how ventilation is the key both to provide suitable IAQ and to decrease the energy use. Following conclusions were stated: (1) HV leads to considerable energy savings, while ensuring acceptable IAQ levels. (2) Ventilation of spaces with low or absent occupancy annually leads to considerable energy waste in the world. (3) IAQ and buildings' energy performance are not only affected by characteristics of buildings, but also by methods of ventilation, environmental conditions and controlling behaviors of occupants. (4) Health issues and symptoms, as well as bad occupants' performance, might be provoked by poorly designed ventilation. For this reason, ventilation rates higher than minimum standard requirements are suggested by many studies. Nevertheless, the topic of relation of ventilation rate with indoor health should be further deepened in several types of buildings (offices, day care centers, schools, homes), in several climates and especially in outdoor polluted regions (where more attention to filtration and air cleaning should be paid). (5) Literature lacks of studies regarding HV strategies smart-window based. These strategies could help reducing the energy consumption while maintaining proper IAQ. (6) Energy consumption cannot be reduced under the levels at which discomfort and unhealth are caused to occupants. (7) nZEBs shift the assessment of buildings' energy consumption from a yearly scale to a daily scale, for a balance among demand, storage and production. In this framework, predictive and dynamic control of buildings, comprising HV, can become a winning strategy for a more efficient use of available energy.

Aldawoud (2017) [135] used CFD to study the behavior of several alternative configurations (size and orientation, solar shading) of inlet and outlet openings in a naturally ventilated standard office building in a hot-humid climate. The aim was to maximize wind-driven cross-ventilation by the most efficient design of windows. The paper stated that: (1) Acceptable thermal comfort conditions (thermal regulation perspective) and temperature can be achieved by cross-ventilation. (2) Not adequate outdoor temperatures (too high) and wind conditions (too low) may be present in summer in order to provide enough internal air movement to ensure thermal comfort. Nevertheless, 4 - 8 °C of temperature reduction are achievable. (3) In other seasons (November-April), NV is a valid alternative to air-conditioning. (4) Large inlets and orientations of inlets and outlets are directly proportional with the airflow rate. Larger inlets should be exposed to the main direction of wind. On the contrary, similar small areas of inlets and outlets led to a bigger resistance with lower differences of pressure and less air circulation. Therefore, an important effect on airflow is obtained by building orientation. (5) Airflow is enhanced also by adding horizontal shading devices outside of the outlets. This has the effect of making the differences of pressure higher.

A comparative analysis of the air-change performance of MV and NV was made in two schools in Seville (Spain, dry-summer subtropical-Mediterranean climate) by Gil-Baez et al. (2017) [136]. Levels of humidity, CO_2 and temperature were analyzed in association with occupation, and data obtained were validated with simulations in a third building with cross NV. Here, stack ventilation was tested. The following aspects were pointed out: (1) Based on studies performed in cold climates, MV has been widely adopted in recently built schools, in order to overcome air-tightness to achieve adequate IAQ. Nevertheless, in mild climates the number of hours requiring a heating system is moderate, and near Zero Energy Buildings could be obtained by NV, without compromising indoor comfort. (2) In environments with high occupation and defined schedules (like schools) NV could provide the IAQ necessary for a proper learning environment and remove heat from internal gains such as windows and occupation. (3) Suddenly reduction of CO_2 concentration below the 1000 ppm limit was observed with windows' opening in winter days. Moreover, no parallel temperature reduction was observed. Since heating system was off, this means that internal gains were more significant than NV losses (positive effect of thermal inertia). (4) Usage of NV allowed energy savings between 11 % and 26 % and CO_2 emissions lowering of 31 % - 49 % with respect to MV. Moreover, the NV tested allowed draughts and heat losses to be minimized, due to less presence of air inlets. The socio-economic impact of using NV in schools of Mediterranean regions would be important, due to the high number (87000 schools) in Spain, Greece, France and Italy. This measure would save approximately 46500 tons of CO_2 only in the Andalusia area. (5) A proper design of NV systems, such as windows with automated control, is necessary, since they need to satisfy both energy savings and IAQ requirements. (6) When noise level is low and unpolluted environment is present, NV is a proper solution. Otherwise, with noisy locations or colder weathers, solutions of HV could be implemented (i.e., MV with heat recovery coupled with windows with an automatic control). (7) More research is necessary in mild and Mediterranean climate regions in order to promote the use of NV and develop commercial solutions.

A presentation of a strategy of building design using a HV system to provide energy efficiency measures in a Eighties social housing complex of Modena (Italy) was provided by Barbolini et al. in 2017 [137]. MV (with heat recovery and earth tubes) was used during the heating season. On the other hand, free running use (open trickle ventilators on windows, vertical shaft ventilators, mitigation of heat loads by means of insulation and mass, free night cooling) were used during the non-heating season. Aerodynamic principles to maximize pressure differences due to stack effect were implemented for vertical shafts. Combined heat and power system, solar thermal collectors, PV and solar panels were also used to further minimize the energy demand. Indoor comfort was assessed by the adaptive model during the warm season, and was verified with CFD modeling. It was found out that, in warm season, acceptable indoor conditions can be met in a free running net-zero energy building. For this reason, conversely than the current tendency of using HVAC during hot season, HV ventilation can be suggested, with NV in summer and MV in winter.

In a baseline simulated office building with two floors, a model predictive control (MPC) was built by Chen et al. (2018) [83] in three climate zones of the USA (Atlanta, Los Angeles and San Francisco). The aim was to maintain acceptable indoor conditions with energy consumption minimization, when using HV. Validation showed that occupants' thermal comfort was maintained by MPC, which was therefore performing as expected.

Usman & Bakar (2019) [138] analyzed thermal comfort of a residential premise in Malaysia by means of CFD analysis. The effect of adding a ceiling fan MV system assisting NV was assessed. It was noticed that, by adding this system, there was an improvement in the values of PMV and PPD indexes.

Raji et al. (2020) [82] used CFD and EnergyPlus in order to study six NV strategies in on 12^{th} floor of a 21-storey office building in Delft (Netherlands, temperate maritime climate). It was observed that thermal comfort and fresh air were guaranteed for up to 90 % of occupancy time during summer by NV strategies, and therefore a high share of energy can be saved with this strategy. The different strategies had similar performance, except than the ones combined with a poorly ventilated double skin façade or with atrium design. In fact, double skin façade was observed to have the risk to become too cold or too warm, making it necessary to have a building management system to control vents operation. Minimum temperature set-point is important for windows operation and thermal comfort. For this reason, it needs to be correctly set according to outdoor variations of temperature. Scenarios with vertical shafts (atria or solar chimneys) did not show advantages with respect to the scenarios driven by wind. This might be due to the office geometry (narrow plan) and location (city with high wind velocity along the year). In fact, highest advantages of stack ventilation occur with buildings with a deep plan, where it is difficult for cross ventilation to occur. It was finally highlighted how structure associated or architectural configuration limitations exist for improving or adding NV to existing buildings. Moreover, applying night-time NV during summer could even extend the percentage of hours with comfort conditions. For high-rise buildings, HV is necessary when suboptimal external conditions (wind, temperature or noise) and design failures (architectural design layout or tenancy patterns change) are present.

An investigation on the performance of hybrid ventilation in industrial buildings was performed by Meng et al. (2020) [81], by means of experimental scale model with a heat source in Xi'an University (China). Hybrid NV driven by buoyancy coupled with a mechanical system for exhaust was used. At different velocities of the mechanical exhaust, efficiency of the HV and distributions of temperature were observed. After highlighting how indoor environment and ventilation energy can be optimized by means of HV, the study concluded that an optimal velocity needs to be identified in order to maximize HV efficiency, since non-optimal thermal environment and airflow short circuiting, as well as excessive energy consumption, can be created by a disproportionate MV rate.

Torresin et al. (2021) [139] performed an online survey among 848 people working from home during the COVID-19 pandemic in London and Italy, during winter lockdown. A focus on the perception of the acoustic environment while relaxing or working and on the elements influencing the window opening behavior was given. The HVAC typology did not give any significant difference in soundscape appropriateness for relaxing, and the ventilation strategy did not give any significant difference in soundscape appropriateness for working. Nevertheless, in general, during working and relaxing activities, spaces with less dominant noises from building services were judged as more appropriate. No significancy associated with the sky or building view, noise sensitivity, presence of a quiet side, gender and age were found in the windows opening behavior while working from home. Even if in noisy urban areas, occupants tended to keep open windows at least sometimes when using NV or MMV. In Italy, participants working from home were more incline to open windows when a vegetation view was present. Moreover, higher noise levels were compensated by other benefits from NV in the windows opening behavior. This suggested the idea of the existence of an "adaptive acoustic comfort" in NV facilities [140], [141], to be further investigated in order to define acoustic opportunities for NV in buildings. In fact, elements such as the perception differences between MV and NV and the presence of pleasant outdoor acoustic contexts are not taken into account in present standards.

An empirical study about the change of classrooms environmental conditions during COVID-19 pandemic was performed by Monge-Barrio et al. (2022) [142]. Surveys were conducted during the heating seasons of 2020 and 2021, in nine naturally ventilated secondary/high schools of Pamplona (Spain). Moreover, a detailed building monitoring was implemented in one of the schools. When present, MV was not used due to the high noise produced and the high consumption of energy, so all the facilities where only naturally ventilated during both the periods considered. A mean CO_2 concentration reduction of 1400 ppm (1000 ppm observed) and a mean temperature reduction of 2 °C (18 °C observed) were noticed, with a 31 % increase of the heating energy consumption. The authors highlighted how these lower temperature values can be admissible only during a pandemic situation, without vaccines' availability. Moreover, they stated that a plan should be prepared by schools, in order to improve indoor conditions, with cross ventilation and installation of CO_2 and temperature monitoring systems. When outdoor conditions require it, complement Heat Recovery Ventilation and thermal envelope improvement would also help in providing healthy and safe classrooms with low CO_2 emissions and low consumption of energy. Therefore, the effects of NV used for air-change were studied with both an IAQ and thermal comfort perspective.

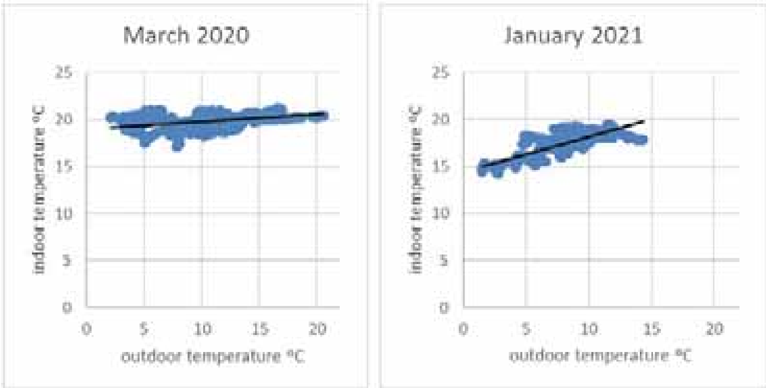

Figure 46: Comparison of temperatures measured in March 2020 and January 2021 as function of outdoor temperature, reproduced from Monge-Barrio et al. (2022) [142]

Another research on an educational building was conducted by Elnabawi & Saber (2022) [143]. The authors evaluated an integrated HV (exploiting NV without compromising comfort) and photovoltaic (PV) system in urban facility in Bahrain (hot-arid climate). The performance was assessed by means of yearly energy savings and CO_2 emissions, as well as the potential to provide comfort on a thermal point of view (thermal regulation perspective). The analysis was made by a dynamic simulation validated using annual consumption data. It was observed that overheating hours (or cooling hours) can be reduced of the 23 % by the automatic operation of windows. Moreover, HV had a better performance in the cool season (33.5 % savings vs. 17.1 % in summer). The annual reduction is equal to 23 % with the hybrid ventilation, and 85 % when adding the PV solar system as a primary energy source. Finally, it was highlighted how extending the upper and lower comfort limits (from 25 °C to 22-29 °C) led to higher energy savings. This can be further enhanced setting the temperature according to the local climate condition instead than using setpoints from international comfort standards.

An evaluation on the particulate matter ($PM_{2.5}$) and CO_2 in seven naturally ventilated and three mechanically ventilated residential buildings was performed by Yin et al. (2022) [144] in China (Xi'an, cold climate and generally serious pollution). This was made by means of a long-term online monitoring (one year). It was observed that, in the most polluted season (winter), NV was not able to remove $PM_{2.5}$ harm for humans: MV was necessary. A significant improvement in air quality could not be obtained by short-term MV if compared with NV, but results improved when the operation duration increased (minimum daily recommendation of 9 hours). The excess of CO_2 concentration (more than 1000 ppm) was greater with MV (26 %) than with NV (9 %). Moreover, a dependence of CO_2 concentration from indoor-outdoor temperature difference was observed. In Xi'an residential buildings, IAQ control could be implemented with a MV system combined with short-term NV in order to both control $PM_{2.5}$ and CO_2 concentration.

Arata & Kawakubo (2022) [145] performed measurement and questionnaire surveys in an office building of Tokyo (humid climate with hot and humid summers and dry and sunny winters with strong North-East monsoons), in order to test the effects of HV on energy consumption, thermal comfort and productivity during springtime (average temperature of 21 °C). The productivity effects were studied by means of a hierarchical linear model (multi-level analysis). The following considerations were made: (1) Mixed mode can decrease the power consumption while improving workers' satisfaction. (2) Windows' opening time depended on weather conditions, varying each day. (3) On floors with HV, savings in the range of 3.1 - 70.6 % were present with respect to floors with MV only (both the systems maintained similar levels of air temperature and PMV). (4) Male participants' productivity improved of 9.1 %, probably because of decreased concentration of CO_2 and higher air flow and air freshness. (5) Since women productivity increased only of the 0.5 % with HV, gender differences might be present. However, a bias could have been given by the small number of female participants.

5.2.4. Studies not clearly stating a preference

Kalamees (2006) [146] monitored the ventilation (measuring exhaust air flows) and the indoor climate (measuring temperature and RH in living rooms, bedrooms and outdoors) of 28 single family lightweight timber-frame houses in Estonia (Nordic climate). The monitoring was performed continuously during 1 year. Questionnaires (one per house) were also administered to occupants. During the hot season, high indoor temperatures highlighted that original design did not consider thermal comfort requirements. Problems in control systems were shown by large temperature variations in winter. Moreover, average daily amplitudes of RH and temperature were strongly influenced by the ventilation performance. Average air-change rates were lower than recommended by standards, but similar to ones measured in other Nordic countries. Questionnaires highlighted that NV was associated with stuffy air, while MV caused noise issues (which limited its use). Moreover, houses with air leakages in envelope caused cold floors, draught from electric sockets and fluctuating room temperatures during winter.

Ouyang et al. (2006) [147] performed a spectral analysis in five different outdoor locations (building roof, open area outdoor, around buildings, seashore and indoor) to find the characteristics of mechanical and natural wind on the dynamic point of view. It was found that, when mean velocity is not higher than 0.25 m/s, diffusing mechanical wind can reach the characteristics of natural wind. Reaching these characteristics (spectral characteristics of natural wind) can improve occupants’ feeling about mechanical wind.

In 2011, Razman et al. [148] performed a field study in a University hostel in Malaysia (hot and humid climate), in order to identify if thermal comfort can be reached with NV. Measurements were taken for five days between 11:00 and 17:00 and 178 questionnaires' sets were collected. NV helps going for a sustainable environment and saving energy. Thermal condition was perceived as comfortable, but MV would help to make this condition more effective. Thermal comfort was somehow prevented by furniture arrangements and window openings which were an obstacle for adequate air movement.

A review on UK guidelines and regulations in relation to MV systems with heat recovery and a review on the long-term indoor VOC concentrations in super-energy-efficient test houses (considering the effectiveness of trickle ventilators and heat recovery ventilator use) were performed by the study of Yu and Kim (2012) [149]. It was stated that possible high indoor pollution from building materials' emissions and products from combustion can occur in air-tight buildings. Moreover, it was expressed the need to review and examine the several ventilation possibilities to alleviate the indoor pollution while ensuring energy savings. Possible options would be low emission materials or use of air-cleaners to decrease the need of higher air-change rate and thus improve energy savings.

Giridharan et al. (2013) [150] investigated the performance of spaces with MV but passive cooling in a nucleus-type hospital (connected cruciforms blocks with various and little courtyards in between, Figure 4739) in Glenfield (UK). A comparison between thermal comfort criteria and measured temperatures was made during summer 2010, while a prediction of future conditions in ward space was made by means of a calibrated model. The following conclusions were listed: (1) The maximum indoor temperature varied in the range of 27.3 - 29.3 °C, and the nurse station was found to be the warmest zone. Most spaces monitored were found to be within HTM03-01 [151] thresholds in terms of thermal comfort. (2) There is need for adaptive criteria accommodating both cooling and heating conditions, specific for hospitals. (3) The incidence of night-time overheating showed major deviations from criteria of thermal comfort. (4) MV with 1.5 ach^{-1} would provide reasonable conditions of comfort, if good provisions of openings of windows are present. (5) Light touch low carbon interventions may give comfortable conditions in bedrooms in UK Midlands into the 2050s in nucleus-type hospitals, for both extreme and typical years.

Figure 47: Glenfield Hospital aerial view. In yellow the case study wards and waiting area locations Reproduced from Giridharan et al. (2013) [150] (Source: Google Earth image modified [152])

A building model was built by Homod & Sahari (2013) [153] in Malaysia, by means of empirical and physical subsystems model functions. The aim was to focus on the building internal temperature and RH control efficiency by infiltration and ventilation. PMV (as function of HVAC controlled indoor air velocity, temperature and RH) was used to characterize indoor thermal comfort. Twenty-four hours MV simulations with varied flow rate were performed. While highlighting the advantages of MV in guaranteeing thermal comfort, the results point out the possibility of reducing the relying on powered cooling.

Natarajan et al. (2015) [154] used a simultaneous survey among 115 participants and indoor and outdoor measurements, in order to study the applicability of (1) PMV/PPD model (ISO 7730:2005 [155]), (2) adaptive model (ANSI/ASHRAE Standard 55:2013 [156]) and (3) adaptive model (EN Standard 15251 [157]) to assess thermal comfort. The research was performed in three different offices of Bogotà (Colombia, subtropical climate) having three different ventilation regimes (NV, MV and HV). Adaptive and PMV model from Standard 55 was observed to be functional for predicting thermal perception in MV buildings. On the other hand, in NV and HV free-running offices, adaptive models in ASHRAE and EN standards showed less applicability. This was due to a reduced personal control on windows in the two offices part of the survey. PMV model was able to assess conditions of comfort in the HV office, where control conditions were comparable to the MV one. Finally, PMV/PPD and adaptive models' applicability was seen to be strongly dependent on the control possibility which is given to the occupants. For this reason, a classification of environments based on windows' control level (instead of only considering the air conditioning presence) was proposed.

In order to achieve the net zero energy balance, various criteria of ventilation were implemented by Grigoropoulos et al. (2016) [158], in a simulative study (EnergyPlus) of a residential building in a Mediterranean climate (Thessaloniki and Athens, Greece, and Larnaca, Cyprus). In these areas, hot summers are present, with cooling loads prevalent on heating ones, and PV systems are applicable due to high solar irradiance. The base case model scenario was characterized by an air-change rate of 2 air-changes per hour (ACH) during night and early morning. The ventilation rate was gradually increased, also simulating MV, assessing the PV capacity, the primary energy demand and indoor thermal comfort. It was observed that an increase of the ventilation rate to 8 ACH provoked a minor primary energy demand. The energy reduction was never higher than 10 %, and was slightly more marked in Thessaloniki, because of the presence of a milder climate. Moreover, the application of higher rates of ventilation had an even higher impact on thermal comfort, allowing to obtain a 50 % decrease of overheating degree hours in Athens, and a 30 % reduction in Larnaca. MV provided a major control of indoor temperature, but increased the energy demand (20 %) and costs for maintenance. For these reasons, this solution is less applicable in residential buildings in Eastern Mediterranean climates, when microclimate conditions permit the exploitation of night-time ventilation. Other issues (like safety, noise, life cycle costs and feasibility) should be considered when deciding the best solution. In larger multistorey commercial or residential buildings, HV or MV ventilation could be necessary, due to the need of more complicated ventilation techniques for achieving energy savings.

Nardell (2016) [159] provided with a review on the state of possible environmental interventions to overcome the problem of tuberculosis transmission. It was highlighted that interventions to control this illness can also apply to other airborne transmittable diseases. Moreover, measures of environmental control are the most important way of intervention after the identification of unsuspected cases. In fact, transmission is facilitated in overcrowded, congregate and badly ventilated buildings (e.g., prisons, hospitals, refugee camps). Generally, NV is the main air disinfection way, with the advantages of being cheap and broadly available. The drawbacks are the inapplicability under too cold or too hot conditions or other conditions (windows might be closed, for instance, for pest control or security reasons). Moreover, when air conditioning is installed, windows might be kept closed to ensure thermal comfort. MV has the advantage of providing proper disinfection of air, but it might be expensive in the installation, operation and maintenance. Finally, upper room germicidal irradiation was identified as the most cost-effective mean of disinfection.

Lei et al. (2017) [160] monitored the IAQ (O_2, CO_2, temperature and RH) in a students' dormitory of Beijing during winter (January). Questionnaires' surveys were used to analyze mental state and thermal comfort after 7 hours sleeping. A model predicting temperature and IAQ while variating the open area during winter was proposed. The study also aimed to prove that, in dormitories, NV is necessary even in cold climates. It was concluded that increasing the NV area improved IAQ, but decreased thermal comfort. During winter, 0.055 m^2 (giving 0.036 m^3/s of NV) was found to be the proper area of ventilation in dormitories with 10-12.5 m^3 of space per person. With open area bigger than 0.077 m^2, the temperature decreased under 20 °C only after 4 hours. An increase in the students' number should be accompanied with an increase of the open area. Nevertheless, with less than 6.5 m^3 per person, windows' opening is insufficient.

Heebøll et al. (2018) [161] performed a four weeks monitoring of four different Danish classrooms (Atlantic temperate climate) in the winter season (January), one year after a retrofitting was performed. Temperature, CO_2 concentration, use of energy and behavior in door and windows opening were recorded. The rooms, located in Copenhagen, were equipped as follows: (A) decentralized, balanced supply and exhaust MV unit with heat recovery; (B) automatically operable windows with an exhaust fan; (C) automatically operable windows with alternating counter-flow heat recovery through slots in the outside wall; (D) visual feedback display unit showing the current classroom carbon dioxide concentration, thus advising when the windows should be opened. Original approach of manual windows opening was retained in one class, for comparison. The paper allowed to list the following observations: (1) The presence of a CO_2 feedback display caused the opening time to be longer (during occupancy hours including breaks), but this did not cause the decrease of CO_2 concentration to be significant. (2) With automatic opening and exhaust fan, the opening period was 71 % of occupancy time (breaks included), also causing CO_2 concentration to be significantly lower with respect to classrooms with only manual operations. (3) With automatic opening and heat recovery, opening period was 49 %, with no significant lower CO_2 concentration with respect to "only-manual" rooms. (4) In the rooms with MV and with automatic windows and the exhaust fan, the lowest concentrations of CO_2 were measured. (5) No remarkable differences were observed in indoor temperatures of classes with automatic opening of windows and classes with no retrofit. Temperature was generally within comfort ranges in both cases. A significantly warmer temperature was observed in rooms with the display for visual CO_2 feedback or with MV (maybe caused by a valve defect and radiator thermostats' setting). (6) In temperate areas, MV or automated windows opening systems are recommended for classrooms.

An investigation on the use of MV and NV in 46 apartments in 10 cities in China, located in 5 different climate zones (severe cold, cold, hot summer cold winter, temperate, hot summer warm winter), was performed by Lai et al. (2018) [162]. The houses were monitored for one year, and questionnaires were administered to gain information about residents' choices. It was stated that MV, even if more controllable, reliable and comfortable, could generate secondary air pollutants, noise and energy consumption. Moreover, it was found out that average ventilation duration was shorter for MV (7.2 hours vs. 11.0 hours). NV duration increased and MV duration decreased with: warmer climates, warmer season and higher average outdoor temperatures. In colder regions, when temperature reached 24 °C, NV duration began to decrease. When dealing with colder climates, use of supply MV was less than energy recovery ventilation systems, probably due to thermal discomfort. Moreover, MV and NV durations were highly variable and people were not active in the change of the status of ventilation. Noise was reported as a source of discomfort both in case on NV (outdoor) and MV (system). Finally, it was observed that the priority of occupants was thermal comfort instead than healthy IAQ. Nevertheless, when MV allowed to provide healthy indoor conditions, they stated their willingness to spend money on energy. Thus, energy savings, health and thermal comfort were proposed to be the three drivers of ventilation behaviors.

MV and NV effects on indoor climate (thermo-hygrometric and IAQ, thermal regulation and air-change perspectives) of nine homes in Urumqi (China, temperate continental climate with severely cold winters) was investigated by Zhao et al. in 2018 [163], by means of preliminary questionnaires on living habits and one-year indoor monitoring. Four of the houses considered were equipped with NV, four with MV with heat recovery, and one with MV without heat recovery. It was observed that winter indoor climate was dry, but comfortable during the rest of the year. In this season, MV was observed to possibly cause a lower temperature reduction and a lower humidity reduction with respect than a 25 minutes long NV. Both MV and NV would need attention to humidification, especially in the colder season. Moreover, indoor conditions were perceived drier by people living in environments with MV, who also expressed preference for humidifying the rooms: this did not prevent humidity to be lower than in houses with NV. In houses with NV, IAQ was observed to worsen because of too humid conditions when poor ventilation was present. $PM_{2.5}$ concentration was low outside in summer and transition seasons. Moreover, not too hot or too cold temperatures were present. These last aspects make it suitable to improve indoor environmental conditions by NV, saving MV energy.

Fernández-Agüera et al. (2019) [164] studied IAQ and thermal comfort in two different climates in Spain (Seville and Madrid). The investigation was conducted in residential buildings constructed before regulations on energy efficiency (1939-79). The case studies were not equipped with a MV system and had various levels of air-tightness. The IAQ was compared with the air-tightness and a comparison of the behavior in day- and night-areas was performed. It was firstly stated that, in these buildings, NV behavior (and therefore outdoor temperature) was the main driver for the air-change. Indoor-outdoor concentration of CO_2 were similar in spring, summer and autumn in Seville, and only in summer in Madrid. In Seville, this was associated with the behavior of occupants trying to lower the temperature during less irradiated times. In Madrid, poorer thermal comfort was also detected during summer. In both climates, during winter, levels of CO_2 above 1200 ppm were recorded in both Madrid (1900 ppm) and Seville (1400 ppm). Higher values were recorded during night. During this season, occupants, being aware of the of the MV lack, ventilated their flats mainly in the morning, primarily relying on infiltration during the rest of the time. This was the main reason why unhealthy indoor air and poor air quality (both in terms of CO_2 land RH levels) were observed. In fact, low air-change rate and air-tightness both concur in creating high concentrations of CO_2. In areas with warmer climates, this association is less evident, due to the major influence of individual behaviors in terms of ventilation. Healthy conditions could not be maintained, with the consequent risk of condensation, especially in colder climate (Madrid) and in buildings with the highest air-tightness (where windows had been substituted). The practice of windows' openings was observed to cause also a loss of energy. Improvement of ventilation practices and MV systems would ameliorate the IAQ in both locations. In Seville, comfort standards could be met raising winter internal temperatures by means of a more effective heating.

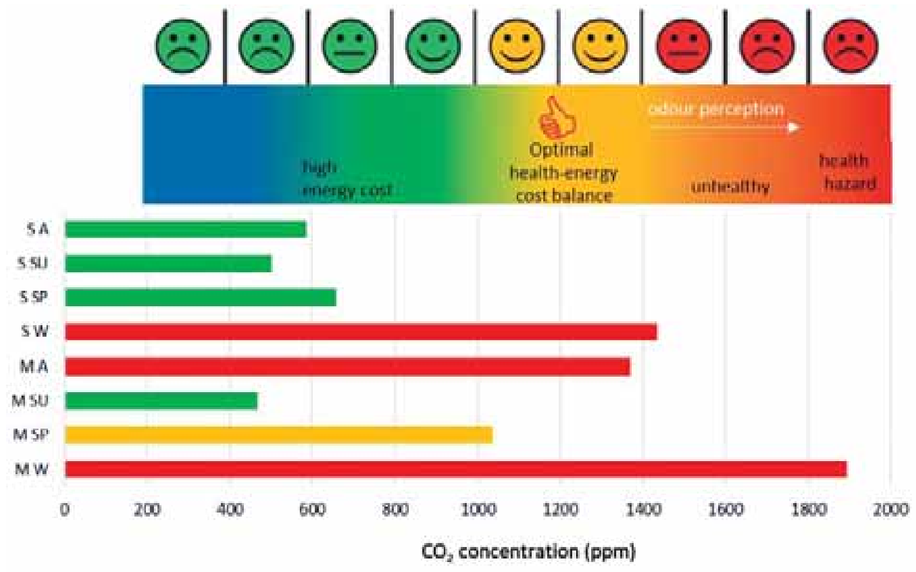

Figure 48: IAQ and balance with ventilation energy consumption. S = Seville; M = Madrid; A = autumn; SU = summer; SP = spring; W = winter. Reproduced from Fernández-Agüera et al. (2019) [164]

Cardoso et al. (2020) [165] used transient simulations in order to compare scenarios with different possible air paths configurations in a Portuguese apartment with highly permeable envelopes and highly variable air-change rate. Both natural and mechanical scenarios were included. A MEV (mechanical extraction ventilation) was present in bathroom and kitchen. On the other hand, unintentional air leakage paths constituted the source for air supply. Only when the MEV was on, a sweeping effect from bedroom to bathroom was observed. Moreover, equivalent air leakage area distribution through different leakage configuration paths was impactful on the air-change rate. It was concluded that the dependence of air-change rates from air-tightness is worth to be studied in Southern Europe, since NV is widely used. IAQ, energy efficiency and comfort strongly depend on it.

Abdul Hamid et al. (2020) [55] monitored air temperature, air humidity, air-change rates and CO_2 in twelve heritage buildings with offices of Sweden. Measurements were coupled with questionnaires to the occupants. The effects of a MV ventilation system with a heat recovery located in a chimney pot (hidden) and of dampers for air-change rate reductions (installed on the pathways for natural airflows, on the chimney tops) were studied. This was done by means of field measurements and energy simulations in two of the buildings. It was observed that, in this type of building, indoor climate is highly dependent on outdoor conditions. In fact, air-change rate is higher during working hours (window openings), higher during working time in summer than in winter (window openings), lower during after-hours in summer than in winter (smaller indoor-outdoor temperature difference). Too cold and draught conditions were observed in cold season, while too warm, dry and stuffy environments was seen in summer (with acceptable CO_2 conditions). Moreover, the two proposed solutions were observed to give a potential reduction in the energy use (also

CO_2 concentration in case of chimneypot MV with heat recovery). Finally, the authors recommend to make other investigations, specific for each building (e.g., thermography with air-tightness testing, emissions, particulate and moisture safety assessments), before taking decisions on the measures to apply. Profitability of measures should be taken into account, as it is fundamental in decision-making processes.

A real-time investigation of $PM_{2.5}$ and CO_2 concentrations in 33 classrooms located in 21 different schools of Beijing, comparing MV systems and NV with air cleaners, was performed by Cai et al. (2020) [166]. Air temperature, humidity and effectiveness of air-cleaning were also monitored. Too low ventilation rates were observed with NV in days of high $PM_{2.5}$ concentration. Nevertheless, both NV and MV were not sufficient to lower enough the $PM_{2.5}$ concentration. MV ensured temperature to be not too low during winter. Nevertheless, during days of central heating switching on or off, indoor temperature was found to be sometimes lower than the 18 °C recommended by Chinese standards, with both NV and MV. NAI (negative air ion) purification modules were observed to tend to elevate the levels of biomarkers related with a higher possibility of oxidative stress. MV had a lower energy efficiency in removing $PM_{2.5}$, but was more effective in the CO_2 reduction.

Scheuring & Weller (2021) [167] performed an EnergyPlus simulation in an office room, in order to study the comfort and energy implications of four strategies of window openings (based on CO_2 and temperature) and one intake/exhaust MV system (based on CO_2), at the three different climates of: (1) Wiegendorf (Germany) - moderate (European continental); (2) Madrid (Spain) – Mediterranean; (3) Hanoi (Vietnam) – subtropical. The paper led to the following considerations: (1) NV can be an alternative to save energy in non-residential buildings, ensuring less costs of maintenance and positive psychological feelings of freshness of air. Nevertheless, NV might lead to higher energy consumption and less IAQ, due to behavior of users. Therefore, controls of NV based on concentration of carbon dioxide and room temperature are needed. (2) In the cold months at moderate climate, long openings could not be used due to thermal discomfort. In the other conditions, NV outperformed MV.

The review by Wolkoff et al. (2021) [47] investigated the influence of microclimatic parameters (room temperature, indoor air humidity, ventilation) on human health, cognitive performance, infection risk and work in offices. It was highlighted that acute and chronic health issues can be reduced by ventilation, which can also enhance the work performance. This is due to control strategies of general emission source and the indoor air pollutants (comprising pathogens) dilution. MV helps diluting and removing the indoor air pollutants, thus giving better comfort and less health risks. When devices like efficient filtration and air cleaning systems are implemented, also exposure to size dependent ambient particles can be reduced. Satisfaction on thermal comfort and overall microenvironment is improved by personal control of ventilation, due to positive physical and psychological impact. Nevertheless, an increased exposure to air pollution, pathogens and allergens (from indoor or outdoor) can occur due to ventilation itself, being cause of health risks. This happens with NV or when not properly designed, maintained or operated MV is present. Deterioration of IAQ perception and harm from new chemicals exposure can also occur due to ozone surface-initiated reactions from systems maintained improperly. Moreover, in the cold season, dry outdoor air can enhance the viability of virus droplets: high ventilation rate with no humidification has to be avoided. Therefore, WHO's air quality guidelines should be met by a "health-based ventilation rate", with an acceptable perception of IAQ by diluting human bio-effluents.

5.3. Further statistics about literature analysis

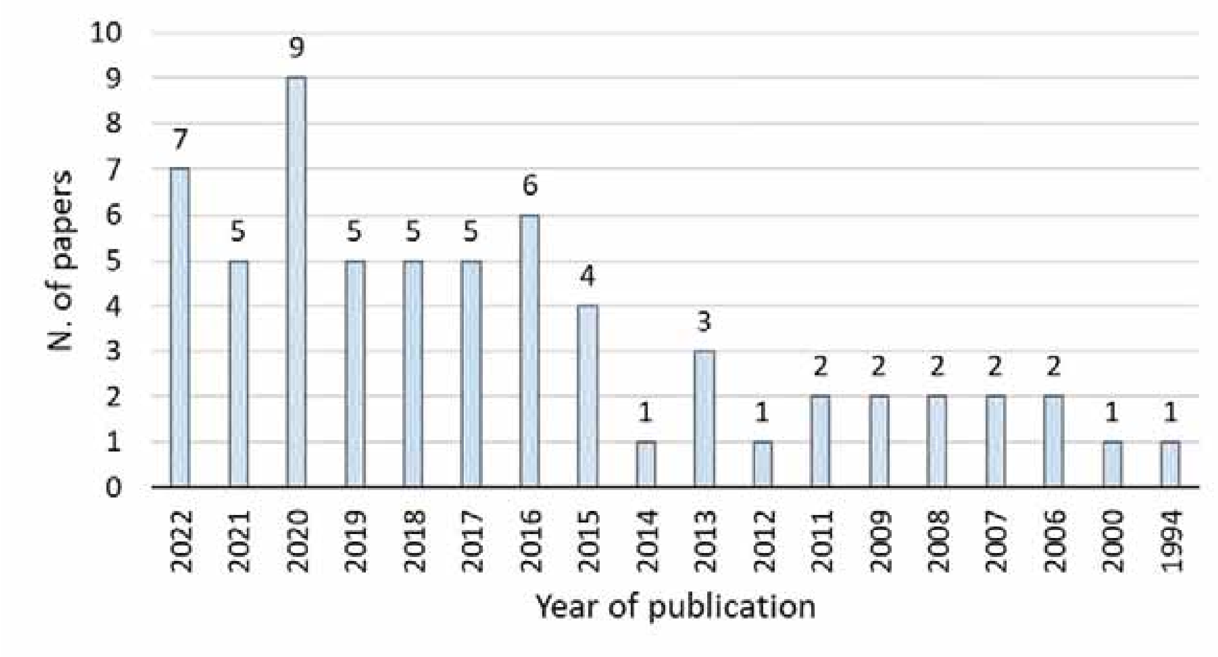

Figure 49: Number of articles for each year of publication

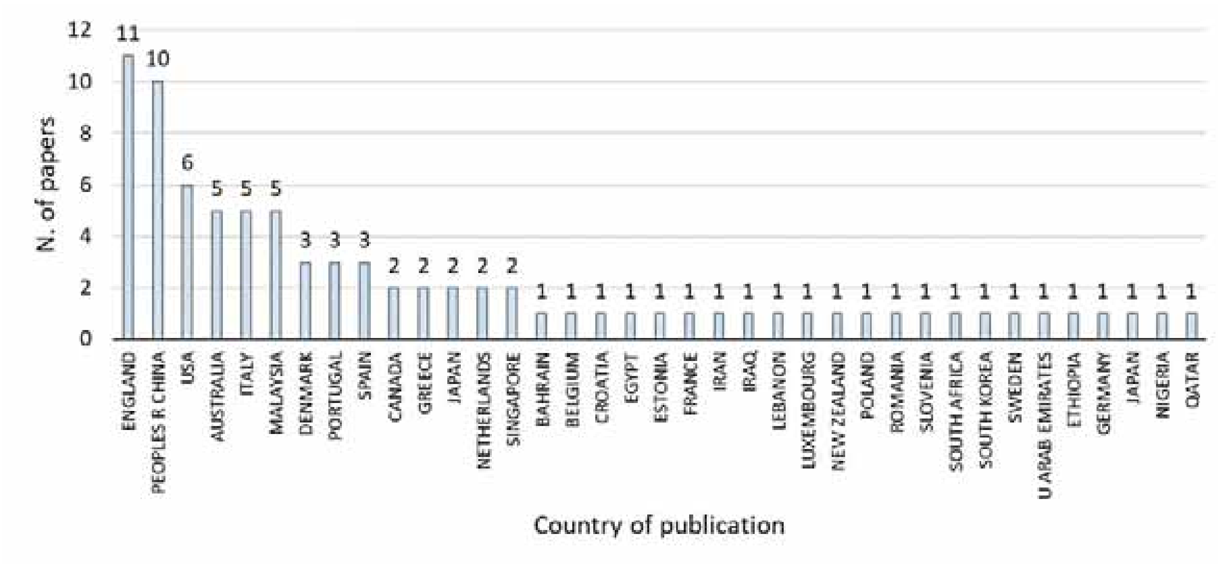

Figure 50: Number of articles for each publication country/region

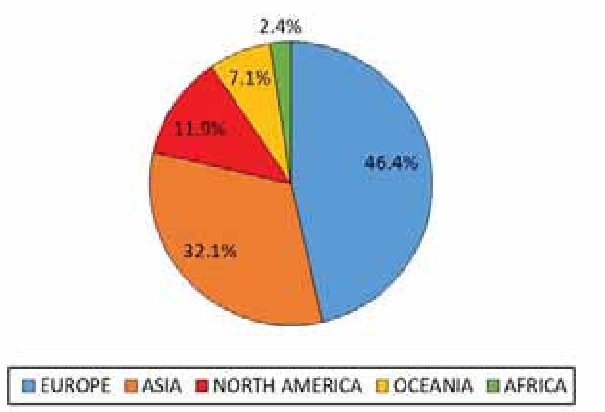

Figure 51: Percentage of articles per continent

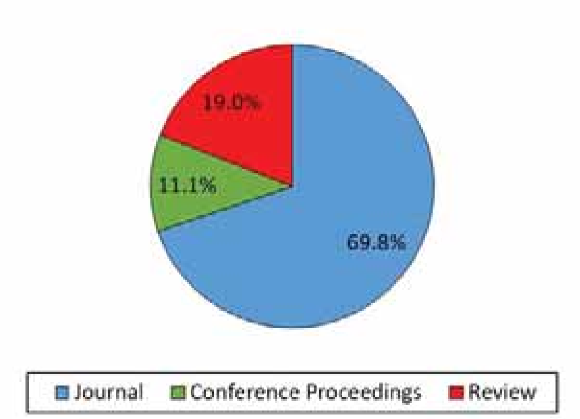

Figure 52: Percentage of articles per type

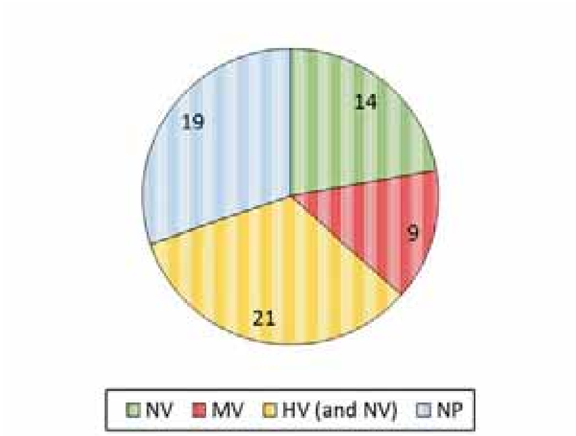

Figure 53: Number of articles per type of ventilation recommended. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no clear preference

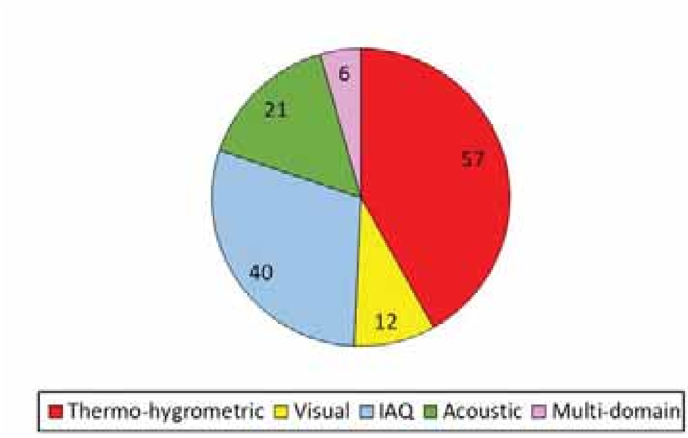

Figure 54: Number of papers treating each comfort domain

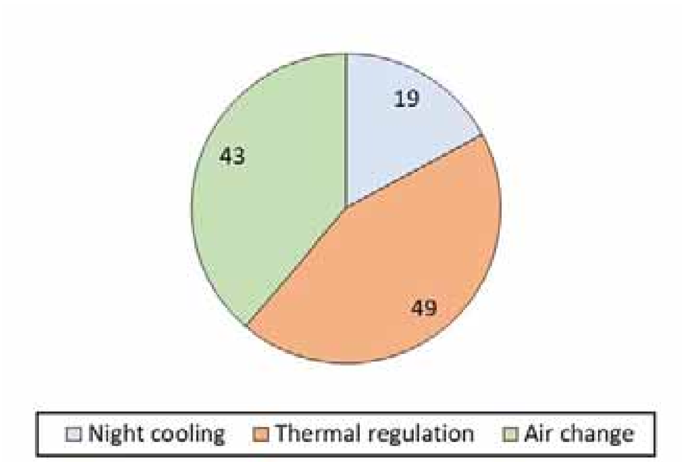

Figure 55: Number of articles considering each ventilation aim

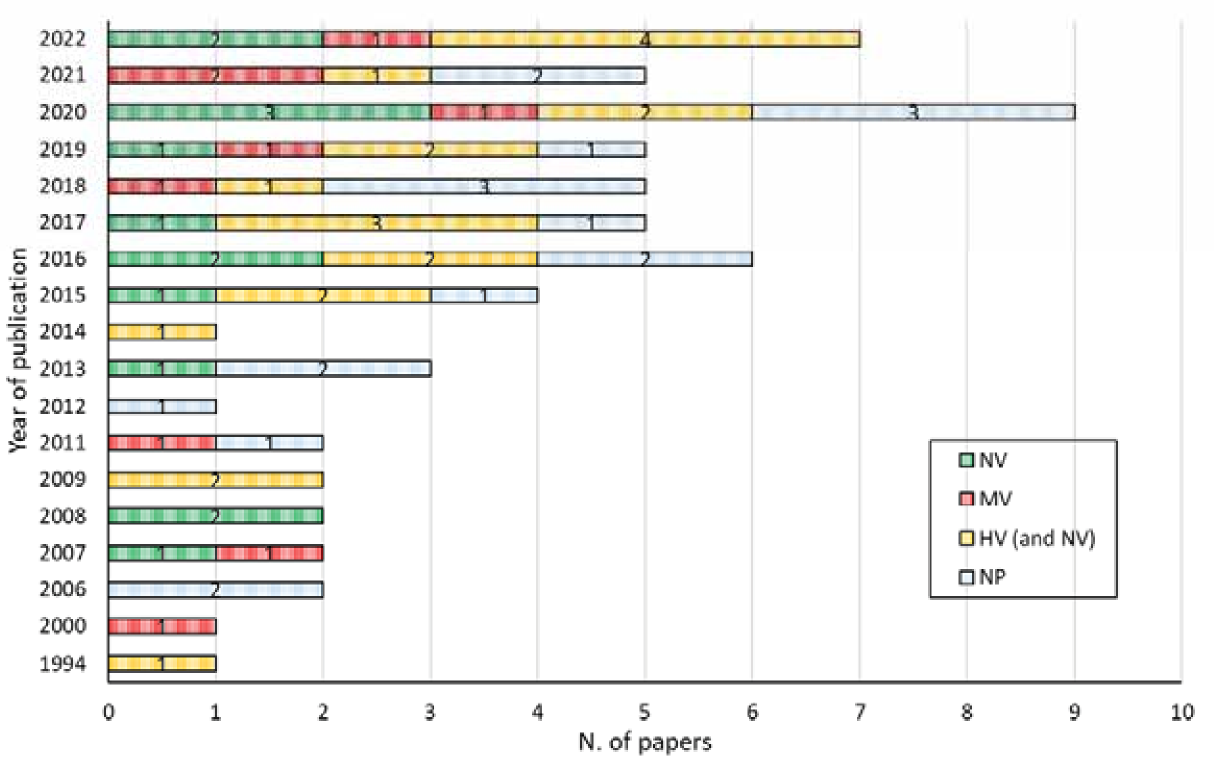

Figure 56: Association between publication year and type of ventilation recommended

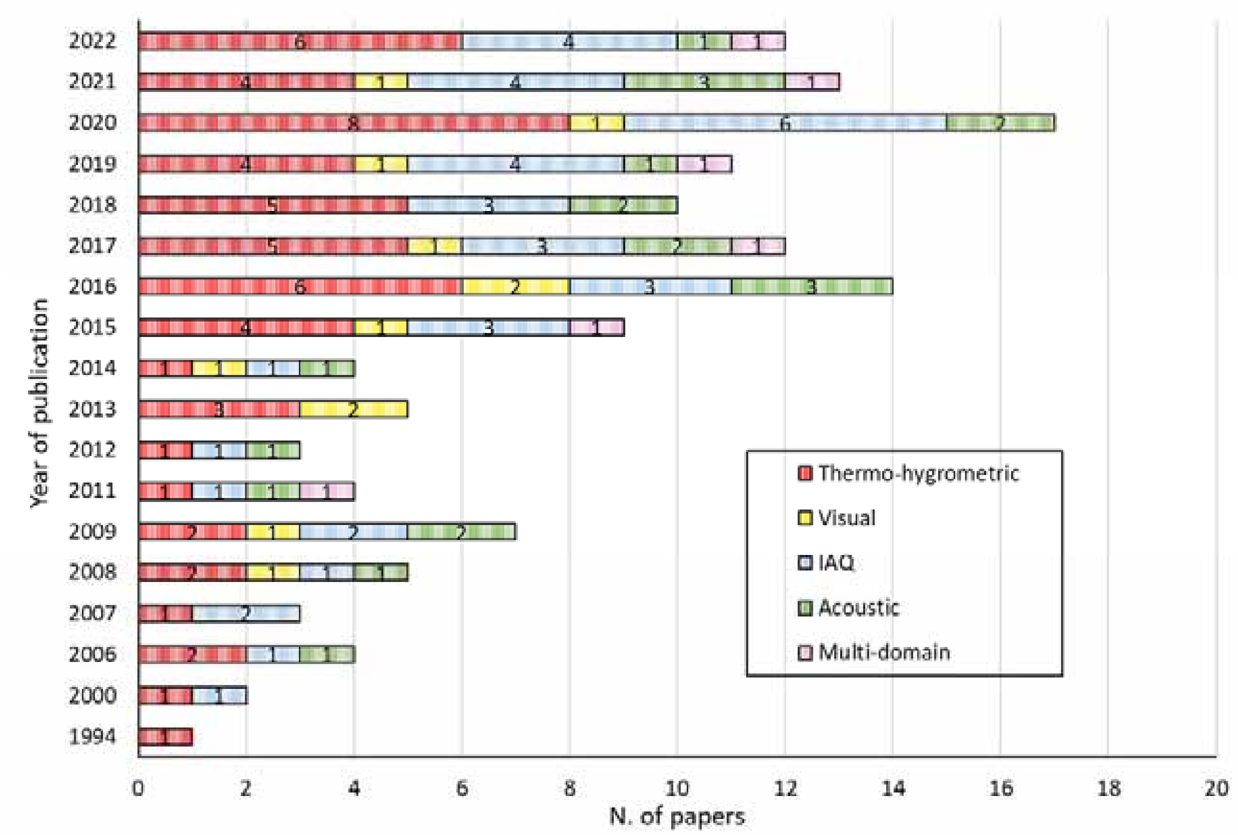

Figure 57: Association between publication year and comfort domain treated

Table 1: Number of articles per type of environment considered

Type of environment	Number of papers
Residential	18
Educational	12
Healthcare	1
Working	14
Industrial	1
Amusement	1
Non-residential (unspecified)	3
Inapplicable (various, unspecified, …)	13

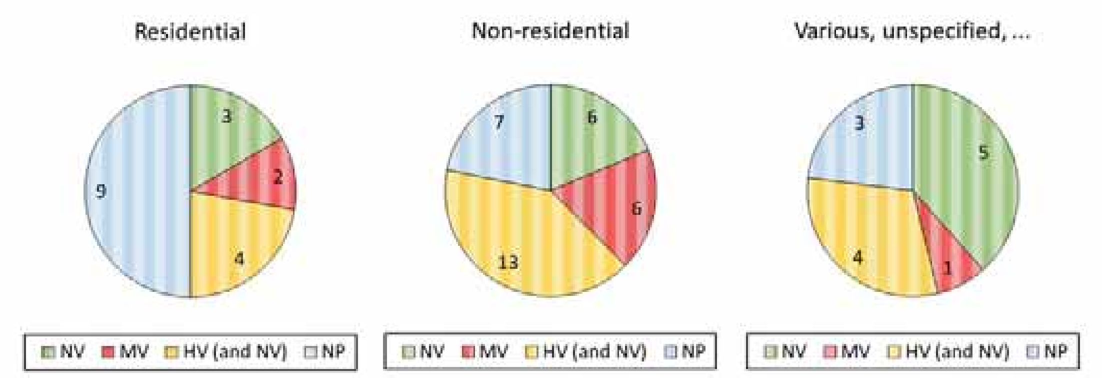

Figure 58: Number of papers per type of ventilation recommended, divided by type of environment. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no clear preference

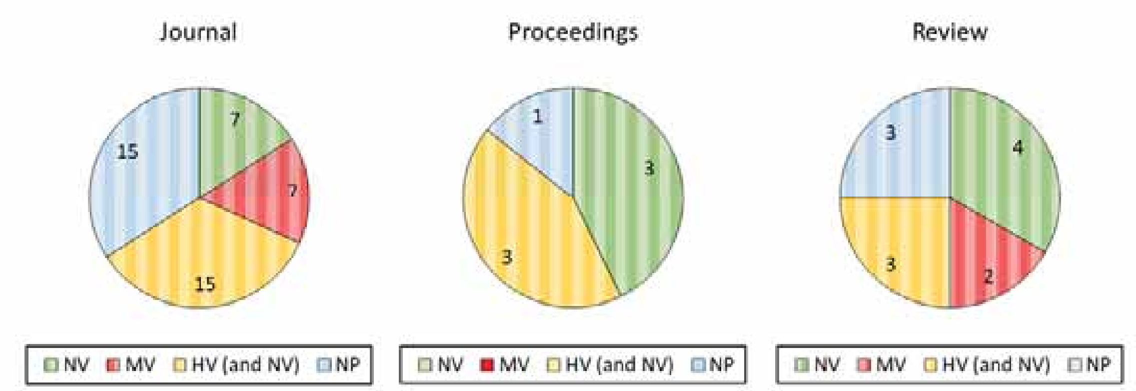

Figure 59: Number of articles per type of ventilation recommended, divided by type of document. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no clear preference

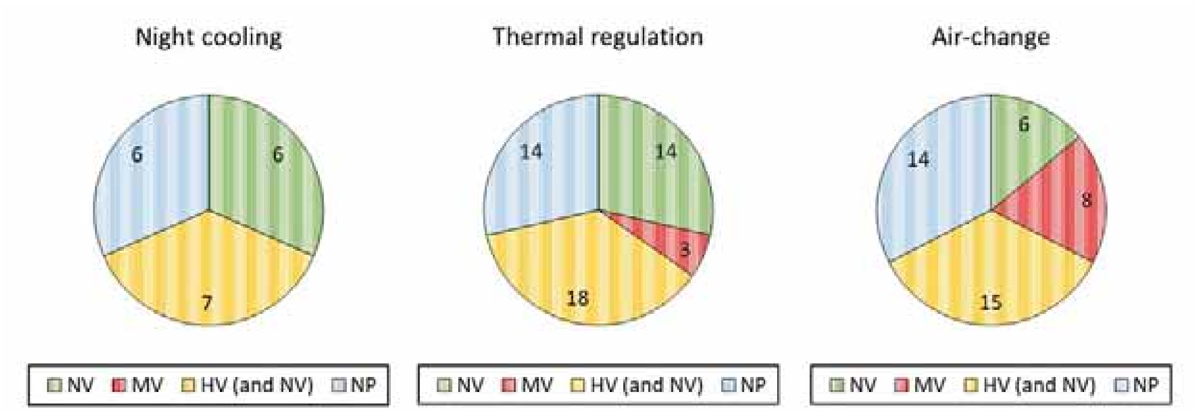

Figure 60: Number of articles per type of ventilation recommended, divided by aim of ventilation considered. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no clear preference

5.4. Main outcomes of literature analysis

Main outcomes are summarized and listed here below:

1. Not many studies comparing NV and MV in terms of indoor comfort and well-being were found. Especially, literature lacks of comparison of NV and MV in some non-residential facilities, such as healthcare ones.
2. The number of papers on the topic is growing in time. A sudden increase is present in 2020.
3. Most papers deal with thermo-hygrometric or IAQ comfort. Other domains are named marginally in less recent papers, and more frequent in the most recent years as part of a multi-domain framework.
4. In most cases, papers dealing with visual or acoustic comfort, or dealing with multi-domain, treat them only marginally (e.g., highlighting that their connections with other domains are important in future research).
5. The necessity to study the lighting and the noise domains connected with NV is pointed out by some papers.
6. When there is a preference of occupants for NV, this is mainly due to control, air movement and access to the outside.
7. Main disadvantages of NV are dealing with the ability to guarantee IAQ and desired comfort conditions. In this sense, main obstacles in using NV are outside pollution, outside noise and outside temperature (too high or too low). Climate change will further limit the NV useful time in warmer regions, but will expand it in colder regions.
8. Nevertheless, there is the need to further deepen the effects of pleasant sounds from outside on indoor comfort. This aspect is not taken into account in standards by now.
9. In many cases, the ability to precisely control the environmental conditions by MV was not perceived by occupants.
10. Another limit of NV is that it might be too dependent on people behavior (in opening windows).
11. Main disadvantages of MV are dealing with the energy consumed, the lack of control and plant's noise. MV systems needs to be properly design in order to minimize these problems.
12. Some papers argue that, if using solutions like heat recovery, MV can save energy with respect to NV.
13. In general, indoor environment and energy consumed are strongly influenced by behavior.
14. Different solutions give different impacts, which can be observed on different indicators of IAQ (CO_2, PM, VOC, …).

15. Attention to elements such as air-tightness of the facility and buildings' materials emissions should also be paid, when designing the ventilation system.
16. Some architectural characteristics like building orientation, position, size of openings, façades, etc., are very important in the design of NV. These elements need to be carefully designed. In this sense, the use of CFD is used or encouraged by many studies.
17. NV and daylight do not compete, but can benefit from similar architectural elements.
18. The type of ventilation to be used is dependent on climate (e.g. use of air conditioning in tropical areas, due to high humidity) as well as economic conditions (two papers stressing the dependence on NV of developing countries). Nevertheless, a proper design and the coupling with other techniques can optimize comfort and energy consumption.
19. HV can be a proper solution to save energy and allow control, using backup MV solutions when proper conditions cannot be maintained by NV alone. Moreover, it permits to use NV when season or time of the day allow it. For these reasons, most studies recommend HV in order to maximize energy efficiency guaranteeing comfort and IAQ in all seasons.
20. The share of papers suggesting NV alone was growing until 2020, mostly because of energy efficiency reasons. After COVID-19 pandemic, this proportion seems to have decreased. In fact, the importance of MV or HV for health and air purification reasons are often emphasized later, especially in some non-residential environments. The need to move the ventilation design from a comfort-based to a health-based approach is sometimes highlighted.
21. MV alone is mostly recommended in non-residential environments. In both residential and non-residential, a considerable share of papers recommend the use of HV. It is also interesting to notice that in papers speaking about ventilation with a general point of view (not referring to a specific environment), NV and HV are mostly recommended.
22. Some papers highlight the necessity of changing standards and guidelines in order to decrease energy consumption, improve comfort and encourage NV. For instance, a classification of environments based on windows' control level instead than considering only air conditioning presence, was proposed by one paper.
23. Not many studies dealing with night cooling were found. The necessary of further studies in the field was highlighted also by some articles. Moreover, when considered, night cooling was mostly treated marginally and within some general considerations.
24. No clear trends in the type of ventilation suggested were observed categorizing the papers per type of document or per aim of ventilation considered. The only remarkable observation is that no conference papers recommending MV only were found.

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ANNEX

9.3.1 Sheets of Destra Adige - Piedicastello district

PARTITIONING OF THE AREA INTO FOUR SUB-AREAS

1. Area 1: ex Italcementi area

2. Area 2: built-up area

3. Aerial view of Destra Adige - Piedicastello district

4. Area 3: two disused road tunnels

5. Area 4: ex Zuffo parking lot

Source of images:

1. https://www.investinitalyrealestate.com/it/property/trento-italcementi-area/ - (accessed Aug. 5, 2022)
2. University of Trento (DICAM)
3. Image from Google Earth - (accessed Aug. 5, 2022)
4. University of Trento (DICAM)
5. University of Trento (DICAM)

HISTORY OF THE SITE_A


1. Piedicastello square, 1800 - 1900


2. Piedicastello square, 1954

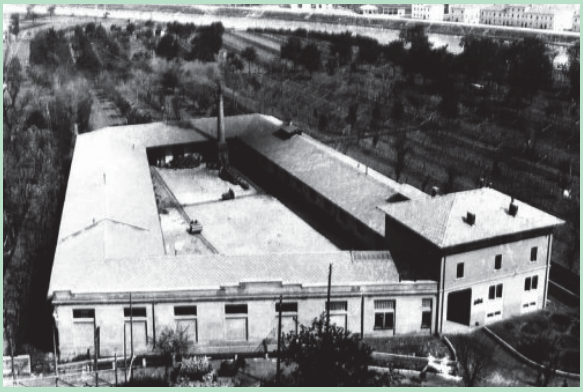

3. View of Piedicastello, 1914


4. Piedicastello square and Brescia street, 1922 - 1935


5. San Lorenzo iron bridge, 1924


6. San Lorenzo concrete bridge, 1960


7. View of the cement factory, 1920


8. View of the metallurgical factory, 1931

Source of images:

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HISTORY OF THE SITE_B

1. View of the Piedicastello primary school, 1930s

2. View of the Piedicastello primary school, 1960s

3. View of the ex Italcementi area, 2012

4. View of the ex Italcementi area, 2015

5. View of Piedicastello, 1914

6. View of Piedicastello, 2000

7. View of the Piedicastello road system, 2005

8. View of the urban-environmental renovation works, 2017

Source of images:

1. https://www.piedicastello.tn.it/documenti/il-borgo/la-ex-scuola-elementare/ - (accessed Aug. 5, 2022)
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8. https://www.dfcostruzioni.it/project/page/3/ - (accessed Aug. 5, 2022)

DISTRICT SQUARE


1. View of historic buildings


2. View of historic buildings


3. View of the square and Brescia street


4. The fountain in the square


5. View of the church and rectory


6. View of pedestrian area


7. View of the playground


8. Play equipment

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)
6. University of Trento (DICAM)
7. University of Trento (DICAM)
8. University of Trento (DICAM)

ROUNDABOUT AND ROAD SYSTEM

1. View of new roundabout

2. Traffic circulation and parking in Brescia street

3. Traffic circulation and parking in Papiria street

4. Traffic circulation and parking in Verrucca street

5. Traffic circulation and parking in Lungadige Apuleio street

Source of images:

1. https://www.trentotoday.it/cronaca/inaugurazione-piazza-piedicastello-11-novembre.html - (accessed Aug. 5, 2022)
2. University of Trento (DICAM)
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5. University of Trento (DICAM)

EX ZUFFO PARKING LOT

1. General view of ex Zuffo parking lot

2. Main entrance

3. Area Zuffo Kiosk bar

4. Bike parking

5. Bike sharing point

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)

DOSS TRENTO PARK

1. View of Doss Trento

2. Doss Trento Nature Park

3. Pedestrian trail to Doss Trento

4. Alpine Museum

5. Cesare Battisti Mausoleum

6. Cannons in front of the Mausoleum

7. Ruins of an early christian basilica

8. Woods covering the top with many plant species

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. https://it.wikipedia.org/wiki/Museo_nazionale_storico_degli_Alpini#/media/File:Trento-museo_storico_truppe_alpine.jpg - (accessed Aug. 5, 2022)
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PIEDICASTELLO TUNNELS

1. Exterior view of the two disused road tunnels - south side

2. Interior view of the White tunnel

3. Set-up for cultural event in the White tunnel

4. Exterior view of the two disused road tunnels - north side

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)

BUILT HERITAGE - Historical buildings


1. View of historic buildings


2. Historical buildings


3. Historical buildings


4. Historical buildings


5. Historical buildings


6. Historical buildings


7. Historical buildings

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)
6. University of Trento (DICAM)
7. University of Trento (DICAM)

BUILT HERITAGE - Workers' housing

1. Gardens

2. Building on the corner of Papiria street and Verrucca street

3. Access with steps to building in Verrucca street

4. Buildings in Papiria street

5. Buildings in Verrucca street

6. Buildings in Papiria street

7. Buildings in Verrucca street

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)
6. University of Trento (DICAM)
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BUILT HERITAGE - Social housing in Lungadige Apuleio street

1. Built area in Lungadige Apuleio street

2. View of a group of social housing

3. Detail of a building of social housing

4. Detail of a building of social housing

5. Recently renovated buildings of social housing

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)

BUILT HERITAGE - Social housing in Doss Trento street

1. View of ITEA social housing

2. 4-storey building

3. 5-storey building

4. Multi-storey apartment blocks

5. 6-storey building

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)

BUILT HERITAGE - Small residential buildings

1. Building in Papiria street

2. Building in Doss Trento street

3. Details of buildings in Doss Trento street

5. Building in Brescia street

4. Building in Doss Trento street

6. Small construction site of building in Doss Trento street

7. Building in Doss Trento street

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)
6. University of Trento (DICAM)
7. University of Trento (DICAM)

SERVICES AND COLLECTIVE SPACES

1. Commercial and service activities in Brescia street

2. Commercial and service activities in Brescia street

3. Restaurant on the square

4. Trattoria on the square

5. Portland Theatre in Papiria Street

6. Public kindergarten in Doss Trento street

7. Building street with the multi-purpose room of the district

8. Bruno Social Centre in Lungadige San Nicolò street

Source of images:

1. University of Trento (DICAM)
2. University of Trento (DICAM)
3. University of Trento (DICAM)
4. University of Trento (DICAM)
5. University of Trento (DICAM)
6. University of Trento (DICAM)
7. University of Trento (DICAM)
8. University of Trento (DICAM)

ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

ANNEX

9.3.2 Table of Meetings with Stakeholders

Table_ Meetings with STAKEHOLDERS_TRENTO DEMONSTRATION PROJECT_ ECD of the New Building in Area 4

WHEN	WHO and WHERE	PARTICIPANTS	ITEMS discussed	NOTE
17.05.2022	**Municipality of Trento** via Alfieri n.6 Trento	**EURAC** - dott. D. Vettorato **UNITN** - prof. A. Frattari **Municipality of Trento** - council member E. Facchin (Mobility and Ecological Transition Department) - ing. G. Franzoi (Mobility and Urban Regeneration Department) - ing. S. Fedrizzi (Urban Planning Service) **DOLOMITI ENERGIA** - ing. N. Fruet	New Building in Area 4: urban planning constraints and its possible function	
24.06.2022	**Citizens of Piedicastello (Trento)** sala circoscrizionale in VIA VERRUCA n. 1 - PIEDICASTELLO	**Municipality of Trento** - council member M. Baggia (Land use planning and private building Department) - council member E. Facchin (Mobility and Ecological Transition Department) **UNITN** - prof. R. Albatici **EURAC** - dott. D. Vettorato **DOLOMITI ENERGIA** - ing. N. Fruet **HABITECH** - dott. M. Curci **Circoscrizione Centro Storico Piedicastello** - ing. C. Geat (President) - citizens and residents	Presentation of ARV project and Trento demonstration site (contribute of D. Vettorati) An experience of geothermal applied to buildings (contribute of Marcello Pegoretti) Piedicastello towards a CCPC? Rounde table and discussion	This is the first public meeting with citizens and residents of the Piedicastello district. Title of the meeting “Geothermal and energy renovation of the of Piedicastello district - The European ARV project”. Promotion with flyer, communication via social facebook groups. https://greendeal-arv.eu/wp-content/uploads/2022/07/Flyer_Piedicastello-meeting.pdf

18.07.2022	**Municipality of Trento** via Alfieri n.6 Trento	**EURAC** - dott. D. Vettorato **UNITN** - prof. R.Albatici, prof. M. Dalprà **Municipality of Trento** - ing. G. Franzoi (Mobility and Urban Regeneration Department) - ing. S. Fedrizzi (Urban Planning Service)	New service building in Area 4 and first hypothesis of location in the parking lot called "ex Zuffo" New layout of the area "ex Zuffo" with reference of the Urban Plan for the Sustainable Mobility (PUMS) of Trento New Building as pilot test for the development and implementation of the PUMS of Trento Possible future expansion of the New Building in Area 4 which could also facilitate the management phase Administrative steps of the authorization process	
20.09.2022	**Municipality of Trento** Via Brennero 312, Trento	**EURAC** - dott. D. Vettorato **UNITN** - prof. R.Albatici, prof. A. Frattari **Municipality of Trento** - ing. G. Franzoi (Mobility and Urban Regeneration Department) - ing. S. Fedrizzi (Urban Planning Service) **HABITECH** - dott. M. Curci, ing. A. Fronk **ARMALAM** - ing. F. Ferrario	State of the art of the authorization process for the New Building in Area 4 Goals, functional program and vision of the New Building in Area 4 Definition of the activities which will take place in each space of the building Functional relationship of the spaces and spatial relationship diagrams Preliminary size of each space and formal and volumetric concept Technical requirements of the spaces and the building system	
September 2022	**Users** online survey	**End Users** - citizen of Piedicastello District - residents in the Trentino region - national associations (such as Gruppo Acquisti Ibrido GAI)	Through a questionnaire opinions of potential end-users were collected to verify the first hypotheses on the functional programme of the New Building in area 4.	https://forms.gle/xwfabSZHqU1VmdPw5

ARV

CLIMATE POSITIVE CIRCULAR COMMUNITIES

ANNEX

9.3.3 Online survey

This Annex contains:

1. the texts of the e-mail used for the dissemination of the questionnaire to involve End Users of the New Building (EV Charging HUB with integrated services) of the Trento demontration project in the early concept design phase (in Italian);
2. the contents of the online questionnaire (in Italian).

1. ACCOMPANYING EMAIL

Indagine per raccogliere informazioni utili all'Università di Trento in merito alle esigenze ed aspettative degli utilizzatori di una infrastruttura di ricarica elettrica di pubblico accesso per auto/motocicli/biciclette

Gentilissimo/a,

si trasmette al seguente link https://forms.gle/xwfabSZHqU1VmdPw5 un breve questionario all'interno del progetto europeo ARV.

ARV, finanziato nell'abito del Green Deal Europeo, esplora la possibilità di generare Comunità Circolari Climatiche e Positive (*Climate Positive Circular Communities* - CPCCs) che si basano sull'interazione e l'integrazione tra gli edifici, gli utenti e i sistemi locali di energia, mobilità e ICT. In particolare, stiamo lavorando per raccogliere informazioni in merito alle infrastrutture di ricarica per i veicoli elettrici o ibridi e conoscere la tua opinione sarebbe importante.

Le domande richiedono pochissimi minuti.

Si tratta di un questionario anonimo, i dati e le informazioni raccolte saranno trattate esclusivamente in forma aggregata. Non sarà diffusa o pubblicata nessuna informazione o risposta individuale.
Ringraziamo in anticipo per la preziosa collaborazione e restiamo a disposizione per eventuali dubbi.

Il questionario può essere diffuso a persone ed enti che ritieni possano essere potenzialmente interessati dall'indagine. Grazie!

UNIVERSITÀ DI TRENTO

Per eventuali richieste di informazioni, contattare lpe.dicam@unitn.it
Persona di riferimento: prof. Rossano Albatici,
DICAM, Università di Trento, via Mesiano 77

Sito web del progetto europeo ARV: https://greendeal-arv.eu/2022/02/14/italy/

2. QUESTIONNAIRE

Grazie in anticipo per aver deciso di dedicare qualche minuto alla compilazione del presente questionario. Le domande che seguiranno richiedono pochi minuti e ci permetteranno di raccogliere informazioni utili.

Ti informiamo, inoltre, che il questionario è anonimo e che i dati saranno trattati in forma aggregata.

Domande

Età

- ○ tra 18-25 anni
- ○ tra i 25-50 anni
- ○ tra 50-60 anni
- ○ più di 60 anni

Dove vivi?

- ○ in centro città/in centro di valle
- ○ in periferia di una città/di un centro di valle
- ○ in un piccolo paese/borgo
- ○ altro (specificare) ___________________________

Quale veicolo elettrico utilizzi abitualmente?

- ○ auto Full Electric
- ○ auto ibrida plug – in
- ○ veicolo commerciale Full Electric o Ibrido plug-in
- ○ scooter/moto/quadriciclo elettrico
- ○ bicicletta a pedalata assistita

Dove lo ricarichi preferibilmente? È possibile selezionare più di una risposta.

- ○ a casa da presa domestica o industriale
- ○ a casa con wall box
- ○ in azienda da presa domestica o industriale
- ○ da colonnine di ricarica a pubblico accesso
- ○ altro, specificare _______________________

Quando lo ricarichi fuori casa come occupi il tempo? È possibile selezionare più di una risposta.

- lavoro
- studio
- svago in prossimità della ricarica
- svago in luogo diverso dalla ricarica
- altro, specificare ______________________

Ti soddisfano le stazioni di ricarica ad accesso pubblico che abitualmente utilizzi o talvolta hai utilizzato?

- molto
- abbastanza
- poco
- per nulla

Ritieni utile nelle vicinanze dei punti di ricarica la presenza di servizi/attrezzature per occupare il tempo di attesa?

- molto
- abbastanza
- poco
- per niente

Durante la ricarica del veicolo come ti piacerebbe occupare il tempo? È possibile selezionare più di una risposta.

- rilassarsi
- lavorare
- usufruire di un piccolo bar o punto di ristoro
- stare con i propri figli/nipoti con l'opportunità di giocare con loro o farli giocare
- fare piccoli acquisti relativi al tuo veicolo o di altro genere
- noleggiare bicicletta o monopattino
- altro, specificare ______________________

Se fosse presente nei pressi di una stazione di ricarica un ambiente chiuso cablato con connessione rete Wi-Fi, ritieni che possa essere utile?

- molto
- abbastanza
- poco
- per niente

Prima o dopo la ricarica del veicolo quali delle seguenti attività complementari potrebbero essere utili? È possibile selezionare più di una risposta.

- autolavaggio
- autofficina
- altro, specificare ______________________
- nessuna attività

Nella stazione di ricarica attrezzata, ritieni utile la presenza di un'area per bambini?

- molto
- abbastanza
- poco
- per niente

Nella stazione di ricarica attrezzata, ritieni utile uno spazio informativo per cittadini/turisti con disponibilità di materiale informativo e promozionale del territorio di competenza?

- molto
- abbastanza
- poco
- per nulla

Nella stazione di ricarica attrezzata, ritieni importante la presenza di servizi igienici?

- molto
- abbastanza
- poco
- per nulla

Dove vorresti fosse localizzata una stazione di ricarica attrezzata? È possibile selezionare più di una risposta.

- nei pressi di un ampio parcheggio
- nei pressi di una stazione di rifornimento di carburante
- in prossimità di un centro commerciale
- in autostrada e/o al suo ingresso/uscita
- sulle arterie di collegamento
- altro, specificare ______________________

ANNEX

9.3.4 Summary report of the online survey

This Annex contains the results of the online survey developed by UNITN to involve End Users in the Early Concept Design phase of the New Building (EV Charging HUB with integrated services) for the Trento demonstration project.

In particular, the questionnaire serves a dual purpose of:

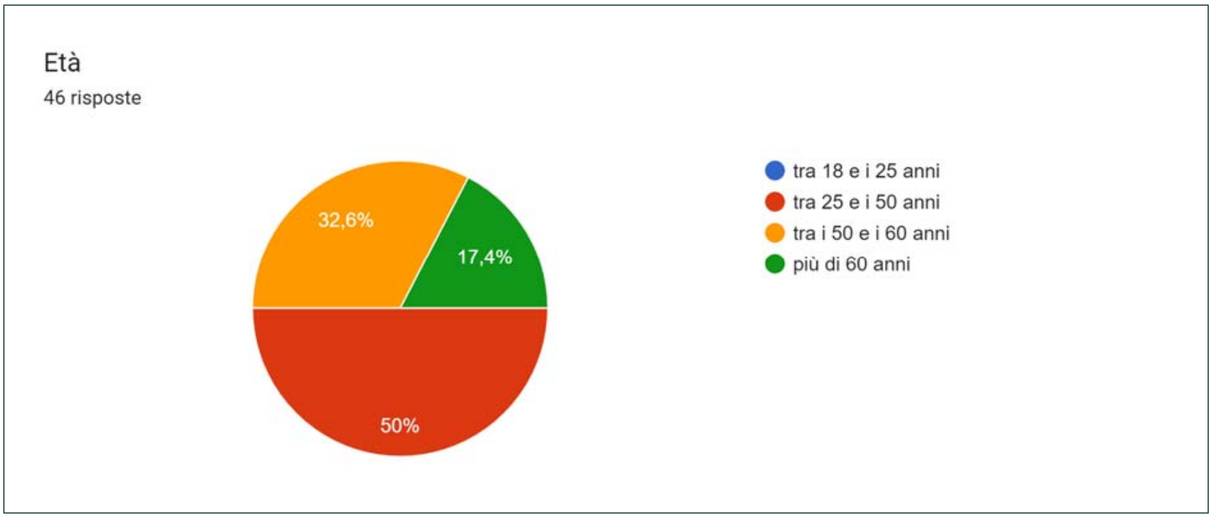
a) investigating the need/expectations of citizens who are owners or users of electric or hybrid vehicles on possible services that could improve the recharging and waiting times at dedicated stations;

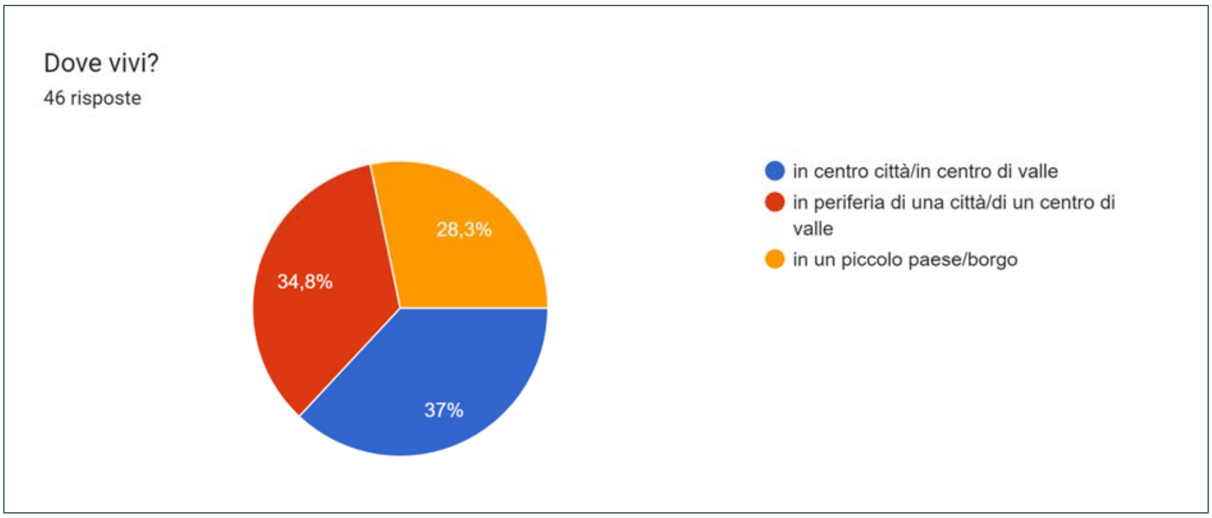
b) communicating and promoting the ARV project and the importance of citizens' engagement in the same.

46 people replied to the questionnaire on 24/11/2022.

The questionnaire was administered in Italian using a google form (gform). The original graphs processed automatically by the gform are shown below.

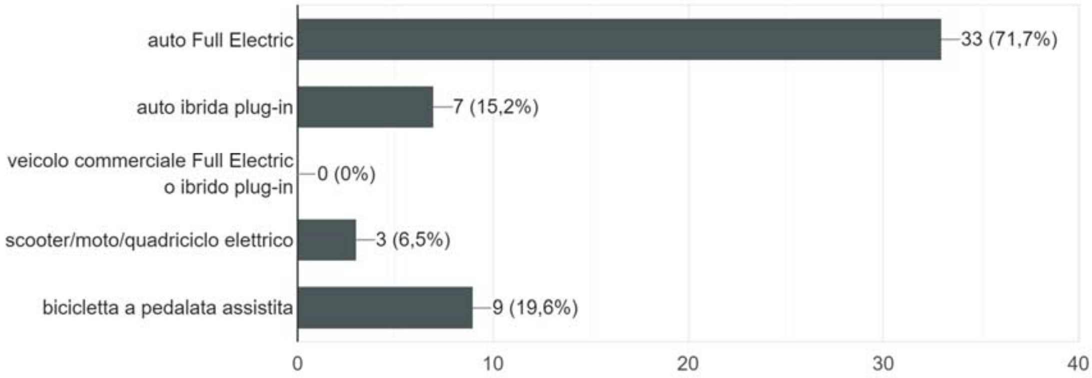
RESULTS OF THE QUESTIONNAIRE





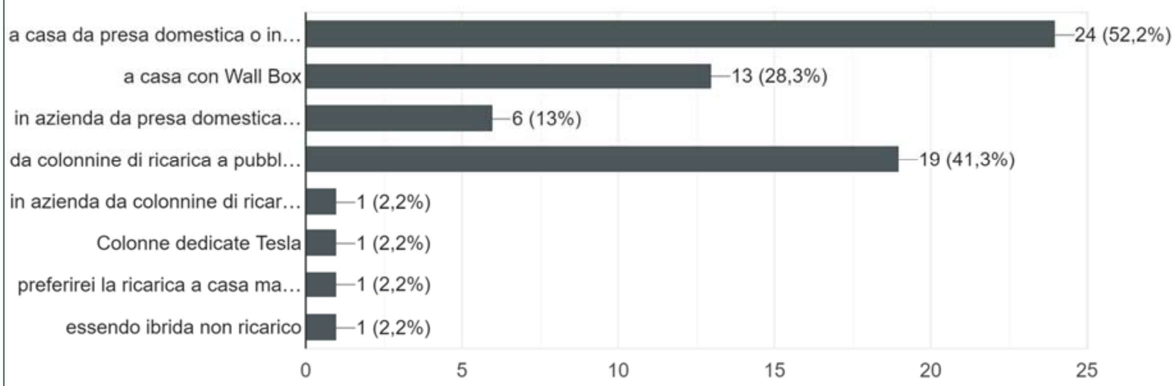
Quale veicolo elettrico utilizzi abitualmente?

46 risposte



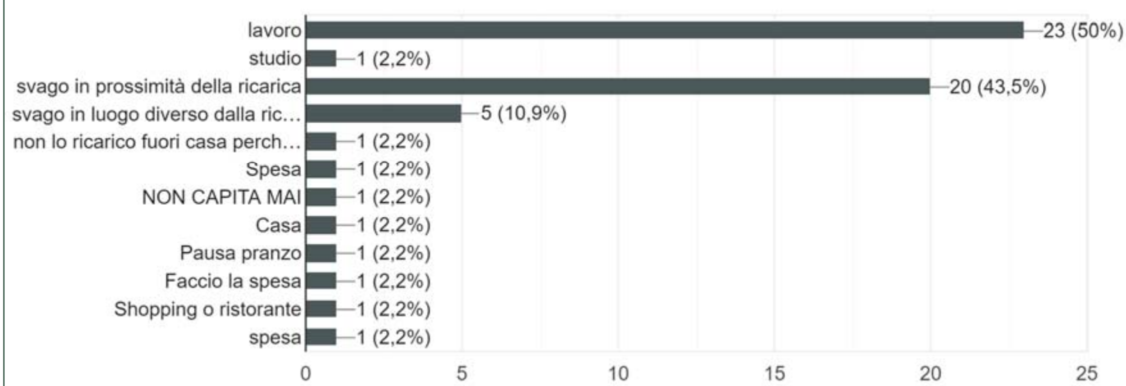
Dove lo ricarichi preferibilmente?

46 risposte



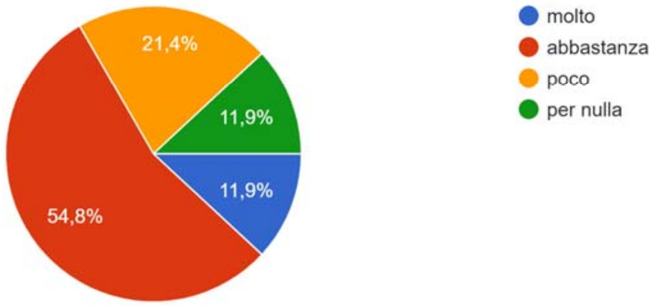
Quando lo ricarichi fuori casa come occupi il tempo?

46 risposte



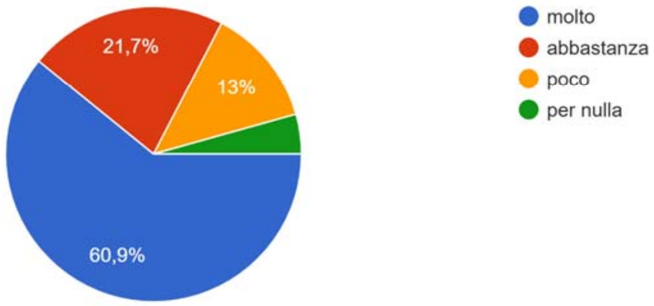
Ti soddisfano le stazioni di ricarica ad accesso pubblico che abitualmente utilizzi o talvolta hai utilizzato?

42 risposte



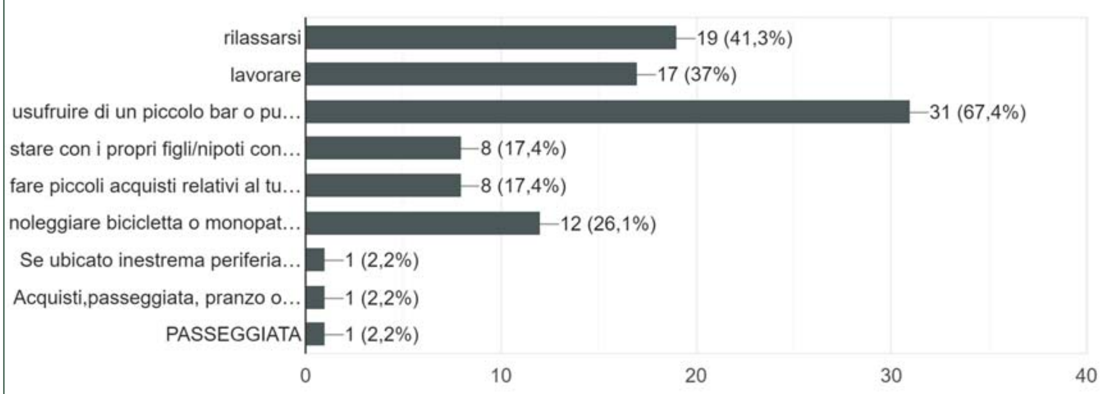
Ritieni utile nelle vicinanze dei punti di ricarica la presenza di servizi/attrezzature per occupare il tempo di attesa?

46 risposte

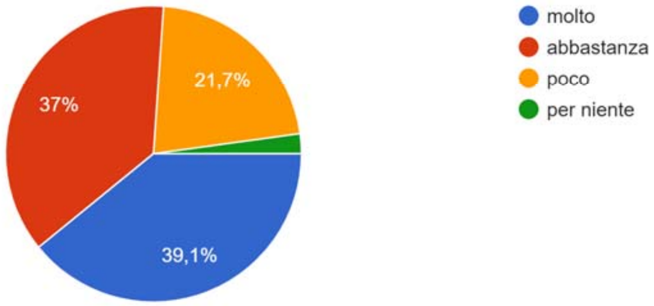


Durante la ricarica del veicolo come ti piacerebbe occupare il tempo?

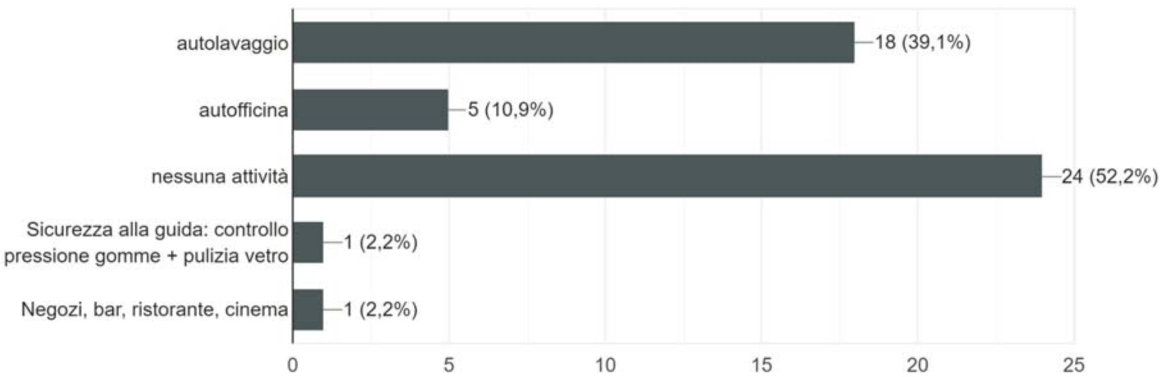
46 risposte



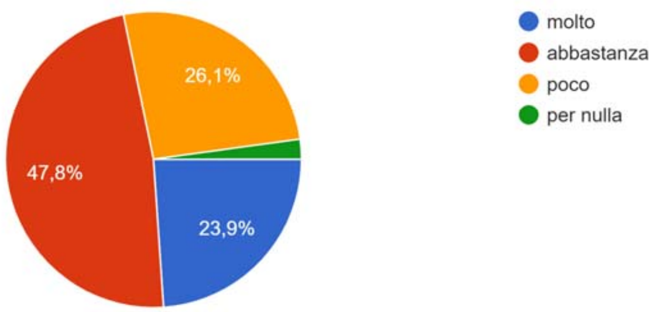
Se fosse presente nei pressi di una stazione di ricarica un ambiente chiuso cablato con connessione rete Wi-Fi, ritieni che possa essere utile?
46 risposte



Prima o dopo la ricarica del veicolo quali delle seguenti attività complementari potrebbero essere utili?
46 risposte

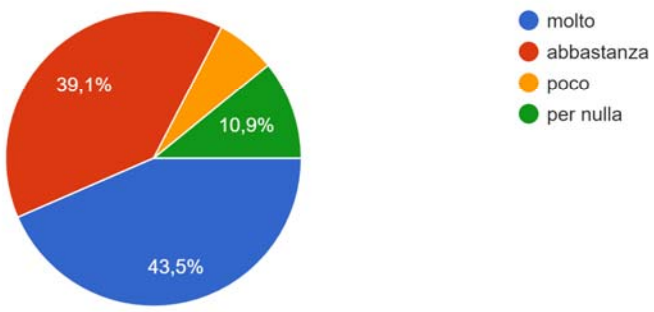


Nella stazione di ricarica attrezzata, ritieni utile la presenza di un'AREA PER BAMBINI?
46 risposte



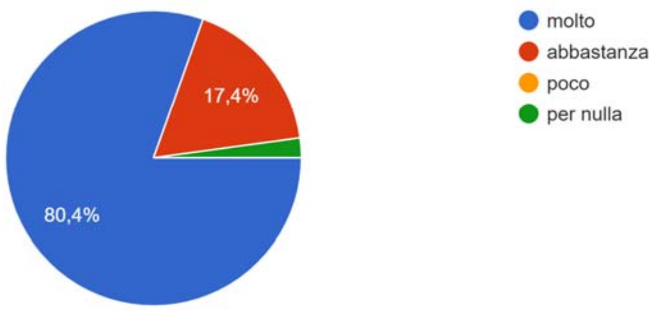
Nella stazione di ricarica attrezzata, ritieni utile uno SPAZIO INFORMATIVO per cittadini/turisti con disponibilità di materiale informativo e promozionale del territorio di competenza?

46 risposte



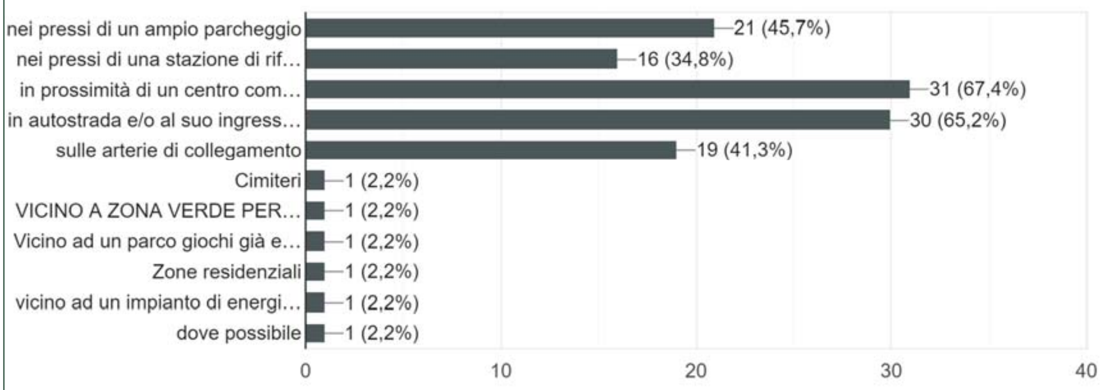
Nella stazione di ricarica attrezzata, ritieni importante la presenza di SERVIZI IGIENICI?

46 risposte



Dove vorresti fosse localizzata una stazione di ricarica attrezzata?

46 risposte



The following information emerges from the online questionnaire which also contains questions with the possibility of selecting one or more answers.

The age groups of participants are: between 25 and 50 years old (50%), between 50 and 60 years old (33%) and over 60 years (17%).

72% of respondents use a full electric car, 15% a plug-in hybrid car, 6.5% an electric scooter and 19.6% an electric bicycle.

52% of the participants recharge their e- vehicle at home with a domestic socket and 28% at home with a wall box, but 41% also recharge from public charging stations, and 13% in the company or in the workplace (if there is the possibility).

When the e-vehicle is not being recharged at home, respondents use the waiting time to work (50%), to relax at the charging station (44%) or somewhere other than the charging station (12%).

The public charging stations usually used fully satisfy only about 12% of respondents; in fact, the presence of services and/or equipment to occupy waiting time at the charging station are useful for 83% of the respondents. To this end, the wishes expressed refer to the following activities: the presence of a small café (67%); the possibility of relaxing (41%), working (37%), renting a bicycle or scooter (26%), spending time with one's children (17%) and doing small shopping (17%). In addition, the presence of a wired environment with a Wi-Fi connection is useful for 76% of participants.

39% of respondents favour the presence of a car wash at the charging station and 11% wish a car workshop. Almost all respondents (97%) require toilets; 83% of respondents agree on the usefulness of an information point for citizens/tourists with promotional material about the area and 72% would like the presence of a children's area.

Finally, as regards the location of the equipped charging station, the options most frequently expressed by participants are: in a large car park (46%), near the entrance to a motorway (65%) and near a shopping centre (67%).

ANNEX

9.3.5 Paper published on *Buildings* journal

buildings

MDPI

Review

Natural and Mechanical Ventilation Concepts for Indoor Comfort and Well-Being with a Sustainable Design Perspective: A Systematic Review

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Abstract: Current literature and guidelines on sustainable design often debate on the advantages of natural ventilation (NV) and mechanical ventilation (MV) on indoor environment and energy consumption. The present systematic review explores the existing literature comparing NV and MV on the indoor comfort and well-being points of view. The findings emphasize that thermo-hygrometric comfort is the main driver of occupants' ventilation behavior, while ventilation design is mainly led by indoor air quality targets. Moreover, more recent papers (especially after COVID-19 outbreak) emphasize the necessity of a health-based approach, contrasting airborne pathogens transmission. In this sense, MV is more frequently recommended in public spaces, while hybrid ventilation (HV) is often suggested as a solution to both ensure proper indoor conditions and energy savings. The concept of well-being is currently under-explored, as the present literature only refers to comfort. The same happens with topics such as visual, acoustic, and multi-domain comfort, as well as passive techniques such as night cooling, or analysis of specific environments such as healthcare facilities. Current knowledge would benefit from an expansion of future research in these directions. The choice of the best ventilation solution cannot ignore the context, type, and condition of energy efficient buildings, in order to properly take into account occupants' well-being.

Keywords: building ventilation; indoor comfort; well-being; energy saving; climate-responsive design

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1. Introduction

It is well-recognized that the building sector has a key role in the framework of energy savings, being responsible for 40% of energy consumption and 36% of emissions of greenhouse gasses in the European Union [1]. For this reason, design concepts such as net-zero energy buildings (nZEBs), net-positive energy buildings (nPEBs), and climate-responsive architecture are fundamental to reduce the carbon footprint. In fact, in nZEBs the total annual energy balance (produced minus consumed) is equal to zero [2,3], while in nPEBs the balance is even positive [4,5]. On the other hand, climate-responsive design allows the creation of a structure intrinsically connected with building location, using responsive technologies to improve the performance of buildings [6–12]. Furthermore, indoor well-being cannot be neglected in buildings' design. The well-being concept is heterogeneous, and efforts have been made to define it. Nevertheless, the two aspects of environmental comfort and satisfaction, as well as cognitive performance, health, and productivity, emerge in the building context [13]. Therefore, a good definition of well-being regards it as the combination of feeling good and functioning well [14]. For these reasons, good indoor air quality (IAQ), thermal, acoustic, and visual conditions, and their interaction (multi-domain approach) as all part of the indoor environmental quality (IEQ), are fundamental not only for health and comfort, but also for other aspects such as physiological and psychological ones (e.g., working performance) and, since occupants tend to take action to make themselves comfortable, energy consumption [15–22]. Occupants can suffer from illnesses and complaints related with comfort, health, and safety in several indoor spaces [23]. Since the World Health Organization (WHO) Sick Building Syndrome declaration in 1986, IAQ, connected with health and comfort, has been strongly considered in indoor design [24,25]. In fact, several pollutants might be present in internal environments, with an adequate air-supply rate necessary to ensure healthy conditions for occupants [26–28]. In this complex framework, ventilation has a key and fundamental role, since it has high impact on both buildings' energy consumption and IEQ. Depending on the ventilation technique, which can be used in combination with other passive solutions such as the use of thermal inertia for night cooling and shadings to avoid solar heat peaks, the carbon footprint can be consistently lowered [29–35]. Moreover, ventilation choice cannot overlook the well-being of occupants, which needs to be the primary aim of indoor design [25,31].

Generally speaking, ventilation techniques can be divided into three main groups: natural ventilation (NV), mechanical ventilation (MV), and hybrid or mixed mode ventilation (HV or MMV). Each of these categories have different implications on energy consumed and comfort. NV, totally relying on natural forces (wind- or buoyancy-driven), can consistently lower buildings' carbon footprint [36–40]. Moreover, the acceptable range of thermal comfort was noticed to be enlarged when NV is present, with higher acceptance of high indoor temperatures when outdoor temperatures are high too [41,42]. This led to the introduction of the adaptive model for naturally ventilated buildings on ASHRAE Standard 55, which is now used together with Fanger's model in naturally ventilated buildings [41,43–45]. In addition to that, NV might be associated with benefits related with environmental and work satisfaction, productivity, and Sick Building Syndrome, as well as improved feeling of control for occupants and access to the outside environment [30,36,46–55]. The use of NV is suggested by Leadership in Energy and Environmental Design (LEED), in order to decrease both the carbon footprint and heating, ventilation, and air conditioning (HVAC) expenses. In this sense, positive correlations between fulfilled LEED rating and satisfaction perceived was demonstrated [56]. Conversely, the possibility to fully regulate temperature, airflow, and air velocity is a clear advantage of MV, of which performance is perfectly predictable and controllable if compared with NV, with positive implications on the IAQ [25,47,57–59]. The use of heat recovery units can partially overcome the drawback of the larger amount of energy with respect to NV [60–63]. Finally, HV can be a good compromise between the two techniques, guaranteeing energy savings, but exploiting MV when proper IEQ conditions cannot be met with NV only [29,30,55,64–69]. Current literature and standards argue on which of the two techniques should be preferred. Controversial opinions about this topic were also highlighted by the COVID-19 pandemic [70]. In fact, the risk of infection is strongly dependent on relative humidity (RH), temperature (T), and ventilation [71]. In this framework, ASHRAE recommended to use NV only in homes where MV or air-purifiers were not installed, in order to avoid thermal discomfort [72–74]. On the other hand, NV was also associated with the buildings' infection management [75,76]. In fact, CIBSE and REHVA recommended massive use of window openings, even in mechanically ventilated buildings and in winter [77,78]. Moreover, during London's lockdown, windows were noticed to be associated with positive cross influences of indoor mental well-being due to positive perceived soundscapes, vegetation view, and natural sounds [48,49]. In a global warming condition, the adaptive comfort model might cease to be fulfilled in plenty of indoor spaces in the next ten years [79], but a higher use of NV in colder climates might be induced by the shifting of climate conditions [30].

In this framework, it is clear that when dealing with concepts such as nZEBs, nPEBs, and climate-responsive architecture, the choice of ventilation technique is of paramount importance. Moreover, comfort and well-being should be among the main drivers in buildings' design, and therefore a strong literature background on how each type of ventilation influences comfort at different climates and seasonal conditions constitutes an important basis for proper design choices.

The aim of the present review to provide a framework on scientific evidence of papers comparing NV and MV in terms of comfort and well-being, in the perspective of performant and sustainable buildings' design (e.g., nZEBs, nPEBs, and climate-responsive buildings). The main hypothesis is that ventilation is firstly aimed to provide IEQ, with energy savings as a very important additional aim. For this reason, the following research questions were explored:

1. Which differences are present between IEQ conditions guaranteed by NV and MV?
2. Which ventilation techniques are more suitable at different climatic, seasonal, and outdoor pollution conditions according to both IEQ and energy perspectives?
3. Which ventilation techniques are more suitable with different building types and uses?
4. Which are the research gaps in terms of effects of NV and MV on the IEQ, depending on the type of building, the ventilation technique and the comfort domain considered?

If integrated with other studies, the articles here summarized can be exploited by policymakers in order to further expand and update ventilation standards and guidelines taking into account both energy consumption and indoor well-being. The development of such guidelines is fundamental for engineers, architects, and planners in order to help them in conscious and contemplated choices during the design process.

2. Methodology

2.1. Research Methodology

A systematic review [80] was performed using AND/OR Boolean operators [13] in a search on the Web of Science [81] database. The search was aimed at identifying all the studies regarding an NV-MV comparison in terms of comfort and well-being. Figure 1 reports the detailed search string used. The PRISMA flow diagram was used in the systematic review process [82].

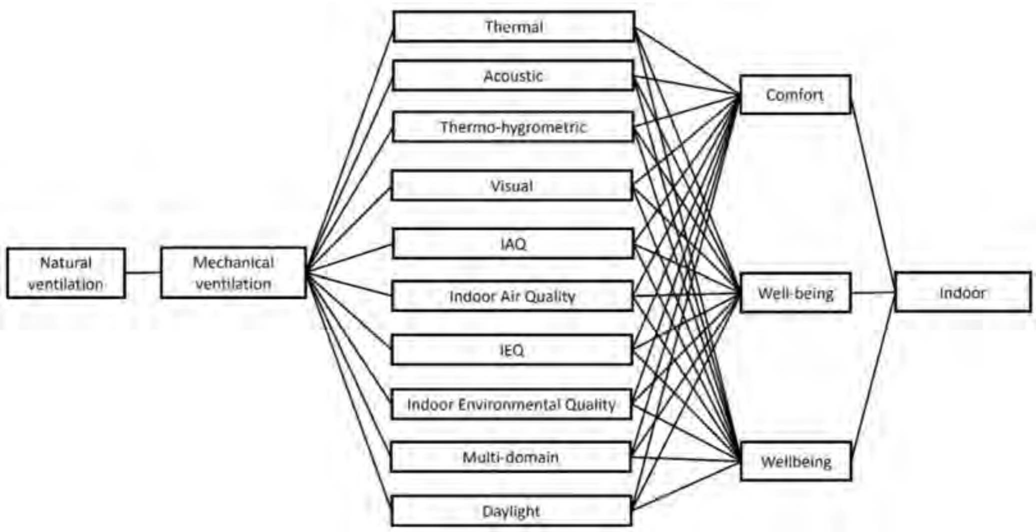

Figure 1. Boolean search string used for the first papers' search query. Keywords on the same column were linked with the "OR" operator, while black lines represent the "AND" operator.

2.2. Inclusion Criteria and Screening Process

All types of articles (journal papers, reviews, and conference proceedings) were included. In order to refine the research, considering only the relevant works, the following inclusion–exclusion process was applied:

1. Limiting of the research to English-written studies within the following research areas: (a) construction building technology; (b) engineering civil; (c) engineering environmental; (d) green sustainable science technology; (e) environmental sciences; (f) public environmental occupational health; (g) environmental studies; (h) architecture;

(i) thermodynamics; (j) engineering mechanical; (k) infectious diseases; (l) regional urban planning; (m) urban studies;
2. Titles and abstracts screening, rejecting all the papers not in compliance with the research questions, thus not comparing NV and MV on a comfort and/or well-being point of view;
3. Rejection of the studies which full text was not available;
4. Full papers' reading.

2.3. Categorization and Data Analysis

Based on the aim of the present research, selected studies were categorized according to different criteria:

1. Type of environment considered (residential, educational, working, healthcare, etc.);
2. Type of paper (journal paper, journal review, and conference proceedings);
3. Comfort domain analyzed by the paper (thermo-hygrometric, visual, IAQ, acoustic, or multi-domain);
4. Type of ventilation recommended, between "NV only", "MV only", "HV (or both HV and NV)", "no clear preference stated".

The geographical area and/or climate the studies were related to were also highlighted when applicable and specified. In the framework of sustainable design such as nZEB, nPEB, and climate-responsive architecture, outcomes in terms of energy consumption and savings were also highlighted. Moreover, when related with NV and when specified, the ventilation aim was also considered, dividing between air change, thermal regulation, and night cooling (as a more specific type of thermal regulation with remarkable passive design applications) [32,33,41,75,83–86]. Keyword co-occurrence analyses were performed by means of the software *VOSviewer 1.6.18*. Further statistics based on the publication year and publication geographic area were also considered.

3. Results

3.1. General Data and Statistics

Details about the number of papers found after each screening phase are reported in Figure 2. A total number of 94 papers was firstly found, with 68 eligible for full paper reading. After this last process, six more papers were rejected, with a final number of 62 papers considered and analyzed in this essay. Further details on the selection process are available in a PRISMA flow diagram in Figure A1 in Appendix A. Most of the included articles (71.0%) are journal papers, followed by reviews (19.4%), and conference papers (9.7%) (Figure 3).

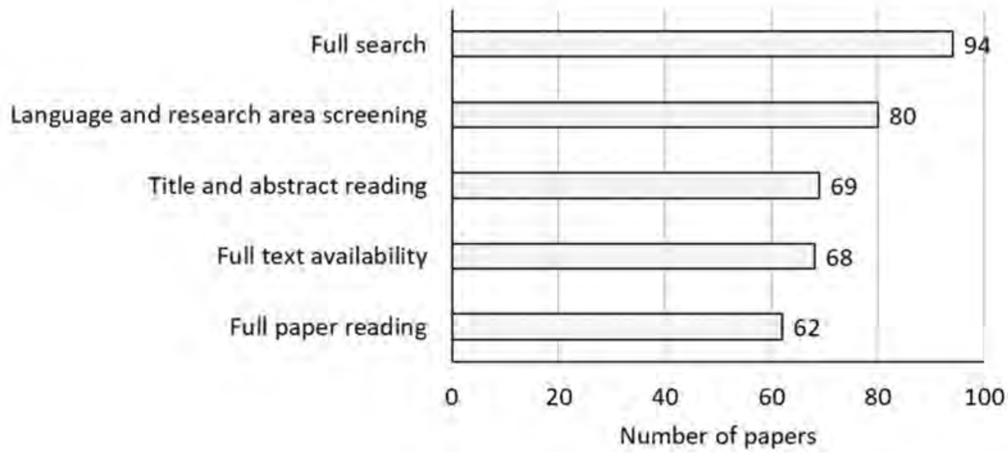

Figure 2. Papers found after each phase of the screening process.

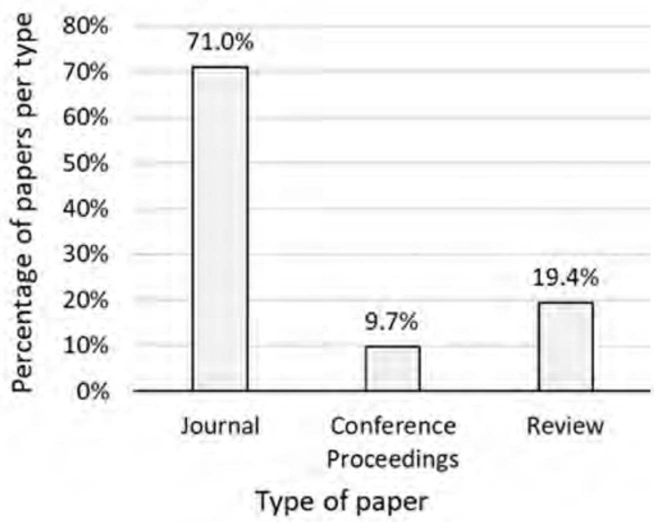

Figure 3. Percentage of papers per type.

Figure A2 shows the number of papers per publication year. It is clear that, starting from 1994, the topic gained a growing interest, with the number of published papers rising year by year (i.e., one in 1994, five in 2021). It is also interesting to notice that year 2020, during the COVID-19 pandemic, showed a peak in the number of papers (9), due to the obvious necessity to deepen the knowledge into ventilation related with infection airborne transmittance. Figure A3 depicts how the majority of the included articles were European (47.0%) and Asian (31.3%). On the other hand, only 4.8% of the papers were African, and none were South American. Details in Figure A4 show that England is the major publisher of included papers (11), followed by China (10), and USA (6).

Eventually, Figure 4 shows the co-occurrence keywords analysis (minimum occurrence number set equal to five for the representation) of the articles included in the present review. With 28 and 27 occurrences respectively, "natural ventilation" and "thermal comfort" were the most frequent keywords. "Indoor air quality" (in the three forms of "Indoor air quality", "Indoor air-quality" and "IAQ") was found 26 times in total. On the other hand, visual and acoustic comfort domains were not frequently explored ("acoustic" and "noise" appeared respectively one and two times, while "daylighting" appeared only once). Furthermore, it is important to highlight that neither the "well-being" nor the "wellbeing" keywords appeared in the articles included.

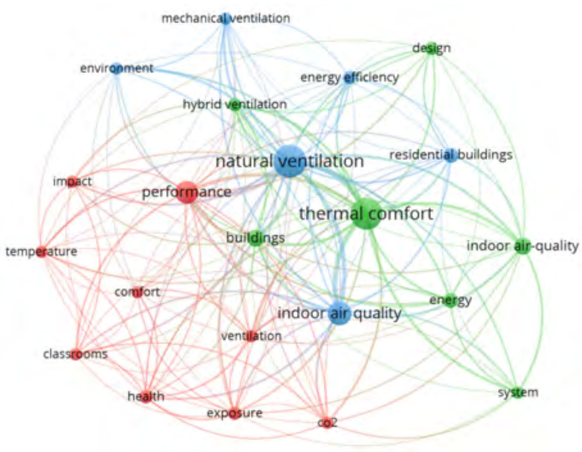

Figure 4. Co-occurrence keywords analysis of the articles included performed with *VOSviewer 1.6.18*, considering the keywords with a minimum number of occurrence equal to 5.

3.2. Papers Related with Residential Environments

In this subsection, results related with papers discussing NV and MV comfort comparison in residential environments are reported. A total number of eighteen articles were found, mainly journal papers (13) and conference papers (4), with only one literature review (1). The highest number of these research (9) were related to case studies located in Europe, followed by Asia (6), Oceania (2), and Africa (1). Ventilation for thermal regulation and ventilation for air change were analyzed, generally with a direct correspondence with thermo-hygrometric comfort and IAQ respectively. Night cooling was also considered in some cases, even though it was mainly listed as a way to better exploit NV. Thermo-hygrometric was the comfort domain most frequently considered by the papers here analyzed (15 articles out of 18), followed by IAQ (10 articles) and acoustics (6 papers). One paper considering visual and multi-domain comfort was found. Contrasting conclusions on which ventilation type is preferrable on the comfort point of view were found, as well as regarding the system providing higher energy savings. Brief summaries of the main findings are reported in this Subsection, in Table 1. The details concerning each paper, key data (type of paper, climate, and ventilation considered and suggested), comfort domains treated and main conclusions are present in Table S1 (available as Supplementary Materials).

Table 1. Key findings related with residential environments.

Thermo-Hygrometric Comfort	
Main findings	**References**
Improvement of thermal comfort or temperature control conditions when using MV or HV, especially when hotter or colder outdoor conditions are present	[87–93]
Good or better performance of NV in terms of thermal comfort	[94,95]
Thermal comfort is one of the main drivers of occupants' behavior associated with NV, with the air change rate and windows opening being dependent on outdoor temperature	[88,96,97]
Necessity of proper design of buildings where NV is planned to be exploited for thermal comfort (architectural elements, windows, openings, orientation, control, etc.)	[98–101]
In a Chinese students' dormitory during winter, temperature and humidity decreased to values under 20 °C and 30% after 4 h of night ventilation with ventilation rates of 0.050 m^3/s and 0.036 m^3/s, respectively	[100]
Too low or too high building tightness is associated with condensation risks	[96]
Too low or too high building tightness is associated with draughts or fluctuating temperature	[101]
In a temperate continental city of China, humidification was seen as an issue with both NV and MV, and occupants perceived drier conditions with MV	[95]
In developing countries, comfort range with NV might be larger (14.6–26.3 °C of comfort range found in an Ethiopian case study), allowing to satisfactorily exploit this ventilation technique	[94]
Thermal comfort, health, and energy savings are the three drivers of ventilation behavior	[97]
Visual comfort	
Main findings	**References**
A higher probability of windows opening was observed in Italy during 2020 winter lockdown, where a vegetation view was present	[102]
IAQ	
Main findings	**References**
Even though their priority is thermal comfort, occupants seem to be more inclined to spend more on energy if healthier environments can be provided	[97]
The use of MV is associated with better air quality or sweeping effect	[87,88,101,103]
MV can mitigate air-tightness issues (lowering the radon concentration from 412 Bq/m^3 to 70 Bq/m^3, and the CO_2 concentration to an average around 760 ppm in a Romanian case study)	[87]

Table 1. *Cont.*

Thermo-Hygrometric Comfort	
Direct link between air change rate (and ventilation behavior) and IAQ conditions	[96,100]
IAQ conditions are strongly dependent on outdoor conditions or air tightness of buildings	[92,95,103]
HV can be a solution when proper IAQ conditions cannot be met with NV alone	[100,104]
Acoustic comfort	
Main findings	**References**
Noise from both outdoors (NV) and systems (MV) can be a discomfort source	[91,92,97,101]
Together with thermal discomfort and stuffy air, noise can be one of the factors reducing the quality of sleep	[88]
During 2020 winter lockdown in Italy and UK, tendency by occupants to keep windows open, at least sometimes, even in urban areas. Necessity to include the concept of pleasant acoustic contexts in standards. Proposal of introduction of an "adaptive acoustic comfort" concept	[102]
Multi-domain	
Main findings	**References**
Study and application of multi-domain concept would be fundamental for the definition of acoustic criteria in naturally ventilated buildings	[102]
Energy consumption and other issues	
Main findings	**References**
MV can allow for reduction in consumption, due to less windows openings	[96]
MV can allow for reduction in consumption, due to the use of heat recovery (86% reduction found with respect to NV)	[87]
NV allows for less demand of energy	[91,93,95]
NV can be exploited with not extreme temperatures or not too high outdoor $PM_{2.5}$ concentration	[95]
Increase in energy consumption up to 20% found with MV in simulative study performed in Mediterranean climate: NV with night cooling suggested for smaller residential buildings, and MV or HV for larger residential or commercial ones	[91]
NV can allow for large energy savings in developing countries (wide comfort range in a field study in Ethiopia). Further research suggested to confirm this conclusion	[94]
Thermal comfort, health, and energy savings are the three drivers of ventilation behavior	[97]
Feasibility, safety, and life cycle costs need to be preliminary analyzed in the design process	[91]
Computational Fluid Dynamics (CFDs) simulations used or encouraged by a significant amount of studies, in order to study air movement and comfort induced by NV or HV	[89,90,98,99]

3.3. Papers Related with Non-Residential Environments

Works related with non-residential environments are here reported. Thirty-one papers were categorized within this group: twenty-five journal papers, two conference papers, and four reviews. Moreover, in this case, most articles were related to case studies located in Europe (12). Five case studies were in Asia and five in North America, while only one case study was in South America, one in Oceania, and one in Africa. One simulative study considered three climate areas, two in Europe and one in Asia. The articles here grouped mainly regard educational (12) and working environments (14). Articles regarding other facilities, such as industrial or healthcare, are also present. Moreover, in the case of non-residential buildings, thermo-hygrometric was the most explored domain (29 papers out of 31), followed by IAQ (21 papers), acoustic (10), and visual (6). Only three articles linkable with the multi-domain concept were found. Present literature is debating whether MV or NV provide better thermo-hygrometric comfort conditions in non-residential buildings. Moreover, similarly to what concerned residential buildings, while papers related with thermo-hygrometric comfort were mainly considering ventilation for thermal regulation, air change was the main focus of studies dealing with IAQ. Visual, acoustic, and multi-domain comfort were only marginally treated. It is finally fundamental to highlight how, after the pandemic, the main focus of the design seems to have changed to the control of pathogens transmission. Key findings are summarized in Table 2, while specific details about each article are reported in Table S2 (Supplementary Materials).

Table 2. Key findings related with non-residential environments.

Thermo-Hygrometric Comfort	
Main findings	**References**
In monitored classrooms in Beijing, both systems provided a too low temperature (below 18 °C) close to the beginning and the end of running heating period	[105]
1.5 ach^{-1} MV suggested in nucleus-type hospitals, in order to provide comfort conditions	[106]
Personalized ventilation suggested in order to have thermal benefits for occupants	[107]
NV alone is not sufficient to ensure thermal comfort in a large semi-transparent ceiling ocean park case study	[108]
NV or HV can be adequate to provide thermal comfort	[30,55,64,67,109–115]
During summer in Dubai, when NV is not sufficient, despite the too high outdoor temperature and too low wind, a reduction of 2–6 °C is possible in office buildings by NV	[109]
Definition of 7 °C outdoor temperature as lower boundary for NV to be ineffective	[115]
Definition of the range of applicability of NV between 10 °C and 25 °C of outdoor temperature	[30]
Preference for NV is often related with the higher degree of control of occupants	[25,30,55,111,116]
The negative effects of NV on productivity are under debate	[111]
A higher productivity by men workers when HV was used instead of MV was found in an office of Tokyo (Japan)	[114]
Dependence of thermo-hygrometric comfort on outdoor temperature and users' behavior	[29,60,67]
Due to global warming, NV use will decrease at warmer climates, simultaneously increasing in colder and mild areas	[30]
HV can be used when non-optimal conditions are achievable with NV only	[67,109,117,118]
Nighttime ventilation and night cooling can be exploited to enhance daily thermal comfort conditions	[30,67]
Specific discomfort conditions (draught, too low temperatures) found with colder outdoor conditions	[117,119,120]
The too low temperatures (around 18 °C) measured in Spanish schools during winter 2021 are admissible only during an emergency situation such as the pandemic	[119]
Importance of particular solutions such as temperature monitoring in schools, local discomfort avoidance (by means of humidifiers, electric heaters of exhaust heat recoveries), building orientation, proper design of the exhaust velocity	[66,112,119,120]
Importance of exhaust velocity optimization (e.g., depending on internal source of heat) in order to maximize thermal comfort and energy efficiency and minimize the short-circuiting risk	[66]
Visual comfort	
Main finding	**References**
Together with IAQ and acoustic, lighting is one of the IEQ aspects which needs deeper studies connected with NV	[111]
Daylight benefits of similar constructive techniques used for NV exploitation, such as operable skylights or high windows. Direct sunlight and large glazed façades can lead to drawbacks on both sides (i.e., overheating and glare)	[30]
Double-skin façades studied for NV have also the capability to provide natural light	[112]
Aspect considered in the study, without direct findings related with NV and MV	[55,106,117]

Table 2. *Cont.*

Thermo-Hygrometric Comfort	
IAQ	
Main findings	**References**
MV can help in providing optimal IAQ	[25,60,107,120–124]
Higher IAQ satisfaction in NV buildings	[113]
Small or no difference in the perception with the two modes	[125]
Difference in the indoor environmental conditions perceived and actually present indoor	[117]
The presence of operable windows can provide a feeling of fresh air perception	[55]
Use of HV recommended, exploiting MV when not sufficient IAQ can be maintained with NV (e.g., too polluted outdoor conditions)	[67,117,118]
NV might not be sufficient in air-tight buildings	[120]
NV will benefit from low polluting mobility solutions such ass electric vehicles	[30]
Most standards focus on perceived IAQ and CO_2 concentration or energy consumption, but several comfort, performance, and health issues are often reported in buildings: necessity to move from a comfort-based to a health-based design. In this sense, benefits can be obtained by the use of personalized ventilation	[107]
Poorly designed or operated ventilation can lead to poor IAQ, which can cause virus airborne transmission due to dry conditions in winter: necessity the adoption of health-based ventilation design	[25]
CO_2 concentration reduction (1000 ppm, with a 1400 ppm decrease) in Spanish schools during the pandemic, due to the most frequent airing	[119]
Importance of having long and frequent airing periods with NV	[67,118,121,126]
Suggestion of automated windows and/or CO_2 and pollutants monitoring devices	[117–119,122]
Acoustic comfort	
Main findings	**References**
Loud noise reported as one factor preventing the use of MV in Spanish schools	[119]
Importance of noise evaluation when designing the ventilation solution	[67,105,118]
Evaluation of noise with measurements or surveys in studies related with NV and MV	[55,117,122,123]
In university classrooms, the intermittent noise of intermittent windows was better tolerated than the continuous one of MV	[117]
Benefits from less noisy mobility will be provided to NV	[30]
Acoustics related with NV will need further studies in the future	[111]
Multi-domain	
Main findings	**References**
IAQ has the potential to influence the other comfort domains (e.g., higher noise with higher IAQ due to higher machines regimes, sunlight causing surfaces' emissions of pollutants). These aspects should be evaluated and studied altogether to assure comfort and health of occupants	[107]
Importance of deepening the studies of all the comfort aspects which are related to NV	[111]
Direct association of noise level and IAQ with MV	[123]
Energy consumption and other issues	
Main findings	**References**
NV or HV allow to save energy	[29,30,67,105,110,111,114,117–119,125,126]
Energy savings of ranging from 3.1 to 85% (coupling it with PV- system) reported with the use of NV or HV	[114]

Table 2. *Cont.*

Thermo-Hygrometric Comfort	
Not using adaptive model encouraging NV in green certification systems, might obstruct designers' and occupants' change in decision	[111]
NV is widely used in schools of developing countries, in order to save energy	[127]
If properly designed and with the use of proper techniques (energy storage or heat recovery), reduction in energy consumption can be achieved with MV	[121,124]
Automatic windows coupled with heat recovery counter-flow system through outside wall slots can reduce the energy consumed in classrooms	[122]
Careful design of ventilation (architecture, presence of heat recovery, technological solutions such as occupancy sensors, temperature or CO_2 monitoring, night cooling coupled with massive elements) encouraged in order to reduce the carbon footprint	[29,66,67,106,109,118–120,123,124,126,127].
The use of local climate conditions instead of international standards, with a consequent expansion of upper and lower comfort limits, can lead to higher energy savings	[110]

3.4. Papers Not Linked to a Specific Environment Type (Various, Unspecified, . . .)

This subsection comprises the articles which do not refer to a specific type of environment. This is due to two main reasons: 1. articles (mainly reviews) referred to all the types of environments in general; 2. studies referred to general mock-ups or models. Consequently, seven papers among the ones in this subsection are literature reviews, constituting the majority of all the reviews considered in the present work. The rest of the articles here explored are journal papers (6). No conference papers are present in this subsection. Similarly, several studies (7) were not linkable to a specific continent, country, or climate. Among the others, four studies were related with Asia, one with Europe, and one was referred to tropical climate in general. Twelve articles out of thirteen considered the thermo-hygrometric domain. The domain was again followed by IAQ (9), acoustic and visual (5 each), and multi-domain (2). Moreover, also in this case, the thermo-hygrometric domain was mostly linked with ventilation for thermal regulation and IAQ was mostly linked with air change. Similarly to residential and non-residential sections, night cooling, when considered, was mainly named or implied (e.g., as ventilation performed at night). Brief summaries of the main results are reported in Table 3, while Table S3 (Supplementary Materials) contains further and specific details about the articles considered in this subsection.

Table 3. Key findings related with various or unspecified environments.

Thermo-Hygrometric Comfort	
Main Findings	**References**
NV can sometimes be inapplicable due to extreme conditions (temperature or running air)	[128]
In hot and humid climates (such as Malaysian) MV can be advantageous on the thermal comfort point of view	[129]
Well-designed NV is often adequate to maintain acceptable indoor thermo-hygrometric conditions	[130–134]
Wider ranges of thermal comfort are present in hot, humid climates, than what is generally indicated in international standard	[131]
Cooling from MV should be used only when adequate thermal comfort conditions cannot be guaranteed	[65]
Ventilation energy can be reduced only if comfort of occupants can be guaranteed	[31]
Importance of well-designed ventilation to guarantee occupants' comfort	[130,135]
Numerical models can be useful for control strategies	[133]
Visual comfort	

Table 3. *Cont.*

Thermo-Hygrometric Comfort	
Main findings	**References**
Similar constructive techniques such as atriums, double skin façades, and apertures can be exploited for both NV and daylight	[31,132]
Used together with the other comfort domains to categorize the studies considered in the review	[136]
IAQ	
Main findings	**References**
Even though NV is the cheapest and most often used environmental disinfection method against airborne transmittable diseases, proper disinfection is provided by MV	[128]
Higher morbidity cases (13–38% increase) and mortality (28% increase) related with NV adoption in residential buildings of Singapore; adoption of technologies such as MV and filtration from current NV in schools would diminish the number of asthma cases; mortality would also be decreased by the use of filtration in workplaces	[137]
Importance of taking into account occupants' behavior and pollutions' sources in ventilation design	[31,130,138]
Acoustic comfort	
Main findings	**References**
Noise is one of the parameters affecting occupants' behavior. Atriums and double-skin façades can be used to exploit NV, while protecting from noise	[31]
Importance of considering outdoor noise when designing ventilation	[130,133]
Used for categorization or marginally considered	[136,138]
Multi-domain	
Main findings	**References**
Elements such as daylight availability (heat-load related), thermal mass, and night ventilation (cooling load related) are essential for thermal comfort	[138]
Thermal perception is also influenced by healthy IAQ	[131]
Energy consumption and other issues	
Main findings	**References**
Energy savings are associated with passive cooling and NV	[65,128,130,132]
Necessity of coupling ventilation techniques with other passive strategies, with the aim of decreasing the carbon footprint of buildings	[131]
Climatic design for passive cooling, use of orientation and materials (e.g., for night cooling) and proper MV operations are fundamental for ventilation design	[130]
Necessity of studies on vernacular apertures and elements, as well as louvered windows to exploit night cooling, in order to maximize NV efficiency in tropical climate	[132]
Importance of more studies in the field of balconies' design, as well as post-occupancy evaluations, for NV optimization	[136]
Remarkable energy savings can be obtained by means of HV: more studies on smart window based HV should be made	[31]
Ventilation of unoccupied or low-occupied spaces leads to a significant amount of wasted energy	[31]
A combination of mechanical and passive cooling and different control strategies can lead to a reduction of more than the 60% of the system size and associated energy used	[65]
Use of models and simulations applied and encouraged in design and evaluation	[129,130,133,134]

3.5. Final Statistics

Table 4, on the left, reports the number of papers suggesting specific ventilation types. Nineteen papers do not express a clear suggestion between MV, NV, and HV. Among the rest of the papers, a relative similar share suggest NV (13) and MV (9), while most studies (21) recommend the use of HV in order to guarantee energy savings with backup mechanical systems when IEQ conditions cannot be maintained by passive techniques only. It is fundamental to stress that papers recommending HV normally suggest it when satisfactory indoor conditions cannot be reached with NV alone. For this reason, it was decided to group together papers recommending HV and both HV and NV, as "HV (and NV)". In the same table, on the right, the number of papers treating each comfort domain is reported. As previously implied, thermo-hygrometric is the mostly explored domain (56 papers), followed by IAQ (40), acoustic (21), and visual (12). Only six papers consider or name the importance of a multi-domain approach.

Table 4. Number of studies suggesting each ventilation type and number of studies treating each comfort domain. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference. T.H.: thermo-hygrometric; Vis.: =visual; IAQ: indoor air quality; Ac.: acoustic; M.Do.: multi-domain.

	Ventilation Type Suggested				Comfort Domain Treated				
	NV	**MV**	**HV (and NV)**	**NP**	**T.H.**	**Vis.**	**IAQ**	**Ac.**	**M.Do.**
N. of papers	13	9	21	19	56	12	40	21	6

Figure 5 allows to explore the association between the publication year and the type of ventilation recommended. It is interesting to notice how the share of papers recommending NV or HV (and NV) seem to slightly increase in time, probably in relation with energy efficiency issues. This trend seems to interrupt in 2021, most likely due to the pandemic, causing more research to suggest the use of MV for health reasons and contrast of virus transmission.

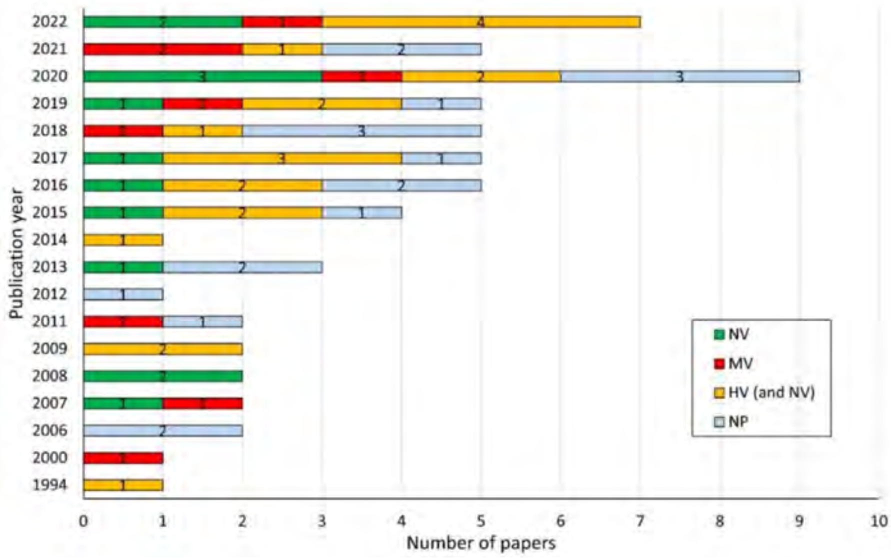

Figure 5. Association between ventilation type suggested and publication year. Numbers indicate the number of papers recommending each ventilation type. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference.

Similarly, Figure 6 shows association of comfort domain treated and year of publication. The share of domains considered does not seem to be correlated with the publication year. Nevertheless, as previous subparagraphs underline, visual and acoustic domain are mainly treated marginally, especially in older publications. New publications, instead, more often link these two domains with the multi-domain approach, which is actually more frequent in recent years. Nevertheless, the approach is mainly suggested without performing complete studies about it.

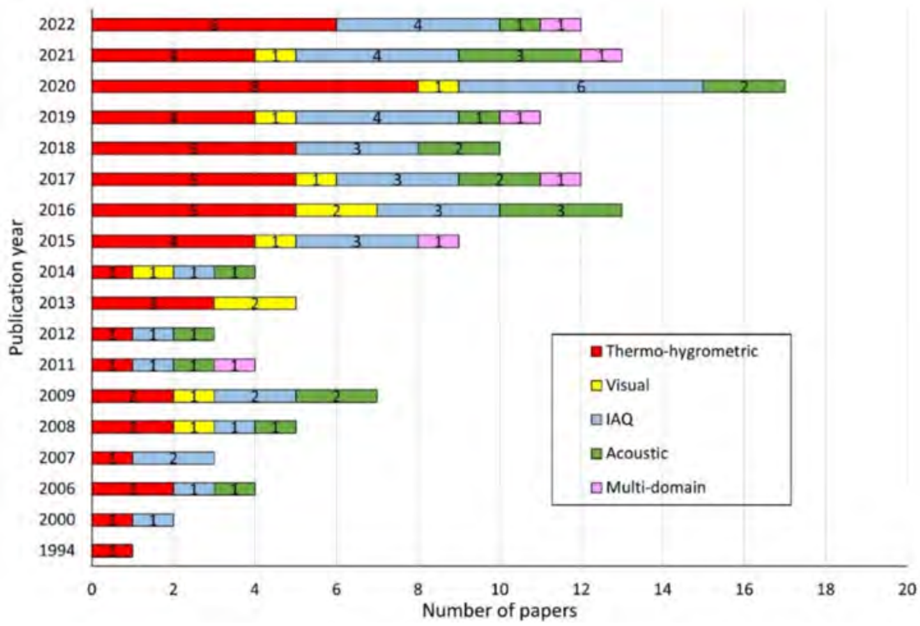

Figure 6. Association between comfort domain treated and publication year. Numbers indicate the number of papers considering each comfort domain.

The number of papers for each building category is reported in Table 5. Eighteen papers refer to residential environments. On the other hand, thirteen studies are not linked with any specific environment (e.g., laboratory studies) or are referred to various types of buildings (typically reviews). The majority of papers (31) regard non-residential environments. The highest share of these refer to educational (schools or universities) facilities (12) or working (office) facilities (14). The rest regard industrial (1), amusement (1) or non-residential buildings in general (2). Only one paper related with healthcare facilities was found. The details about the type of ventilation recommended depending on the building type are reported in Figure 7. It is clear that the share of articles suggesting MV or HV is higher in non-residential buildings.

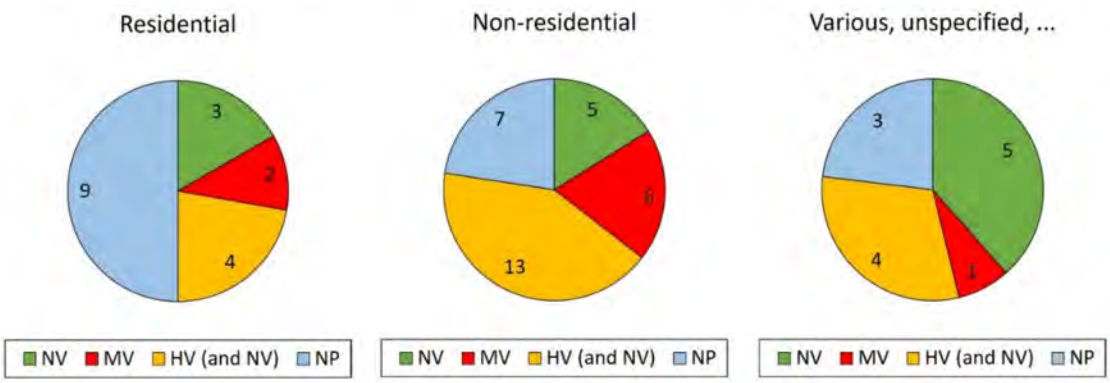

Figure 7. Type of ventilation suggested depending on building type. Numbers indicate the number of papers recommending each ventilation type. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference.

Table 5. Number of studies per building type. Res.: residential; Non-res.: non-residential; Var.: Various/Inapplicable; Edu.: educational; Hea.: healthcare; Wor.: working; Ind.: industrial; Amu.: amusement; Gen.: non-residential in general.

	Res.	Non-Res.							Var.
		TOT	Edu.	Hea.	Wor.	Ind.	Amu.	Gen.	
N. of papers	18	31	12	1	14	1	1	2	13

4. Discussions

The present literature review focuses on the comparison of IEQ conditions provided by natural ventilation (NV) and mechanical ventilation (MV), with the aim of collecting and offering a framework of scientific evidence to be exploited for sustainable design (e.g., nZEB, nPEB, and climate-responsive architecture). For this reason, the comparison of energy consumption by the two ventilation types was also highlighted, when present in the literature analyzed. When present in the analyzed articles, benefits of HV were also stressed.

The study permitted to highlight the following main considerations:

1. The articles comparing NV and MV in terms of indoor comfort and well-being found in literature are not very numerous. Moreover, even though current research is moving to the concept of well-being, this aspect is not explored in the studies included in the present review, as related keywords never appear in the articles analyzed. Most of the papers found regard non-residential facilities, in particular educational and working environments, underlining the key role of ventilation for obtaining healthy and comfortable conditions in highly occupied premises. Surprisingly, only one paper related to healthcare facilities was found. Several papers highlighting the performance of either MV or NV in healthcare facilities are present in the literature, but the comparison between comfort and well-being provided by NV and MV in this type of building is mainly under-explored. This is probably due to the specific field the present review is related with: studies about ventilation in hospitals that mainly deal with sanitation reasons; therefore, the comparison between the ventilation techniques mainly regards that topic instead of indoor comfort. The association between the number of studies and the publication year has been growing in time, with a sudden increase during 2020, due to the COVID-19 pandemic. The highest amount of papers was related to case studies located in Europe and Asia, highlighting a need for more research in other areas of the world. Most papers explored thermo-hygrometric and IAQ domains. When present, other domains were mainly considered only marginally, for instance stating that a relation between them and ventilation (e.g., noise) is present, and that further research in the field is necessary. During the most recent years, some articles highlighting the importance of multi-domain research appeared. Nevertheless, the topic has not been deeply explored yet.
2. Thermal comfort was the most frequently explored domain in all the types of environments. In all cases, contrasting conclusions on whether MV or NV is preferrable were drawn. Confirming what previously found in the literature, the main advantage of MV was recognized to be the ability to precisely set the indoor conditions. Nevertheless, this is not frequently perceived by occupants, who often prefer NV due to a higher degree of control over the environment they occupy and a major air movement, underlining the influence of the sensation of accessing to the outside. In this sense, the thermal environment was observed to be the main driver of occupants' NV behavior, with outdoor temperature (due to climate or season) being the main parameter affecting windows opening. Moreover, a shift in the usage of NV might be observed due to climate change, with the hours of windows opening potentially decreasing at warmer climates, but increasing at mild or colder ones. Furthermore, some articles highlight the presence of wider comfort ranges in warmer and/or developing

countries. This is probably due to reasons dealing with adaptation. The necessity of proper ventilation design to ensure the right indoor thermo-hygrometric conditions without creating local discomfort (such as draught) was stressed by several papers. In this sense, a more local focus, instead of the reference to international standards and the integration of other passive or active technologies such as night cooling or heat recovery, was promoted. No remarkable differences in findings were found among the different environment types.

3. After thermo-hygrometric, IAQ was the second most explored domain by the papers considered. Especially in residential environments, air tightness of refurbished buildings was seen as an issue for IAQ conditions and proper ventilation design. Particularly in non-residential buildings, MV was often associated with better air quality and less CO_2 and particles concentration. Type of ventilation must be carefully chosen depending on several conditions comprising outdoor pollution. In non-residential facilities in particular, a sudden change in perspective was observed after 2020, with a more health-driven vision of ventilation, strongly focused on the stop of airborne transmission of pathogens.
4. Visual and acoustic comfort were mainly explored marginally, as well as multi-domain approach. For instance, some recent works named visual and acoustic domains highlighting that their connection with ventilation, thermo-hygrometric, and IAQ conditions are important for future research, with a multi-domain point of view. Some papers highlighted how daylight and NV often benefit of the same constructive and architectural characteristics, such as high windows or operable skylights. Acoustic comfort was often explored in terms of noise, seen as an issue for the application of NV (when noise from the outside is present) or MV (poorly designed plants). Nevertheless, the effect of outside pleasant sounds or the so called "adaptive acoustic comfort" needs to be further studied and explored.
5. A high number of papers highlighted how energy consumption is the main disadvantage in the use of MV. On the other hand, NV might be too dependent on occupants' behavior and might lead to a loss of energy at colder or warmer conditions. Most papers, especially when dealing with extreme climates or larger and commercial buildings, proposed HV as a solution. This technique allows to lower the carbon footprint of buildings, while ensuring sufficient air change when proper indoor conditions cannot be met with passive solutions. The higher share of papers suggesting MV or HV in non-residential buildings is due to the fact that these facilities are constituted by environments which are normally studied for a higher number of occupants (i.e., schools, offices). For this reason, automated or semi-automated systems seem to be more adequate to guarantee the right amount of fresh air in these facilities. In order to improve the ventilation efficiency and the energy savings, the use of advanced technologies (e.g., heat recovery or energy storage) and proper and careful ventilation design were often promoted. For instance, focus should be placed on the optimal velocity of the exhaust in order to obtain the maximization of energy and ventilation efficiency without creating supply exhaust short-circuiting. In this sense, the use of CFD simulations was encouraged, helping with architectural characteristics improving NV, such as building orientation and position, façades, size, and location of inlets and outlets. Finally, a change in standards and guidelines was suggested by some authors in order to improve energy consumption and energy savings, for instance encouraging NV when possible.

5. Conclusions

Even though ventilation design is often aimed at ensuring adequate IAQ, thermo-hygrometric comfort seems to be the main ventilation behavior driver for occupants. Especially in non-residential buildings and after the COVID-19 pandemic, the approach in ventilation studies has slightly changed to a health-based driven, rather than a comfort- or energy-based one. In general, present research strongly highlights that hybrid ventilation is the most recommended solution in order to guarantee both energy savings and proper IEQ conditions when not achievable with natural ventilation alone. This is particularly true in extreme or polluted climates, where window openings alone can lead to poor indoor conditions, and/or highly occupied or healthcare environments, where NV alone might not be sufficient to maintain an adequate level of IAQ and healthy conditions. The literature analyzed also suggests that, when possible (e.g., residential environments and smaller offices) the hybrid solutions should also consider the necessity of control by occupants, allowing to switch to a total manual system if required. Proper design of ventilation is encouraged, promoting the use of numerical modelling such as CFD analyses, in order to ensure IEQ and avoid issues such as short-circuiting of supply and exhaust air and draught sensation by occupants. From present literature, it was highlighted how some topics remain under-explored. The current tendency in indoor climate studies is to move from the concept of comfort to a more holistic well-being one, considering aspects related with comfort, satisfaction, health, and well-functioning. Nevertheless, the concept of well-being was not explored in the literature here analyzed. Moreover, only marginal attention was provided to visual, acoustic, and multi-domain comfort. Other under-explored topics regard passive technologies such as night cooling, as well as some types of environments such as healthcare facilities.

6. Future Developments

Ventilation is a key factor in the field of sustainable design, specifically regarding nZEB, nPEB, and climate-responsive design, as energy savings strongly depend on ventilation techniques. In this framework, the choice of proper ventilation type (to be energy-driven or IEQ-driven) cannot be made regardless of indoor comfort and well-being. The use of either NV, MV, or HV is highly dependent on the climate, the outside pollution, the building type, and the season. In this sense, the ventilation system should be coupled with sensors and smart home solutions, being able to switch from one typology to another whenever the indoor and outdoor conditions allow or require it. Moreover, warning sensors might be useful to advise occupants on the indoor pollutants and CO_2 concentration when NV is used.

Studies addressing the topic of well-being related with the comparison of NV and MV are beneficial for human-centered indoor building design. Moreover, the literature, standards, and guidelines would benefit from studies on ventilation exploring comfort with a multi-domain perspective. Ventilation is clearly and directly connected with thermo-hygrometric environment and IAQ, but recent studies agree on how all the comfort aspects interact (e.g., noise-IAQ, emissions of pollutants with higher sunlight, phycological aspects). For this reason, comfort studies coupling subjective surveys with objective measurements, and correlating the comfort perception in terms of the four domains with each other would be necessary. Moreover, some environments such as healthcare facilities need further research in terms of comfort related with comparison of different ventilation techniques. Ventilation studies might be mostly health-driven in these environments, but a significant amount of previous literature underline the relationship between healing processes and indoor well-being [52,139–141]: therefore, this aspect cannot be neglected.

The exploitation of night cooling allows to further exploit natural ventilation during nighttime, when lower temperatures are present, using the delay in the heating process of massive elements. Therefore, comparative comfort studies with and without this technique would allow to assess the comfort benefits during morning hours, further encouraging designers and stakeholders to exploit this technique. Other innovative passive solutions have been proposed in the last years, including the use of internal cladding for improving the thermal inertia, the coupling of massive elements with the smart use of shadings, use of compact form to reduce the heat loss through the envelope area, organization of spaces (e.g., non-habitable areas on eastern and western sides to act as additional thermal buffers, living rooms towards south to better exploit solar gains, etc.), air quality control through proper selection of materials in air-tight buildings, etc. [34,35,97,142–153]. The use of these techniques should be explored in terms of indoor well-being when coupled with MV and NV systems.

7. Limitations

The present paper aims at providing an overview on the comparison of IEQ conditions provided by different ventilation types. For this reason, it was chosen to include only papers comprising and treating both the types of ventilation, in order to highlight the points in common and differences in the indoor conditions and energy savings provided by each ventilation technique. For this reason, the research can be expanded considering the two ventilation types separately. Moreover, as it is common in review processes, the final papers analyzed depend on the search query, the inclusion criteria, and the database considered.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings12111983/s1. Table S1. Studies related with residential environments: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." = visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Res." = residential. T = temperature; RH = Relative Humidity; ACR=air-change rate. Table S2. Studies related with non-residential environments: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." =visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Edu." = educational; "Hea." = healthcare; "Wor." = working; "Ind." = industrial; "Amu." = amusement; "Gen." = non-residential in general. T = temperature; RH = Relative Humidity; ACR=air-change rate. Table S3. Studies not related with a specific type of environment: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." =visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Var." = Various/Inapplicable. T = temperature; RH = Relative Humidity; ACR = air-change rate.

Author Contributions: Conceptualization, L.Z. and R.A.; Methodology: L.Z. and R.A.; Formal Analysis: L.Z.; Investigation: L.Z.; Resources: R.A.; Data curation and data interpretation: L.Z.; Writing—Original Draft Preparation: L.Z.; Writing—Review and Editing: L.Z. and R.A.; Visualization: L.Z.; Supervision: R.A.; Project Administration: R.A.; Funding Acquisition: R.A. All authors have read and agreed to the published version of the manuscript.

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Appendix A

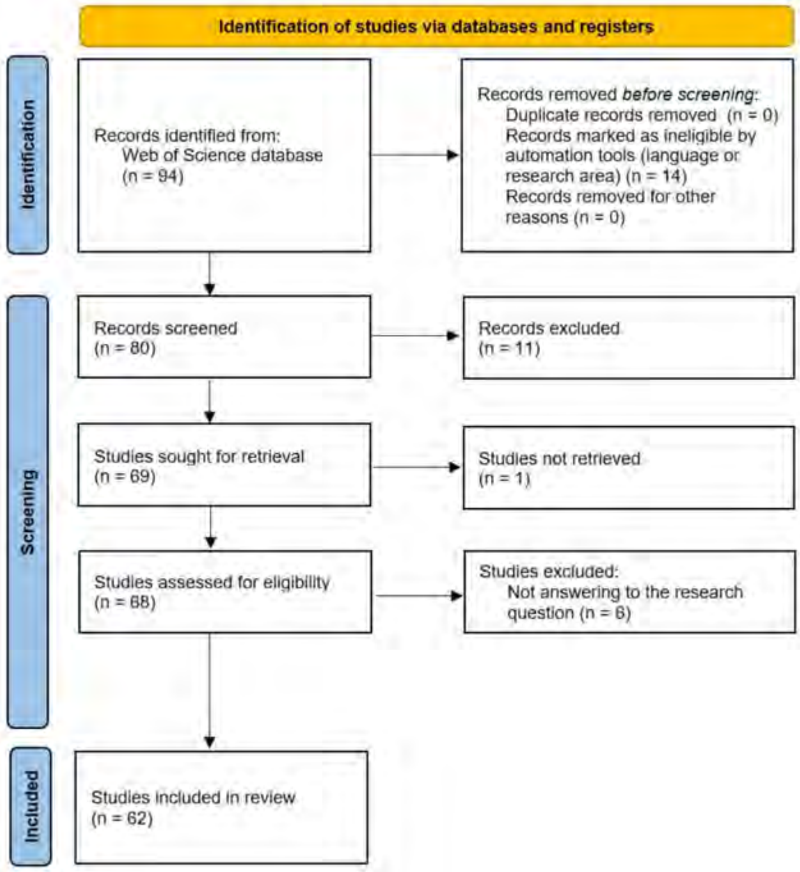

Figure A1. PRISMA flowchart depicting the inclusion/exclusion and screening process. Adapted with permission from PRISMA Website [82].

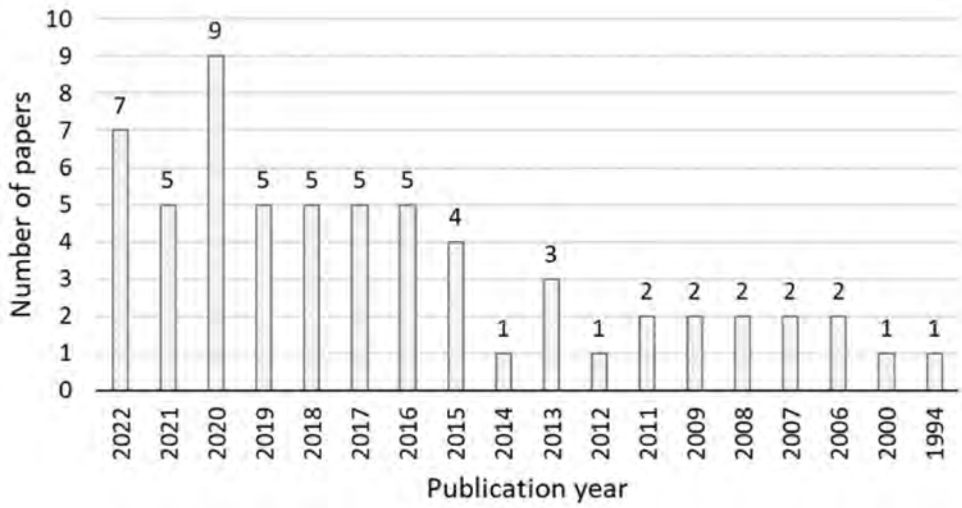

Figure A2. Papers found for each publication year.

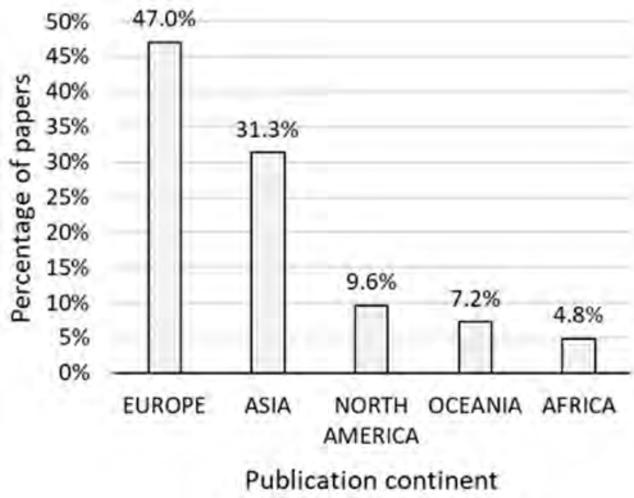

Figure A3. Percentage of papers produced in each continent.

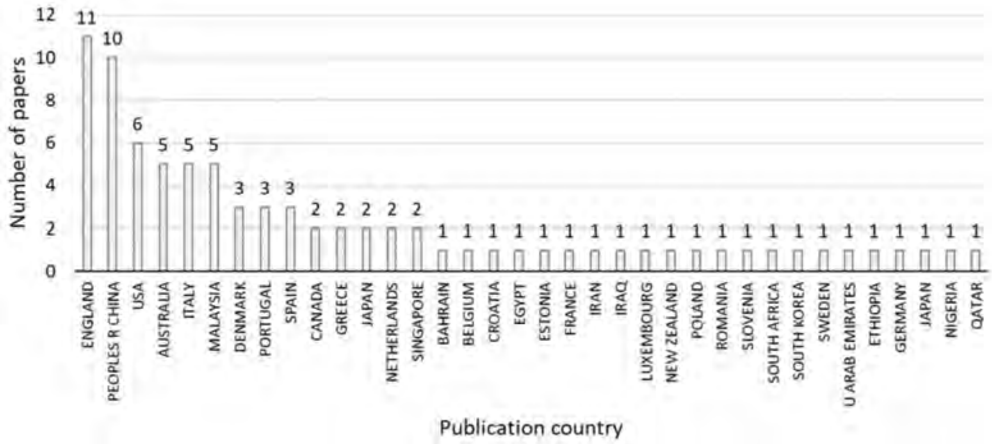

Figure A4. Papers found for each country/region.

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CONCLUSION AND FUTURE UPDATES

This document is the first version of the **DESIGN GUIDELINES OF CLIMATE POSITIVE CIRCULAR COMMUNITY (CPCC) in TRENTO**, with particular reference to the **WP4_ SUSTAINABLE BUILDING (RE)DESIGN.**

Following feedback received in the first year of the project and following the activities that will be carried out in the next two years, **these guidelines will be annually supplemented and adjusted** as necessary.

The document will be also revised based on the feedback given and lessons learned. This continuous process will lead to a proven, validated, and consistent guidelines at the end of the project and one updated version of the current version of the document.

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GLOSSARY OF TERMS

Table A.1. *Abbreviations used in the report.*

Abbreviation	Description
BAPV	Building Applied Photovoltaics
BEMS	Building Energy Monitoring System
BIPV	Building-Integrated Photovoltaics
CO_2	Carbon Dioxide
CPCC	Climate Positive Circular Communities
DD	Development Design
DeD	Detailed Design
ECD	Early Concept Design
EPBD	Energy Performance of Buildings Directive
EV	Electric Vehicle
GHG	Greenhouse Gas
H2020	Horizon 2020
HVAC	Heating, Ventilation, and Air Conditioning
IAQ	Indoor Air Quality
ICT	Information and Communication Technologies
IEQ	Indoor Environmental Quality
KPIs	Key Performance Indicators
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LowEx	Low Exergy
NZC	Net Zero Cities
nZEB	nearly Zero-Energy Building
PED	Positive Energy District
PV	Photovoltaic
RES	Renewable Energy Systems
SDGs	Sustainable Development Goals
V2G	Vehicle-to-Grid
WP	Work Package
ZEN	Zero Emission Neighbourhood

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