

Annual Report 2025



International Energy Agency

Annual Report 2025

Energy in Buildings and Communities Technology Collaboration Programme

Published by INIVE on behalf of the International Energy Agency
Energy in Buildings and Communities Technology Collaboration Programme

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Front cover:

'The Buildings Energy Code Working Group (BECWG) addresses codes for new and existing low-rise, mid-rise and high-rise buildings'.

Source: Meli Stylianou, BECWG, 2025

Publisher:

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EBC Executive Committee Chair's Statement

Improving the performance of new buildings and retrofitting existing ones is widely recognized as central to achieving global energy efficiency and climate goals. While the sector has shown encouraging signs, including a notable improvement in energy intensity over the past year, a critical reality gap remains: current policy trajectories still fall short of the sustained progress required for a net-zero pathway. This year's Annual Report moves beyond statistics to highlight how the Energy in Buildings and Communities Technology Collaboration Programme (EBC TCP) is actively addressing these challenges. From relaunching the Building Energy Codes Working Group (BECWG) to tackle the global regulatory deficit to pioneering research on grid-integrated controls, the focus is shifting from isolated equipment upgrades to optimizing buildings as complete, intelligent systems.

According to the International Energy Agency (IEA) 2024 Energy Efficiency report, buildings account for approximately 28% of global final energy consumption (about 120 EJ in 2023). Energy demand in buildings has grown by about 0.9% per year since 2010, driven by population growth, expanding floor area, and increasing cooling demand. The United States, the European Union, and China together represent nearly half of global building energy use.

The report indicates that building energy intensity improved by an average of 1.4% per year between 2010 and 2023, with a stronger improvement of 2.6% recorded in 2023. Under current policies, improvement is projected to remain below 1% per year through 2030. Announced pledges would raise this to about 2% per year, while a net-zero pathway requires sustained improvements of approximately 4.4% per year. Under the net-zero scenario, global building energy demand would fall by around 17% by 2030.

Building energy codes are identified as a critical policy lever, a point recognized by the EBC TCP since 2019, when the BECWG was established. To fully explore the potential impact of building energy codes, the BECWG is being relaunched with the creation of an Advisory Committee comprising experts from 14 countries. The task facing the group is substantial as more than half of newly constructed global floor area in 2023 was built without mandatory efficiency requirements. The BECWG faces additional challenges because its membership is currently limited to economically advanced countries, while the greatest need for information exists in the more than 100 countries that still lack mandatory building energy codes. Efforts are under way to attract broader participation, including from countries not formally part of the EBC TCP. The vision of the BECWG is to develop into a hub where information is available to those who need it.

Furthermore, the IEA 2024 Energy Efficiency report mentions that existing buildings represent the largest opportunity for efficiency gains, as most of the 2030 building stock already exists. According to the report, only around 50 countries regulate efficiency in existing buildings, typically triggered during major renovations.

Electrification is a major driver of Greenhouse gas (GHG) reductions and efficiency gains in buildings, often achieved through the retrofit of existing buildings in many jurisdictions. The IEA report focuses on equipment, noting that heat pumps can reduce heating energy use by 60–70% compared with efficient gas boilers, even in poorly insulated homes, and by up to 90% when combined with high levels of insulation. However, this perspective does not capture the broader challenges and opportunities available.

The IEA report addresses one-for-one equipment replacement rather than exploring the opportunities associated with designing and retrofitting buildings as a system. In addition, it does not fully consider opportunities related to improved building operation. By contrast, the IEA EBC TCP addresses these aspects through Annex 91: Grid Integrated Control of Buildings and the completed Annex 84: Demand Management of Buildings in Thermal Networks.

Buildings are central to achieving global energy efficiency and climate goals, which underpins the emphasis of this report on how EBC Annexes have addressed the wide range of challenges facing the sector over the past year.



Meli Stylianou
EBC Executive Committee
Chair and Member for Canada

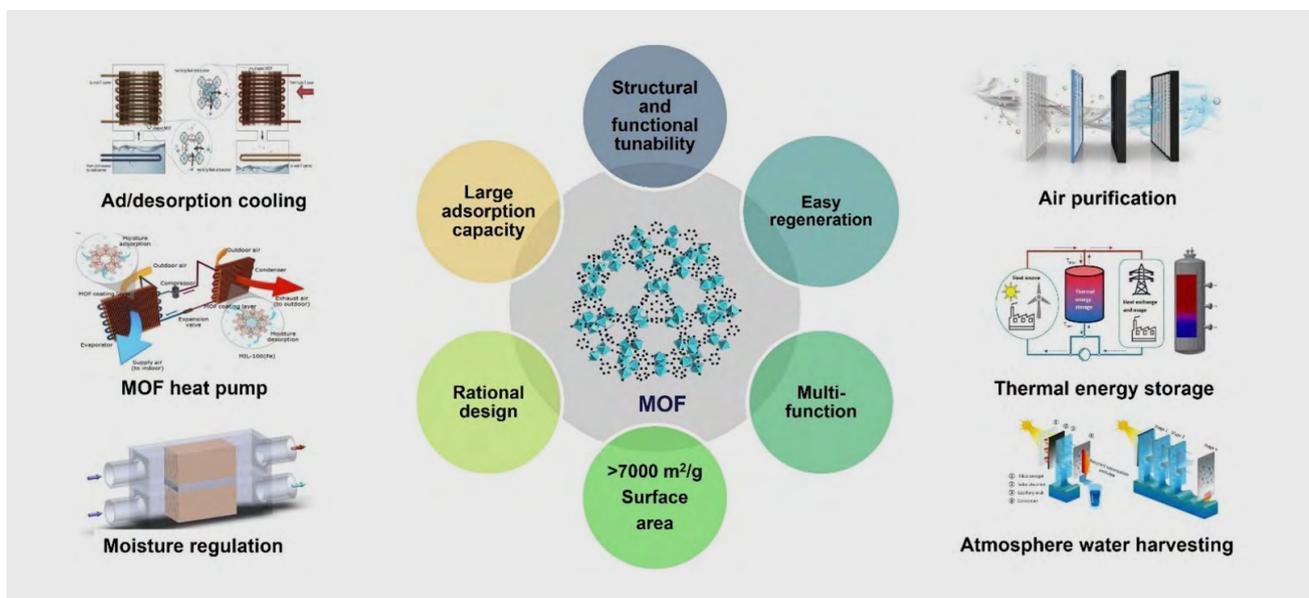
Smart Materials for Sustainable Buildings

The rapid growth of heating, ventilation, and air-conditioning (HVAC) systems in buildings worldwide has become a major driver of global energy use. Heating alone accounts for about 45% of building-related emissions and still relies heavily on fossil fuels, which supply more than half of its energy demand. Cooling typically relies on mechanical compression processes that use volatile fluorinated gases with high Global Warming Potential (GWP). Remarkably, the core technology behind modern air conditioning has changed only marginally over the past century. Despite their widespread adoption, these systems continue to be energy-intensive and impose a significant environmental burden. Reinventing the way we heat and cool buildings, through the development and deployment of advanced smart materials and innovative physical and chemical processes, offers a promising pathway to significantly reduce energy demand, improve indoor air quality, and mitigate the environmental and climate footprint associated with modern living.

In recent decades, chemists and materials scientists have created a wide range of innovative smart materials with remarkable abilities for regulating heat and moisture. Among

them, Metal–Organic Frameworks (MOFs), a field recognized with the 2025 Nobel Prize in Chemistry, along with phase change materials (PCMs) and polymer hydrogels, stand out for their exceptional performance. These materials can be engineered directly into walls, ceilings, or ventilation systems, where they help control temperature and humidity either automatically or with minimal energy input. They can also be integrated into mechanical systems, such as adsorption heat pumps or chillers, humidity pumps, thermal batteries, air cleaners, etc. By stabilizing indoor conditions and improving air quality, they offer a promising way to reduce the energy needed for air conditioning, ventilation, and air purification, making buildings more comfortable and sustainable at the same time.

IEA EBC Annex 92 aims to develop energy-efficient strategies for heating, cooling and air purification by leveraging novel smart materials, particularly advanced sorbents such as MOFs (or Covalent Organic Frameworks [COFs]) and their composites, through cross-disciplinary international collaboration. This ambitious initiative gathers existing scientific knowledge and data on emerging sorbent materials for



MOFs applications for built environment control
Source: Menghao Qin

heating, cooling, and dehumidification, pollutant removal, and thermal energy storage, while exploring both current and innovative applications of these materials in heating, air-conditioning, air purification, and thermal storage systems. It will also identify and address key knowledge gaps by fostering links across different disciplines. Experts in building science, materials chemistry, mechanical engineering, materials science, and environmental health will work together with a broad range of stakeholders to accelerate the development of more efficient and sustainable heating, cooling, and indoor air quality (IAQ) control systems based on smart materials.

Recent advances in smart materials

In the field of advanced materials, considerable progress has been achieved in the past few decades with the emergence of a series of new classes of organic, inorganic and hybrid crystalline or amorphous materials (polymers, coordination polymers, hybrid perovskites, inorganic and organic two-dimensional [2D] materials...). This includes not only the development of new porous solids (mesoporous silica, MOFs, COFs, porous cages, hydrogels...) but also materials with sometimes unique physical and chemical properties such as stimuli-responsive frameworks (e.g. phase change materials, flexible porous solids...). MOFs and COFs are regarded as among the most versatile classes of smart materials; these ordered porous solids possess unprecedented chemical and structural diversity. To date, this has led to the

discovery of more than 130,000 experimentally reported MOF structures while theoretical calculations suggest an almost infinite number of possible metal-ligand combinations. MOFs and COFs exhibit tunable hydrophilic/hydrophobic balance as well as variable pore size (0.3 to > 5 nm) and shapes (channels, cages, 1D to 3D porosity). These porous materials have so far been proposed for a wide range of potential applications, including gas storage, separation, catalysis, energy, remediation, sensing or biomedicine. When MOFs are constructed from non-critical metals and simple organic building blocks, their production at an industrial scale can be achieved through batch or continuous flow routes, at moderate costs comparable to those of other synthetic porous solids like zeolites. The first commercial applications of MOFs have emerged only very recently, primarily in CO₂ capture and cooling and dehumidification, paving the way for broader industrial deployment. Although COFs and porous organic cages often exhibit greater chemical stability than most MOFs in liquid-phase environments, further efforts are still needed in order to address scalability challenges due to the use of toxic/expensive building blocks/solvents during synthesis. MOFs/COFs are also usually much easier to regenerate within a narrow range of temperature or pressure than the traditional activated carbons, zeolites or hydrogels, paving the way for the design of new, less energy-demanding processes (remediation, separation, catalysis...).

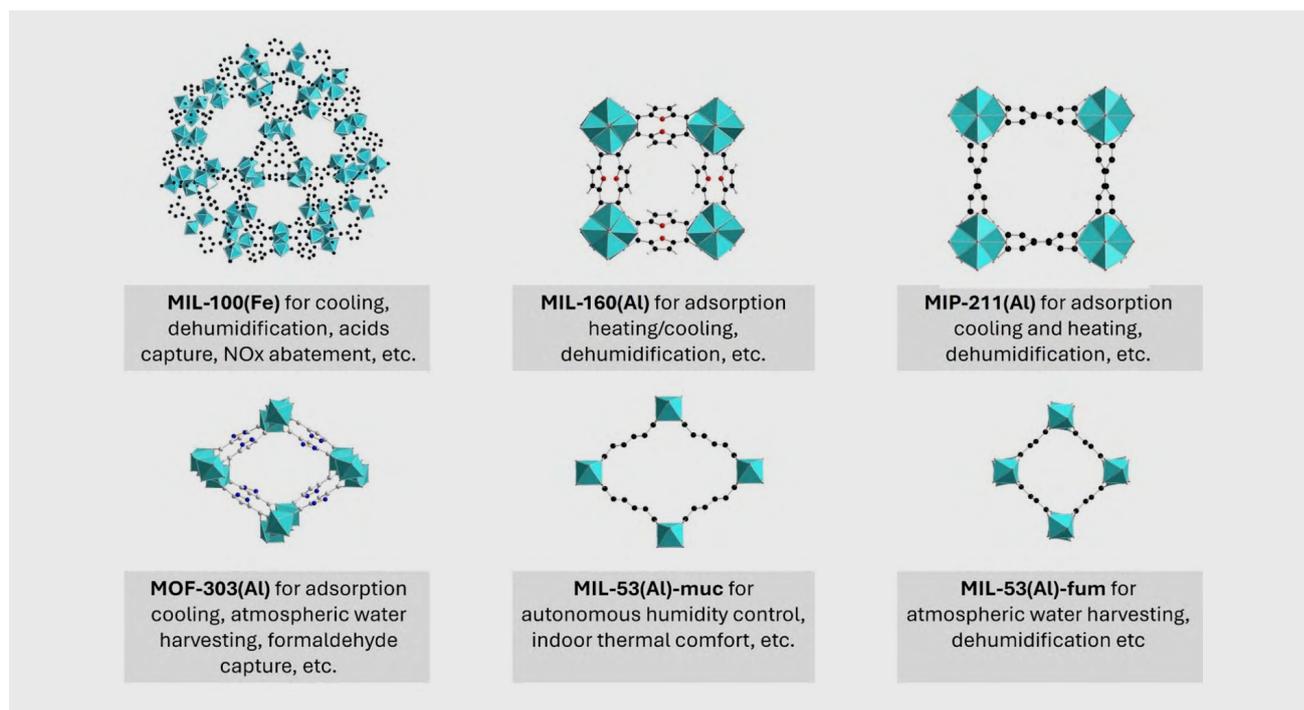


Illustration of MOF structures and their applications.
Source: Christian Serre

The vast majority of these discovered MOFs have resulted from advances in synthetic methods (e.g., high-throughput synthesis) or in advanced characterization techniques (X-ray diffraction, electron diffraction and Nuclear Magnetic Resonance [NMR]...), driven largely by chemical intuition and in many cases, serendipity. The recent emergence of artificial intelligence methodologies, combined with new combinatorial synthesis and characterization tools is expected to accelerate the design of functional porous solids for targeted applications including indoor air quality management and adsorption-based heat transfer systems.

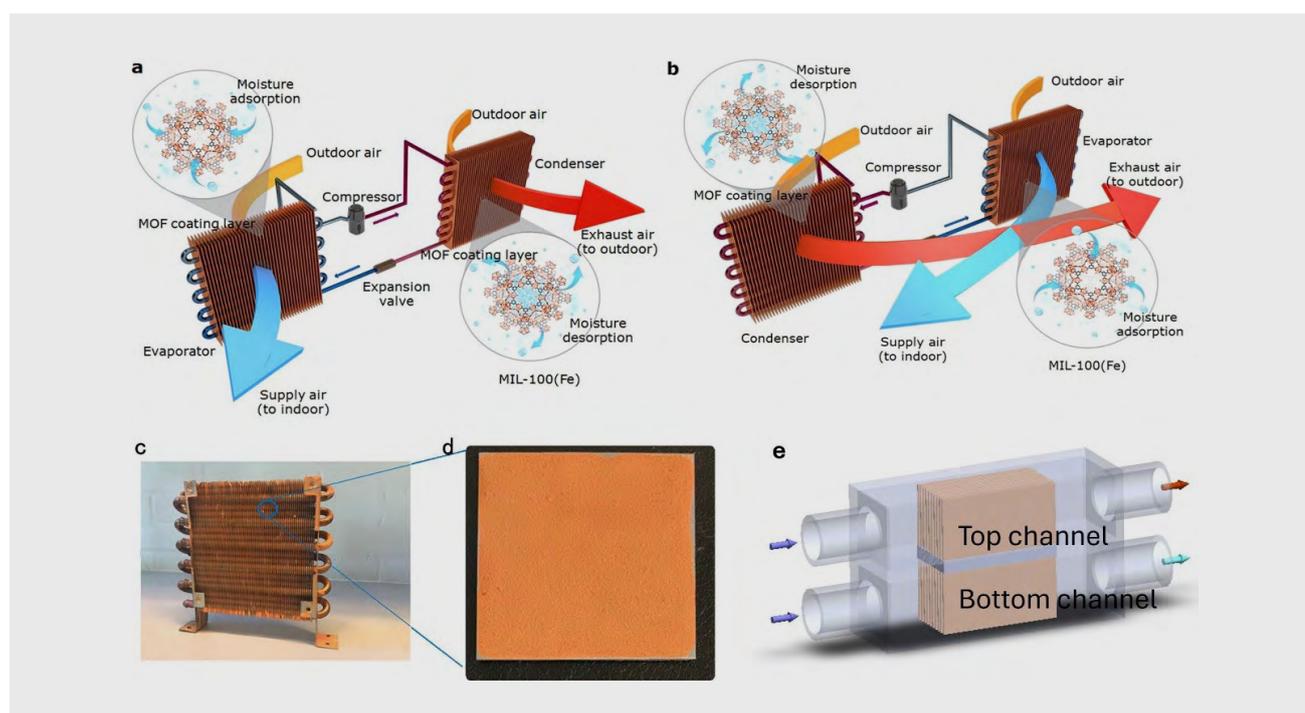
MOFs for cooling/heating and dehumidification

As highly efficient water adsorbents, many MOFs hold great promise for cooling and humidity control applications in buildings. Their organic-inorganic hybrid characteristics lead to a uniquely steep water vapor uptake. The exceptional chemical and structural diversity of MOFs allows for precise tuning of the hydrophilic/hydrophobic balance, often enabling easier water release within a narrow range of relative pressures due to their S-shaped isotherms, and at moderate temperatures (40–80 °C) owing to their amphiphilic environment, together with high working capacities of up to 2 g of water vapor per gram of MOF under practical conditions. Importantly, MOFs have also demonstrated remarkable long-term stability over repeated heating and cooling cycles leading recently to the first commercial applications in the field of dehumidification and cooling.

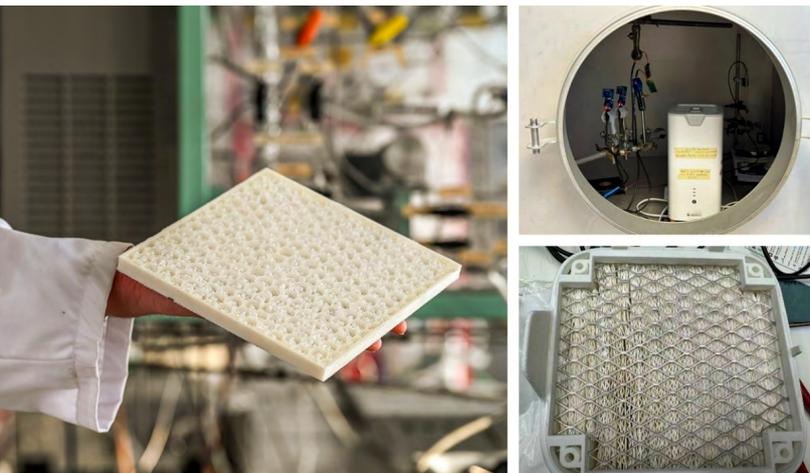
These properties enable MOFs to outperform most conventional sorbents, making them highly attractive for energy-efficient technologies that use water as a safe and environmentally friendly working fluid, often powered by low-grade renewable or waste heat. Emerging applications include autonomous indoor dehumidification (i.e., precise control of indoor relative humidity within desired ranges), adsorption heat pumps and chillers, air conditioning, thermal energy storage, and even atmospheric water harvesting. Reflecting this growing potential, many research groups and startups worldwide are now developing MOF-based technologies to translate these innovations from the laboratory into real-world building systems.

MOFs for indoor air purification

Another important application of MOFs in buildings is the removal of gaseous indoor pollutants. Owing to their exceptionally high surface areas, tunable pore structures, and adjustable surface chemistry, MOFs can selectively capture a broad spectrum of indoor contaminants at very low concentrations. At the laboratory scale, researchers have developed functional, scalable, and robust MOFs capable of removing or degrading volatile organic compounds (VOCs) (formaldehyde, acids...), carbon oxides, nitrogen oxides, sulfur oxides, ammonia, hydrogen sulfide, ozone, and even radon under ambient conditions. Some MOFs can maintain strong adsorption performance under typical indoor relative humidity levels of 40–60%.



(a–b) MOF-based heat pump systems; (c–d) MOF-coated heat exchanger; (e) MOF-based humidity pump. Source: Sci. Rep. 8, 15284 (2018) and Build. Environ. 187, 107396 (2021)



MOF-based filters and air cleaner
Source: Nicolas Sadovnik

Among these materials, aluminum-based MOFs such as Al-3,5-PDA or MOF-303 have demonstrated outstanding potential for formaldehyde capture, a major indoor toxin released from furniture, coatings, and building materials. In particular, Al-3,5-PDA exhibits significantly higher formaldehyde removal capacity than conventional sorbents under both low- and high-humidity conditions, with a maximum adsorption capacity about six times greater than that of modified activated carbons. In addition to their high selectivity and capacity, these MOFs can be regenerated easily either through simple water soaking or heating at moderate temperatures, enabling repeated use without producing harmful by-products. Meanwhile, both academia and industry are advancing large-scale manufacturing methods, supporting their practical integration into HVAC systems and stand-alone air purifiers. As scalable synthesis continues to mature, MOFs are expected to play an increasingly important role in next-generation indoor air-cleaning technologies.

Given the broad application potential of MOFs in buildings, many leading research institutions and companies worldwide are already pursuing independent research in this area. EBC Annex 92 aims to establish a cross-disciplinary international platform that brings together top experts from chemistry, materials science, building physics, and the built environment to drive coordinated innovation and accelerate the translation of MOFs from fundamental research, to laboratory-scale design, and ultimately to early-stage industrial deployment. The initiative is also expected to open up a new research direction and frontier for building physics and building technologies. The superior sorption capability

of MOFs for targeted pollutants (such as formaldehyde) also makes it an ideal material for developing reliable low-cost sensors for indoor air quality control.

The main activities of EBC Annex 92 include systematically reviewing, analyzing, and evaluating emerging smart materials (with a focus on MOFs [or COFs]) for different applications and climates, and establishing selection criteria tailored to specific use cases. The initiative will further optimize the performance of selected materials and develop suitable shaping and fabrication methods to meet application requirements. In parallel, innovative sorption-based heating/cooling systems, air purification approaches, and thermal energy storage concepts will be developed and validated. Laboratory-scale experiments will be combined with numerical modeling and optimization to quantify performance and identify key design parameters. Ultimately, the initiative will deliver practical guidelines, models, and tools to support the design, operation, and management of novel HVAC and indoor environmental control systems, complemented by case studies to demonstrate and refine the proposed solutions. The expected audiences include researchers and professionals in building engineering, chemistry and materials science, and mechanical engineering; HVAC and materials manufacturers; building designers and consultants; policy, regulatory, and standards bodies; as well as building owners and end users.

Looking ahead, MOFs and other smart functional materials are expected to become key enabling technologies for next-generation buildings, supporting deep integration with HVAC systems, building envelopes, and thermal energy storage technologies. By designing and leveraging the unique functional properties of these emerging materials, it will be possible to achieve more precise control of indoor temperature, humidity, and air quality with substantially lower energy input. As a result, these materials are poised to play an important role in advancing sustainable, healthy, and resilient built environments.

Further information
www.iea-ebc.org

**Menghao Qin, Christian Serre, Guillaume Maurin,
Xin Zhang, Jianshun Zhang (EBC Annex 92)**

New Research Projects

—————
**AIR CLEANING FOR SUSTAINABLE AND
RESILIENT BUILDINGS**

(EBC ANNEX 99)
—————

**FLEXIBILIZATION AND OPTIMIZATION
OF HEAT PUMP SYSTEMS IN EXISTING BUILDINGS
THROUGH DIGITALIZATION**

(EBC ANNEX 98)
—————

Air Cleaning for Sustainable and Resilient Buildings

EBC ANNEX 99

EBC Annex 99 tackles how to maintain high indoor air quality (IAQ) in airtight, energy-efficient buildings without increasing outdoor-air ventilation in ways that raise energy use or bring in polluted air. This new project will develop an evidence-based framework for integrating particulate and gaseous air-cleaning technologies with ventilation and heating, ventilation, and air conditioning (HVAC) to support energy targets, health protection, and resilience during stress events (for example, smoke episodes and infection outbreaks). A key innovation is treating air cleaning as a measurable, designable part of sustainable ventilation aligned with the Energy Performance of Buildings Directive (EPBD) implementation, including harmonized metrics such as Clean Air Delivery Rate (CADR)/kWh to compare pollutant removal against energy use. Since its approval in 2025, the project has been structured into four Subtasks and early work highlights the need for validation and harmonized methods – especially for gas-phase, hybrid, and integrated energy-IAQ solutions. By the end of the project, Annex 99 is expected to deliver a usable evaluation framework, practical guidance, and field-validated case studies that support certification and real-world implementation.

Objectives

The project objectives are to:

- develop a harmonized assessment framework and common performance indicators for air-cleaning solutions in buildings;
- establish robust methods to compare pollutant removal effectiveness and energy use across technologies and system configurations;
- define and evaluate practical integration and control strategies for combining air cleaning with ventilation and HVAC systems;
- strengthen building resilience by identifying approaches that maintain acceptable IAQ during challenging outdoor-air and indoor-source events;
- generate evidence through laboratory, semi-real, and field demonstrations to produce transferable case studies across building types and climates; and
- translate the results into implementable guidance and

inputs to standardization and certification pathways that support broad adoption in practice.

Deliverables

The planned deliverables from this project include:

- A standardized framework and performance metrics for energy-efficient air cleaning (e.g., CADR/kWh), including EPBD-relevant assessment concepts.
- A modelling and simulation report covering airflow, pollutant removal, and energy balance for combined ventilation and air cleaning strategies.
- Procedures and guidelines for EPBD alignment, showing how air cleaning performance can be incorporated into EPBD implementation, certification, and energy performance assessments.
- System integration and control deliverables: guidance on integration configurations, plus reports on control automation and performance under variable conditions, supported by validation and benchmarking results from laboratory and semi-real testing.
- Resilience and health-focused outputs: state-of-the-art report (wildfires, overheating and infection control), health & exposure assessment report, and adaptation strategy guidelines for resilient design and operation.
- Field demonstrations and standardization package: long-term field validation report, recommendations for standardization and certification procedures, and a dissemination package (web portal and industry road-map).
- The annex final report consolidating results, conclusions, and policy recommendations across all Subtasks.

Progress

In 2025, the Annex focused on start-up activities to enable coordinated research and development across the participating teams. The main progress was engaging and aligning the Subtask Leaders on scope, priorities, roles, and how the Subtask outputs should connect. No open forums, workshops, or conferences were used as inputs in 2025; progress was driven by direct coordination with the Subtask leaders and preparation of the kick-off meeting.

AIR CLEANING AND VENTILATION



Simultaneous ventilation and air cleaning

Air Cleaning and Ventilation
Source: EBC Annex 99

Meetings

In 2025, Annex 99 activities were initiated through coordination discussions led by the Operating Agent with the Subtask Leaders to align on scope, roles, and preparations for implementation. No formal Annex-wide project meetings (with a defined agenda and recorded minutes) were held in 2025.

Project duration

2026–2030

Co-Operating Agents

Alireza Afshari, Aalborg University, Denmark
Sasan Sadrizadeh, KTH Royal Institute of Technology, Sweden

Participating countries

Australia, Belgium, Czech Republic, P.R. China, Denmark, Finland, Norway, Singapore, Sweden, UK, USA
Observers: Estonia, Poland, Romania

Further information

www.iea-ebc.org

Flexibilization and Optimization of Heat Pump Systems in Existing Buildings through Secondary-Side Digitalization

EBC ANNEX 98

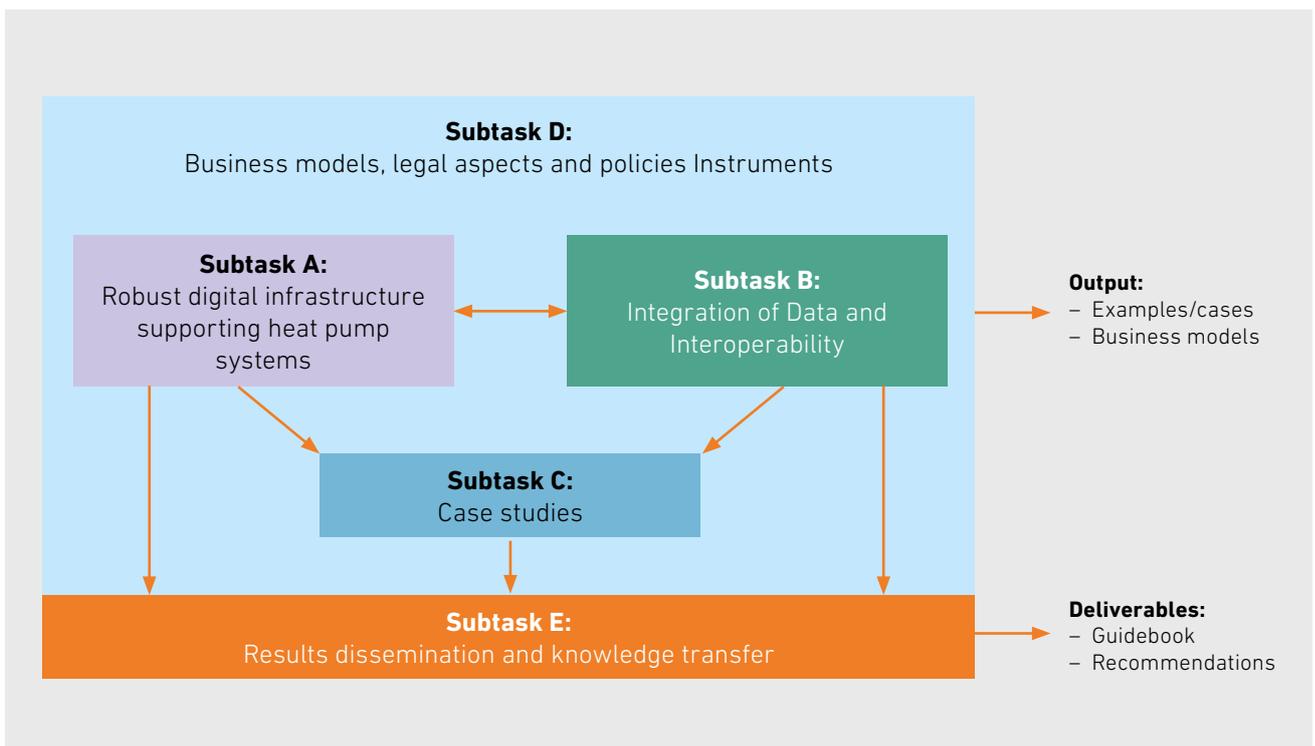
The digital transformation of heat pump systems, anchored by robust data integration and real-time control, represents a pivotal step toward a more efficient and sustainable energy future. By blending advanced technological innovations with a rigorous assessment of economic, regulatory, and market factors, Annex 98 sets a benchmark in energy system optimization.

Through international cooperation activities, the efficient application of heat pump technologies in new energy systems and buildings is demonstrated, as well as solutions for enhanced energy security and increased use of renewable energies are developed. Furthermore, specific solutions for a sector-coupled energy system and affordable solutions for the supply of buildings with heating and cooling, with a focus on heat pump technology, will be developed in close cooperation with other International Energy Agency Technology Collaboration Programmes (IEA TCPs). This leads to further

savings in primary energy, increased flexibility in energy applications, and greater sustainability in building heating.

The Annex is focused on the utilization of digitalization measures of heat pump systems to optimize the operation of heat pump-based heating systems in buildings and to create safer, more efficient, and environmentally sustainable heating infrastructures.

The Annex addresses these results and focuses on the secondary side optimization of heat pump systems through extensive digitalization of these systems. This is intended to lower system temperatures on one hand, which allows for a more efficient and optimized operation of the heat pump system. On the other hand, the utilization of flexibility potentials through the increased and optimized use of heat pumps in an energy system dominated by fluctuating input from renewable energies should be demonstrated.



Structure of EBC Annex 98 'Flexibilization and optimization of heat pump systems in existing residential buildings through digitization'
Source: EBC Annex 98

Objectives

This project is designed to excel in the digital optimization of heat pump systems by focusing on secondary-side components. By leveraging real-time sensor data and standardized communication protocols, it aims to create a paradigm shift in how building heating and cooling systems are operated – whether for new installations or retrofits. The objective extends beyond pure technical integration to also address economic, regulatory, and socio-technical dimensions.

By putting in place a strong digital infrastructure, the Annex's main objective is to create awareness for opportunities for the integration of digital processes and enhance the effectiveness, affordability, and environmental performance of heat pump systems in buildings as a whole. This will combine real-world demonstration procedures with data and signals from sensors in various heat pump systems. In order to fully realise the potential of communication across different domains in the future application of heat pump technology, the Annex will concentrate on analysing appropriate protocols and standards for data integration and assisting in the removal of obstacles or silos.

Summarising the following objectives will be considered within the framework of the project:

- Raise awareness of the advantages of integrating signals and data from several areas to ensure that heat pump systems in buildings operate as efficiently as possible.
- Look into ways to standardise data transmission protocols and ensure interoperability between the upstream infrastructure and the components of heat pump systems.
- Evaluate non-technical obstacles and facilitators, such as business models, legal considerations, and policy tools, for the digitalisation of secondary heat pump system processes.
- Build on findings from other IEA projects both from the 'heat pump technologies' and 'district heating and cooling' program, to offer an up-to-date, cutting-edge overview of the digitalisation of heat pump systems and associated secondary-side systems in the form of research and development projects, demos, and case studies.
- Disseminate the findings of the Annex via knowledge transfer activities including:
 - national workshops and special conference contributions;
 - an electronically available guidebook;
 - scientific publications in journals and conferences.

Deliverables

The primary deliverable of the Annex is a clear, practical, and user-friendly design guidebook for key stakeholders within the main target groups, including housing companies, project developers, building owners and planners, heating, ventilation, and air conditioning (HVAC) installers, and system providers and actors from the energy supply sector. The guidebook will include an executive summary tailored for decision-makers.

The dissemination of documents and other information is focused on providing practitioners with research results. Methods of information dissemination include conventional means such as presentations at workshops and practice articles. Regular workshops will be organized in all participating countries to present the latest project results and to provide an exchange platform for the target audience. Some of the workshops might be organized within the framework of national or international conferences or symposia.

Progress

Based on the results of projects in the IEA TCPs on 'heat pump technologies' and 'district heating and cooling,' discussions about the new project were initiated. Based on these discussions, an initial project proposal was prepared. The project preparation phase began in mid-2025 with an expert workshop. In 2025, the work concentrated on start-up activities. The main progress was setting up a work plan and establishing a group of Subtask Leaders to efficiently run the project.

Meetings

The following meetings were held in 2025:

- May 2025: International online workshop on the digitalization of heat pump systems and secondary side systems, held as an Annex definition meeting.
- October 2025: First preparation phase expert meeting in Kassel, Germany.

Project duration

2026–2029

Operating Agent

Dietrich Schmidt, Fraunhofer IEE, Germany

Participating countries (provisional)

Austria, Belgium, Denmark, France, Germany, Italy, Sweden, UK

Further information

www.iea-ebc.org

Ongoing Research Projects

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SUSTAINABLE COOLING IN CITIES

(EBC ANNEX 97)
—————

GRID INTEGRATED CONTROL OF BUILDINGS

(EBC ANNEX 96)
—————

**HUMAN-CENTRIC BUILDING DESIGN AND OPERATION
FOR A CHANGING CLIMATE**

(EBC ANNEX 95)
—————

**VALIDATION AND VERIFICATION
OF IN-SITU BUILDING ENERGY PERFORMANCE
MEASUREMENT TECHNIQUES**

(EBC ANNEX 94)
—————

**ENERGY RESILIENCE OF THE BUILDINGS
IN REMOTE COLD REGIONS**

(EBC ANNEX 93)
—————

**SMART MATERIALS FOR ENERGY-EFFICIENT
HEATING, COOLING AND IAQ CONTROL
IN RESIDENTIAL BUILDINGS**

(EBC ANNEX 92)
—————

**OPEN BUILDING INFORMATION MODELLING
FOR ENERGY EFFICIENT BUILDINGS**

(EBC ANNEX 91)
—————

**LOW CARBON, HIGH COMFORT
INTEGRATED LIGHTING
(EBC ANNEX 90)**

**WAYS TO IMPLEMENT NET-ZERO
WHOLE LIFE CARBON BUILDINGS
(EBC ANNEX 89)**

**EVALUATION AND DEMONSTRATION OF ACTUAL ENERGY
EFFICIENCY OF HEAT PUMP SYSTEMS IN BUILDINGS
(EBC ANNEX 88)**

**ENERGY AND INDOOR ENVIRONMENTAL
QUALITY PERFORMANCE OF PERSONALISED
ENVIRONMENTAL CONTROL SYSTEMS
(EBC ANNEX 87)**

**INDIRECT EVAPORATIVE COOLING
(EBC ANNEX 85)**

**BUILDING ENERGY CODES
(EBC WORKING GROUP)**

**POSITIVE ENERGY DISTRICTS
(EBC ANNEX 83)**

**AIR INFILTRATION AND
VENTILATION CENTRE – AIVC
(EBC ANNEX 5)**

Sustainable Cooling in Cities

EBC ANNEX 97 – IEA CITIES TCP

The effects of climate change are becoming increasingly severe in urban areas, where extreme weather events such as prolonged heat waves, are intensified by the urban heat island effect. With over 55% of the global population living in cities, addressing these challenges has become critical.

EBC Annex 97 builds on EBC Annex 80 'Resilient Cooling of Buildings'. One key insight from Annex 80 was that sustainable and resilient cooling of buildings in urban areas is intrinsically tied to heat mitigation and the introduction of cooling solutions that do not compromise the outdoor liveability by heat and noise release. This project is tackling this challenge. It is carried out jointly with the IEA Technology Collaboration Programme on Decarbonisation of Cities and Communities (Cities TCP) and focuses on three key aspects:

- First, it aims to improve outdoor climate conditions in cities to create comfortable and healthy living environments. This involves interventions at different spatial scales, from city-wide planning to neighbourhood-level initiatives and building specific strategies. Optimizing urban morphology through design, landscaping, and green and blue infrastructure integration can enhance airflow, reduce outdoor temperatures, and provide

shading. The use of cool materials in outdoor spaces can also improve outdoor comfort and indirectly benefit indoor environments.

- Second, the project focuses on strategic solutions for sustainable cooling of buildings. Efforts prioritize reducing cooling demand and meeting it with energy-efficient, climate-friendly, socially equitable, and affordable approaches. Alternatives to conventional air conditioning, such as district cooling, seawater cooling, and radiative cooling, are explored to minimize energy waste and mitigate heat and noise pollution. Balanced systems that optimize seasonal environmental heat sinks can further enhance energy efficiency and reduce environmental impacts.
- Third, the project highlights the critical link between outdoor climate mitigation and sustainable cooling solutions. A conducive outdoor environment is essential for the success of these technologies, as extreme heat conditions can undermine their effectiveness. Additionally, unmanaged excess heat from air conditioners can exacerbate outdoor heat stress, particularly during heat waves, reducing quality of life in urban areas.

Objectives

The project aims to increase and spread international knowledge on effective heat mitigation and sustainable cooling in cities, with emphasis on the interaction between heat mitigation in outdoor spaces and cooling of buildings. It seeks to develop and support the application of measures that serve people's health, safety and wellbeing while enhancing energy efficiency and contributing to carbon neutrality. To achieve this, four specific objectives have been defined:

- *Fundamentals*: Establish a knowledge base on environmental quality criteria for indoor and outdoor spaces, and key performance indicators for urban cooling. This considers indoor and outdoor air quality and comfort, health, productivity, safety, energy efficiency, environmental impact, and cultural and socio-economic aspects. It also involves analyzing human-centric indicators such as heat vulnerability indices.

A temporary installation at the Vienna Climate Biennale 2024, as an impetus for the realization of climate-effective green and blue infrastructure, in particular urban rivers.

Source: IBR&I, Vienna, 2024



- *Methods*: Develop protocols for simulations and experimental methods to assess heat mitigation and cooling technologies, including evaluation of simulation tools and the identification and development of experimental evaluation methods for urban heat and countermeasures.
- *Solutions*: Identify and assess solutions to improve heat mitigation in urban outdoor areas and cooling in buildings, focusing on their interaction. Measures include urban design, airflow, shading, evaporation, cool materials, district cooling and natural heat sinks. The focus is on resilient, robust, and affordable technologies, considering technical, energetic and socio-economic aspects.
- *Policy*: Transfer research results to real-world applications, identify best practices for policymaking, and strengthen existing networks to amplify global adoption of sustainable cooling practices and maximize project impact.

Deliverables

The Annex will produce:

- A state-of-the-art (SotA) report of sustainable cooling in cities.
- Key performance indicators for evaluating urban cooling solutions and their impact on people.
- Guidelines for experimental and simulation methods.
- Technology profiles and urban cooling guideline.
- Policy recommendations including a policy brief.

Progress

The Annex entered 2025 in its official one-year preparation phase following a unanimous decision of the IEA EBC Executive Committee. The first preparation meeting was held in April 2025 in Vienna, followed by a second meeting in September 2025 in Montreal. Several remote meetings among the Subtask Leaders (STL) were also held in April, June, September and October.

Throughout 2025, the draft Annex Text was continuously updated in line with the evolving work plan. A detailed work plan for the working and reporting phase was developed, outlining activities for each subtask including objectives,

methods, expected results, target audiences, impacts, schedules and milestones. Work on the development of the SotA report was initiated.

Cooperation with the Air Infiltration and Ventilation Centre (AIVC) and venticool was initiated to increase the impact and dissemination of research outcomes. Through the IEA Cities TCP, a link to the Mediterranean Association of National Agencies for Energy Management (MEDENER) was established. The IEA Secretariat was asked to support further cooperation with organisations from hot countries of the Global South.

The Annex was presented internationally at the ASHRAE AIVC IEQ 2025 Conference in Montreal. The Annex website was launched, and participants and interested teams were regularly informed through newsletters.

Meetings

The following meetings were held in 2025:

- January, May, June, September, November 2025: STL Preparation Meetings 01–05, online.
- April and September 2025: Annex Preparation Workshops in Vienna and Montreal.
- April and October 2025: Cities TCP ExCo Meetings in Rome and Berlin.

Project duration

2026–2030

Co-Operating Agents

Peter Holzer and Philipp Stern, IBRI Institute of Building Research & Innovation, Austria

Participating countries

Australia, Austria, Belgium, Brazil, Canada, P.R. China, Denmark, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, Turkey, UK, USA
 Limited Sponsor (Cities TCP): India

Observers: UAE

Further information

www.iea-ebc.org

Grid Integrated Control of Buildings

EBC ANNEX 96

The International Energy Agency (IEA) identifies the need for demand-side action to improve 'system-wide efficiency'. This includes the emerging need for load shifting (managing the time of energy consumption). This is required to improve the security of energy systems, as part of the transition to variable renewable energy resources. It also enables buildings to reduce emissions by consuming energy when grid carbon intensity is lower.

Load shifting in buildings can be achieved with various thermal and electrical energy storage assets that routinely occur in buildings (for example, hot water, heating, ventilation, and air conditioning (HVAC), electrical batteries and electric vehicles). These assets are known as 'flexible' loads and are capable of being dispatched using modern digital technologies.

In their Net Zero Emissions by 2050 Scenario, the IEA is calling for a tenfold increase in demand response availability from buildings between 2020 and 2030. Consistent with IEA recommendations, this Annex aims to unlock the availability of flexible loads in buildings by focusing on (i) digital and interoperability frameworks necessary for automating asset dispatch and resource quantification, and (ii) by improving the technology readiness level (TRL) and commercial readiness level (CRL) of flexible heating and cooling products and services.

Key industry challenges that this Annex will address include:

- Lack of awareness and scale of technologies for providing flexibility: Industry practitioners need to know what heating and cooling flexibility products and services are the most widely useable, predictable and cost-effective. Case studies are needed to provide confidence.
- Dispatchable load (capacity) is difficult to measure and forecast. Hence, it is not trusted; Flexibility markets need authoritative tools to both (i) forecast the upcoming availability of flexibility resources, and (ii) ex-post measure delivered flexibility.
- The information and data, needed to trade flexibility resources, is difficult to obtain: Interoperability specifications, guides, standards and interoperability testing

frameworks are required to streamline digital connectivity and information processing.

- Traditional resource assessment methods are deterministic rather than stochastic: The 'firmness' of flexible resources needs to be treated in aggregate (rather than solely on an individual asset-by-asset basis). Rebound effects, when flexible resources return to service, need to be better understood.
- Emissions abatement policies and rating systems typically use average annual emissions intensity factors, which disincentivize shifting consumption to times when renewable energy makes up a greater share of the energy supply mix: Policy makers need evidence of the potential impact of using more granular (for example, hourly) time-of-use emissions intensity factors.

Objectives

The vision of this project is to provide building owners and energy market participants with a framework of concepts, procedures, tools and evidence – that can enable trustworthy, automated, cost-effective trading of flexibility resources from buildings at scale. To achieve this, the Annex objectives are to:

- advance the TRL/CRL of flexible load technologies available in buildings;
- develop the digital framework(s) for exposing flexible load resources to energy markets/schemes;
- demonstrate the potential for automating flexibility aggregation and orchestration processes through modern digitalisation technologies;
- assess the potential to use flexible loads to reduce emissions in building, by better matching demand with grid time-of-use emissions; and
- drive adoption of Annex results through case studies, business model innovation and results dissemination.

Deliverables

The planned deliverables from this project include:

- Energy market reference scenarios describing how flexibility can participate in relevant jurisdictions, along with relevant digital platform requirements.

'Flextrack' AI Competition
Source: University of Wollongong

- A guide to measurement and verification (M&V) for flexible demand financial settlement.
- A report describing modelling analysis of the impact of coordinated management of fleets of flexible buildings.
- A state-of-the-art (SotA) report, and assessment of technologies for delivering flexible demand from heating and cooling services.
- A report on the potential for flexibility to reduce time-of-use based greenhouse gas emissions.
- A repository of case studies of flexibility in real world applications, accessible through a web portal.
- An industry roadmap report detailing intervention opportunities to grow the flexible demand industry.

Progress

The Annex entered its working phase in June 2025 with the participation of over 60 organizations across 21 countries. An initial survey of flexibility use-cases (in buildings) identified 16 use-cases, addressing one or more of 8 grid needs/markets. Most use-cases are incentivized through 'implicit' flexibility mechanisms (penalizing consumption) rather than 'explicit' flexibility mechanisms (incentivizing load reduction). More detailed workflow analysis is being conducted for these use cases. Test labs are being recruited to conduct interoperability testing of devices. A first 'asset orchestration' common exercise was launched. The common exercise will test the ability of different control strategies to dispatch flexible assets in a way that delivers a target aggregate load profile from a cluster of virtual buildings. 6 groups have committed to developing artificial intelligence (AI) control algorithms for this exercise.

A SotA review is underway, structured around 5 layers (or steps) involved in implementing flexibility services in buildings. A new web portal is being developed to host case stud-

ies being collected from real world implementations around the world.

An AI "Flextrack Challenge" was completed on the Alcrowd competition platform. The challenge called on participants to build machine learning models that can identify demand response events and measure their impact (by distinguishing normal energy use from intentional demand response shifts). 92 teams, from 50 countries, competed for \$10,000 in cash prizes and \$10,000 in travel grants.

The Annex has the support of, and is being promoted by, the Mission Innovation "Affordable Heating and Cooling" Innovation Community.

Meetings

- The following meetings were held in 2025:
- April 2025: Second preparation-phase expert meeting in Leuven, Belgium.
 - October 2025: International Pilot Projects Forum in Montreal, Canada.
 - October 2025: First Expert Meeting in Montreal, Canada.

Project duration
2024–2029

Co-Operating Agents

Stephen White, CSIRO, Australia
Rongling Li, Technical University of Denmark, Denmark

Participating countries

Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Turkey, UK, USA

Further information

www.iea-ebc.org

Human-Centric Building Design and Operation for a Changing Climate

EBC ANNEX 95

People play an integral role in building performance and adaptation to climate change across both spatial and temporal scales. They affect the market and design for new buildings, construction practices, and the operation and management of buildings through their life cycle. In a rapidly changing climate, diverse stakeholders hold the key to achieving optimal levels of performance as defined by the following dimensions: resilience and adaptability to extreme events; equitable allocation of building space and access to comfortable, healthy spaces; and mitigation of climate change.

This project places humans at the centre of the challenge and treats them as the solution rather than the problem. Building upon the success of EBC Annexes 66 'Definition and Simulation of Occupant Behavior in Buildings' and 79 'Occupant-Centric Building Design and Operation', the project explores the evolving role of humans in the energy transition. As building envelopes and equipment become more efficient, the influence of people on building energy consumption becomes increasingly significant. Modern trends such as teleworking have led to diverse occupancy patterns, while rising global expectations for comfort require re-evaluation of how humans are integrated into building design and operation.

The project focuses on four key areas: human-building interactions at the building scale; human-building interactions at the community scale; building design and retrofit; and building operations. It has been established jointly as EBC Annex 95 with the IEA Technology Collaboration Programme on User-Centred Energy Systems (Users TCP) and brings together researchers from engineering, architecture, information technology, psychology, and health sciences.

Objectives

The objectives of the project are to:

- produce new knowledge about how building occupants around the world respond to changing climate conditions, particularly extreme events, and how they are adapting to the energy transition;

- establish working definitions and key performance indicators to evaluate sufficiency, equity, and resilience in buildings;
- develop recommendations for building design and retrofit that address principles of resilience, sufficiency, and equity for a changing climate;
- examine the role that behavioural nudging of building operation can play in helping occupants stay safe during extreme events and comfortable during normal operation; and
- explore how communities and social infrastructure can establish resilience in the face of climate change.

Deliverables

The planned deliverables from this project include:

- A teaching repository of built environment innovations for climate adaptability.
- Practical strategies for surviving heat and extreme events.
- An online global repository of sufficiency and equity case studies.
- Guidelines for incorporating sufficiency perspectives in the built environment industry.
- Guidelines on multi-domain computational and artificial intelligence (AI) tools for human-centric design.
- Guidelines for facilitating reflective design practice in the building industry.
- A report on behaviour nudging in building operations.
- A best practices guideline for user-friendly control interfaces.
- A comprehensive final report.

Progress

In 2025, the project transitioned from its preparation phase into the working phase, with significant research activities underway across all four Subtasks. Two expert meetings were held: an online meeting in May and an in-person meeting in Lausanne, Switzerland in September.

The Annex advanced the understanding of occupant behaviour and well-being across cultures. Teams collected adaptive strategy data from seven countries including USA, Brazil,



Annex 95 Fall Meeting in Lausanne, Switzerland (September 1–2, 2025)
Source: EBC Annex 95

Denmark, France, Hungary, Netherlands, and the UK, and developed standardized protocols for cross-cultural comparison. Work progressed on understanding thermal comfort a draft position paper under development. Research on communicating adaptive behaviour through apps and interfaces formed a core group and developed interview protocols.

Moreover, progress on equity and sufficiency concepts was made. A proposal for a position paper on best practices in participatory energy research was accepted by the journal *Building and Environment*. A journal article titled 'Do Homebuyers Prioritize Sustainability? Examining the GHG Emission Impact of Housing Choices' was published in *Building and Environment*. Teams identified sufficiency measures across geographical contexts and began developing a framework for energy poverty analysis focused on residential buildings.

In addition, multiple design-focused activities were initiated. An opinion paper on multi-stakeholder sustainability collaboration was published. Work began on reviewing computational design support methods for a changing climate and examining how design studios prepare future professionals for human-centric building design. A survey of building design practitioners on decision-making and reflective practice entered final review stages.

The Annex also advanced building operations research. A position paper on behaviour nudging for human-centric operations reached an advanced draft stage with journal submission planned. Regular meetings progressed work

on fan-induced air speed preferences across cultures and building interface design. Case studies on nudging for window and thermostat use behaviour continued.

The Knowledge Mobilization Committee established the project's LinkedIn presence and created a repository mapping members' involvement with codes and standards committees.

Meetings

The following meetings were held in 2025:

- May 2025: 2nd Expert Meeting (planned for Spokane, WA, USA, but pivoted to online)
- September 2025: 3rd Expert Meeting in Lausanne, Switzerland.

Project duration

2024–2029

Co-Operating Agents

Liam O'Brien, Carleton University, Canada
Marianne Touchie, University of Toronto, Canada
Julia Day, Washington State University, USA
Zoltan Nagy, Eindhoven University of Technology, The Netherlands

Participating countries

Australia, Austria, Belgium, Brazil, Canada, Denmark, France, Germany, Ireland, Italy, the Netherlands, Singapore, Sweden, Switzerland, UK, USA

Observers: Egypt

Further information

www.iea-ebc.org

Validation and Verification of In-situ Building Energy Performance Measurement Techniques

EBC ANNEX 94

In recent years, there has been a rapid growth in the availability of cost-effective technologies that measure the energy performance of buildings in-situ. This growth has been driven by concerns over the performance gap between the real energy performance of buildings and that predicted by models, including those used for regulatory purposes. Innovation has been accelerated by the availability of smart meter data, weather data, and low-cost sensors that can measure the indoor environment. In fact, the building fabric thermal heat transfer coefficient (HTC) performance of more homes has likely been measured more often in the last few years than in all previous years combined.

This new capability to measure millions of buildings in-situ has the potential to transform the energy performance of building stocks globally, for example by enabling the following:

- Quality assurance of new buildings and the retrofit of existing buildings to eradicate the thermal performance gap.
- Correct sizing of heating and cooling systems to improve their energy efficiency and reduce capital costs.
- Quantification of building energy flexibility for demand response to support the electrification of heat.
- Reliable Energy Performance Certificates that drive the sale and rental value of buildings.

Image of participants attending the first working meeting at TU Wien, Vienna.
Source: TU Wien



- Accurate energy demand predictions from improved models that help to engage households and de-risk heat-as-a-service solutions.

EBC Annex 94 aims to increase confidence in the use of in-situ building energy performance measurement techniques by bringing together a network of experts, stakeholders, and facilities to accelerate their development and deployment. The work will help characterize and close the performance gap between the expected and actual energy use of dwellings. A key focus of the work is to better understand the needs of potential applications and the differing requirements of different users. Translating building thermal performance measurements to actionable insights will also be investigated through the study of investigative techniques to disaggregate any underlying problems with thermal performance.

The Annex will span a range of technology readiness levels by both addressing the validation and verification of existing in-situ building energy performance measurement techniques and aims to extend the applicability of methods to new climates and typologies. The building typologies to be studied include flats and high-performing homes (for which current methods have not yet been tested or refined). A key challenge of the work is to extend the seasons and climates in which the thermal performance of buildings may be accurately measured, requiring the collection of a large dataset, from across the globe, of buildings in differing climates. This will enable the development of measurement techniques for cooling dominated climates; currently the research is concentrated primarily on heating dominated climates.

Objectives

Annex 94 aims to advance the adoption of in-situ building energy performance measurement techniques through the following objectives:

- develop new knowledge and understanding of the breadth of real-world applications for in-situ building energy performance measurement techniques and the technical requirements of those applications across different sectors and applications;

- extend fabric thermal performance measurement methods to new building typologies and climates, improving applicability, accuracy, and robustness;
- co-create a new framework for the verification and validation of in-situ building energy performance measurement techniques. This will reconcile the current disparate approaches and provide the playbook of methods required for evaluating accuracy;
- develop building performance diagnostics to diagnose the reasons for thermal performance gaps. These will aim to disaggregate HTC measurements to identify the cause of observed underperformance and avoid expensive forensic studies; and
- collect and curate data sets to support the Annex’s work and create a legacy resource. This will include new and existing simulated data, data from field trials in occupied homes and data from test houses.

Deliverables

Annex 94 began its work in 2025 and has planned a range of deliverables, as follows:

- Maintain an up to date website.
- Prepare reports, to be compiled into a project summary report.
- Develop an online repository of open-source methods and datasets.
- Collaborate with the Dynastee Network of Excellence on full-scale testing and dynamic data analysis, including international workshops, annual training courses, and broader dissemination activities.
- Produce an executive summary and policy brief for non-academic audiences.

Progress

Annex 94 was approved by the EBC Executive Committee (ExCo) and began the working phase in June 2025. The scope of the Annex was finalized during the final preparation meeting in April 2025. Sub-task leaders held meetings with their working groups online. Work continued during the first working meeting in October 2025. Each meeting of the Annex has included a mini-conference on work relevant to the annex.

Presentations can be found on YouTube via the Annex website. The first academic paper of the Annex was published in 2025. A collaboration between five organizations in three countries, the paper reviews methods for assessing the measured HTC of buildings. The number of such tests that have been carried out was reported, for the first time [K. Ritosa, M. Collett, S. Juricic, G. Henshaw, M. Li, S. Roels, R. Fitton (2025) Review of methods for assessing the measured heat transfer coefficient (HTC), Building and Environment, Volume 289, 2026, 114082, ISSN 0360-1323. Available online].

The importance and timeliness of the Annex was reinforced by the release of the UK Government’s Warm Homes Plan, which includes plans to support the development of in-situ thermal performance methods and establish quality assurance and validation systems to support their use. Members of the Annex have met with the government team leading this work and are sharing expertise on validation and verification.

Meetings

The following meetings were held in 2025:

- April 2025: Final preparation meeting at Saxion University of Applied Sciences, Enschede, the Netherlands.
- October 2025: First working meeting at TU Wien, in Vienna, Austria.
- Sub-task working meetings: various, online.

Project duration
 2024–2028

Co-Operating Agents
 Prof David Allinson, Loughborough University, UK
 Prof Cliff Elwell, University College London, UK
 Prof Richard Fitton, University of Salford, UK

Participating countries
 Australia, Belgium, France, Ireland, the Netherlands, Spain, UK, USA

Further information
www.iea-ebc.org

Energy Resilience of the Buildings in Remote Cold Regions

EBC ANNEX 93

Energy resilience of buildings is a topic that has been overlooked in building regulations and in building design in general. However, energy resilience is especially relevant in cold, very cold and subarctic remote locations where loss of energy supply can be difficult to restore within short time-scale. Such cold regions cover almost one fifth of the Earth's total area (excluding Antarctica and Greenland). The main communities in these regions include dwellings for indigenous and local people, military installations, customs and border protection stations, construction and industrial camps, research centers, government, and community services. Except for Antarctica, the cold climate zones are mostly situated in the northern hemisphere due to the distribution of landmass. The logistics of construction, repair, and maintenance in such remote locations are unique and challenging.

For people to survive in the cold, buildings must be warm and comfortable in normal operations and habitable during crisis caused by blackouts and energy shortages. Due to the current climate warming trends, energy crises, and critical political situations, these buildings are at risk of energy shortage and blackouts. Therefore, the study and enhancement of the resilience of buildings, heating, ventilating, and air-conditioning (HVAC), and energy supply systems in cold climates is especially important. The resilience of thermal energy systems in extreme climates is also important. While metrics and requirements for availability, reliability, and quality of power systems have been established, similar metrics and requirements for thermal energy systems are not well understood, despite the clear need for such metrics in the Earth's cold regions. A few research projects have been conducted to address the resilience of buildings in warm, hot, and humid climatic conditions due to the higher population and local economic challenges for example. However, in cold climate conditions, the resilience issue has not been extensively addressed. Under these conditions, building resilience is essential to ensure habitability and survivability for the occupants; such infrastructure must be planned and designed to withstand disruptive events.

This Annex is intended to support a broad community of relevant public policy and decision makers, researchers, planners, architects, and engineers. The development of methods to increase the overall energy resilience of buildings and building communities is critical for many stakeholders. Therefore, for long-term outreach impact, the results and findings of the Annex will be communicated by tailoring the results and guidelines based on the target audience.

Objectives

The objectives of the project are to:

- identify major threats specific to cold regions that hinder the normal operation of buildings and energy systems; develop definitions, frameworks, and key performance indicators for energy-resilient buildings, communities, and energy supply systems; and establish requirements for habitability, survivability, indoor air quality, and building sustainability levels in cold regions for 'black sky' operations;
- document and assess existing practices through case studies across cold regions with different local conditions;
- develop guidelines for energy- resilient and efficient buildings and energy systems for different cold regions, with these addressing technical, social, and economic aspects; and
- disseminate best practices for planning and construction of energy-resilient buildings and communities in cold regions through technical papers, conference presentations, and training.

Deliverables

The project's main deliverables are as follows:

- Develop a guidebook that provides:
 - a map of the threats, challenges, and energy security risks to the building clusters in cold regions;
 - the basic definition and framework of the energy resilience concept;

- physiological/psychological research on the gaps in our understanding of human resilience;
 - building cluster maps, energy efficiency, and resilience regulations for energy-efficient and resilient buildings;
 - guidelines on updating the building codes in cold regions;
 - the identification of new methodologies to be adopted in building design for resilience in cold regions;
 - a description of electricity and heat production, and cooling;
 - a description of obstacles such as the availability of building-related products, costs, supply chain challenges, and skilled labor;
 - recommendations for new solutions in energy system design; and
 - case studies.
- A project summary report covering outcomes, guidelines, and best practices dedicated to the target audience.
 - Scientific publications, conferences, webinars, workshops and summer schools, newsletters, website and social media dissemination.

Progress

In 2025, the Annex made significant progress in advancing research on buildings and energy systems in cold regions, data collection, collaboration, knowledge transfer, and engagement. Japan, the USA, China, Norway, Canada, Denmark, Sweden and Finland officially joined the Annex. Iceland joined as an observer. Key activities included the development of climate specifications, building regulations, resilience assessment methods and requirements, mechanical and energy systems, district heating and storage, permafrost-related challenges and construction best practices, and requirements for indoor environmental conditions during emergency (Black Sky) situations. Case studies were collected from Japan, China and Greenland, and additional case studies are expected from Sweden, Norway, Iceland, the USA, and Canada. Two working meetings were held – one in Norway and one online – which supported chapter development and reporting. International engagement included participation in HEALTHY BUILDINGS 2025 in Iceland, conferences in the USA and Australia, and a site visit to the Hellisheidi Geothermal Power Plant in Iceland and Kiruna, Sweden. Potential Annexes were identified for collaboration, including PVPS Task 15 and IEA Task 70/Annex 90. Knowledge dissemination progressed through an edited book, nine published papers, and training sessions on energy



Wood based residential building in the cold climatic region of Sweden (Kiruna), under construction
Source: IEA EBC Annex 93

resilience. Outreach via the website and LinkedIn increased followers, and a funding application was submitted to support ongoing Annex activities.

Meetings

The following meetings were held in 2025:

- March 2025: Working meetings in Narvik, Norway and Kiruna, Sweden.
- October 2025: A working meeting, online.

Project duration

2025–2028

Co-Operating Agents

Dr Hassam ur Rehman, VTT Technical Research Centre of Finland, Finland
Dr Alexander Zhivov, US Army Engineer Research and Development Center, USA

Participating countries

Canada, P.R. China, Denmark, Finland, Japan, Norway, Sweden, USA
Observers: Iceland

Further information

www.iea-ebc.org

Smart Materials for Energy-efficient Heating, Cooling and Indoor Air Quality Control in Residential Buildings

EBC ANNEX 92

The rapid increase in the use of heating, ventilation, and air-conditioning (HVAC) systems in buildings worldwide has become a major driver of global energy demand. Heating alone accounts for approximately 45% of building-related emissions, with more than 55% of its final energy consumption still reliant on fossil fuels. Meanwhile, cooling primarily relies on the compression of volatile fluorinated gases. The core technology of mechanical cooling has seen little change since its invention over a century ago. However, these traditional systems are neither energy-efficient nor environmentally friendly. Combined, space and process heating and cooling constitute the largest contributors to global energy consumption and greenhouse gas emissions. Transforming heating and cooling technologies through the use of innovative functional materials and advanced physical-chemical processes offers a significant opportunity to reduce HVAC energy demand, enhance indoor air quality (IAQ), and mitigate negative environmental and climate impacts.

This project is developing energy-efficient heating, cooling and air purification strategies by using novel smart materials, especially advanced sorbents, such as metal-organic frameworks (MOFs) – awarded the Nobel Prize in Chemistry in 2025 – phase change materials (PCMs), hydrogel and their related composites, through cross-disciplinary international collaboration. The project is gathering the existing scientific knowledge and data on novel sorbent materials for heating, cooling and dehumidification, pollutant removal, and thermal energy storage. It is studying current and innovative use of these materials in heating, air-conditioning, air purification, and thermal storage systems. It is also identifying and bridging the knowledge gaps by establishing links between different disciplines. In the project, experts from building science, materials chemistry, mechanical engineering, material sciences, and environmental health are working together with other stakeholders to accelerate the development of better and more energy-efficient heating, cooling, and IAQ control systems by using advanced materials.



The 1st International Symposium on Smart Materials for Built Environment Control (SMBEC2025), Paris, France, 10–11 June 2025.
Source: Menghao Qin

Objectives

The main aim of the project is to develop energy-efficient heating, cooling and air purification strategies by using novel smart materials, especially advanced sorbents (MOFs, PCMs and hydrogels) and their related composites, through a cross-disciplinary international collaboration.

The specific project objectives are to:

- establish a cross-disciplinary international collaboration platform to develop breakthrough cooling/heating technologies by using smart materials;
- review, analyze, and evaluate novel sorbent materials suitable for energy-efficient heating, cooling, and air purification, with selection criteria to be set up for different applications.
- develop or further improve the performance of the selected materials for specific applications in different climates;
- develop suitable shaping methods of the best sorbents to adapt to the criteria of the different applications;
- identify or further develop innovative sorption heating and cooling systems using new materials;
- develop innovative air purification systems using new sorbent materials. Both the active system and passive approaches will be studied.
- develop innovative heat storage systems using new sorbent materials;
- carry out laboratory tests to measure the performance of the new solid-state heating and cooling, and air purification systems—numerical modeling and optimization is also being conducted;
- develop guidelines regarding design and control strategies for novel heating, cooling, and air purification systems using novel sorbent materials;
- identify or further develop models and tools that will be needed to assist designers and managers of buildings in using the guidelines;
- identify and investigate relevant case studies where the above-mentioned performances can be examined and optimized; and
- disseminate each of the above findings.

Deliverables

The project's planned deliverables are:

- A project summary report (Target group: researchers and professionals, HVAC and materials manufacturers, building designers and consultants, policy, regulatory and standards bodies).
- An overview report on methods and tools for selecting smart materials for energy-efficient heating, cooling, IAQ control, and thermal energy storage strategies (Target

group: HVAC and materials manufacturers, building designers and consultants, researchers and professionals).

- A collection of case studies and demonstrations of energy-efficient heating, cooling air cleaning, and thermal energy storage using smart materials (Target group: HVAC and materials manufacturers, building designers and consultants, researchers and professionals).
- A collection of scientific publications in high-level journals (Target group: researchers and professionals).

Progress

Annex 92 organized the 1st International Symposium on Smart Materials for Built Environment Control (SMBEC2025) in Paris from 10 to 11 June. The symposium brought together over 120 leading experts and scholars from top universities and institutions worldwide to explore the forefront of advanced materials for energy-efficient built environment control, an emerging field of growing global importance.

The research on MOFs was awarded the Nobel Prize in Chemistry in October 2025. Some of the Annex 92 participants have close collaborations with two Nobel laureates – Prof. O. Yaghi and Prof. S. Kitagawa. Annex 92 is the first and, to date, the largest international collaboration project on MOFs for energy-efficient buildings. New MOF materials were developed and characterized for cooling, autonomous humidity control, and IAQ control applications. In 2025, 12 publications were produced in leading journals and conference proceedings.

Meetings

- June 2025: The 1st International Symposium on Smart Materials for Built Environment Control (SMBEC2025, Paris).
- June 2025: 1st expert meeting in Paris, France.
- October 2025: 2nd expert meeting at the Technical University of Denmark, Copenhagen, Denmark.
- November 2025: A workshop for Danish industry participants.

Project duration

2024–2028

Operating Agent

Menghao Qin, Technical University of Denmark (DTU), Denmark

Participating countries

Belgium, Canada, P.R. China, Denmark, France, Germany, R. Korea, Portugal, Spain, Sweden, UK, USA
Observers: UAE, India

Further information

www.iea-ebc.org

Open Building Information Modelling for Energy Efficient Buildings

EBC ANNEX 91

Despite widespread adoption of Building Information Modelling (BIM), energy-related information is still inconsistently defined, exchanged and reused across planning, simulation and operation. This leads to data loss, manual effort and a persistent gap between designed and actual energy performance. For policy makers, this limits the effectiveness of regulations and standards that rely on digital planning and verification.

EBC Annex 91 addresses this problem by advancing Open BIM approaches based on internationally standardized data models such as Industry Foundation Classes (IFC), complemented by specifications like Information Delivery Specification (IDS). The Annex focuses on making energy-relevant information explicit, interoperable and verifiable across software tools and project phases. Its innovation lies in combining process definitions, information requirements and ontology alignment with validation through real use cases and toolchains for building energy modelling.

In 2025, the Annex moved further into concrete workflows and specifications. Early results show that clearly defined BIM-to-BEM (Building Energy Modelling) entry points and standardized information definitions can significantly improve data quality and interoperability. By the end of the project, Annex 91 will deliver practical guidance and specifications that support policy goals related to energy performance, digitalization and market uptake of Open BIM.

Objectives

The project objectives are to:

- integrate energy efficiency assessment and optimization as a core element of Open BIM workflows;
- improve interoperability between BIM authoring tools and building energy modelling tools;
- define standardized BIM-to-BEM processes covering design and operation; and
- contribute evidence and input to international Open BIM standardization relevant for energy policy.

Deliverables

The following project deliverables are planned:

- Documented Open BIM use cases addressing energy-efficient design and operation.
- Collection of machine-readable data to support BIM processes in the freely accessible platform www.bimbibliothek.at.
- Information Delivery Specifications and ontology mappings supporting energy performance assessment.
- Dissemination through workshops, webinars and peer-reviewed publication.

Progress

During 2025, Annex 91 focused on consolidating research activities across participating organizations and translating them into structured, comparable workflows. Research topics were organized using a lifecycle-based matrix covering design, operation and refurbishment, and mapped against processes, tools and data. This enabled partners to align work, avoid duplication and identify synergies with direct relevance for standardization and policy implementation.

Substantial progress was made in defining BIM-to-BEM entry points and addressing the energy performance gap between design and operation. Workflow mapping, ontology alignment with the IFC schema and the development of IDS were advanced in parallel. National and international workshops in 2025 were used to test these approaches against real projects, particularly in relation to HVAC modelling and dynamic simulation. Outcomes from these activities directly informed ongoing guideline development and scientific publications, ensuring that results are grounded in practice and transferable to regulatory and market contexts

Meetings

The following meetings were held in 2025:

- March 2025: Plenary consortium meeting in Aachen, Germany.
- October 2025: Plenary consortium meeting in Stockholm, Sweden.
- Monthly online coordination meetings throughout 2025.

Project duration

2024–2026

Operating Agent

Gerhard Zucker, AIT Austrian Institute of Technology, Austria

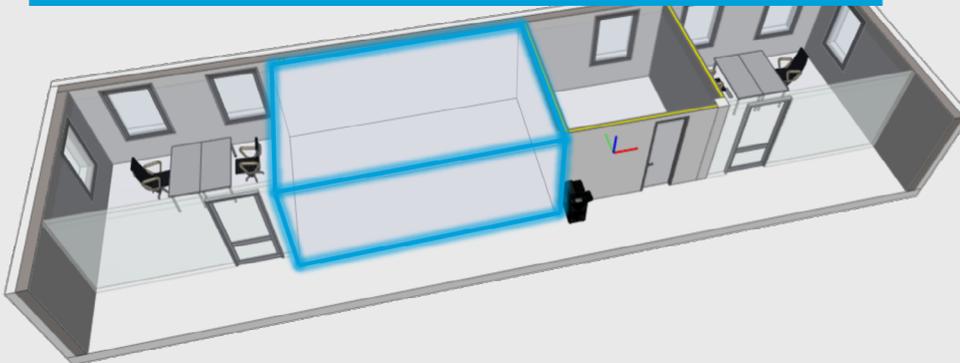
Participating countries

Australia, Austria, Belgium, Brazil, Canada, Denmark,
Germany, Ireland, Italy, Sweden, Switzerland, UK

Further information

www.iea-ebc.org

Name	Value	Unit	Description
IfcSpace	Office		
	2		
Pset_SpaceHVACDesign			
TemperatureSetPoint	22	°C	Indoor temperature setpoint
AsiP_SpaceHVACDesign			
CO2SetPoint	800	Ppm	Setpoint CO2
Pset_SpaceHVACDesign			
HumiditySetPoint	35	%rH	Humidity setpoint
AsiP_SpaceHVACDesign			
MaxAirVelocity	0,25	m/s	Max. air speed
Pset_SpaceOccupancyRequirements			
OccupancyNumber	2	pax	Occupancy requirements



Integration of parameters into BIM planning process: requirements for indoor climate on room level, defined in the BIM model helps to design HVAC systems and improve control strategies for building operation
Source: Project TGA Connect (<https://projekte.ffg.at/projekt/5136385>)

ments', 'Digitalized Lighting Solutions for low carbon build environments', 'Low carbon daylighting and lighting solutions: practical applications'.

- A white paper on current state-of-the-art of lighting simulation software tools for visual and non-visual performance evaluation.
- A simple software tool to rate low carbon scenarios.
- Standardization: initiation of new work items by appropriate standardization bodies on bidirectional scattering distribution function (BSDF) daylight system characterization, and
- industry workshops and seminars for practitioners.

Progress

Life Cycle Assessment in Lighting – International Survey and Status Quo of Scientific Literature.

To understand the current status of LCA in lighting technology, a survey of 15 participating countries in IEA SHC Task 70/EBC Annex 90 and a review of 59 scientific articles was conducted. The survey examined decarbonization efforts and the use of LCA in the building sector, including lighting and façade/daylighting. Key challenges include limited access to LCA tools and databases, low transparency in methodologies, insufficient LCA training for architects and engineers, and overall complexity. Simpler tools for assessing environmental performance and carbon emission limits in building regulations – similar to energy rating – are needed. The literature review shows a shift toward more integrated LCA approaches in luminaire design, emphasizing circular economy principles and modularity. Designing products for disassembly improves maintenance and reduces environmental impact, with modular LED luminaires cutting carbon footprints by about 30% through component replacement instead of full disposal. Remaining barriers include labor costs, certification gaps, and limited manufacturer data. Standardized data and stronger collaboration between manufacturers and environmental experts are essential. Façade and daylighting systems are less studied, with most research focusing on windows, frames, and glazing, while shading systems remain underexplored. Simulation studies dominate over real world applications. Across all lighting scenarios, the use phase has the highest environmental impact, highlighting the importance of efficient planning, energy conscious operation, and consistent maintenance.

Links to building design processes: Virtual reality in lighting design, BSDF standardization activity and new RADIANCE features.

Shading or daylighting devices are of growing importance in the context of increasing building overheating risks while

maintaining high visual comfort for occupants. The corresponding standardization effort of a group of IEA Task 70/Annex 90 experts on BSDF generation for complex fenestration systems is well under way. ISO/CIE CD 25176: 'BSDF data generation for complex fenestration systems' committee draft was accepted and will now be filed, in the next step, as a draft international standard (DIS) by ISO TC 274.

Virtual reality (VR) is emerging as a significant yet still underutilized tool in lighting design. A study of IEA Task 70/Annex 90 highlights how VR is explored in academic settings and how it is adopted by professionals in practice. It shows that professionals recognize the potential of VR and view it as a promising resource for evaluating lighting concepts. However, its adoption remains limited. Participants in the study emphasized the importance of accurate representations of light distribution within virtual environments. They also expressed a strong need for intuitive and open-source VR tools that make the technology more attractive.

Radiance is the most widely used lighting simulation engine in professional building-performance simulation and embedded in dozens of tools for building simulation. It has now undergone a major revision with the inclusion of hyperspectral rendering capabilities, an update of its general software architecture implementing a C++ class hierarchy and can now be used in Python-scripting via 'pyradiance'.

Meetings

The following meetings were held in 2025:

- March 2025: 5th Task Meeting in Innsbruck, Austria.
- September 2025: 6th Task Meeting in Changsha, China.

Project duration

2023–2026

Operating Agent

Dr. Jan de Boer, Fraunhofer Institute for Building Physics, Germany

Participating countries

Australia, Austria, Belgium, Brazil, P.R. China, Denmark, Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Turkey, USA
Observers: Greece, Poland, South Africa

Further information

www.iea-ebc.org

Ways to Implement Net-zero Whole Life Carbon Buildings

EBC ANNEX 89

This project focuses on the pathways and actions needed by various stakeholders and decision-makers to implement whole life cycle-based net-zero greenhouse gas (GHG) emissions from buildings in policy and practice. This means explicitly considering both embodied and operational GHG emissions across all stages of the built asset life cycle, referred to as 'whole life carbon' (WLC) for brevity. The ultimate ambition is to achieve the overarching goal of the Paris Agreement, which is to limit global warming to well below 2° Celsius, and preferably to 1.5° Celsius, above pre-industrial levels by aiming to achieve climate neutrality at latest by 2050. The policies, initiatives and actions that share, support and contribute to this goal are referred to here as 'Paris-goal compatible'.

To date, Annex 89 has advanced from conceptual alignment towards the consolidation and validation of implementation-oriented guidance across all subtasks. Expert meetings and workshops held during the reporting period enabled critical discussions on Paris-goal-compatible target-setting, methodological boundaries for net-zero whole life carbon assessment, and the role of tools, policy instruments, and stakeholder processes in real-world application. Early conclusions highlight the need for clear system boundaries, transparent accounting rules, and consistent links between assessment outputs and decision-making contexts. By the end of the project, the Annex is expected to deliver integrated guidance on whole-life carbon targets, assessment frameworks, and enabling instruments, supported by practical examples and lessons learned to facilitate the effective implementation of net-zero WLC buildings across different national and regulatory contexts.

Objectives

The project objectives are to:

- develop guidelines and recommendations on establishing WLC targets (including carbon budgets) for the building and real estate sector at various scales and perspectives and identifying critical carbon reduction pathways and actions;
- establish Paris-goal compatible assessment frameworks and evaluating the suitability and application(s) of

different assessment methods to achieve NetZ-WLC buildings at various scales;

- map and assess the relevance and effectiveness of a range of tools, aids and instruments available to different stakeholders in their decision-making contexts and objective(s);
- understand the conditions that are conducive for in-practice uptake and more effective implementation of context-based solutions and actions by key stakeholders; and
- ensure efficient and effective engagement and knowledge exchange with diverse stakeholder groups and disseminating results.

Deliverables

The planned deliverables for the project include:

- A report on guidelines and recommendations on establishing carbon reduction paths and actions towards NetZ-WLC buildings based on relevant contexts of countries and jurisdictions.
- A report on guidelines for selection and application of assessment methods to estimate and determine Paris-goal compatible NetZ-WLC status of buildings.
- A report on enabling tools and instruments to increase NetZ-WLC building implementation at national and regional (e.g., EU) level.
- A report on enabling and disabling factors for implementation of NetZ-WLC initiatives, and lessons learnt for transferring to different contexts.

Progress

In 2025, Annex 89 advanced on the work packages and deliverables for each subtask. Two international expert meetings were held in Zürich (June) and Trondheim (November), each strategically aligned with the regional Sustainable Built Environment (SBE) conference series, enabling close interaction between annex experts, the wider research community and policy-oriented stakeholders.

The Annex further refined Paris-goal-compatible target-setting frameworks and national mitigation pathways, with

a strong emphasis on harmonizing terminology, scopes, and system boundaries across countries. Dedicated sessions focused on national roadmap approaches, building-stock modelling, and capability-based frameworks to support countries at different stages of readiness.

The work also advanced the background reports by addressing use cases for Life Cycle Assessment methods in the built environment, carbon data needs, and the distinction between negative emissions and avoided emissions. A dedicated workshop on climate science was organized in Zurich, which provided critical scientific input on biogenic carbon, temporal aspects of emissions, and the non-equivalence between fossil and biogenic GHG emissions, directly informing the methodological recommendations under development.

In parallel, the Annex generated a systematic mapping and evaluation of tools, aids, and policy instruments through expert surveys, literature reviews, and comparative analysis. The work focused on identifying best-practice examples, quality-assurance mechanisms, and usability gaps relevant for regulatory, design, and procurement contexts. The Annex also expanded the collection and analysis of ambitious building projects and stakeholder experiences. Surveys and follow-up discussions were used to better understand real-world implementation processes, organizational conditions, and non-technical barriers and enablers to net-zero whole-life carbon buildings.

Coordination, communication, and dissemination activities were further strengthened. Annex 89 experts actively contributed to international conferences and policy dialogues, including dedicated sessions at the SBE Zurich and SBE Trondheim conferences. Several papers authored by Annex 89 participants have been published in the IOP Conference Series: Earth and Environmental Science following the SBE Zurich conference, with additional full papers currently in preparation based on contributions presented in SBE Trondheim. The project also supported cross-Annex collaboration (notably with Annex 91), issued expert feedback on key regulatory drafts such as FprEN 15978 and the Delegated Act of



Group Photo of Annex 89 participants in the 5th Expert Meeting in Trondheim, Norway, 24–26 November 2025
Source: IEA EBC Annex 89

the European Energy Performance of Buildings Directive (EPBD) Recast, and coordinated commentaries and outreach activities to increase the visibility and policy relevance of Annex 89 outcomes.

Meetings

The following meetings were held in 2025:

- June 2025: 4th Expert Meeting in Zurich, Switzerland.
- November 2025: 5th Expert Meeting in Trondheim, Norway.

Project duration

2023–2027

Operating Agent

Alexander Passer, Graz University of Technology, Austria

Participating countries

Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, R. Korea, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Turkey, UK, USA
Observers: Egypt, Greece, Hungary, India, Slovenia

Further information

www.iea-ebc.org

Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

EBC ANNEX 88

Heat pumps are among the most promising technologies for the decarbonization of buildings. In the past, their energy efficiency has mainly been evaluated at the product level, largely due to the extensive efforts of the heat pump manufacturing industry. Various testing and rating standards have been developed and implemented to label heat pump products, allowing comparison of energy efficiency among products of the same type (e.g., room air conditioners). However, several aspects must be considered when estimating the actual energy efficiency of heat pumps in buildings using only such product-level information. One of the most critical factors is the relationship between the full capacity of selected heat pumps and the thermal needs (loads) they must meet. This type of building-level evaluation is the focus of Annex 88. Annex 88 aims to improve the accuracy of energy calculation methods for heat pumps in building energy codes, where energy use by heat generators, including heat pumps, is assessed. The project is carried out in collaboration with the IEA Heat Pumping Technologies (HPT) TCP and its Task Force.

Objectives

The overall objective of Annex 88 is to establish the scientific basis for more accurate estimation of the energy effi-

ciency of heat pump systems (HPS) for building heating and cooling, and for more reliable and transparent design strategies for their application in buildings.

Deliverables

The project deliverables are:

- State of the art report on the evaluation and demonstration of actual energy efficiency of HPS in buildings.
- Guidelines for load-based test methods for HPS.
- Monitoring of actual characteristics and behaviour of HPS.
- Guidelines for calculating energy use of HPS in buildings.
- Design guidelines for HPS in buildings based on the evaluation of energy use and efficiency.
- Recommendations for policy and decision makers.

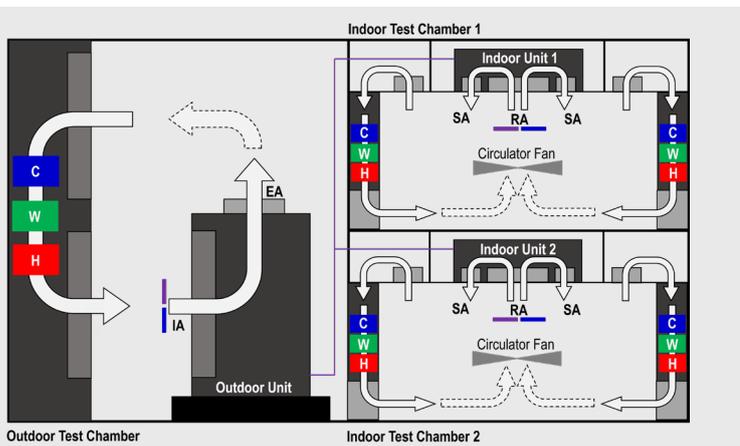
Progress

In 2025, the contents of final reports were determined and discussed.

The Subtask on test methods of heat pump products, focuses on newly developed test methods (in Canada, Japan 1, Japan 2, Germany, ISO, CEN) for heat pump air conditioners and air-to-water heat pumps (hydronic space heating systems). An example of these test methods is shown in Figure 1 (Japan 2 test method). A major reason why results from current test methods for low part-load conditions should be used carefully in energy calculation methods relates to the characteristics of the test methods and the indices used for labelling heat pump products. Energy efficiency during operation with thermal output much smaller than full capacity is particularly important for energy calculations of HPS. In practice, designers often select sufficiently large heat sources to avoid the risk of capacity shortage. As a result, part-load ratios between 10% and 50% occur frequently in buildings. Under such low part-load conditions, intermittent operation (on-off cycle) may occur and negatively affect energy efficiency. Therefore, it is important that heat pump products and systems maintain continuous operation as much as possible to improve efficiency under low part-load ratios. However, many current test methods allow special control during tests, such as fixing compressor rotation

Figure 1: Schematic representation of a test method for a load-based test method (Japan 2) implemented for the Japanese building energy code, where thermal needs (loads) are provided directly to indoor chambers serviced by tested VRF system's indoor units.

Source: EBC Annex 88



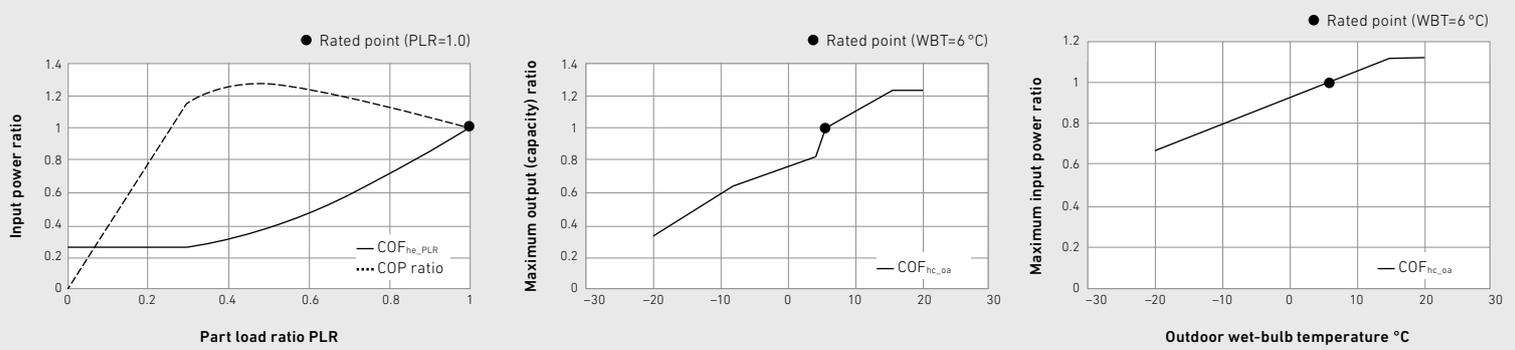


Figure 2: Example of energy calculation method for heat pump systems using correction factors depending on outdoor conditions and part load ratio
Source: EBC Annex 88

speed, which makes it difficult to evaluate realistic energy efficiency under low part-load conditions. In addition, integrated indices such as seasonal performance are often calculated assuming maximum loads close to the full capacity of the tested products, which may differ from actual operating conditions in buildings.

The Subtask on monitoring methods and data, addresses methods for field monitoring of HPS, through which actual energy efficiency and relevant phenomena can be observed. Knowledge on field monitoring methods should be shared more broadly through the deliverables of Subtask B2. Monitoring data should also be shared among building and HVAC engineers.

The Subtask on energy calculation methods, has analysed current energy calculation methods. Two main modelling approaches can be identified:

- a) Using test performance data for very few conditions (often only the rated point and condition) together with default empirical functions, the energy input (kW) of HPS is calculated while accounting for parameters such as outdoor conditions and part-load ratio. This approach is used by most national energy calculation tools.
- b) Test results for several conditions with various part-load ratios and outdoor temperatures are pre-processed to identify a characteristic function describing the efficiency of the heat pump product. This function is then used to evaluate efficiency under operating conditions in the energy calculation. This approach aims to align with EN 14825, and the possibility of applying load-based test methods is being investigated.

Figure 2 is an example of approach (a), where energy input at each timestep is calculated using the following equations:

$$\text{Energy Input (kW)} = \text{Rated input (kW)} \times \text{COF}_{\text{he_0a}} \times \text{COF}_{\text{he_PLR}}$$

$$\text{COF}_{\text{he_PLR}} = f(\text{Part load ratio})$$

$$\text{Part load ratio} = (\text{Output (heat need) at each time}) / (\text{Rated output (kW)} \times \text{COF}_{\text{hc_0a}})$$

For approach (b), the background theories have already been standardized in European standards, and the required test points (e.g., six testing points defined in EN 15316-4-2) have been identified. A current challenge is the need for load-based test methods that use the product's native control (rather than special control used only during testing) in combination with EN 14825. Therefore, more attention should be given to coordinating approach (b) with product testing standards.

Product-level heat pump tests may be carried out by manufacturers, while third-party inspections verify compliance under the same operating conditions. For this reason, operating conditions in test standards are defined very precisely by fixing the product state during tests. However, this requirement in current test standards may limit the applicability of test results for building-level evaluation.

Meetings

Annex 88 held web-meetings in April, May, June, July, August, September, October and November 2025.

Project duration
2022–2027

Operating Agent
Takao Sawachi, Building Research Institute, Japan

Participating countries
Australia, Brazil, Canada, P.R. China, Germany, Italy, Japan, the Netherlands
Observers: Philippines

Further information
www.iea-ebc.org

Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems

EBC ANNEX 87

Personalised environmental control systems (PECS) with the functions of heating, cooling, ventilation, lighting and acoustics have advantages of controlling the localised environment at occupants' workstations by their preferences instead of conditioning an entire room to uniform conditions. This may substantially improve comfort, satisfaction, health of the occupants, and energy efficiency of the entire heating, ventilation and air-conditioning (HVAC) system. Personalised ventilation can also protect against cross-contamination, which is critical in open-plan offices and workplaces with close distances between occupants. It is foreseen that there will be an increasing interest and market for PECS in the future, as buildings will need to be future-proofed, for example, against pandemics, heat waves, and power outages. The main application of PECS is for workplaces with mainly sedentary activities, such as offices, including open-plan spaces, banks, and control centres. Due to the COVID-19 pandemic, when many people started to work at home, there will also be home working places where PECS may be a solution.

The project is in its working phase and has the overall objective of establishing design criteria and operational guidelines for PECS and quantifying the benefits of PECS in terms

of health, comfort, energy, and costs. This includes control concepts and guidelines for operating PECS in spaces with general ambient systems for heating, cooling, ventilation and lighting. The scope includes all types of PECS for local heating, cooling, ventilation, air cleaning, lighting and acoustics. It includes desktop systems, which are mounted on desks or integrated in furniture or chairs with heating/cooling and ventilation functions. It also includes wearables, where heating/cooling and ventilation are included in garments or devices attached to occupants' bodies.

Objectives

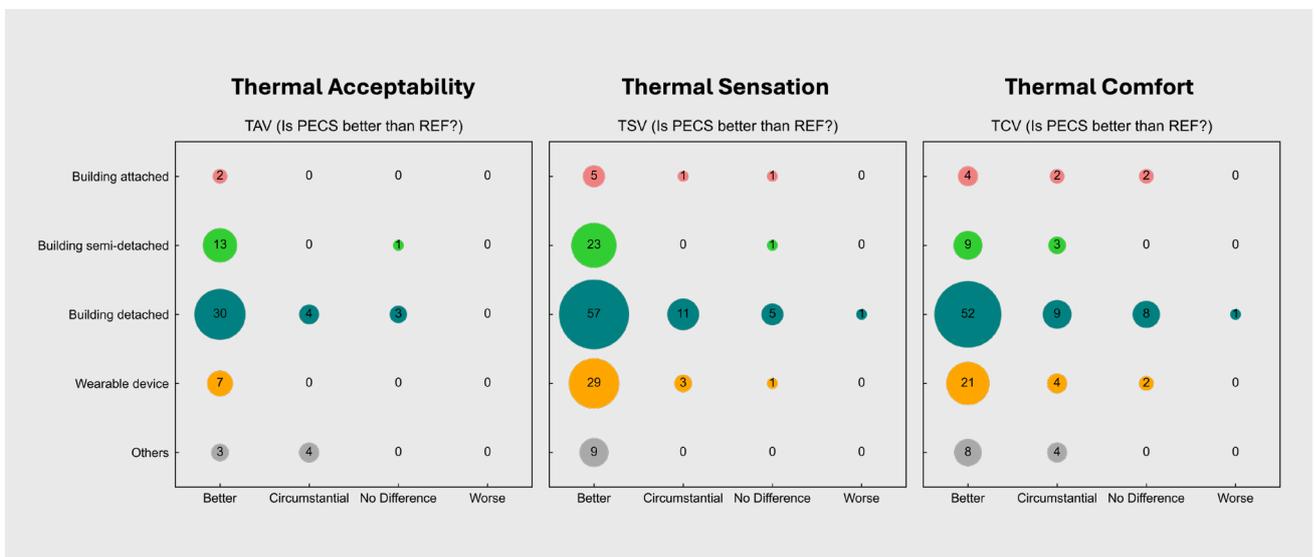
The project objectives are to:

- define design criteria for PECS;
- develop operation guidelines for PECS;
- establish control concepts and guidelines for operating PECS in spaces with general ambient systems for heating, cooling, ventilation, and lighting; and
- quantify the benefits of PECS regarding health, comfort, energy, and costs.

Deliverables

The deliverables from the project are planned as follows:

- A state-of-the-art report on PECS.



From a literature review, the figure shows that for all types of PECS the performance on thermal comfort is better than other systems
Source: EBC Annex 87

- A guidebook on requirements for PECS.
- A guidebook on PECS design, operation and implementation in buildings (including integration of PECS with ambient conditioning systems).
- A report on test methods for performance evaluation of PECS.
- Universal criteria about requirements, characteristics, and performance of PECS to be used in national and international standards.

Progress

The project completed the third year of its three-year working phase in 2025, which will be followed by a one-year reporting phase. At the Executive Committee (ExCo) meeting in November 2025, a one-year extension of Annex 87 was approved.

The project defined PECS as *‘a system that can provide individually controlled thermal, air quality, acoustic or luminous environments in the immediate surroundings of an occupant, without directly affecting the entire space and other occupants’ environment’*.

The Annex progressed well during 2025, with the main achievement being the submission of three review articles. The Annex (Operating Agents, Subtask Leaders and their participants) has been very active both in terms of work and dissemination.

The fifth meeting of the working phase was held in Stuttgart, Germany, in a hybrid format in 2025. There were 18 in-person attendees (Annex participants and guests) and around 25 online attendees (Annex participants and guests). The sixth meeting of the working phase was held in Montreal, Canada, in a hybrid format in September 2025. There were 16 in-person attendees (Annex participants and guests) and around 20 online attendees.

The Operating Agents provided general updates from the Annex and the subtask leaders reported progress in their subtasks; discussions were held on topics relevant to the Annex and PECS technology.

The group has had fruitful and constructive discussions. A technical presentation session was also organised (internal to the annex). Progress in the subtasks and next steps were discussed. Most subtasks achieved substantial progress by dividing the work into smaller parts. Most of the work so far is based on the developed systematic review tables, which

have been contributed substantially to the annex deliverables and scientific articles. A work plan for each subtask until the next expert meeting was prepared. Several online subtask meetings and sub-subtask meetings were held.

Work is underway to develop a uniform terminology to be used in the Annex. This will also be disseminated externally when ready. An updated version of the Technology Readiness Level assessment collection is also being developed to better capture the current market status and the status of standards.

In addition, further publications are being prepared based on the activities carried out in the Annex, building on the extensive reviews carried out.

- A Seminar on PECS was held at the 2025 ASHRAE Winter Conference in Orlando, FL, USA, in February 2025.
- A symposium on PECS was organized at the COBEE 2025 Conference in Eindhoven, the Netherlands, in July 2025 (12 participants).
- A workshop on PECS was organized at the CISBAT 2025 Conference in Lausanne, Switzerland, in September 2025 (approximately 15 participants).
- Discussions were also held on planning PECS-focused workshops at several 2026 conferences, including IAQVEC 2026 (USA), CATE 2026 (USA), Indoor Air 2026 (Singapore), Roomvent 2026 (Czechia), and AIVC 2026 (Republic of Korea).

Meetings

The following meetings were held during 2025:

- April 2025: The 5th working phase meeting (hybrid format) in Stuttgart, Germany.

Project duration

2022–2027

Co-Operating Agents

Ongun Berk Kazanci and Bjarne W. Olesen, International Centre for Indoor Environment and Energy (ICIEE), Department of Environmental and Resource Engineering, Technical University of Denmark, Denmark

Participating countries

Australia, Belgium, Brazil, Canada, P.R. China, Denmark, Finland, France, Germany, Italy, the Netherlands, R. Korea, Singapore, Sweden, Switzerland, Turkey, UK, USA

Further information

www.iea-ebc.org

Indirect Evaporative Cooling

EBC ANNEX 85

Buildings account for almost one-third of total energy use, with over 10% used for air conditioning and indoor thermal comfort in hot seasons. So, changing the approach to air conditioning is one of the essential solutions to meeting cooling demands without increasing energy use and carbon emissions. Although, over 85% of cooling worldwide is achieved by mechanical vapour compression refrigeration, more than 40% of cooling could be provided by evaporative cooling, especially in dry climate zones.

The main types of evaporative cooling technologies are:

- direct evaporative cooling (DEC) to produce cooling air or cooling water; and
- indirect evaporative cooling (IEC) to produce cooling air or cooling water.

Thus, this project is studying the feasibility of indirect evaporative cooling (IEC) technologies and is providing a road-map about how to use evaporative cooling technologies in various dry climate zones. The target audiences of the Annex include design and planning practitioners involved in cooling system design and selection of real projects; scientific communities focused on the study of cooling or evaporative cooling processes; government officials responsible for formulating energy-saving policies in response to climate change; and manufactures of evaporative cooling equipment or products. The following project tasks have been defined:

- Real case study collection.
- Feasibility analysis of IEC technologies.
- Performance analysis of IEC technologies.
- Simulation analysis of IEC technologies.

Objectives

The project objectives are as to:

- investigate IEC systems as well as cooling towers, including cost, space, maintaining, and environment impacts, to find out the limitations of using IEC worldwide;
- conduct field studies of existing IEC systems applied in different climates to build a field-testing database;

- develop a general theoretical analysis method for IEC processes, to guide the design of different IEC systems;
- evaluate the water and electricity use of IEC processes;
- set up a system simulation model and tool for various kinds of IEC processes and systems used in different types of buildings under different dry climates; and
- develop guidelines for designing the IEC systems for different types of buildings under different dry climates and water resource conditions.

Deliverables

The planned main deliverables of the project include:

- A book, provisionally entitled 'The Indirect Evaporative Cooling Source Book', compiling the project outputs, including investigation and analysis of real cases, feasibility analysis, guidance and modelling.
- A simulation tool for various types of IEC technologies applicable to different types of buildings and dry climate zones, incorporating the basic modeling of different IEC/DEC, from basic understanding and formulae used for heat and mass transfer processes inside, and a unified nomenclature.

Progress

During 2025, progress was documented in the following reports:

- A report on 'Feasibility analysis of IEC/DEC', using the indicator-based methods to provide a macro-level feasibility assessment first across different world regions, followed by performance analyses of specific IEC and DEC processes.
- A report on 'Performance Analysis of IEC/DEC', including detailed performance of IEC/DEC equipment, the heat and mass transfer performance of paddings and heat exchangers, electricity cost, the real testing performance, optimization methods, and water use.
- A report on 'Simulation analysis', presenting the simulation of different kinds of IEC/DEC processes, finally to

form a group of simulation procedures, or further to form a simulation tool, with case studies for using the simulation tool or procedure for simulating an IEC/DEC system.

- A report on 'Typical cases collection', presenting real cases from different countries, to show the current applications of IEC/DEC technologies, providing the basic information of the project as well as the real testing performance of the system and processes, including the electricity use performance, water use performance, and any existing problems.

Meetings

The following meetings were held during 2025:

- May 2025: 22nd online meeting and in person workshop in Cordoba, Spain.
- September 2025: 23rd online meeting and in person workshop in Beijing, China.
- October 2025: 24th online meeting and in person workshop in Beijing, China.

Project duration

2020–2026

Operating Agent

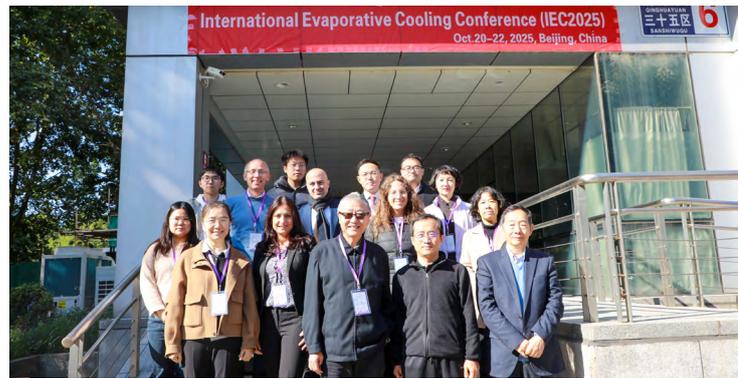
Xiaoyun Xie, Building Energy Research Center, Tsinghua University, P.R. China

Participating countries

Belgium, P.R. China, Denmark, France, Italy, Spain, Turkey, USA
 Observers: Algeria, Egypt

Further information

www.iea-ebc.org



A group of EBC Annex 85 participants at Tsinghua University, Beijing, China
 Source: EBC Annex 85



A group of EBC Annex 85 participants at the University of Cordoba, Cordoba, Spain
 Source: EBC Annex 85



A group of EBC Annex 85 participants at Tsinghua University, Beijing, China
 Source: EBC Annex 85

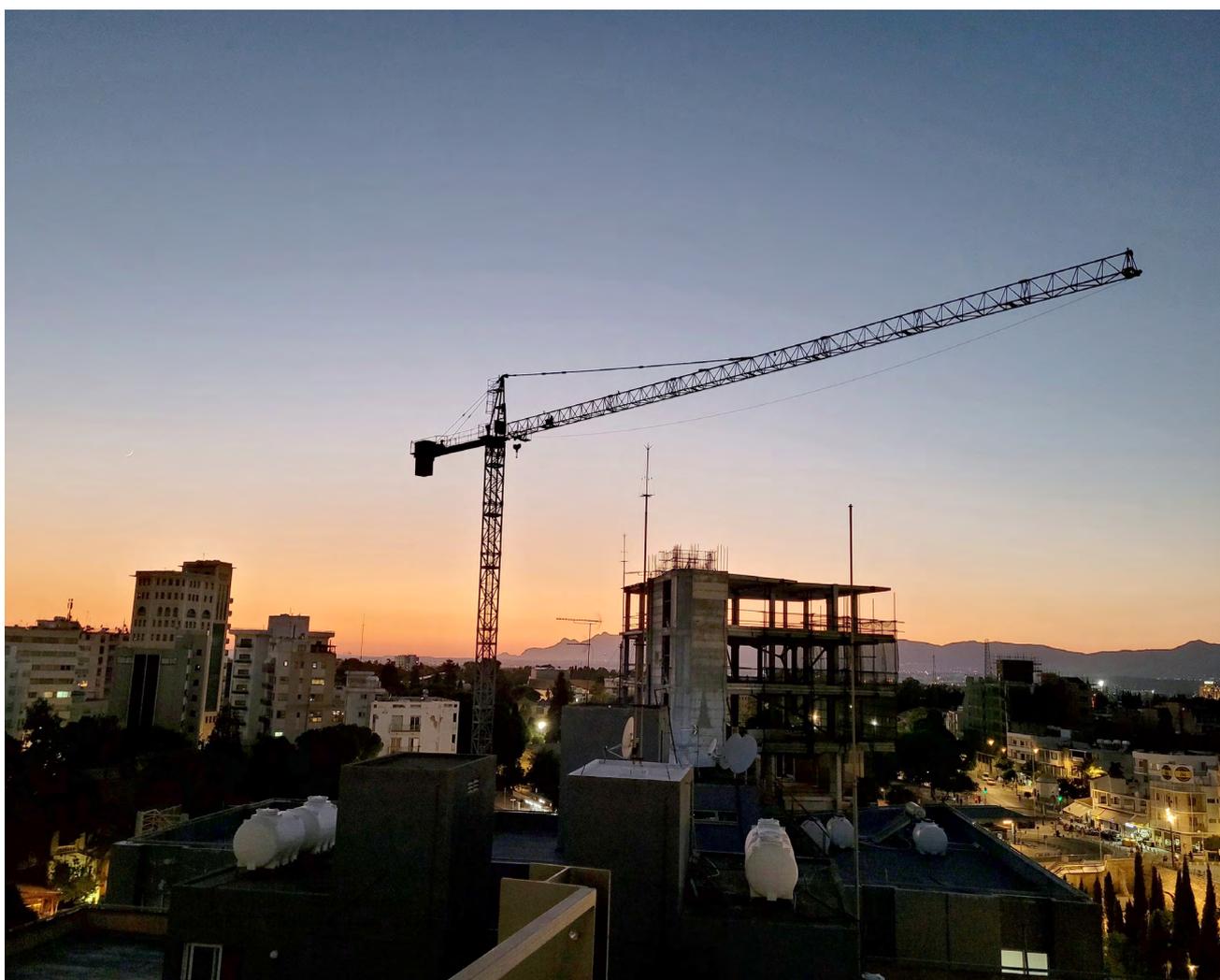
Building Energy Codes

EBC WORKING GROUP

Energy efficiency codes are among the most effective and durable policy instruments available to governments. By setting minimum performance requirements, they prevent inefficient buildings and equipment from entering the building stock, thereby avoiding decades of locked-in energy waste. However, even in jurisdictions with extensive history in this area, building energy codes are facing key challenges, including the need to meet ambitious policy objectives, such as zero net energy construction standards and the substantial amount of time it takes for building codes to integrate re-

search and technology breakthroughs, thus potentially limiting the energy savings potential of building energy codes.

The project was launched to address these challenges. Its goals are centred around furthering research and collaboration efforts for building energy codes to advance energy efficiency in buildings and communities. It is dedicated to widening the consideration of building energy codes in EBC projects, along with the integration of project results into enhancing the existing building energy codes.



BECWG activities address both new and existing buildings
Source: Meli Stylianou, BECWG, 2025

Objectives

The project objectives are to:

- enhance understanding of impactful options and practices regarding building energy codes across different countries;
- provide methods for cross-national comparisons that lead to meaningful information sharing; and
- foster collaboration on building energy code issues that leads to enhanced building energy code programmes by incorporating new technologies, practices, and issues.

Deliverables

The project is undertaking three major activities to achieve these objectives, which are listed below:

- *Analysis and technical reports:*
The project is conducting surveys on building energy codes information to understand the range of practices across participating nations. Drawing on the results of these surveys, the project is developing reports around various topics of interest, such as building energy codes for existing buildings and best practices for code compliance.
- *Organization and facilitation of webinars:*
The project is hosting and facilitating several workshops and webinars for participating countries to exchange information on their building energy code systems. It is also hosting an Annual Building Energy Code Symposium, which allows the project participants to exchange ideas on relevant topics of interest.
- *Dissemination:*
In addition to conducting analyses and facilitating webinars, the project is working towards disseminating its research findings to wide range of regional stakeholders and collaborating with them closely to promote code improvements and implementation of best practices.
It is disseminating its findings through the EBC website, conference papers, and newsletters.

Progress

The Building Energy Codes Working group (BECWG) underwent a change in management in 2025; nevertheless, the group published an international survey of mandatory whole life/embodyed carbon requirements in building codes and regulations, along with a Canada-focused survey examining the role of building codes in protecting occupants from overheating from the Canadian perspective.

The working group also organized its 7th Symposium entitled "Next Generation Building Energy Codes", where presenters discussed modern building code approaches to resilience and multi-hazard mitigation, and the potential of artificial intelligence for building energy codes.

The BECWG, in its new manifestation, will develop a framework to map out group priorities and capabilities, enabling members to identify commonalities and resources for mutual benefit, and will strive to include jurisdictions beyond its mostly heating-dominated current participants.

Meetings

In 2025, the project held the following meetings:

- June 2025: Webinar titled 'Mandatory Whole Life/ Embodied Carbon Requirements in Building Regulations'.
- November 2025: 7th Annual EBC Building Energy Codes Working Group Symposium 'Next Generation Building Energy Codes'.

Project duration

2018–2026

Operating Agent

Meli Stylianou, Natural Resources Canada, Canada

Participating countries

Australia, Canada, P.R. China, Denmark, France, Italy, Japan, R. Korea, New Zealand, Sweden, Switzerland, UK, USA

Further information

www.iea-ebc.org

Positive Energy Districts

EBC ANNEX 83

The concept of Positive Energy District (PED) describes an urban area within a city that is capable of generating more energy than it consumes while being agile and flexible enough to respond to energy market price variations. However, the formulation of PED definitions cannot be based merely on an annual mathematical net balance: PEDs also rely on energy efficiency solutions and support the minimization of impacts on the connected centralized energy networks by offering options to increase onsite load-matching and self-use of energy, technologies for short- and long-term energy storage, as well as providing energy flexibility through smart controls and techniques. In this context, the concept of PED is aimed at facilitating the transition of urban environments toward carbon-neutral communities by incorporating lighthouse innovation areas that promote the coordinated development of energy efficient technologies, improved public acceptance of building energy systems, and new sustainability paradigms and business models.

As a novel area for research, the PED concept needs further refinement of definitions, improvement in energy and systems modeling for truly holistic design of neighborhoods, and development of new integrated sustainability assessment approaches. Further, testing within case-studies is needed for bi-directional improvements between practical application and methodological advances.

Objectives

The main objectives of the project are to:

- map the city, industry, research and government (local, regional, national) stakeholders and their needs and roles with the specific PED project objectives to ensure the principal stakeholders are involved in the development of relevant definitions and recommendations;
- create a shared in-depth definition of a PED through a multi-stakeholder governance model;
- develop the required information and guidance for implementing the necessary technical solutions (at building, district and infrastructure levels) that can be replicated and ultimately scaled up to the

city level, giving emphasis to the interaction of flexible assets at the district level, as well as to economic and social issues such as acceptability;

- explore novel technical and service opportunities related to monitoring solutions, big data, data management, smart control and digitalization technologies as enablers of PEDs; and
- develop the required information and guidance for the planning and implementation of PEDs, including both technical and urban planning. This includes economic, social and environmental impact assessments for various alternative development paths.

Deliverables

The following deliverables have been developed as part of Annex 83 activities:

- Definitions and key concepts for PEDs.
- Methods, tools and technologies for realizing PEDs.
- Governance principles and impact assessment for PEDs.

The following deliverables are in the finalization stage:

- Case studies on PEDs and related technologies.
- A book on 'Positive Energy Districts: Fundamentals, Assessment Methodologies, Modeling and Research Gaps'.

Progress

The Annex was extended by six months to June 2026. During the reporting period, all core activities and most deliverables were completed, including the consolidation of the knowledge base supporting PED implementation.

The work clarified PED terminology, boundary conditions and development pathways across diverse urban contexts. Comparative analyses and stakeholder engagement showed how governance capacity, institutional frameworks, and multi-actor collaboration influence implementation outcomes. A planning framework was developed to guide cities from early visioning and feasibility to implementation and monitoring.

Technological and methodological analyses reviewed key PED-enabling solutions, confirming the central role of photovoltaics, heat pumps, efficient building envelopes, energy storage, and energy sharing supported by smart control and flexibility management. Case studies demonstrated that combining renewable supply, efficiency measures and flexibility mechanisms is essential to achieve reliable district performance. Interoperability challenges among modelling tools were identified, with ontology-based approaches highlighted as key enablers for data integration, co-simulation and multi-domain assessment.

An integrated sustainability assessment framework covering environmental, economic, and social dimensions was developed and tested, combining life-cycle assessment, life-cycle costing, and social impact indicators. Results showed that embodied emissions and material choices significantly influence performance, while affordability, citizen engagement and perceived fairness influence long-term acceptance. A multi-benefit toolbox was produced to support decision-making and stakeholder dialogue.

The PED Database was expanded and consolidated as a joint initiative of Annex 83, Positive Energy Districts European Network (PED-EU-NET), and the Driving Urban Transitions (DUT) Partnership. The platform provides verified information on more than 100 PED case studies, enabling comparison of implementation pathways, technologies and governance models and supporting data-driven decision making.

Findings confirmed that PED implementation requires systemic integration of energy, mobility, and ICT infrastructures, adaptive governance, and continuous stakeholder engagement. The Annex delivered operational guidance and assessment tools to support replication and scaling across diverse urban contexts.

Annex 83 finalized PED guidelines translating research into practical recommendations for planners, municipalities, and practitioners. The guidance synthesizes findings from case studies, modelling activities, and sustainability assessments, addressing definitions, planning and design strategies, governance approaches, and performance evaluation to support informed decision-making and scaling of PED solutions across diverse urban contexts.

The second Blended Intensive Programme (BIP) on PEDs was held in September 2025, organized by Dalarna University and co-hosted by Annex 83. Targeting graduate

exchange students, it combined online and on-site learning on PED planning, implementation, and assessment, with approximately 20 participants.

The 4th IEA EBC Annex 83 PhD Summer School was held in Palermo, Italy, in June 2025, hosted by the University of Palermo with around 30 students from diverse backgrounds. It provided advanced training on PED assessment methodologies, implementation strategies and replication pathways through lectures, case studies and interactive sessions, addressing technical, environmental and governance dimensions.

Meetings

The following meetings were held in 2025:

- March 2025: 10th Working Meeting at Dalarna University, Borlänge, Sweden.

Project duration

2020–2026

Co-Operating Agents

Francesco Reda, VTT Technical Research Centre of Finland, Finland

Francesco Guarino, University of Palermo, Italy

Participating countries

Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden Switzerland, UK

Further information

www.iea-ebc.org



Group picture, Annex 83 IV Summer school in Palermo, Italy
Source: EBC Annex 83

Air Infiltration and Ventilation Centre

EBC ANNEX 5

EBC Annex 5 'Air Infiltration & Ventilation Centre (AIVC)', has been advancing knowledge on ventilation and air infiltration since its establishment in 1979. For over 45 years, AIVC has adapted to evolving challenges, providing resources in the field that support energy efficiency and high indoor environmental quality (IEQ) in buildings.

As efforts intensify to achieve a carbon-neutral building stock by 2050, energy-efficient ventilation remains essential for health and IEQ. This importance is reflected in the continued relevance of AIVC's work and in the Executive Committee's approval to extend AIVC for the 2027–2031 period.

Objectives

The objectives of the AIVC are as follows:

- enabling the production of high quality and influential documents of international status regarding energy efficient ventilation and air infiltration;
- generating strategic advice and design guidance on air infiltration and ventilation related issues in new and renovated buildings;

AIVC Board's visit to NRC's Building Science Facilities in Ottawa
Source: EBC Annex 5/AIVC



- communicating and disseminating information in relation to smart ventilation, resilient ventilative cooling, building and ductwork airtightness and indoor environmental quality, through conferences and workshops, webinars, data-bases, social media, and a high visibility web presence.

Deliverables

- *Events*: the AIVC Annual Conference, one to two workshops per year on specific topics, and a number of webinars per year.
- *Publications*: conference and workshop proceedings, technical notes, ventilation information papers and contributed reports, and a biannual newsletter.

Progress

In 2025, the AIVC focused its work mainly on thirteen projects, the AIVC Industry Advisory Committee, the 45th AIVC–ASHRAE IEQ joint Conference: "IEQ 2025: Rising to new challenges: Connecting IEQ to a sustainable future", the workshop in Stuttgart: "Indoor Environmental Quality in Sustainable Buildings", and nine webinars. Furthermore, the AIVC facilitated remote discussions and supported dissemination activities for EBC annex 87 "Personalized Environmental Control Systems" & EBC Annex 97 "Sustainable Cooling in Cities".

The latest AIVC project launched includes:

- Handling low emitting buildings and air cleaning in energy performance regulations

Previously launched projects which were still running in 2025 include:

- Ventilative cooling and thermal comfort in national EPB regulations
- Measurement for Exterior Wall Airtightness of High-Rise Buildings Using Stack Effect/Individual Air Conditioning and Outdoor Air Entering through Entrance Doors
- Designing building ventilation for epidemic and disaster preparedness
- EPBD recast in relation to IEQ and ventilation

- Energy Recovery Ventilation
- Personalized Environmental Control Systems (PECS)
- Building and ductwork airtightness regulations in various countries
- Building ventilation regulations in various countries
- Temperature take-back effect in the context of energy efficient ventilation strategies
- Indoor Air Quality Metrics
- Supplementing Ventilation with Gas-phase Air Cleaning
- Competent Tester Schemes for Building Airtightness Testing

In 2025, the AIVC released several key publications:

- Technical Note TN74: Smart Ventilation in Residential Buildings.
- Two Ventilation Information Papers (VIPs) on trends in building ventilation requirements and inspection in Ireland and Italy.
- Contributed reports CR20: A method for testing gas-phase air cleaners, CR21: Performance of Portable Gas-Phase Air Cleaners and Impact on Indoor Air Quality. A Literature Review and CR22: Quantifying population harm from indoor air contaminants in dwellings.
- Annotated Bibliographies BIB14: Retrofitting the Building Stock: Challenges and Opportunities for Indoor Environmental Quality – Overview of the AIVC 2024 Conference sessions.

In 2025, the AIVC hosted a series of nine webinars covering a variety of topics.

- *February*: AIVC & IEA-EBC Annex 78 held a webinar on Energy Performance of Gas Phase Air Cleaning
- *March*: AIVC organized a webinar on Recent standards and guidelines on CO2 application and interpretation
- *May*: Two webinars co-organized by AIVC with Venticool and TightVent, focusing respectively on improving buildings' thermal resilience to overheating (lessons learned) and on building and ductwork airtightness trends and regulations in Estonia, Germany, and the U.S.
- *June*: AIVC & TightVent held the webinar Inspection of ventilation systems in non-residential buildings.
- *September*: AIVC, organized a webinar on Emerging Risks of Indoor Mould: Assessment Methods, In-Situ Measurements & Predictive Modelling.
- *October*: AIVC & TightVent, organized the webinar Comparing Ventilation Trends in Southern Europe: Italy, France & Spain.
- *November*: AIVC & TightVent, organized the webinar From Inspections to IAQ Measurement: Exploring Databases for Better Indoor Environments.

- *December*: One webinar exploring the topic of Improving Indoor Air Quality in Schools.

In 2023, the AIVC Board established an Industry Advisory Committee (IAC), a group of voluntary industry leaders dedicated to the goals of the AIVC, representative of industry but not exclusively advocating for industry, who are proposed and retained at the discretion of the board of the AIVC. The advisory committee met twice in 2025.

AIVC maintains a strong and close collaboration with the TightVent platform which focus is on building and ductwork airtightness and the venticool platform which focus is on resilient ventilative cooling.

To foster greater interaction with related organizations and enhance its societal impact, AIVC is also a founding member of the Indoor Environmental Global Alliance and has collaboration agreements with ASHRAE, REHVA, EVIA, ISIAQ and ABAA.

AIVC continues to facilitate collaboration between various initiatives. As an example, the Advisory Board of Practitioners (ABoP), an initiative launched in March 2021 by EBC Annex 80, AIVC & venticool, facilitates regular exchange between Annex 80 scientists, practitioners, planners and representatives from relevant industries. As of 2024, following the completion of EBC Annex 80, the ABoP operates under the joint umbrella of AIVC and venticool. 2 meetings were held in 2025.

Meetings

The AIVC Board organized two board meetings in 2025, which were held in:

- March 2025: Stuttgart, Germany
- September 2025: Montreal, Canada

Project duration

1979–2031

Co-Operating Agents

Peter Wouters, INIVE, Belgium
Arnold Janssens, INIVE/UGent, Belgium

Participating countries

Australia, Belgium, Canada, Denmark, France, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, R. Korea, Spain, UK and USA
Observers: Greece

Further information

www.iea-ebc.org

Completed Research Projects

ENERGY EFFICIENT INDOOR AIR QUALITY MANAGEMENT
IN RESIDENTIAL BUILDINGS
(EBC ANNEX 86)

DEMAND MANAGEMENT OF BUILDINGS
IN THERMAL NETWORKS
(EBC ANNEX 84)

ENERGY FLEXIBLE BUILDINGS TOWARDS RESILIENT
LOW CARBON ENERGY SYSTEMS
(EBC ANNEX 82)

DATA-DRIVEN SMART BUILDINGS
(EBC ANNEX 81)

SUPPLEMENTING VENTILATION
WITH GAS-PHASE AIR CLEANING, IMPLEMENTATION AND
ENERGY IMPLICATIONS
(EBC ANNEX 78)

Energy Efficient Indoor Air Quality Management in Residential Buildings

EBC ANNEX 86

Improving the energy performance of both new and existing residential buildings is a fundamental prerequisite for meeting global climate objectives. Residential buildings represent the largest share of the overall building stock and therefore hold the greatest potential for significant impact. Yet, achieving high levels of energy efficiency must go hand in hand with maintaining a healthy, acceptable, and desirable indoor environment. Striking this balance remains one of the defining challenges of contemporary building policy and practice.

The IEQ-Global Alliance (IEQ-GA) defines Indoor Environmental Quality (IEQ) as encompassing four core dimensions: the thermal environment, indoor air quality (IAQ), lighting, and the acoustic environment experienced by occupants. Among these, IAQ has emerged as a central concern, as highlighted by the recent IAQ focused event at the United Nations (UN) General Assembly, due both to its direct impact on health and its significant interaction with energy performance. While ventilation remains the primary strategy for IAQ management, complementary technologies such as advanced air filtration and air cleaning systems are increasingly available. However, despite this growing diversity of approaches, no coherent framework currently exists for systematically assessing and comparing the performance of different IAQ management strategies. Annex 86 was established to address this gap. Its central focus has been assessing performance trade-offs, identify optimal solutions, and develop the methodological foundations required to achieve maximum energy efficiency while guaranteeing high levels of indoor air quality across new, renovated, and existing residential buildings. The Annex does not propose a single prescriptive tool, but rather a coordinated framework of interoperable components – a suite of methodological 'building blocks' designed to strengthen confidence in performance-based assessment. This cooperative structure enables stakeholders to adopt, test, and refine performance-based approaches in a mutually reinforcing manner, fostering the evolution of a robust, evidence-driven ecosystem for IAQ management.

The scope of the Annex focused on residential buildings because they represent the largest segment of the building stock. They are also understudied and accommodate the broadest range of non-specific uses. Additionally, residential building projects often lack sufficient funding for extensive bespoke engineering and therefore require robust cost-effective standardized solutions that can be implemented at large scale. The Annex built on the work of Annex 68 and collaborated closely with Annex 5 (AIVC) in the organization of the meetings and dissemination of results.

Achievements

One of the Annex's most significant achievements is the adoption of Disability-Adjusted Life Years (DALYs) as a common metric for quantifying the health burden of exposure to contaminants in indoor air. The developed methodology underpins the world's first harm-based compliance pathway incorporated into ASHRAE Standard 62.2, representing a major advancement in the alignment of building standards with public health objectives.

Beyond health metrics, the Annex developed and tested a set of metrics for multi-criteria assessment frameworks that evaluate IAQ management across multiple performance dimensions, including energy efficiency, cost, resilience, and robustness. These approaches enable decision-makers to assess not only average system performance but also reliability under stress.

The Annex also quantified the economic and social costs of poor IAQ. Case studies demonstrated that interventions such as the use of low-emission materials, filtered ventilation, and optimized airflow rates can substantially reduce these costs, strengthening the case for performance-based regulation.

Given the pivotal role of simulation in implementing performance-based methods, another major achievement was the creation of two open datasets compiling global literature on pollutant sources, typical exposure levels, and concentration distributions. The datasets and associated algorithms,

publicly accessible through the Pandora and Global IAQ databases, provide a critical foundation for future data-driven IAQ management.

A further major achievement is the proof-of-concept development of novel smart materials as active components in IAQ management strategies. The Annex demonstrated that Metal–Organic Frameworks (MOFs) can outperform conventional sorbents by up to an order of magnitude and can be engineered for easy regeneration and targeted performance. The research findings directly inform the objectives of Annex 92, which focuses on advancing smart materials for heating, cooling, and air quality control in residential buildings.

Finally, the Annex assessed the implementation potential of performance-based IAQ approaches. The results underscore the importance of continuous verification throughout a system's life cycle. Regulatory frameworks should therefore provide not only performance criteria and indicators but also mechanisms for verification, validation, and stakeholder support across all stages — from design to operation. Participants in the Annex continue to advance this approach through their contributions to CEN TC 156 WG 25 ISO TC 205/163 JWG 4 on Energy Performance of Buildings, ensuring its integration into emerging European and international standards.

Taken together, these achievements constitute a comprehensive toolkit for an ecosystem that supports policymakers, designers, and industry leaders seeking to transition from prescriptive to performance-based approaches in IAQ management. The results of the Annex demonstrate that by combining robust metrics, transparent data, innovative materials, and adaptive regulatory frameworks, it is possible to simultaneously enhance energy performance, protect occupant health, and promote a resilient, future-ready building stock.

Publications

- 'A literature list for energy efficient IAQ management', presents a comprehensive literature list for those looking for more in-depth reading, available as plain text as well as in four different common reference manager formats.
- 'An open registry for the rating of IAQ management strategies', details the open-access datasets, including the Pandora database for emissions and source characterization, and repositories on GitHub and Zenodo for exposure analyses.

- 'Methods and tools for the rating of IAQ management strategies', serves as the integrated synthesis, compiling the most significant methods and tools developed across the Annex into a single, accessible report. It provides concise summaries of each Subtask, complemented by references for deeper exploration.
- 'Energy Efficient IAQ management strategies – applications', showcases applications of the Annex's methods through practical demonstrations of tools, and documentation of joint exercises and outreach webinars.

Meetings

The following meetings were held in 2025:

- April 2025: Stuttgart, Germany.
- September 2025: Montreal, Canada.

Project duration

2020–2025

Operating Agent

Jelle Laverge, Ghent University, Belgium

Participating countries

Australia, Austria, Belgium, Brazil, Canada, P.R. China, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Turkey, UK, USA

Observers: Chile, Greece

Further information

www.iea-ebc.org

Annex 86 participants taking part in an AIVC podcast (from left to right: Valerie Leprince, Cerema; Benjamin Jones, Nottigham University; Pawel Wargocki, DTU)

Source: Simon Jones, Air Quality Matters



Demand Management of Buildings in Thermal Networks

EBC ANNEX 84

District heating and cooling networks are increasingly integrating renewable and variable heat sources, improving overall system efficiency while increasing operational complexity. A persistent challenge has been the effective involvement of connected buildings in balancing supply and demand, for example, lowering peak demand without compromising indoor comfort, system reliability, or customer acceptance. Although buildings offer significant short-term thermal storage capacity, practical guidance on how and under which conditions this potential can be used has been limited.

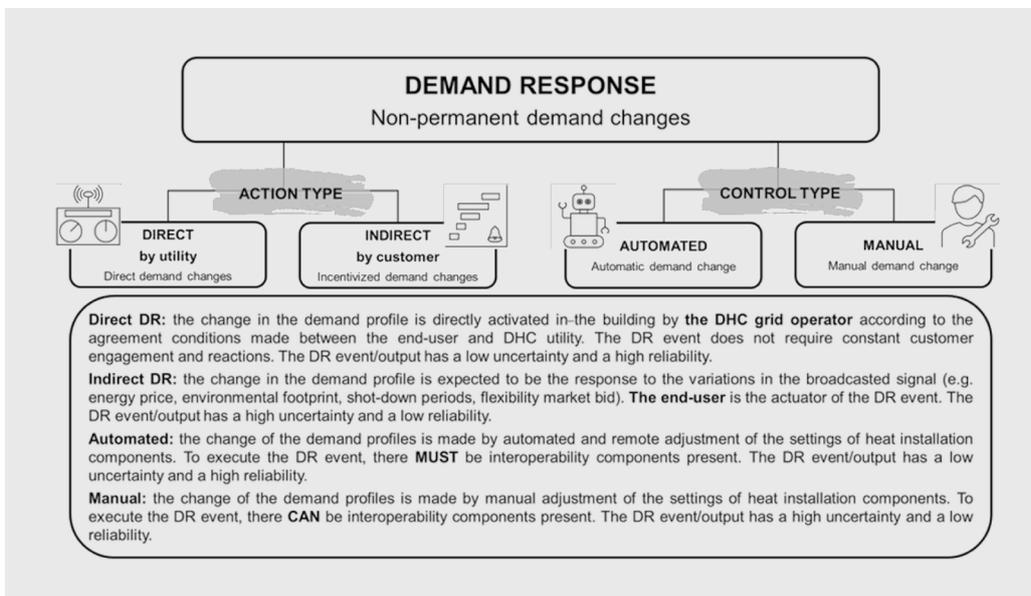
EBC Annex 84 addressed this gap by developing a structured, evidence-based framework for demand management of buildings in thermal networks. The Annex shows how buildings can provide operational flexibility through controlled load shifting and the use of thermal storage, supported by suitable technologies, data-based control approaches, and clear cooperation models between utilities and customers. A key innovation is the consistent treatment of buildings as active elements of the thermal system rather than passive heat consumers, supported by a shared terminology and assessment approach applicable across different network

types and national contexts. Hence, demand response in thermal networks can actively contribute to system operation when implemented in a coordinated and transparent manner.

Achievements

In 2025, Annex 84 completed its research activities and finalized the reporting phase. All planned milestones and deliverables were achieved, and the results were presented during the Annex's Closing Webinar in April 2025.

A central outcome is an improved understanding of collaboration requirements between district heating utilities and building owners. Based on surveys, interviews, experience from practical implementations, and international case studies, demand response programmes are more likely to be accepted when indoor comfort is maintained, participation rules are transparent, and incentives are clearly communicated. In contrast, limited information and complex pricing structures reduce engagement. These findings provide direct input for policy frameworks supporting flexibility in thermal network operation and consumer protection.



Terminology applied in IEA EBC Annex 84 for demand response
Source: EBC Annex 84

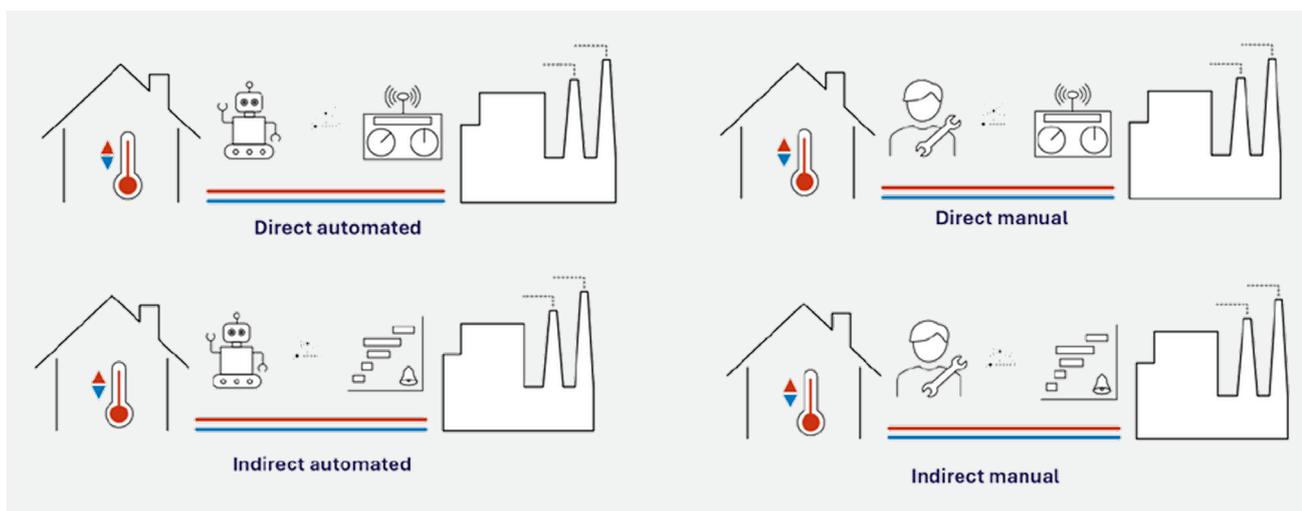


Illustration of the four types of demand response according to EBC Annex 84
Source: EBC Annex 84

At the building level, Annex 84 assessed technical solutions enabling demand management and their practical limitations. The results show that flexibility potential depends strongly on building type, construction period, and data availability. Buildings with sufficient thermal mass, envelope insulation, and modern control systems can shift heat demand for several hours, reducing peak loads without noticeable impacts on comfort. However, this potential is often not fully utilized due to insufficient coordination between building systems, substations, and network operation.

Further achievements include the assessment of digital methods and tools supporting demand management, identifying both their current applicability and remaining challenges related to interoperability, scalability, and data quality. This provides a realistic basis for targeted investment and standardization efforts.

Finally, the Annex analyzed 29 international case studies, translating research outcomes into practical insights. The analysis shows that daily load shifting is the dominant demand management objective and that thermal energy storage – frequently using building mass – is the prevailing flexibility resource. The case studies further indicate that system-level benefits, particularly peak load reduction and more efficient network operation, are achieved more consistently than direct customer benefits, which depend strongly on incentive design and direct communication.

Publications

The main project deliverables are as follows:

- 'Demand Management of Buildings in Thermal Networks – Project Summary Report', May 2025.

- Reports covering collaboration models, building-level technologies, digital methods and tools, and comparative analysis of international case studies on demand response in district heating and cooling systems.
- Videos and presentations from the Annex 84 closing webinar.
- *Scientific publications:*
 - 'Strengths, weaknesses, opportunities and threats of demand response in district heating and cooling systems. From passive customers to valuable assets', Smart Energy, Volume 14, 2024.
 - 'Do the customers remember? The fade-out effect from the demand response applied in the district heating system in Denmark', Journal of Physics: Conference Series, Volume 2600.
 - 'Exploring smart heat meter data: A co-clustering driven approach to analyse the energy use of single-family houses', Applied Energy, Volume 371, 2024.

Meetings

No meetings were held in 2025.

Project duration
2020–2025

Operating Agent
Anna Marszal-Pomianowska, Aalborg University, Denmark

Participating countries
Austria, Belgium, Denmark, Germany, Italy, the Netherlands, Singapore, Spain, Sweden, Switzerland, Turkey, UK

Further information
www.iea-ebc.org

Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems

EBC ANNEX 82

Demand side energy flexibility is increasingly being viewed as an essential enabler for the swift transition to resilient low-carbon energy systems that displace conventional fossil fuels with renewable energy sources while maintaining, or even improving, the operation of the energy system. Although the benefits of utilizing energy flexibility from the built environment are generally recognized, solutions that reflect diversity in building stocks, consumer behavior, and market rules and regulations need to be developed for successful implementation. The project's work focuses on the aggregated scale, to provide characterization methods, analysis of the dominant factors impacting available flexibility, control strategies, examples of business models and opportunities for the different stakeholders within the following tasks:

- building clusters and multi-carrier energy systems for energy flexibility and resilience;
- a common exercise on flexibility characterization methods and case studies;
- stakeholder acceptance and engagement;
- development of appropriate implementation (business) models.

Achievements

Annex 82 has completed all deliverables, all of which are available on its website.

The first deliverable, summarized the state-of-the-art methodologies and evaluations of energy flexibility at the building cluster level. Addressing energy flexibility at this level remains challenging due to technical and non-technical barriers. Technical barriers identified for the early planning, design, and operation phases include the development of integrated modeling tools, control strategies addressing the building cluster or portfolio level, and quantitative methodologies and indicators. Dominant factors influencing energy flexibility relate to occupants, building characteristics, energy systems and storage, control systems, and external factors (for example, weather and market).

Research teams involved in the Annex investigated building-grid interaction signals, a generalization of "price signals".

These signals must be aligned with the service objectives, such as load shifting versus load reduction. Characterizing energy flexibility involves the characterization and prediction of the building load.

The Annex work highlighted the scarcity of field studies demonstrating energy flexibility at the building cluster or portfolio level. Two field implementations conducted within the Annex are described in the report: the use of a novel control algorithm (signal matrix model predictive control) to control space heating, domestic hot water heating, and a stationary battery, and the coordinated use of the different assets in a fully equipped occupied building for flexibility. The Annex advanced the state-of-the-art methods to characterize, model, and harness energy flexibility of building clusters and portfolios, enabling further demonstration projects to build on the promising results of these field studies.

The second deliverable, focused on policy and regulation, price-incentive structures, business models, and key factors influencing customers' willingness and possibilities to take part in energy demand flexibility. Countries with the most ambitious policies were found to be the most advanced in deploying energy flexibility in commercial and residential buildings, confirming the importance of policy support. However, the diffusion of energy flexibility among smaller consumers remains limited. The relatively small number of aggregators identified highlights the need for additional policies to create a market for flexibility. At the same time, the emergence of energy communities in a few countries underscores the importance of considering alternative organizational approaches to activating the energy flexibility potential beyond aggregators and market-based solutions. Finally, implicit demand response was found to be relatively widespread in countries with dynamic pricing and Time-of-Use (ToU) pricing for small consumers (including households), indicating that its potential should not be overlooked in policymaking. Price incentives for energy flexibility vary considerably across countries, with some demonstrating significant uptake of dynamic and/or ToU schemes and others showing limited adoption.



Annex 82 final meeting in May 2025 in Leuven, Belgium
 Source: EBC Annex 82

Multiple stakeholders are involved in the energy system, with business models often encompassing several actors. Numerous value propositions were identified, including energy bill savings, acquisition of new equipment and technology, financial incentives, etc. Most stakeholder categories also emphasized societal or community contributions, highlighting benefits beyond financial gains. Dominant types of systems and equipment targeted by business models are Heating, Ventilation, and Air Conditioning (HVAC) systems (mainly heat pumps and air conditioners), followed by photovoltaic (PV) panels and electric batteries. The reviewed business models primarily focus on load shedding and load shifting. Regarding revenue streams, 30% of the cases involved a combination of subscription fees, equipment purchases, research funding, and professional service fees, demonstrating that revenues often rely on multiple sources.

Publications

- The main project deliverables are as follows:
- A report on methodologies and evaluations of energy flexibility for clusters of buildings;
 - A report of review and assessment of market, policy and stakeholder participation in building energy flexibility; and
 - A project summary report.

Meetings

- The following meetings were held in 2025:
- May 2025: 8th final working meeting in Leuven, Belgium.

Project duration
 2019–2025

Operating Agent
 Rongling Li, Technical University of Denmark, Denmark

Participating countries
 Australia, Austria, Belgium, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, UK, USA

Further information
www.iea-ebc.org

Data-Driven Smart Buildings

EBC ANNEX 81

IEA-EBC Annex 81 'Data Driven Smart Buildings' investigated emerging 'Artificial Intelligence' software tools for optimising energy consumption, in digitally enabled 'Smart Buildings'.

The Annex investigated relevant data-driven artificial intelligence (AI) algorithms, including those for automated Fault Detection and Diagnosis (FDD), Model Predictive Control (MPC) and Buildings to Grid (B2G) applications. These technologies can reduce energy waste by up to 40%. They can also provide 'dispatchable' demand response, a critical resource for backing up variable renewable energy, as part of the global clean energy transition.

The Annex also investigated the data management and digital infrastructure requirements necessary for deploying these applications. This included consideration of innovative data modelling frameworks for achieving semantic interoperability.

The Annex focused on the operational phase of non-residential buildings, where the relevant software applications benefit from (or require) near real time data processing.

The Annex identified key challenges preventing industry adoption of cost-effective energy management opportunities through digitalisation. These include:

- Interoperability and data access barriers;
- Economic and first cost sensitivity barriers;
- Workforce skills and capacity barriers; and
- Information and implementation complexity barriers.

The Annex identified key actions that government policy makers can take to help address these barriers. Examples of government initiatives were identified, where one or more of these recommendations have been adopted.

Achievements

The Annex was well received and successfully delivered. The Annex had participation across 18 countries, with over 50 entities contributing to the research. Around 40 to 60 experts typically attended Annex meetings.

The Annex disseminated results widely through (i) seven online research webinars (ii) contribution to an International Energy Agency (IEA) regional training event in Singapore, and (iii) various public forums. Annex 81 public forums



Annex 81 'Policy Package' for Increasing Adoption of Energy Optimisation in Buildings Through Digitalisation
Source: Research Institutes of Sweden (RISE), created using Microsoft Copilot (Enterprise license)

ranged from day long conferences to ½ day workshops. These events were held in Australia, Hong Kong, Turkey, Brazil, the Netherlands, USA and the UK. The International Conference on Building Data Acquisition, Ontology and Modelling (organized by Annex participant Hong Kong EMSD) attracted over 300 participants and had over 10,000 views for the live broadcast.

The Annex maintained a LinkedIn social media feed and made its results available using its website. The Annex provided a submission to a government consultation related to the Annex's topic.

The Annex engaged machine learning scientists from around the world in two new AI competitions, relating to (i) predicting heating and cooling loads from site meter data, and (ii) optimising energy efficient control of building Heating, Ventilation, and Air Conditioning (HVAC) services. The competitions generated new AI algorithms.

Annex 81 helped to raise awareness of the emerging role of digitalization as a means of scalably implementing energy efficiency and flexible demand services across the non-residential building stock. It particularly articulated and promoted concepts of 'digital-readiness' for HVAC systems in buildings – based on data information standards and minimum digitalization requirements (for implementing energy services).

Technical requirements, developed by Annex participants, were provided to the Australian Building Codes Board and have been included as optional requirements in Section J9D3 of the draft 2025 version of the Australian National Construction Code (NCC).

The Annex's flagship 'Opportunities for Government Leadership on Data-Driven Smart Buildings' policy-roadmap report provides authoritative evidence and suggestions to help underpin future policies for the adoption of grid interactive efficient buildings.

Publications

The Annex delivered or contributed to a substantial body of work. The reports and the online repository of case studies provide relevant information to address knowledge gaps in the industry. The collected data sets and benchmarking tools provide high quality ground-truth data and capability to help fast track the next generation of AI research for buildings.

Publications include:

Annex Reports

- A report on digital infrastructure for data-driven smart buildings.
- A report on model predictive control.
- A report on data-driven smart building software applications.
- A state of the art report on data-driven smart buildings.
- A survey report on 'metadata schemas for data-driven smart buildings.
- A guideline report on data-sharing for buildings and HVAC systems.
- A roadmap report on opportunities for government leadership on data-driven smart buildings.
- A guide on data platforms for data-driven smart buildings.

Databases

- Building Data Directory.
- FDD Dataset Repository.
- MPC Dataset Repository.
- Building to Grid Dataset Repository.

Software tools

- BOPTEST Framework.
- Energy-Flexibility-KPIs software tool.

Website

- Online Data-Driven Smart Buildings Case-Study Repository

Meetings

No meetings were held in 2025.

Project duration

2019–2025

Operating Agent

Dr Stephen White, CSIRO, Australia

Participating countries

Australia, Austria, Belgium, Canada, P.R. China, Denmark, Finland, Ireland, Italy, Japan, the Netherlands, Norway, Singapore, Spain, Sweden, Turkey, UK, USA

Further information

www.iea-ebc.org

Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

EBC ANNEX 78

Globally, ventilation of buildings accounts for approximately one-fifth of the energy use needed to provide an acceptable indoor environment. Moreover, the requirements for ventilation in most standards and guidelines assume acceptable quality (clean) outdoor air, which is often not the case.

There are increasing numbers of publications in many countries related to air cleaning and increasing sales of gas-phase air cleaning products. This introduces a demand for verifying the efficacy of air cleaning on indoor air quality for comfort, well-being, and health. It is thus important to learn whether air cleaning can supplement ventilation by improving air quality, i.e. whether it can partly substitute the ventilation rates required by standards. Finally, the energy impact of using air cleaning as a supplement to ventilation needs to be estimated. This project focuses on gas-phase air cleaning but does not include filtration.

In some locations in the world, the outdoor air quality is so bad that it may be better to avoid ventilation. In such cases, the alternative to using ventilation is to substitute it with air cleaning, so that the indoor air can be kept at high quality. Even when outdoor air is of good quality, the substitution of ventilation for air cleaning could reduce the rate of outside air supplied indoors, and thereby energy used for heating/cooling of ventilation air and for transporting the air (fan energy) can be saved.

The worldwide use of gas-phase air cleaning has increased in recent decades. However, there is limited information on the performance of gas-phase air cleaners – particularly in-situ – including whether they can substitute for ventilation, any potential risks associated with their use, and how they contribute to energy savings and reduced carbon footprint. Moreover, there are currently no standards that allow systematic and repeatable benchmarking of gas-phase air cleaner performance.

These challenges shaped the project's direction, providing answers on the energy benefits of using gas-phase air cleaners, their potential to substitute for ventilation, the de-

velopment of standards for testing, and their long-term performance. The Annex brought together partners from different institutions, facilitating knowledge exchange and the publication of papers based on ongoing activities funded locally by various agencies.

Achievements

The project's achievements have been disseminated through papers summarizing the activities undertaken during its execution (more than 17 publications in scientific journals), as well as through webinars, workshops and conference sessions (over 14 external seminars, workshops, and conference sessions) held throughout the project. In addition, the Annex made significant contributions to the standardization of a test method; one standard was completed: 'ISO 16000-44:2023, Indoor Air-Part 44: Test Method for Measuring Perceived Indoor Air Quality for Use in Testing the Performance of Gas Phase Air Cleaners'.

A major achievement of the Annex was the establishment of a concept for partially substituting ventilation with gas-phase air cleaning technology. Furthermore, a method for measuring the clean air delivery rate (CADR) of gas-phase air cleaners – based on perceived air quality – was developed and verified.

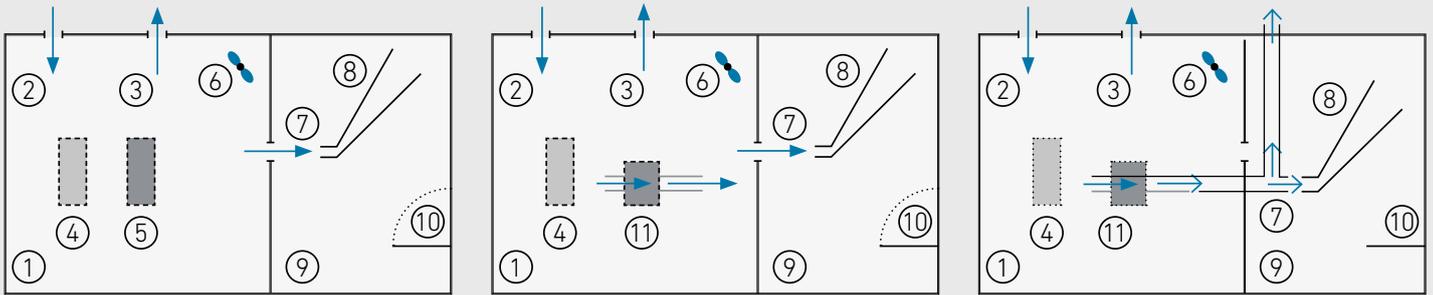
The energy performance of gas-phase air cleaning technologies was investigated using computer simulations without any data for systems in operation. In addition, a metric, CADR per kW – defined as the clean air delivery rate divided by the energy used for heating, cooling, and ventilation – was developed to compare the energy performance of air cleaners with that of increased ventilation airflow, with and without an energy recovery unit.

Publications

The main project deliverables are as follows:

- 'Energy benefits of using gas-phase air cleaning'
- A validated procedure for supplementing (partly substituting) required ventilation rates with gas-phase air cleaning.

POSITION OF AIR CLEANER ISO 16000-44



a)
A test room for a standalone air cleaner

- ① test chamber
- ② clean and temperature/humidity conditioned air supply inlet
- ③ exhaust outlet
- ④ emission source
- ⑤ An air cleaner
- ⑥ mixing fan

b)
A test room for a duct air cleaner

- ⑦ tube or duct
- ⑧ sniffing device, complying with relevant specifications and requirements of ISO 16000-28
- ⑨ front/anterior space in which human panel enter
- ⑩ Doors where panel enters
- ⑪ in duct air cleaner

c)
A test room for a duct air cleaner (single-pass condition)

Position of air cleaner ISO 16000-44
Source: Annex 78

- 'A method for testing gas-phase air cleaners'.
- A report on the long-term performance of air cleaning.
- 'Performance of Portable Gas-Phase Air Cleaners and Impact on Indoor Air Quality. A Literature Review'.

Other deliverables include:

- 'AIVC VIP 42: The Concept for Substituting Ventilation by Gas Phase Air Cleaning'.
- More than 17 publications in scientific journals.
- Over 14 external seminars, workshops, and conference sessions.
- One standard completed: 'ISO 16000-44:2023 "Indoor Air-Part 44: Test Method for Measuring Perceived Indoor Air Quality for Use in Testing the Performance of Gas Phase Air Cleaners'.

Meeting

No meetings were held in 2025.

Project duration

2018–2025

Co-Operating Agents

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Participating countries

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Further information

www.iea-ebc.org

Background Information

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EBC AND THE IEA

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RECENT PUBLICATIONS

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EBC EXECUTIVE COMMITTEE MEMBERS

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EBC OPERATING AGENTS

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EBC PROJECTS
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EBC and the IEA

THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Cooperation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster cooperation among the thirty IEA member countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D). The current framework for international energy technology RD&D cooperation was approved by the IEA's Governing Board in 2020.

This framework provides uncomplicated, common rules for participation in RD&D programmes, known as Technology Collaboration Programmes (TCPs), and simplifies international cooperation between national entities, business and industry. The TCPs are established by legal agreements between countries that wish to pursue a common programme of research in a particular area. In fact, there are now around 40 such TCPs - for more information see:

www.iea.org/tcp

There are numerous advantages to international energy technology RD&D collaboration through the TCPs, including:

- reduced cost and avoiding duplication of work,
- greater project scale,
- information sharing and networking,
- linking IEA member countries and non-member countries,
- linking research, industry and policy,
- accelerated development and deployment,
- harmonised technical standards,
- strengthened national RD&D capabilities, and
- intellectual property rights protection.

ABOUT EBC

Approximately one third of primary energy is consumed in non-industrial buildings such as dwellings, offices, hospitals, and schools where it is utilised for the heating and cooling, lighting and operation of appliances. In terms of the total energy end-use, this consumption is comparable to that used in the entire transport sector. Hence the building sector represents a major contribution to fossil fuel use and related carbon dioxide emissions. Following uncertainties in energy supply and concern over the risk of global warming, many countries have now introduced target values for reduced energy use in buildings. Overall, these are aimed at reducing energy use at least by between 5% and 30%. To achieve such a target, international cooperation, in which research activities and knowledge can be shared, is seen as an essential activity.

In recognition of the significance of energy use in buildings, in 1977 the International Energy Agency has established a Technology Collaboration Programme on Energy in Buildings and Communities (EBC-formerly known as ECBCS). The function of EBC is to undertake research and provide an international focus for building energy efficiency. Tasks are undertaken through a series of 'Annexes', so called because they are legally created as annexes to the 'Implementing Agreement' on which the EBC TCP is established. These Annexes are directed at energy saving technologies and activities that support technology application in practice. Results are also used in the formulation of international and national energy conservation policies and standards.

OBJECTIVES AND STRATEGY

The objectives of the collaborative work conducted by the EBC Technology Collaboration Programme are derived from the major trends in construction and energy markets, energy research policies in the participating countries and from the general objectives of the IEA. The principal objective of the EBC TCP is to facilitate and accelerate the introduction of new and improved energy conservation and environmentally sustainable technologies into buildings and community systems. Specific objectives of the EBC programme are to:

- support the development of generic energy conservation technologies within international collaboration;
- support technology transfer to industry and to other end users by the dissemination of information through demonstration projects and case studies;
- contribute to the development of design methods, test methods, measuring techniques, and evaluation/assessment methods encouraging their use for standardisation;
- ensure acceptable indoor air quality through energy efficient ventilation techniques and strategies;
- develop the basic knowledge of the interactions between buildings and the environment as well as the development of design and analysis methodologies to account for such interactions.

The research and development activities cover both new and existing buildings, and residential, public and commercial buildings. The main research drivers for the programme are:

- the environmental impacts of fossil fuels;
- business processes to meet energy and environmental targets;
- building technologies to reduce energy use;
- reduction of greenhouse gas emissions;
- the 'whole building' performance approach;
- sustainability;
- the impact of energy reduction measures on indoor health, comfort and usability;
- the exploitation of innovation and information technology;
- integrating changes in lifestyle, work and business environments.

MISSION STATEMENT

The mission of the IEA Energy in Buildings and Communities Programme is as follows: 'To support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation.'

NATURE OF EBC ACTIVITIES

a. Formal coordination through shared tasks: This represents the primary approach of developing the work of EBC. The majority of Annexes are task-shared and involve a responsibility from each country to commit manpower.

b. Formal coordination through cost shared activities: EBC currently supports one cost shared project, Annex 5, the Air Infiltration and Ventilation Centre (AIVC). In recent times, Annex 5 has subcontracted its information dissemination activities to the Operating Agent, by means of a partial subsidy of costs and the right to exploit the Annex's past products.

c. Informal coordination or initiation of activities by participants: Many organizations and groups take part in the activities of EBC including government bodies, universities, nonprofit making research institutes and industry.

d. Information exchange: Information about associated activities is exchanged through the EBC and through individual projects.

The EBC website (www.iea-ebc.org), for example, provides links to associated research organizations. Participants in each project are frequently associated with non IEA activities and can thus ensure a good cross-fertilization of knowledge about independent activities. Information exchange additionally takes place through regular technical presentation sessions and 'Future Buildings Forum' workshops. Information on independent activities is also exchanged through the EBC newsletter, which, for example, carries regular reports of energy policy development and research activities taking place in various countries.

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Canada
P.R. China
Czech Republic
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France
Germany
Italy
Ireland
Japan
R. Korea
New Zealand
The Netherlands
Norway
Portugal
Singapore
Spain
Sweden
Switzerland
Turkey
United Kingdom
United States of America

COORDINATION WITH OTHER BODIES

In order to achieve high efficiency in the EBC Technology Collaboration Programme (TCP) and to eliminate duplication of work it is important to collaborate with other IEA buildings-related TCPs. The coordination of strategic plans is a starting point to identify common RD&D topics. Other actions are exchange of information, joint meetings and joint projects in areas of common interest. It is a duty of the Chairs of the respective Executive Committees to keep the others informed about their activities and to seek areas of common interest.

COLLABORATION WITH IEA BUILDINGS-RELATED TECHNOLOGY COLLABORATION PROGRAMMES

The EBC TCP continues to coordinate its research activities with the following other IEA buildings-related TCPs, including through strategic planning and sometimes through joint collaborative projects:

- District Heating And Cooling (DHC)
- User-Centred Energy Systems (Users)
- Energy in Buildings and Communities (EBC)
- Energy Conservation through Energy Storage (ECES)
- Heat Pumping Technologies (HPT)
- International Smart Grid Action Network (ISGAN)
- Photovoltaic Power Systems (PVPS)
- Solar Heating and Cooling (SHC)
- Energy Efficient Electrical Equipment (4E)
- Decarbonising Cities and Communities (Cities)

EBC also collaborates with representatives of all buildings-related TCPs at Future Buildings Forum (FBF) Think Tanks and Workshops. The outcome from each Future Buildings Forum Think Tank is used strategically by the various IEA buildings-related TCPs to help in the development of their work programmes over the subsequent five year period. Proposals for new research projects are discussed in coordination with these other programmes to pool expertise and to avoid duplication of research. Coordination with SHC is particularly strong.

COLLABORATION WITH THE IEA SOLAR HEATING AND COOLING PROGRAMME

While there are several IEA TCPs that are related to the buildings sector, the EBC and the Solar Heating and Cooling TCPs focus primarily on buildings and communities. Synergies between these two programmes occur because one programme seeks to cost-effectively reduce energy demand while the other seeks to meet a large portion of this demand by solar energy. The combined effect results in buildings that require less purchased energy, thereby saving money and conventional energy resources, and reducing greenhouse gas emissions. The areas of responsibility of the two programmes have been reviewed and agreed. EBC has primary responsibility for efficient use of energy in buildings and community systems. Solar designs and solar technologies to supply energy to buildings remain the primary responsibility of the SHC TCP. The Executive Committees coordinate the work done by the two programmes. These Executive Committees meet together approximately every two years. At these meetings matters of common interest are discussed, including planned new tasks, programme effectiveness and opportunities for greater success via coordination. The programmes agreed to a formal procedure for coordination of their work activities. Under this agreement during the initial planning for each new Annex/Task initiated by either programme, the other Executive Committee is invited to determine the degree of coordination, if any. This coordination may range from information exchange, inputting to the draft Annex/Task Work Plan, participating in Annex/Task meetings to joint research collaboration.

The mission statements of the two programmes are compatible in that both seek to reduce the purchased energy for buildings; one by making buildings more energy efficient and the other by using solar designs and technologies. Specifically, the missions of the two programmes are:

- EBC TCP: to accelerate the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge and technologies through international collaborative research and innovation.
- SHC TCP: to enhance collective knowledge and application of solar heating and cooling through international collaboration in order to fulfill the vision.

The two programmes structure their work around a series of objectives. Four objectives are essentially the same for both programmes. These are:

- technology development via international collaboration;
- information dissemination to target audiences;
- enhancing building standards;
- interaction with developing countries.

The other objectives differ. The EBC TCP addresses life cycle environmental accounting of buildings and their constituent materials and components, as well as indoor air quality, while the SHC TCP addresses market impacts, and environmental benefits of solar designs and technologies. Both Executive Committees understand that they are addressing complementary aspects of the buildings sector and are committed to continue their coordinated approach to reducing the use of purchased energy in buildings sector markets.

NON-IEA ACTIVITIES

A further way in which ideas are progressed and duplication is avoided is through cooperation with other buildings-related activities. Formal and informal links are maintained with other international bodies, including:

- Mission Innovation (MI), and
- The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

Recent Publications

Air Infiltration and Ventilation Centre (AIVC) – EBC Annex 5

Databases

AIRBASE – bibliographical database, containing over 24,000 records on air infiltration, ventilation and related areas, Web based, updated every 3 months

AIVC Conference Proceedings

– 44th AIVC Annual Conference, held in Dublin, Ireland, October 2024

Ventilation Information Papers

– VIP 48.3: Trends in building ventilation requirements and inspection in Ireland, 2025
– VIP 48.4: Trends in building ventilation requirements and inspection in Italy, 2025

Technical Notes

– TN 74: Smart Ventilation in Residential Buildings, 2025

Contributed Reports

– CR20: A method for testing gas-phase air cleaners, 2025
– CR21: Performance of Portable Gas-Phase Air Cleaners and Impact on Indoor Air Quality. A Literature Review, 2025
– CR22: Quantifying population harm from indoor air contaminants in dwellings, 2025

Annotated Bibliographies

– BIB 14: Retrofitting the Building Stock: Challenges and Opportunities for Indoor Environmental Quality – Overview of the AIVC 2024 Conference sessions, 2025

Working Group on Building Energy Codes

– International Survey of Mandatory Whole Life/Embodied Carbon Requirements in Building Codes and Regulations, 2025
– Research summary: Exploring the role of building codes in protecting occupants from overheating — a Canadian perspective, 2025

Data-Driven Smart Buildings (EBC Annex 81)

– Final Report
– Subtask B Report
– Subtask C Report

Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems (EBC Annex 82)

– Project summary report, 2025
– Methodologies and evaluations of energy flexibility for clusters of buildings, 2025
– Review and assessment of market, policy and stakeholder participation in energy flexibility of buildings, 2025
– Price-responsive control using deep reinforcement learning for heating systems: Simulation and living lab experiment, 2025
– Exploring the impacts of consumer reaction to dynamic heat prices in district heating, 2025
– Impact of building-grid interaction signals on energy flexibility at cluster Level: Insights from two case studies, 2025
– Energy flexibility at multi-building scales: A review of the dominant factors and their uncertainties, 2025
– A methodological framework for designing dynamic heat price for demand response in district heating, 2025

Positive Energy Districts (EBC Annex 83)

– Linking environmental impact assessment and positive energy districts: A literature review, 2025
– Leveraging positive energy districts surplus for the achievement of the sustainable development goals, 2025
– Development of integrated energy sharing systems between neighboring zero-energy buildings via micro-grid and local electric vehicles with energy trading business models, 2025

Demand Management of Buildings in Thermal Networks (EBC Annex 84)

– Project summary report, 2025
– Description and comparative analysis of case studies, 2025
– Evaluation and Summary, 2025
– Tools and methods to leverage the thermal demand response potential in buildings connected to thermal networks, 2025

– Collaboration models – overview of involved actors, existing practices, potential barriers and limitations, recommendations, 2025
– Role of monitoring, sensing and control technology, 2025
– Supply, storage and distribution of heat, cold, domestic hot water, and electricity on building level for demand response and flexibility option, 2025
– Classification of building types connected to DHC systems, 2025

Energy Efficient Indoor Air Quality Management in Residential Buildings (EBC Annex 86)

– Project summary report, 2025
– Energy efficient IAQ management strategies – applications, 2025
– Methods and tools for the rating of IAQ management strategies, 2025
– An open registry for the rating of IAQ management strategies, 2025
– A literature list for energy efficient IAQ management, 2025

Energy Resilience of the Buildings in Remote Cold Regions (EBC Annex 93)

– Advanced energy systems in energy-resilient and zero/positive energy buildings, communities, and districts, 2025
– Optimising energy flexibility in Finnish residential buildings: A comparative study of PI, rule-based and model predictive control strategies, 2025
– EPCDescriptor: A multi-attribute visual network modeling of housing energy performance, 2025
– Implication of building renovation and renewable integration on the energy resilience in the Nordic climate: Techno-economic analysis using questionnaire-based thresholds, 2025
– Modeling the impact of diverse extreme climate scenarios on residential buildings with renewable energy and storage in cold regions: A techno-economic analysis, 2025
– Tangible benefits of improved building airtightness, 2025

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Energy Efficient Indoor Air Quality Management in Residential Buildings – EBC Annex 86

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Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems – EBC Annex 87

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Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings – EBC Annex 88

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Ways to Implement Net-zero Whole Life Carbon Buildings – EBC Annex 89

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Low Carbon, High Comfort Integrated Lighting – EBC Annex 90

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Open Building Information Modelling for Energy Efficient Buildings – EBC Annex 91

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Smart Materials for Energy-efficient Heating, Cooling and Indoor Air Quality Control in Residential Buildings – EBC Annex 92

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Energy Resilience of the Buildings in Remote Cold Regions – EBC Annex 93

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Validation and Verification of In-situ Building Energy Performance Measurement Techniques – EBC Annex 94

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Annex 95**

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Sustainable Cooling in Cities – EBC Annex 97

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**Flexibilization and Optimization of
Heat Pump Systems in Existing Buildings
through Secondary-Side Digitalization –
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EBC Projects

Annex 1	Load Energy Determination of Buildings	Annex 43	Testing and Validation of Building Energy Simulation Tools
Annex 2	Ekistics and Advanced Community Energy Systems	Annex 44	Integrating Environmentally Responsive Elements in Buildings
Annex 3	Energy Conservation in Residential Buildings	Annex 45	Energy Efficient Electric Lighting for Buildings
Annex 4	Glasgow Commercial Building Monitoring	Annex 46	Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 6	Energy Systems and Design of Communities	Annex 47	Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 7	Local Government Energy Planning	Annex 48	Heat Pumping and Reversible Air Conditioning
Annex 8	Inhabitants Behaviour with Regard to Ventilation	Annex 49	Low Exergy Systems for High Performance Buildings and Communities
Annex 9	Minimum Ventilation Rates	Annex 50	Prefabricated Systems for Low Energy Renovation of Residential Buildings
Annex 10	Building HVAC System Simulation	Annex 51	Energy Efficient Communities: Case Studies and Strategic Guidance for Urban Decision Makers
Annex 11	Energy Auditing	Annex 52	Towards Net Zero Energy Solar Buildings (NZEBS)
Annex 12	Windows and Fenestration	Annex 53	Total Energy Use in Buildings – Analysis and Evaluation Methods
Annex 13	Energy Management in Hospitals	Annex 54	Integration of Microgeneration and Other Energy Technologies in Buildings
Annex 14	Condensation and Energy	Annex 55	Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance and Cost
Annex 15	Energy Efficiency in Schools	Annex 56	Cost Effective Energy and CO ₂ Emissions Optimization in Building Renovation
Annex 16	BEMS 1– User Interfaces and System Integration	Annex 57	Evaluation of Embodied Energy and Carbon Dioxide Equivalent Emissions for Building Construction
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