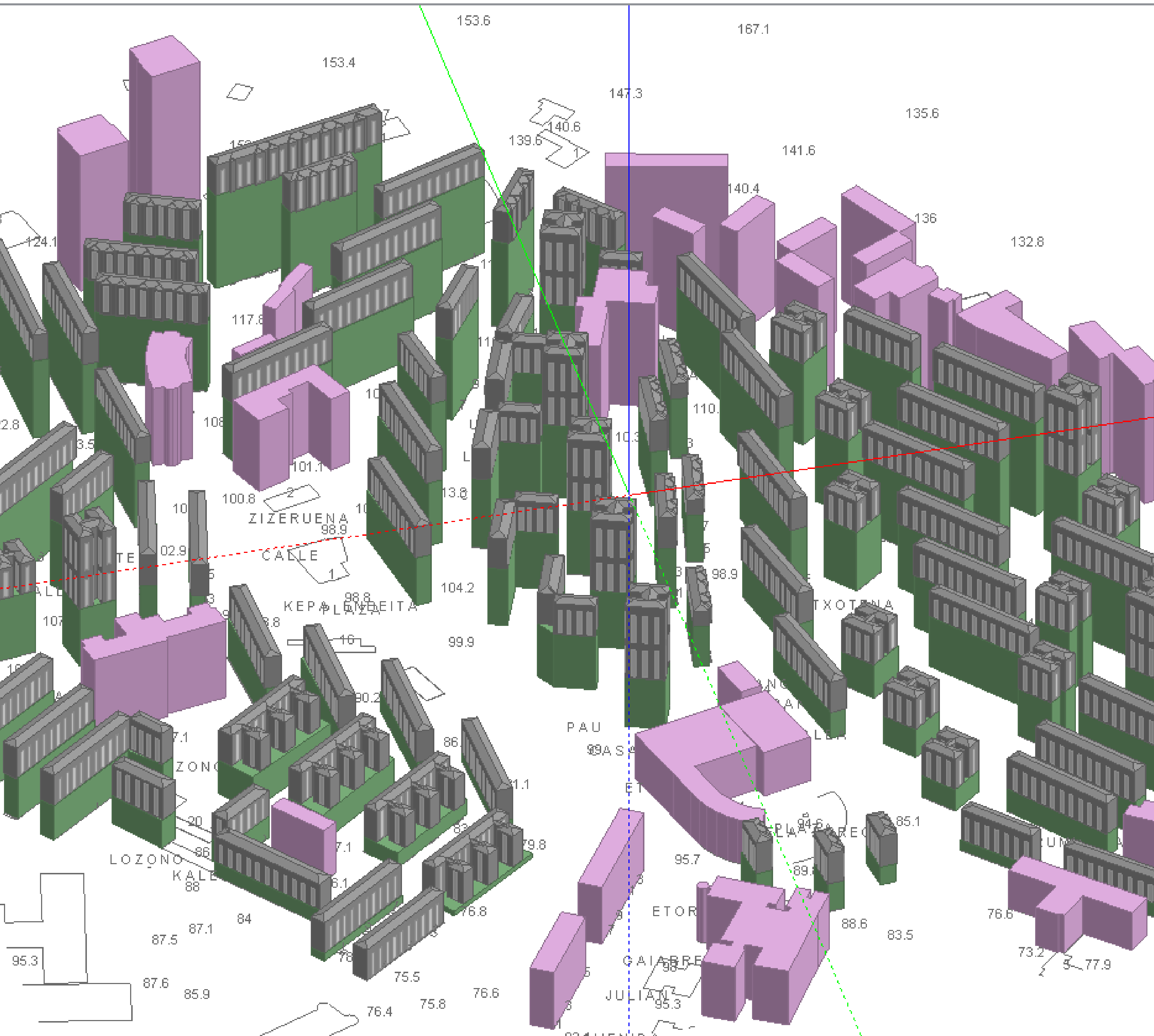
EBC

Energy in Buildings and
Communities Programme

Annual Report 2021



Energy in Buildings and
Communities Programme

International Energy Agency

EBC Annual Report 2021

Energy in Buildings and Communities Programme

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

Technology Collaboration Programme
by iea

Participating countries in EBC: Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Italy, Ireland, Japan, R. Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Türkiye, UK and USA.

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Front cover image: The model for the Spanish case study for building renovation at the district level combining energy efficiency and renewables
Source: EBC Annex 75

AECOM Ltd Registered Office: Aldgate Tower, 2 Leman Street, London, E1 8FA, United Kingdom

Publisher: The EBC Executive Committee Support and Services Unit (ESSU), C/o AECOM Ltd, The Colmore Building, Colmore Circus Queensway, Birmingham B4 6AT, United Kingdom

www.iea-ebc.org
essu@iea-ebc.org

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EBC Executive Committee Chair's Statement

During 2021, many nations and regions revised their targets for reducing greenhouse gas (GHG) emissions by 2030 and 2050. Meanwhile, the International Energy Agency's flagship publication, 'Net Zero by 2050: a Roadmap for the Global Energy Sector', was published in May 2021, in advance of COP26 held in November 2021. As one of those responsible for carbon emissions, the buildings sector is addressed by this roadmap, with targeted reductions of energy end-use, primary energy and carbon emissions agreed upon nationally, leading to announcements of international commitments.

In the sector supplying energy, various technologies to reduce GHG intensity per unit amount of end-use energy such as electricity and fossil gas are being tackled. But, the improvement of the energy efficiency of buildings and communities remains essential, at least before sufficient totally decarbonized energy is available on the market with reasonable prices, even though this is only anticipated to be attained by 2050.

When we tackle the energy efficiency of buildings, what is the most critical current issue? It is evident that practitioners engaged in decision making about specifications for buildings and their technical services (heating, ventilation, air conditioning, domestic hot water, lighting, control systems, appliances) should have metrics by which the various aspects of the design can be evaluated quantitatively for their energy performance and for their energy use under expected usage during actual operation. While these are easy to ask for, it is difficult to develop and implement such metrics. It has been said that legal restraints (building energy codes and regulations) are the most effective methods in the buildings sector to guide their energy performance, and various metrics are already utilized in regulations. However, better metrics are being developed and further technological improvements are needed for them.

To this end, 'real building energy use' was one of the priority themes in the EBC Strategic Plan for 2014-2019. Moreover, in the present EBC Strategic Plan for 2019-2024, 'planning, construction and management processes to reduce the performance gap between design stage assessment and real world operation' is one of our five strategic objectives.

To improve the metrics, intensive research and development activities are still needed such as for hardware / software (control) of energy systems in buildings and communities, demonstrations / validations (living labs), function / indoor environmental performance, occupants' behaviour / building use, and so on. These themes are tackled by our projects known as Annexes and Working Group. I hope readers will find hints in this Annual Report to support research activities and applying our findings in practice.

Dr Eng Takao Sawachi
EBC Executive Committee Chair and Member for Japan

PATHWAY TO NET ZERO EMISSIONS BY 2050

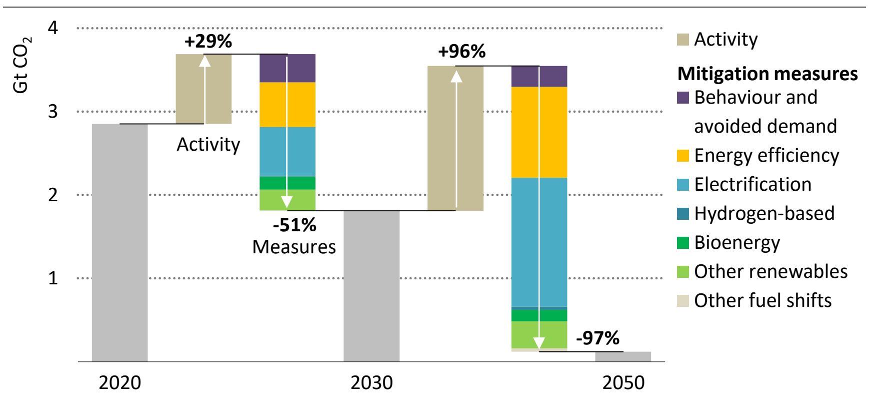
A ROADMAP FOR THE GLOBAL ENERGY SECTOR - SPECIAL IEA REPORT SUMMARY FOR THE BUILDINGS SECTOR

One of our biggest challenges the world is now facing is climate change that continues to intensify and impacts our planet and way of life. The extent of climate change will depend on our success in controlling and limiting global emissions over the coming decades. In 2015, nearly 200 nations signed the Paris Agreement, the most ambitious climate accord to date, which commits to 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C' to mitigate the worst impacts of climate change. To strengthen global ambitions and action on climate built on the foundations of the Paris Agreement, more than 100 governments have pledged to achieve net zero emissions (NZE) before 2050, following the 26th Conference of the Parties (COP26) of the United Nations Framework Convention on Climate Change conference, held in Glasgow, UK, in November 2021. Reducing global greenhouse gas emissions (expressed as equivalent carbon dioxide, CO_2, emissions) to net zero by 2050 is consistent with efforts to limit the long-term increase in average global temperatures to 1.5°C. While these commitments are a positive first step, they must now be followed by collaborative actions.

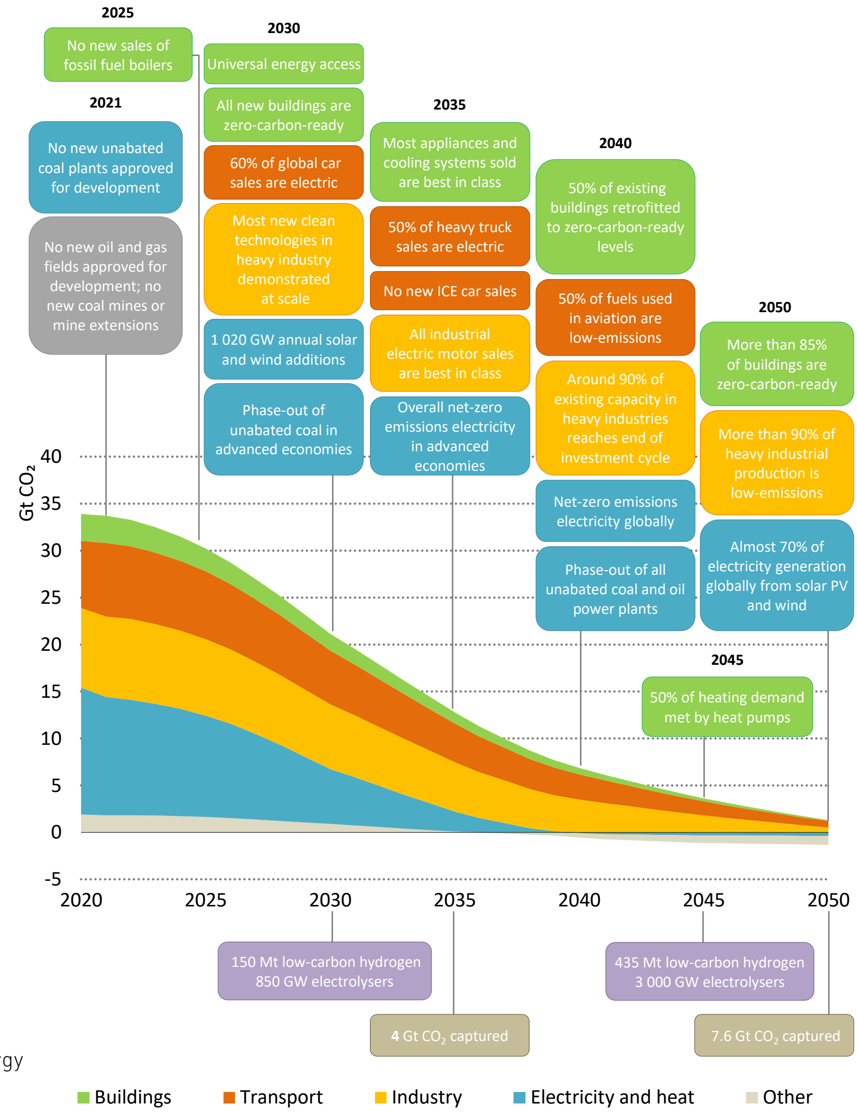
IEA Net Zero by 2050: a Roadmap for the Global Energy Sector Net Zero by 2050 – Analysis - IEA

In 2021, the International Energy Agency (IEA) published a special report that was designed to inform the high-level negotiations that took place at COP26 in Glasgow. This report is a comprehensive study of how to reach net zero energy-related and industrial process CO_2 emissions globally by 2050 while ensuring secure and affordable energy supplies, universal energy access by 2030, and continued economic growth. It sets out a pathway to net zero and shows what is needed across the energy conversion, industry, transport and buildings sectors, and by when, to achieve the net zero goal. The key milestones in the pathway to net zero are shown in the figure oppposite.

According to the report, the key pillars of decarbonisation of the global energy system are energy efficiency, behavioural changes, electrification, renewables, hydrogen and hydrogen-based fuels, bioenergy and carbon capture, utilisation and storage (CCUS). The global pathway to net zero emissions by 2050 detailed



Global direct CO_2 emissions reductions by mitigation measure in buildings for reaching net zero emissions.
Notes:
Activity = change in energy service demand related to rising population, increased floor area and income per capita.
Behaviour = change in energy service demand from user decisions, e.g. changing heating temperatures.
Avoided demand = change in energy service demand from technology developments, e.g. digitalisation.
Source: IEA Net Zero by 2050: a Roadmap for the Global Energy Sector



Key milestones in the pathway to net zero.
Source: IEA Net Zero by 2050: a Roadmap for the Global Energy Sector

in this report requires all governments to significantly strengthen and then successfully implement their energy and climate policies.

The report also examines key uncertainties, such as the roles of bioenergy, carbon capture and behavioural changes in reaching net zero. It assesses the costs of achieving the NZE goal, the likely impacts on employment and the economy, and the implications of NZE for various sectors, citizens, and governments.

By 2050, the energy world would look completely different, where most of electricity generation comes from renewable sources, with wind, solar PV and nuclear power. Solar is the world's single largest source of total energy supply, and energy supply from fossil fuels fall dramatically. Fossil fuels that remain are used in goods where the carbon is embodied in the product such as plastics, in plants fitted with carbon capture, and in sectors where low-emissions technology options are limited.

Zero-carbon-ready Buildings

Concerning buildings, the IEA report states, '*the buildings sector includes energy used in residential, commercial and institutional buildings and non-specified other [types]. Building energy use includes space heating and cooling, water heating, lighting, appliances and cooking equipment.*' In the buildings sector, the first key milestones in the pathway to net zero include no new fossil fuel boilers being sold globally from 2025, with both achieving universal energy access and all new buildings are zero-carbon-ready by 2030. From 2030, 2.5% of buildings are retrofitted to be zero-carbon-ready each year, achieving 50% retrofitted to zero-carbon-ready level by 2040. A zero-carbon-ready building is defined in the IEA report as being '*highly energy efficient and either uses renewable energy directly or uses an energy supply that will be fully decarbonised by 2050, such as electricity or district heat. This means that a zero-carbon-ready building will become a zero-carbon building by 2050, without any further changes to the building or its equipment*'.

Building energy codes are the fundamental policy instrument to drive such changes and need to be introduced in all regions by 2030. Zero-carbon-ready building energy codes should cover both building operations (Scopes 1 and 2) and emissions from the manufacturing of building construction materials and components (Scope 3, or embodied carbon emissions). The important role in lowering energy demand by passive design features, building envelope improvements and high energy performance equipment also needs to be recognised. These codes need buildings to become flexible resources for energy systems, using connectivity and automation to manage building electricity demand and the operation of energy storage devices, including electric vehicles.

The two main drivers of decarbonisation of the buildings sector are energy efficiency and electrification. According to the IEA report, '*that transformation relies primarily on technologies already available on the market, including improved envelopes for new and existing buildings, heat pumps, energy-efficient appliances, and bioclimatic and material-efficient building design*.'

According to the NZE pathway, over 85% of buildings are zero-carbon-ready, reducing average useful heating intensity by 75%, with heat pumps meeting over half of heating needs by 2050. It is recognised that not all buildings are best decarbonised with heat pumps, therefore bioenergy boilers, solar thermal, district heat, low-carbon gases in gas networks and hydrogen fuel cells all play a role in making the global building stock zero-carbon-ready by 2050.

Zero-carbon-ready buildings should adjust to user needs and maximise the efficient and smart use of energy, materials and space to facilitate the decarbonisation of other sectors. Increased digitalisation and smart controls improve flexible systems operations, management of variable renewable and more efficient demand response. New and existing zero-carbon-ready buildings should integrate locally available renewable resources, e.g. solar thermal, solar PV, PV thermal and geothermal, to reduce the need for utility-scale energy supply. If needed, thermal or battery energy storage should support local energy generation. Behaviour changes are also important in the NZE pathway including changes in temperature settings for space heating or reducing excessive hot water temperatures. Additional behaviour changes such as greater use of cold temperature clothes washing and line drying, facilitate the decarbonisation of the electricity supply. There is scope for these reductions to be achieved rapidly and at no cost.

As the IEA have concluded in this special report, the world has a viable pathway to building a global energy sector with net-zero emissions in 2050, but it is narrow, extremely challenging and requires an unprecedented transformation of how energy is produced, transported and used globally. It requires all stakeholders – governments, businesses, investors and citizens – to take action now and every year after, so that the goal does not slip out of reach.

Further information

www.iea.org/reports/net-zero-by-2050

Summarised by the EBC Executive Committee Support and Services Unit (ESSU)

New Research Projects

ENERGY AND INDOOR ENVIRONMENTAL QUALITY PERFORMANCE OF PERSONALISED ENVIRONMENTAL CONTROL SYSTEMS

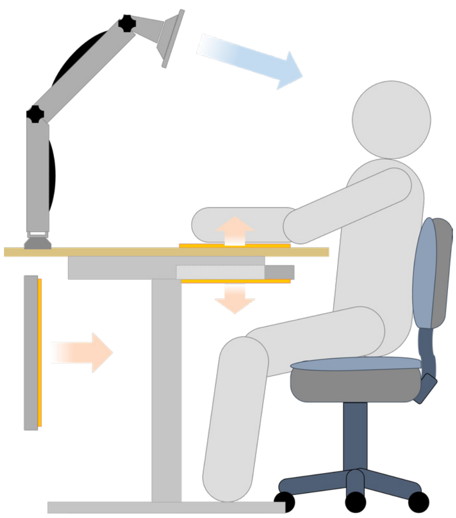
(EBC ANNEX 87)

Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems

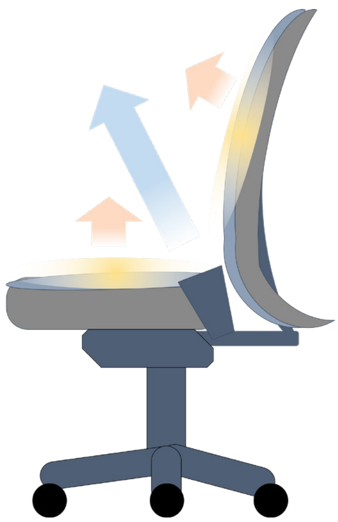
EBC ANNEX 87

Personalized environmental control systems (PECS) for heating, cooling, ventilation, lighting and acoustic allow control of the localised environment at occupants' workstations by their preference instead of conditioning an entire room to uniform conditions. This improves comfort, satisfaction, health of occupants, and the energy efficiency of the entire heating, ventilation and air-conditioning (HVAC) system substantially. Personalized ventilation can also protect against cross-contamination, which is critical in open-plan offices and workplaces where occupants are closely spaced. Market share and interest in PECS is likely to increase, as pandemic-proofing becomes a consideration in building design. Suitable applications of PECS are for workplaces with mainly sedentary activity such as offices, banks and control centres. Due to the COVID-19 pandemic, where many people have been working from home, there will likely be an increase in home working places for which PECS may also be a solution.

EBC Annex 87 has recently begun, with the overall objective to establish design criteria and operation guidelines for PECS and to quantify the benefits of PECS regarding 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 controlling local heating, cooling, ventilation, air cleaning, lighting and acoustics. It includes desk-mounted systems and integration of furniture 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.



A generic example of a desktop-based personalized heating, cooling, and ventilation system.
Source: EBC Annex 87



A generic example of a chair-based personalized heating, cooling, and ventilation system.
Source: EBC Annex 87

Objectives

The main 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;
- quantify the benefits of PECS regarding health, comfort, energy, and costs.

Deliverables

The deliverables from the project are expected to be as follows:

- a state-of-the-art report on PECS;
- 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 proposal was developed in 2021. A one-year preparation phase for the project was approved at the November 2021 EBC Executive Committee Meeting.

Meetings

In 2021, two preparatory expert meetings were held to develop the project proposal. A large number of international experts and interested parties joined these meetings. The first meeting was held in September 2021 and the second meeting was held in October 2021. Both meetings were held online.

Project duration
2021–2026

Operating Agents
Ongun Berk Kazanci and Bjarne W. Olesen, International Centre for Indoor Environment and Energy (ICIEE), Technical University of Denmark, Denmark

Participating countries (provisional)
To be confirmed

Further information
www.iea-ebc.org

Ongoing Research Projects

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

INDIRECT EVAPORATIVE COOLING
(EBC ANNEX 85)

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

BUILDING ENERGY CODES
(EBC WORKING GROUP)

POSITIVE ENERGY DISTRICTS
(EBC ANNEX 83)

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

DATA-DRIVEN SMART BUILDINGS
(EBC ANNEX 81)

DATA-DRIVEN SMART BUILDINGS
(EBC ANNEX 81) RESILIENT COOLING OF BUILDINGS
(EBC ANNEX 80)

OCCUPANT-CENTRIC BUILDING DESIGN AND OPERATION
(EBC ANNEX 79)

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

COST-EFFECTIVE BUILDING RENOVATION AT DISTRICT LEVEL COMBINING ENERGY EFFICIENCY AND RENEWABLES
(EBC ANNEX 75)

COMPETITION AND LIVING LAB PLATFORM
(EBC ANNEX 74)

TOWARDS NET ZERO ENERGY RESILIENT PUBLIC COMMUNITIES
(EBC ANNEX 73)

ASSESSING LIFE CYCLE RELATED ENVIRONMENTAL IMPACTS CAUSED BY BUILDINGS
(EBC ANNEX 72)

BUILDING ENERGY EPIDEMIOLOGY:
ANALYSIS OF REAL BUILDING ENERGY USE AT SCALE
(EBC ANNEX 70)

STRATEGY AND PRACTICE OF ADAPTIVE THERMAL COMFORT IN LOW ENERGY BUILDINGS
(EBC ANNEX 69)

AIR INFILTRATION AND VENTILATION CENTRE - AIVC
(EBC ANNEX 5)

Energy Efficient Indoor Air Quality Management in Residential Buildings

EBC ANNEX 86

The energy performance of new and existing residential buildings needs to be radically improved to meet ambitious climate change goals while maintaining a healthy, acceptable and desirable indoor environment. While ventilation is the main strategy that is adopted for indoor air quality (IAQ) management, other technologies influencing IAQ (e.g. air filtration) are available as well. However, there is no coherent assessment framework to rate and compare the performance of IAQ management strategies. This project is therefore focusing on assessing the IAQ performance and identifying the optimal solutions for maximizing energy savings while guaranteeing a high level of indoor air quality in new, renovated and existing residential buildings.

To achieve this, the aim of this project is to gather existing scientific knowledge and data on pollution sources in buildings, investigate opportunities of applying 'Internet of Things' (IoT) -connected sensors; to study current and innovative case studies of IAQ management strategies and develop road maps to ensure the continuous performance of the proposed solutions over their lifetime.

The project is focused on residential buildings, because they represent the largest section of the building stock. They are also understudied and have the broadest range of uses. Additionally, residential building projects often lack the funds for extensive bespoke engineering and therefore require robust cost-effective standardised solutions that can be implemented at large scale.

For the study of specific IAQ management strategies, the project is mainly focusing on the use of smart materials (materials that have an ability to actively or passively influence IAQ in the space) and smart ventilation (as defined by AIVC VIP nr. 38), since these are strategies that have a high energy efficiency potential. Air cleaners are already being studied in EBC Annex 78, and are therefore not studied in detail in this project.

We bring experts from mechanical engineering, building science, chemistry, data science and environmental health together with other stakeholders to work towards consensus on the basic assumptions that underlie such a performance assessment and practical guidelines and tools to bring the results to practice.

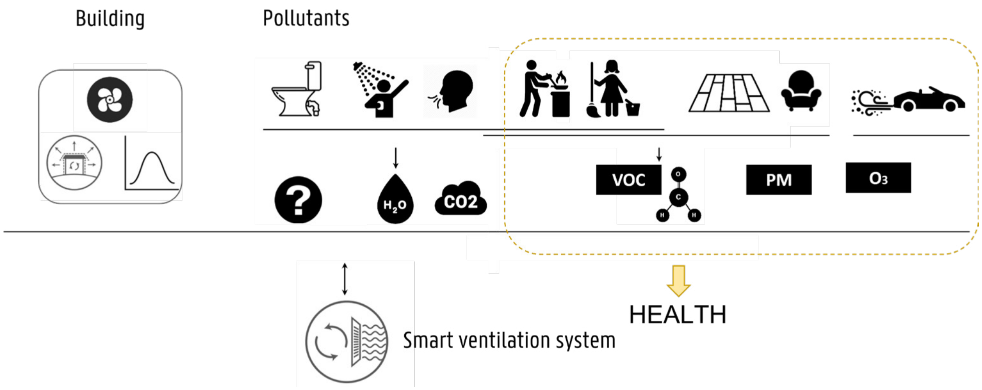
The project main goal is to accelerate the development of better and more energy efficient IAQ management strategies to address rapidly changing expectations of home environment due to the challenges of peak oil, climate change and pandemics.

This project is further developing work carried out in the EBC Project, 'Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings' and is collaborating with the EBC Project, 'Annex 5: Air Infiltration and Ventilation Centre (AIVC)' in organizing meetings and disseminating of project results.

Objectives

The main objectives and scope are as follows:

- Develop a consistent set of metrics to assess energy performance and indoor environmental quality of an indoor air quality management strategy.
- Propose an integrated rating method for the performance assessment and optimization of energy efficient strategies of managing the IAQ in new and existing residential buildings.
- Identify or further develop the tools to assist designers and managers of buildings in assessing the performance of an IAQ management strategy using the rating method.
- Gather existing scientific knowledge and data on pollution sources in buildings to provide new standardized input data for the rating method.
- Study the potential use of smart materials as an IAQ management strategy.
- Develop specific IAQ management solutions for retrofitting existing buildings.
- Improve the energy efficiency of the indoor air quality management strategies in operation and to improve their acceptability, control, installation quality and long-term reliability
- Disseminate the project findings.



A proposal to integrate health based metrics related to occupant activities, emissions from materials and outdoor pollutants in the numerical performance assessment of smart ventilation systems.
Source: Klaas De Jonge, AIVC Webinar, November 2021

Deliverables

The planned deliverables for the project include:

- a comprehensive overview of all the literature that was used and highlighted during the project;
- a set of open databases that brings together all the (references to) data collected to support the work in the project;
- an overview report on methods and tools for the rating of IAQ management strategies;
- a collection of case studies and demonstrations of energy efficient IAQ management strategies.

Progress

The working phase for the project was approved at the June 2021 EBC Executive Committee Meeting. All the project subtasks have been working on the first targets. The Pandora database was made available through a web-interface as a first step towards developing the open database deliverable. The collection of data has started for the literature review.
The intermediate results and activities in the project were reported in a series of webinars disseminate through the collaboration with AIVC.

Meetings

The following meetings were held during 2021:

- a series of webinars in April, October and November 2021 (www.aivc.org/events/webinars),
- an online symposium for project participants in September 2021, and
- online project meetings in April, June, and September 2021.

Project duration
2020–2025

Operating Agents
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, Türkiye, UK, USA
Observers: Chile

Further information
www.iea-ebc.org

Indirect Evaporative Cooling

EBC ANNEX 85

Building energy consumption accounts for almost one-third of total energy consumption. Over 10% of building energy consumption is used for air conditioning and indoor thermal comfort in hot seasons. Changing the air conditioning mode is one essential solution to meet cooling demand without increasing power consumption and carbon emissions. Although over 85% of cooling worldwide is achieved by mechanical refrigeration, more than 40% of the cooling can 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;
- indirect evaporative cooling (IEC) to produce cooling air or cooling water.

This project aims to study the feasibility of IEC technologies and provide the roadmap of using these technologies in various dry climate zones.

The following project tasks are planned:
- Definition and field study
- Feasibility study of IEC technologies
- Fundamental study
- Simulation tool and guidelines

The targeted audience of the project includes design and planning practitioners, scientific communities, government officials and manufactures.

Objectives

The aim of the project is to develop international co-operation on IEC technology development. The project is focusing on discovering the current challenges of using IEC technology and reaching a scientific and applicable roadmap of applying IEC in various dry climate zones. The project objectives are to:

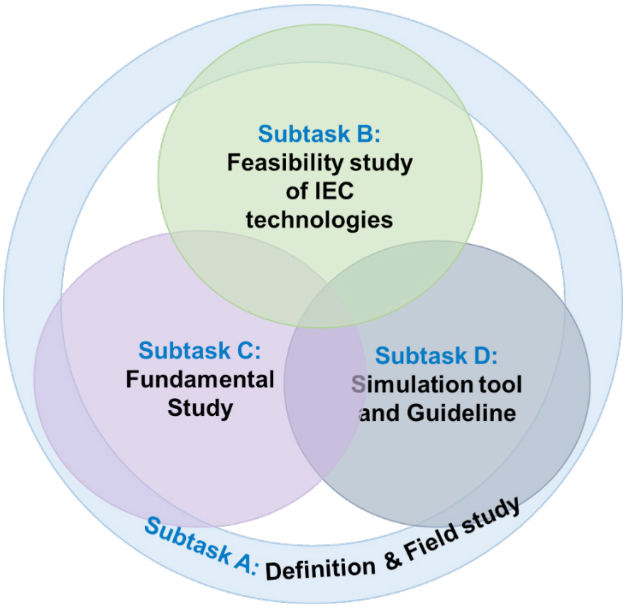
- investigate IEC and conventional cooling systems to gather the information on the equipment and maintenance cost, space requirements, environmental impacts and limitations of using IEC widely;
- carry out field testing of existing IEC systems in various climate zones to build a field test database;
- develop a general theoretical analysis method of IEC processes to guide the design of various IEC systems;
- evaluate water and electricity consumption of IEC processes;
- model the IEC systems and create a tool to simulate different types of buildings under various dry climate zones;
- develop a guide for designing the IEC systems for different types of buildings under various 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', (including theoretical analysis results for the general performance of indirect evaporative cooling technologies; fundamental analysis results through thermal analysis and optimisation; design guidelines for indirect evaporative cooling technologies and feasibility analysis of indirect evaporative cooling technologies);
- a simulation tool for various types of IEC technologies for different types of buildings and dry climate zones;
- a collection of case studies and feasibility analysis of indirect evaporative cooling technologies worldwide;
- reports of fundamental analysis result through thermal analysis and optimisation;
- design guidelines for indirect evaporative cooling technologies.

Progress

Information about typical projects from China, Denmark, Belgium has been collected, with further projects from France and USA underway. Two real-world cases have been collected from China, one from Denmark, and another case from Belgium.



This schematic shows the relation of the four project Subtasks. 'Definition & field study' focuses on collection of real application cases of indirect evaporative cooling (IEC) / direct evaporative cooling (DEC) technologies, and the real application performance as well as possible constraints of using IEC / DEC technologies. 'Feasibility study of IEC technologies' focuses on performance analysis of IEC / DEC technologies, including cooling performance, electricity consumption, water consumption performance and other aspects of operational performance. 'Fundamental study' focuses on internal performance analysis including process construction and internal parameters optimisation with thermal analysis and thermodynamic analysis - This represents the theoretical basis of the other three subtasks. 'Simulation tool and guideline' is providing a tool to be used in the other three Subtasks.
Source: EBC Annex 85

The typical system and process have been analysed, including IEC water chiller process; cross IEC air cooler process and countercurrent combined parallel IEC air cooler. Cooling efficiency and water consumption efficiency are identified. Water consumption could be evaluated and compared with electricity consumption, which takes about 20%~30% of total electricity consumption. Cooling performance combined electricity consumption as well as water consumption performance has been analysed for the typical systems, to show the basic level of the performance, suitable application climates of the systems are obtained according to the analysis.

Thermal analysis has been carried out for basic evaporative cooling process. 'T-Q charts' are used to show heat and mass transfer process and analyse the transfer losses. Matching performance is identified for evaporative cooling process, including flow rate matching and inlet parameter matching, to direct the process design. Thermal analysis is carried out for Typical IEC / DEC processes, including IEC water chillers, cross IEC air coolers and counter-current IEC air coolers. Optimised process structures are discussed as well as internal optimized parameter, including both thermal parameter and flow parameter consider flow resistance. Literature review of IEC technologies is started.

A questionnaire was circulated to understand participants' experiences with simulation, simulation tools, IEC systems, numerical models, and data availability to validate developed models. This covered common simulation tools, such as EES, Matlab and GenOpt, and so on.

Real field-testing data of several cases have been collected for IEC water chillers and cooling towers for verifying the simulation analysis. Typical process simulation has been carried out, including IEC air coolers, cooling towers and IEC water chillers.

A building simulation exercise was carried out for some participating countries. A typical building was defined and simulation work was carried out in different climates. The cooling load variation curves with climates are obtained and could be used as the basis for IEC / DEC process performance analysis.

Meetings

The following online meetings were held in 2021:
- 3rd project workshop meeting, in April 2021,
- 4th project workshop in September 2021, and
- 5th project workshop in December 2021.

Project duration
2020 – 2025

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

Participating countries
Australia, Belgium, P.R. China, Denmark, France, Türkiye, USA
Observer: Egypt

Further information
www.iea-ebc.org

Demand Management of Buildings in Thermal Networks

EBC ANNEX 84

The collective heating and cooling of buildings, known as district heating and cooling (DHC) networks are considered the most sustainable ways to meet the heating and / or cooling demand in the dense populated areas where heat pump installation is impractical. In the IEA strategy Net Zero by 2050, the DH networks are estimated to provide globally more than 20% of final energy demand for space heating. In the European Union only, this share could be up to 50% in 2050.

The energy planners consider the coupling of electricity and heating / cooling sector as a strategic element delivering flexibility needed for successful decarbonisation and smart transition of future energy systems. In order to fulfil their role in the future, the DHC networks are currently undergoing a major upheaval. The planned revolution requires that no longer must the production follow the demand but the demand must be flexible to adjust according to variable production from renewable energy, such as sun and wind. This cannot be achieved without energy optimisation and control at customer level to reduce return temperatures and enable heat and / or cooling demand response from customer installations.

As research has proven - and international communities such as the OECD or EU, are emphasising - meeting the milestones on the decarbonisation roadmaps will not be feasible solely by technology development. It must be accompanied by engagement of occupants, customers, users, since they are the ones to choose, use and tweet about new technological and user-friendly solutions. Therefore, buildings and customers should not anymore be just considered as a simple demand-side variable, but rather as communities that are capable of delivering technical solutions (e.g. different way of storage) and systemic interventions (e.g. advanced control, pre-loading of buildings) and / or co-creating sustainable business cases for DHC network development, and thus speeding up the process towards carbon-free societies.
There is a lack of projects that directly investigate what social and technological challenges must be overcome at the demand side in order to fruitfully harvest the energy flexibility potential offered by buildings to enhance the operation of DHC networks and thereby viable and successful transition towards low-carbon future and smart energy systems.

Objectives

Objectives

The overall project aim is to provide a comprehensive knowledge base and tools for successful activation of the demand management of buildings in DHC Nets. The project is investigating both the social, technological and management challenges and how these can be overcome for various building typologies, climate zones and local conditions as well as how digitalisation of heating demand (real-time data from smart meters) can speed up the activation process.

The specific objectives of the project are to:

- map partners / actors involved in the energy chain in DHC Nets for different building typologies, network configurations and local legal framework;
- provide recommendations for collaboration models / instruments viable and beneficial for all partners;
- evaluate and provide design solutions for new and existing building heating and cooling substations and installations for successful demand management;
- develop methods and tools to utilise the smart heat meter data for real-time data modelling of DHC Nets;
- provide knowledge from and drive adaptation and visualisation of project results through case studies.

Deliverables

The planned deliverables from this project include:

- comprehensive knowledge about the actors involved in the demand response of building in thermal networks;
- design guidelines for new and existing DHC

substations and heating / cooling installations with specification of minimum technological requirements for enabling demand management beneficial for buildings and DHC Nets;
- method to derive new dynamic building characteristics from real-time data from smart heat meters used for DHC Nets real-time modelling;
- case studies of demand management at either single technology, building or DHC community level.

Progress

After the first preparation phase, the project had his first working meeting in the fall of 2021. The aim of it was to kick-off the initial activities in the project including a review of terminology and technologies at building sites applicable for demand management activation, and tools used for modelling of thermal storage potential of building(s). The meeting was also used to complement already existing database of case studies in the project.

Meetings

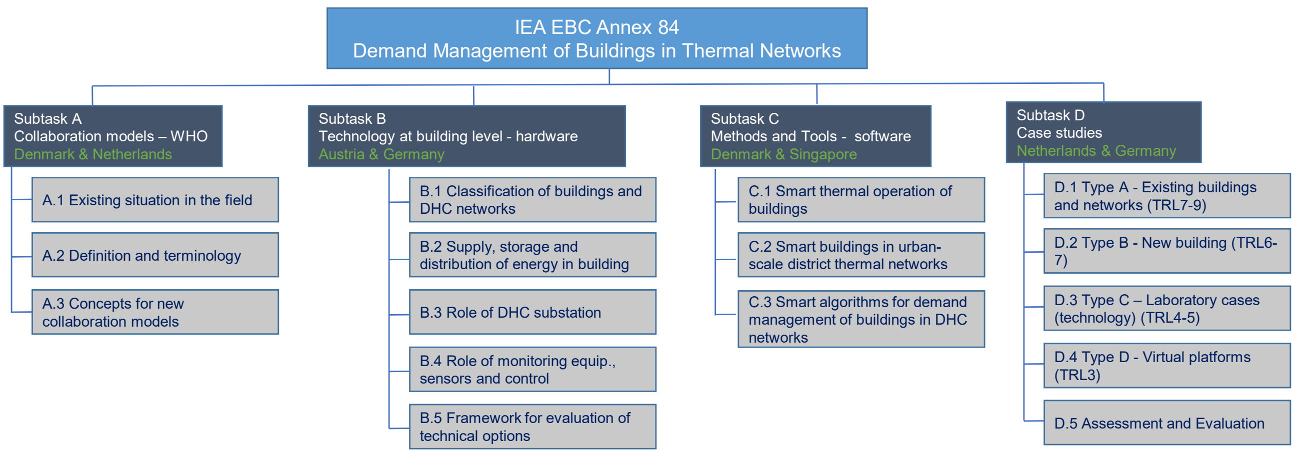
In 2021, the following meetings took place:
- 2nd preparation workshop was held online in May 2021,
- 1st working meeting was held in September 2021 as hybrid meeting with on-site participation in Copenhagen, Denmark

Project duration
2020–2025

Operating Agents
Anna Marszal-Pomianowska, Aalborg University, Denmark

Participating countries
Austria, Belgium, Denmark, Italy, the Netherlands, Singapore, Türkiye, UK

Further information
www.iea-ebc.org



Structure of the project with specification of the Subtasks.
Source: Anna Marszal-Pomianowska, Aalborg University

Building Energy Codes

EBC WORKING GROUP

Several countries are adopting increasingly stringent, yet cost-effective building energy codes. This is a result of the significant reductions in energy use these countries have observed after introducing updated codes. 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 net zero energy construction standards, and the substantial amount of time it takes for building codes to integrate research and technology breakthroughs.

In 2018, the IEA's EBC Programme launched the Building Energy Codes Working Group (BECWG) to address these challenges. The BECWG goals are centered around furthering building energy codes research and collaboration efforts to advance energy efficiency in buildings and communities. It is dedicated to the consideration of building energy codes in EBC annexes, along with the integration of annex results into enhancing the existing building energy codes.

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;
- 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:

- Activity 1: Analysis and technical reports. The project is conducting surveys on basic code 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.
- Activity 2: 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. The project is also hosting an Annual Building Energy Code Symposium, which allows the project members to exchange ideas on relevant topics of interest.
- Activity 3: Dissemination. In addition to conducting analyses and facilitating webinars, the project is working towards disseminating their research findings to wide range of regional stakeholders and collaborate with them closely to promote code improvements and implementation of best practices. The project is disseminating the findings through the EBC website, conference papers, and quarterly newsletters.

Progress

Analysis and technical reports

- In 2021, the project published two reports titled 'Building Energy Codes and Other Mandatory Policies Applied to Existing Buildings' (led by Australia) and 'Best Practices for Building Energy Codes Compliance' (led by the United States).
- The project began work on a paper titled 'Virtual Building Energy Code Inspections' (led by the United States) scheduled for completion in 2022. The paper examines early adopters of virtual building energy code inspections in various countries and identifies when they add value to a jurisdiction.

Organization and facilitation of webinars

- As part of its webinar series, the project hosted two webinars in 2021. The webinars focused on balancing costs and benefits of building energy codes and

Researchers measure the performance of heating, ventilation, and air conditioning (HVAC) systems. Having robust and frequent inspections of building plans, construction, and energy-intensive equipment improves compliance and our understanding of building energy codes.
Source: Pacific Northwest National Laboratory, 2019

building energy codes and other mandatory policies applied to existing buildings. In addition, the project hosted a webinar on cross-national comparison of building energy codes around the world (presented at the 2021 U.S. National Energy Codes Conference).

- The project held its third Annual Symposium virtually in November 2021. The event comprised a business meeting for working group members and two technical sessions on building energy codes, which were open to the public. These technical sessions focused on building energy codes to achieve carbon reductions, and national roadmaps that incorporate building energy codes.

Dissemination

- The project published three newsletters in 2021, communicating details on activity updates, papers, upcoming webinars, and research highlights.
- The project met with EBC Annex 80's Resilient Cooling of Buildings subtask on Policy Actions to explore opportunities for collaboration on codes / regulations that advance resilient cooling strategies.
- Project participants also participated in reviewing the buildings chapter and Summary for Policymakers of the upcoming IPCC 6th Assessment Report, Working Group III (Mitigation).

Meetings

- EBC Building Energy Codes Working Group Annual Symposium in November 2021
- Webinar on 'Codes Around the Globe: A Cross-national Comparison of Building Energy Codes' 2021 National Energy Codes Conference Summer Seminar Series in September 2021
- Webinar on 'Building Energy Codes and Other Mandatory Policies Applied to Existing Buildings' in June 2021
- Webinar on 'Balancing Costs and Benefits of Building Energy Codes: An Evaluation of Methodologies for Assessing Cost-Effectiveness' in April 2021

Project duration
2019–2022

Operating Agents
David Nemtzow, Department of Energy, USA
Michael Donn, Victoria University of Wellington, New Zealand
Meredydd Evans, Pacific Northwest National Laboratory, USA

Participating countries
Australia, Brazil, Canada, P.R. China, Ireland, Italy, Japan, New Zealand, Portugal, Singapore, Sweden, UK, USA

Further information
www.iea-ebc.org

Positive Energy Districts

EBC ANNEX 83

The concept of Positive Energy District (PED) describes an area within the city boundaries, capable of generating more energy than is consumed, while being agile / 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 should first be based on energy efficiency solutions, support the minimisation of impacts on the connected centralised energy networks by offering options for increasing onsite load-matching and self-use of energy, technologies for short- and long-term energy storage, and providing energy flexibility with smart controls and techniques. In this context, the concept of PED is aimed to facilitate the transition of the urban environment toward carbon neutral communities by including in the urban areas lighthouse innovating areas pushing towards synchronised and parallel development of energy efficient technologies, public perception of building energy systems, new sustainability paradigms and business models. However, as a novel research idea, the PED concept needs further refinement of definitions, improvement in energy and systems modelling for true holistic design of neighborhoods; development of new and integrated sustainability assessment approaches and testing of all aforementioned points within case-studies to establish bi-directional improvements between practice and methodological advances. The project aims at targeting these issues with an integrated approach.

Objectives

The main objectives and scope are as follows:

- Map the city, industry, research and government (local, regional, national) stakeholders and their needs and role with the specific PED project objectives. The main purpose is to ensure the involvement of the principal stakeholders in the development of relevant definitions and recommendations.
- Create a shared in-depth definition of a positive energy district by means of 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 and also economic and social issues such as acceptability.
- Explore novel technical and service opportunities related to monitoring solutions; big data; data management; smart control and digitalisation technologies as enablers of PEDs.
- 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 planned main project outcomes are as follows:

- definitions and key concepts for positive energy districts;
- methods, tools and technologies for realising positive energy districts;
- governance principles and impact assessment for positive energy districts, and case studies on positive energy districts and related technologies.

Progress

The project work in 2021 has seen substantial advancement of the literature review throughout all subtasks; the development of several innovative research activities together with many scientific publications and several workshops and seminars.

The literature review was developed with focus on several different aspects. One of the aspects investigated was the creation of a PED case-studies database, aimed at mapping the variability of a wide range of parameters involved in the definition of PEDs. More than 60 case studies were investigated through literature review

Group photo from the online January 2021 Experts Meeting.
Source: EBC Annex 83

and big data mining collecting around 20 parameters of relevant impact on PED design.

The literature review was also developed throughout the topic of sustainability applied to PEDs. The environmental, economic and social domains were investigated by creating a literature repository with around 100 entries including scientific papers and project reports. An extended report on the topics of sustainability assessment state of the art is in its finalisation stage.

Furthermore, an online repository was also developed for PEDs including available monitored and simulated data of the case studies investigated.
Lastly, the layout for the data collection approach and methodology was structured for the PED demo case-studies to be investigated within the project.
In 2021 the project tasks have planned and implemented different internal and open workshops on:
- PED definitions;
- Energy System Component Data Library, aimed at harmonising data modelling for energy systems components;
- PED performance assessment. The workshop was titled 'Positive Energy Districts (PED) performance assessment: methodologies, key performance indicators and future outlooks' and included more than 100 participants among internal annex participants and external ones.

All outcomes of the open forums and workshop have been used in developing project deliverables and meeting the project objectives.

Meetings
- 1st Working Meeting held in January 2021
- 2nd Working Meeting held in April 2021
- 3nd Working Meeting held in September 2021

Project duration
2019 – 2024

Operating Agents
Pekka Tuominen and Francesco Reda, VTT Technical Research Centre of Finland Ltd., Finland

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, Türkiye, UK

Further information
www.iea-ebc.org

Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems

EBC ANNEX 82

As buildings account for approximately 40 % of annual energy use worldwide, they must play a significant role in providing safe and efficient operation of the future resilient energy systems. The potential of buildings to play a central role in this transition is greatest where consumers and "prosumers" (e.g. buildings with PV) are able to modulate their demand / conversion / storage capacity in order to satisfy the needs of the energy networks while still ensuring good thermal indoor climate and minimal disruption to the building occupants. Flexibility can be offered either at the scale of a single building or at the scale of clusters of buildings. Energy flexible buildings and clusters rely on some form of storage and advanced control strategies to adapt their dynamic energy use to support the energy networks, which makes them inherently more resilient.

The aim of this project is to extend the findings from the completed EBC Project, 'Annex 67: Energy Flexible Buildings' (see page 54). The EBC Annex 67 project has revealed areas where further work is needed to ensure that energy flexibility from buildings will become assets for future energy networks. The areas identified are:

- scaling from single buildings to clusters of buildings (aggregation);
- energy flexibility and resilience in multi-carrier energy systems (electricity, district heating / cooling and gases);
- acceptance / engagement of the stakeholders;
- business models.

Objectives

The project objectives are as follows:

- demonstrate and further develop the project characterisation and labelling methods in order to make them commonly accepted;
- investigate aggregation of energy flexibility from clusters of buildings both physically connected and commercially connected (not necessarily physically connected) via an aggregator;
- investigate the aggregated potential of energy flexibility services from buildings and clusters of buildings located in different multi-carrier energy systems;
- demonstrate energy flexibility in clusters of buildings through simulations, experiments and field studies;
- map the barriers, motivations and acceptance of stakeholders associated with the introduction of energy flexibility measures in buildings and clusters of buildings;
- investigate how to include the views of stakeholders in the development of feasible technical solutions;
- investigate and develop business models for energy flexibility services to energy networks;
- formulate recommendations to policy makers and government entities involved in the shaping of future energy systems.

Deliverables

The planned deliverables from this project include:

- a summary of the project findings;
- a collection of case studies;
- recommendations for policy makers and government entities;
- a project summary report.

Progress

The project is still in the early phase and the workplan of the four project tasks have been detailed. The project tasks organise monthly or bi-monthly task meetings. The literature reviews have started on:

- methodologies & tools from planning to operation for energy flexible districts /communities
- energy flexibilities and resilience for buildings and communities
- understanding customer participation in building demand management programs and service thresholds for flexible operations

Demonstration of heating flexibility in smart homes in Copenhagen, Denmark:
(left) An overview of the newly built Nordhavn district, and (right) facades of the Sundmolehusene apartments.
Source: DTU; reference: Demand side management of heat in smart homes: Living-lab experiments.
https://doi.org/10.1016/j.energy.2020.116993

The investigation of business models for energy flexibility has begun. On-going tasks include:

- identifying the different kinds of business cases from existing case studies both viewed from the consumer and the grid operator point of view
- investigating stakeholder motivations and barriers

In addition, a group of participants have started to work on the definition of research questions for common exercises.

A '10 Questions' article is invited to submit to the Journal Building and Environment. In the article, ten research questions are posed that are the basis for the work in the project.

Meetings

The following meetings were held online in 2021:

- 3rd preparation meeting took place in April 2021,
- 1st working meeting took place in October 2021.

Project duration
2019–2025

Operating Agents
Søren Østergaard Jensen, Technical University of Denmark, Denmark
Rongling Li, Technical University of Denmark, Denmark

Participating countries
Austria, Belgium, Canada, P.R. China, Denmark, Finland, France, Germany, Ireland, the Netherlands, Portugal, Spain, Switzerland, UK, USA

Further information
www.iea-ebc.org

Data-Driven Smart Buildings

EBC ANNEX 81

Digital technology has potential to save energy through advanced control and operation of building heating, ventilation and air-conditioning (HVAC) systems. Emerging digital technologies include:
- the 'Internet of Things';
- Artificial intelligence (AI), machine learning (ML) and related data analytics techniques;
- digital platforms and semantic web technologies.

The project aim is to accelerate an adoption of digitalisation and energy saving data-driven services in non-residential buildings. It seeks to optimise energy consumption from HVAC equipment through data-driven control strategies and equipment fault diagnostics. It also aims to address interoperability and other data management barriers which prevent digital technologies from being adopted at scale.

In collaboration with the Mission Innovation Affordable Heating and Cooling Innovation Challenge, the project is supporting researchers and innovators through the hosting of AI competitions.

Objectives

The project objectives are to:
- provide knowledge, standards, protocols and procedures for low-cost high-quality data capture, sharing and utilisation in buildings;
- develop a methodology for control-oriented building modelling that facilitates testing, developing and assessing the impacts of alternative energy-efficient building HVAC control strategies in a digital environment;
- develop building energy-efficiency (and related) software Applications that can be used and ideally commercialised for reducing energy consumption in buildings;
- drive adoption of project results through case studies, business model innovation and results dissemination.

Deliverables

The planned deliverables from this project include:
- a proposal for governments to lead by example in the use of data-driven smart building solutions in their own buildings and, particularly, to adopt the HVAC data-sharing principles and processes developed in this project;
- a report on functional-requirements for a 'minimum viable product' (MVP) Open Data Platform that could support low transaction cost data-sharing amongst an ecosystem of building services innovators;
- an online repository of exemplar data sets for building analytics research;
- data-driven control-oriented building models suitable for model predictive control in different building typologies and scenarios;
- a software repository, containing prototype software implementations and Application descriptions for energy saving HVAC services;
- a 'grand challenge' / 'hackathon' style competition for incentivising innovators to develop data-driven applications.

Progress

In 2021, work progressed on the production of a range of state-of-the-art reports relating to data platforms, meta-data schemas and data-driven services such as model predictive control (MPC) and fault detection and diagnosis (FDD). The aim of these reports was to better understand the commercial landscape of available tools and services in the field of data driven smart buildings. These reports will be summarized in an overarching review report for the project.

Meta-data schemas, suitable for the operational phase of a building's life cycle, were reviewed. These schemas provide means for exchanging data with relevant contextual meaning. This enables machines to reason with data, ultimately enabling machine learning and other advanced analytics tools to be readily deployed across diverse buildings and HVAC types.

What is a data-driven smart building?
Source: EBC Annex 81

Platforms for exchanging data between industry stakeholders, were also reviewed - covering attributes relating to (i) platform governance, (ii) data access and security, (iii) data streaming protocols and interoperability, (iv) data storage, management and retrieval, (v) enablement of building automation and (vi) software application hosting.

Various Model Predictive Control (MPC) 'test cases' were collected and six of them were selected for deployment in the BOPTest benchmarking test environment

Each MPC test-case contains relevant datasets, a control-oriented model and an emulator suitable for deployment in the BOPTest environment.
A pilot survey was conducted on the technical obstacles involved in deploying data-driven MPC solutions. The survey highlighted the importance of data issues as a key barrier to widespread adoption.

Fault Detection and Diagnosis (FDD) data sets, with relevant ground truth data annotation, are also being collected and shared as a means of testing the efficacy of FDD algorithms being developed by Annex participants.
An industry panel was organised to explore practical challenges to the implementation of smart building technologies. The panel also explored perceptions of what it is to be a 'data-driven smart building'. The resulting word cloud (illustrated above) hints at a vision of a smart building as one that has understated automation, working in the background, to anticipate and responsively (i) service the needs of occupants and (ii) optimise the operation of equipment parts as an integrated system. Meta-KPIs are under investigation to further define the digitalisation needs of grid interactive efficient buildings.
The project completed its first competition on reinforcement learning for dispatch of storage in grid integrated buildings. A consortium including nine project participants have successfully attracted funding under ERAnet Smart Energy Systems joint call 2020 (Mission Innovation Call 2020) on 'Digital Transformation for Green Energy Transition'. This will enable the project to deliver the previously anticipated competitions.

Meetings

The following meetings were held in 2021:

- the third Research Results Webinar in February 2021,
- the second Expert Meeting, online, in May 2021,
- the fourth Research Results Webinar in June 2021,
- the third Expert Meeting, Online in September / October 2021.

Project duration
2020–2024

Operating Agents
Stephen White, CSIRO, Australia

Participating countries
Australia, Austria, Belgium, Canada, P.R. China, Denmark, Ireland, Japan, the Netherlands, Norway, Singapore, Sweden, UK, USA

Further information
www.iea-ebc.org

Resilient Cooling of Buildings

EBC ANNEX 80

The use of energy for space cooling is growing faster than for any other end use in buildings. Rising demand for space cooling is already putting enormous strain on electricity systems in many countries, as well as driving up greenhouse gas emissions. There is no doubt that the global demand for space cooling will continue to grow for decades to come. Meeting peak electricity demand would become a major challenge. It is therefore vital to curb the rapid growth in demand for air conditioning and achieve sustainable development of the sector of cooling.

The project is investigating resilient cooling applications against a variety of external parameters such as climate, building typologies, internal loads and occupancy profiles, various levels of BMS capabilities and automation, new buildings and retrofitting of existing buildings.

Objectives

The general objective of the project is to support a rapid transition to an environment in which resilient low-energy and low-carbon cooling systems are the mainstream and are the preferred solutions for cooling and avoiding overheating issues in buildings. The specific objectives of the project are to:

- quantify the potential benefits of resilient cooling for a wide range of building typologies, climate zones, functional specifications and other boundary conditions;
- systematically assess benefits, limitations and performance indicators of resilient cooling;
- identify barriers to implementation and conduct research to overcome such barriers and facilitate implementation on a large scale;
- provide guidelines for the integration of resilient cooling systems in energy performance calculation methods and regulations. This includes specification and verification of key performance indicators;
- extend the boundaries of existing low energy and low carbon cooling solutions and their control strategies, and develop recommendations for flexible and reliable resilient cooling solutions that can create comfortable conditions under a wide range of climatic conditions;
- investigate the real performance of resilient cooling solutions through field studies, and analyse performance gaps and develop solutions to overcome them;
- analyse, exchange and encourage policy actions, including minimum energy performance standards, building codes, financial incentives and product labelling programmes, educational initiatives, as well as others;
- establish links with other international programmes, such as KIGALI – Cooling Efficiency Programme, Mission Innovation Challenge #7 and other related IEA Technology Collaboration Programmes.

Deliverables

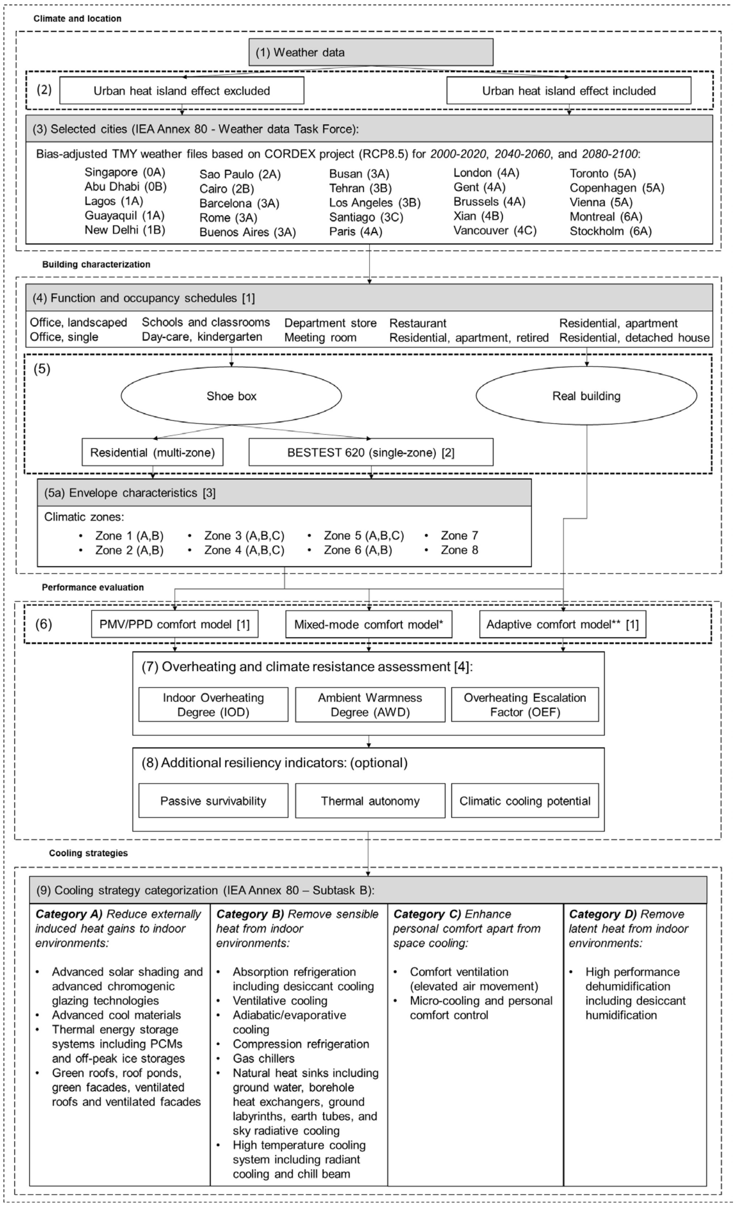
The project is producing the following deliverables:

- an overview and state-of-the-art report for resilient cooling;
- a resilient cooling source book;
- a report on resilient cooling field studies;
- resilient cooling design and operation guidelines, and
- recommendations for policy, legislation and standards.

Progress

In 2021, the project reached the third year of its working phase and continued to contribute to resilient cooling in the various fields of its mission statement. The definition and development of fundamentals like the definition of resilience and thermal conditions or generation of future weather files for building simulation has been being finalised. While the assessment of cooling technologies is in progress the last phase of the project would also focus on pushing technological boundaries.

The definition of key performance indicators of resilient cooling, an important task of the project, has progressed substantially. Three categories, each consisting of three levels of indicators expressing their specificity have been defined as following:



Framework for evaluating the resilience of different cooling technologies, modified based on the framework developed by the EBC Annex 80 Thermal Condition Task Group.
Source: Attia et al., Framework to evaluate the resilience of different cooling technologies. Sustainable Building Design Lab, Liege Belgium, DOI: 10.13140/RG.2.2.13865.93282021

- comfort and health metrics;
- energy and environment metrics;
- socio-economic.

Metrics for carbon emissions as well as exceedance hours for humidity are also being considered. The collection of metrics is planned to be finalised and tested in the technology assessment, which is being carried out through dynamic simulations. For that purpose, the simulation task group created a methodology guideline to ensure high-quality comparable results across the numerous participating institutions.

Several working groups continued and finished their tasks. The weather data task group has created Typical Meteorological Years (TMY) as well as representations of heat wave events for future time periods (2020s, 2050s, 2090s) which are available for download on the EBC Annex 80 website. Data will be published for cities covering most climate zones from the ASHRAE classification (ANSI/ASHRAE Standard 169). The definition of a framework for the evaluation of cooling technologies has been completed by a second task group. The framework has been published in an open access report (see figure).

The project also published the paper on "Resilient cooling strategies - a critical review and qualitative assessment" in Energy and Buildings Journal (https://doi.org/10.1016/j.enbuild.2021.111312).

Started in March the "Advisory Board of Practitioners of Resilient Cooling" meets on a regular basis to share their knowledge and experience on topics such as the definition of resilience as regards cooling, key performance indicators and metrics of resilient cooling and future weather data for building simulations.

Meetings

The 4th Expert Meeting was held online in April and the 5th Expert Meeting at Politecnico di Torino in October 2021 in Turin, Italy.

Project duration
2019–2023

Operating Agent
Peter Holzer, IBR&I Institute of Building Research and Innovation, Austria

Participating countries
Austria, Australia, Belgium, Canada, P.R. China, Denmark, France, Italy, Japan, UK, USA

Further information
www.iea-ebc.org

Occupant-centric Building Design and Operation

EBC ANNEX 79

Occupants' interactions with their interior environments have been identified as a major influence on building performance. Reasons for these – mostly comfort-related – interventions are, among others, dissatisfaction with the building automation or systems' controls, inappropriately designed or malfunctioning interfaces and building systems, or disregard of occupants' needs in building design and operation. According to different studies, the energy consumption of buildings can vary by up to a factor of two as a result of occupants' interventions.

Despite significant progress in experimental research and occupant behaviour modelling, design and building operation practice shows that many of the models do not represent the manifold human interactions with a building appropriately enough, and that there is no guidance for designers and building managers on how to apply occupant behaviour (OB) models in standard practice. This project seeks to bridge this gap between science and building practice, to provide new insight into comfort-related occupant behaviour and interactions in buildings, and to exploit new data mining techniques to enhance occupant modelling.

Objectives

The overall goal of the project is to integrate and implement knowledge and models of occupancy and occupant behaviour into the design process and building operation in order to simultaneously improve energy performance and occupant comfort. The key areas of focus include:

- multi-domain indoor environment exposure and its impact on energy-related behaviour;
- interfaces and the design features that affect usability and promote energy-efficient behaviours;
- application of 'big data' and sensing to generate new knowledge about occupants;
- development of occupant-centric building design and control strategies.

Deliverables

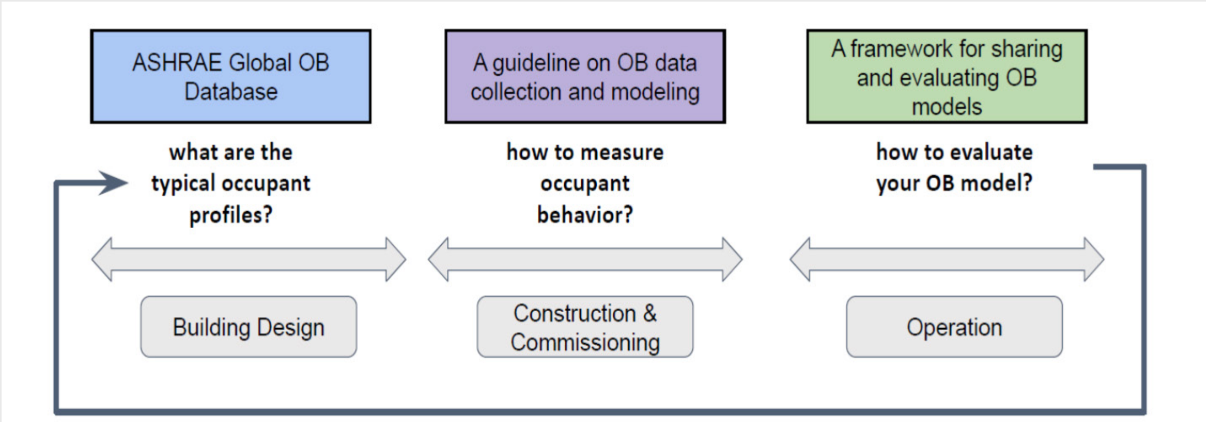
The main planned project outcomes are as follows:

- a comprehensive report giving an overview of the most significant activities and contributions of the project to different audiences;
- a book that includes fundamentals on comfort, consideration of occupants and occupant behaviour in design processes, occupant modelling and simulation, and case studies on occupant centric design;
- a guideline for technologies and best practices to collect occupant-related data for applications in occupant modelling for simulation and for occupant-centric controls;
- a database of occupancy and occupant behaviour data (ASHRAE Global OB Database; www.ashraeobdatabase.com).
- a database with occupant behaviour models that is based partially on the ASHRAE Global OB Database;
- a collection of documented case studies of buildings or spaces that demonstrate occupant-centric controls.

Progress

In 2021, one of the project task groups has been working on a framework for multi-domain indoor environment exposure studies. It defines and expands on aspects that should be considered when designing, performing and reporting future studies. Further, current IEQ standards are being examined in view of the robustness of their underlying reasoning and evidentiary basis. An international round-robin-test in climate chambers is prepared for investigating physiological responses of occupants exposed to multi-domain environmental stimuli.

The project also focused on identifying suitable techniques for filling missing data in occupant behaviour data sets. In another activity, an open-source repository with standardised existing and novel OB models is being implemented for the application in building control. In a related activity, evaluation metrics for different model



Planned workflow for data and models regarding occupant-centric building design and operation.
Source: EBC Annex 79

types are investigated. Further, the transferability of existing occupant behaviour models to different domains and settings is explored. Regarding data handling, cases of privacy risks and possible anonymisation methods are investigated.

Methods and guidelines to choose fit-for-purpose occupant modelling approaches have been developed. Interviews with practitioners reveal challenges, barriers and needs to develop effective communication mechanisms of the occupant-related assumptions among the building design stakeholders. Further, the existing DNAS ontology and obXML schema are extended and existing datasets have been identified to be used for synthetic population models development and verification, including the occupant survey conducted by EBC Annex 66, the ASHRAE Global Thermal Comfort Database, the special issue for Nature Scientific Data, and the ASHRAE Global OB Database.

Seventy interviews with operations professionals have been completed and analysis is ongoing. In another activity, a set of descriptors and a framework for collecting data about case study buildings is being created through a survey capturing the various attributes of an occupant-centric operations case study. Further, a simulation environment for the development and assessment of occupant-centric control algorithms has been developed and implemented. Finally, occupant-centric building operations in the context of residential and non-residential demand-response are analysed.

In addition to this, several cross-task activities have been launched. Topics include the availability and quality of occupant data in the early design phase, advancing agent-based modelling of occupant behaviour, a framework for occupant behaviour models documentation, development of the mentioned ASHRAE Global OB Database, the characterisation of human factors and ergonomics for the built environment, a dynamic glossary of the project, and human-system interfaces for OCC.

The project was present at the ASHRAE Winter and Summer Conferences with three seminars, the European Healthy Buildings Conference with a workshop, and the CISBAT Conference with contributions to the topic of Human and Building Interaction. Another workshop was organised at the ACM BuildSys. Further, EBC Annex 79 was invited to contribute to two EBC Webinars on 'Reducing the Performance Gap between Design Intent and Real Operation and on Energy Codes / Performance Standards'. EBC Annex 79 continued its close cooperation with ASHRAE by leading a set of chapters on measuring occupancy and occupant behaviour in buildings in the ASHRAE Performance Measurement Protocol.

Meetings

The following meetings were held in 2021:

- The 3rd Working Phase Expert Meeting took place in Trondheim, Norway and online in April 2021.
- The 4th Working Phase Expert Meeting took place in Spokane, USA and online in September 2021

Project duration
2018 – 2023

Operating Agents
Andreas Wagner, Karlsruhe Institute of Technology, Germany
Liam O'Brien, Carleton University, Ottawa, Canada

Participating countries
Australia, Austria, Belgium, Canada, P.R. China, Denmark, Germany, Italy, the Netherlands, Norway, Singapore, Sweden, Switzerland, 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 an increasing number of publications in many countries related to air cleaning and there are also 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, wellbeing and health. It is thus important to learn whether air cleaning can supplement ventilation with respect to 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 is focusing 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 potential of air cleaning to improve air quality while displacing ventilation energy use makes it an intriguing subject for development. This potential does however require more detailed evaluation. There is a need to develop standard test methods for the performance of air cleaning devices. Consequently, this EBC project has been established on the use of gas-phase air cleaning technologies.

Objectives

The project objectives are to:

- bring researchers and industry together to investigate the possible energy benefits of using gas phase air cleaners (partial substitution of ventilation with outdoor air);
- establish procedures for improving indoor air quality and reduced amount of ventilation with outdoor air by gas phase air cleaning;
- establish a test method for air cleaners that considers the influence on the perceived air quality and pollutants in indoor air.

Deliverables

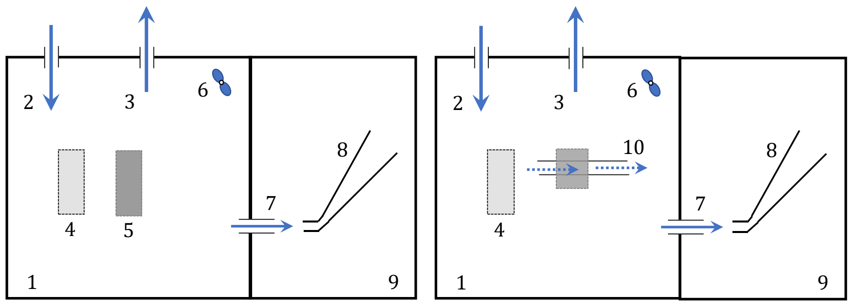
The following deliverables are being produced in the project:

- a method for predicting the energy performance of gas-phase air cleaning technologies and the possible reduction of energy use for ventilation;
- a validated procedure for supplementing (partly substituting) required ventilation rates with gas-phase air cleaning;
- a test method for air cleaning technologies that includes chemical measurements and perceived air quality as measures of performance;
- a report on the long-term performance of air cleaning;
- models for predicting the performance of gas phase air cleaning equipment.

Progress

In 2021 a description of the concept for substituting ventilation with gas phase air cleaning was finalised. This report is now available as AIVC VIP42 (https://www.aivc.org/resource/vip-42-concept-substituting-ventilation-gas-phase-air-cleaning).

A report 'Review on the research of existing indoor air filtration and cleaning technologies published from 2010 to 2019' on an extensive literature review of air cleaning technologies was finished. This description includes



A schematic diagram of a large test chamber / room, including a test chamber / room (1), clean and temperature / humidity conditioned air supply (2), exhaust outlet (3), odour emission source(s) (4), air cleaner(s) (5), mixing fan (6), tube of duct (7), sniffing device (8), front / anterior space in which the human panel enters (9) and in-duct air cleaner(s) (10). On the left hand side, the test for standalone air cleaner is shown, and on the right hand side the test for in-duct air cleaner(s).
Source: ISO / DIS 16044 (Draft) Indoor air — Part 44: Test method for measuring perceived indoor air quality for use in testing the performance of gas phase air cleaners

technologies such as sorbent air cleaning, photocatalytic oxidation (PCO), plasma oxidation, ultraviolet germicidal irradiation (UVGI), non-thermal catalyst oxidation and botanic air cleaning.

To examine the energy impact of using air cleaning continued in 2021. Papers were presented at international conferences including BuildingSimulation2021 where the paper on 'Gas phase air cleaning effects on ventilation energy use and the implications of CO2 concentration as an IAQ indicator for ventilation control' was published.
During 2021 the project leadership has also participated in standardisation work. ISO TC146SC6WG25 has now a first document describing a procedure for measuring Perceived Air Quality (PAQ) for testing air cleaners.
In 2021 planning work has been done to test this procedure and provide information for developing a new standard for testing air cleaners. First trial experiments were carried out and detailed tests will be conducted in 2022.

Meetings

The virtual project meetings were organised in May and October in 2021.

Project duration
2018–2024

Operating Agents
Bjarne W. Olesen and Pawel Wargocki, International Centre for Indoor Environment and Energy, Technical University of Denmark, Denmark

Participating countries
Czech Republic, Denmark, Italy, Japan, P.R. China, Singapore, Sweden, USA, Türkiye

Further information
www.iea-ebc.org

Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables

EBC ANNEX 75

Buildings are a major source of greenhouse gas emissions. Reducing their energy use and associated greenhouse gas emissions is particularly challenging for existing building stock. In contrast to the construction of new buildings, there are often architectural and technical hurdles for achieving low emissions and low energy use in existing ones. The cost-effectiveness of reaching high energy performance in existing buildings is often lower than in the construction of new buildings. However, there are specific opportunities for district-level solutions in cities that must be explored. In this context, the project aims to clarify the cost-effectiveness of various approaches combining both energy efficiency measures and renewable energy measures at district level. At this level, finding the balance between these two types of measures for the existing building stock is a complex task and many research questions remain regarding implementation strategy.

Objectives

The project's general objectives are to:

- investigate cost-effective strategies for reducing greenhouse gas emissions and energy use in buildings at district level, in an urban context, combining both energy efficiency measures and renewable energy measures;
- provide guidance to policymakers, companies working in the field of the energy transition, as well as building owners, on how to cost-effectively transform existing urban districts into low-energy and low-emission districts.

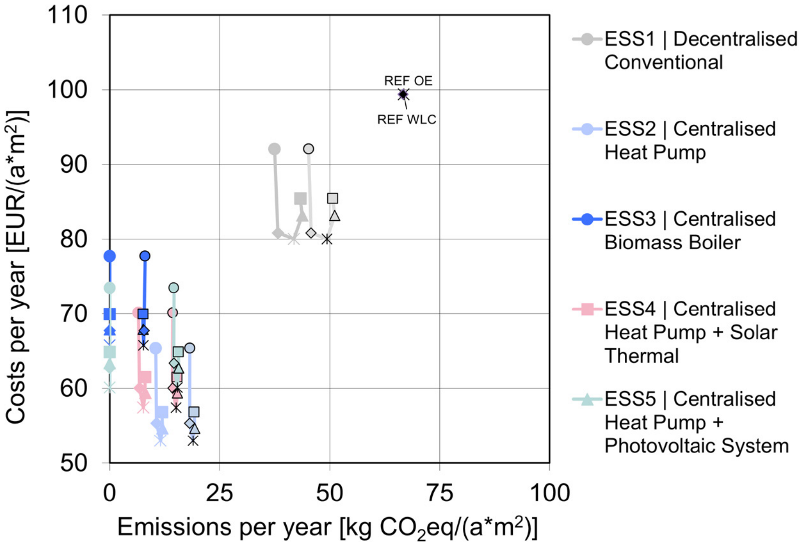
Its focus objectives are to:

- give an overview of various existing and emerging technology options and how challenges occurring in an urban context can be overcome;
- develop a methodology to identify cost-effective strategies for renovating urban districts, supporting decision-makers in the evaluation of the efficiency, impacts, cost-effectiveness, and acceptance of various solutions;
- illustrate such strategies in selected case studies and gather best-practice examples;
- give recommendations to policymakers and energy-related companies on how they can influence the uptake of cost-effective combinations of energy efficiency measures and renewable energy measures in building renovation at district level.

Deliverables

The following project deliverables are planned:

- a technology overview report on identifying energy efficiency measures and renewable energy measures at district level.
- a methodology report on cost-effective building renovation at district level.
- supporting tools for decision-makers with identification and adaptation of tools to support the application of the methodology in generic and case-specific assessments.
- a report on the application of the methodology in generic districts.
- a report on strategy development.
- a report on parametric assessments for case studies.
- a report on good practice examples showing strategies for transforming existing urban districts into low-energy and low-emission districts.
- a report on enabling factors and obstacles to replicate successful case studies.
- Good practice guidance for transforming existing districts into low-energy and low-emission districts.
- a report on policy instruments, including recommendations for subsidy programmes and for encouraging market take-up.
- a report on business models and models for stakeholder dialogue.
- guidebooks containing guidelines for policymakers and energy-related industry on how to encourage the market uptake of cost-effective strategies combining energy efficiency measures and renewable energy measures and guidelines for building owners and



Cost-optimal methodology applied to the Portuguese case study. Comparison of results with and without embodied energy, where each point is a building envelope renovation package combined with a renewable energy system.
Source: EBC Annex 75

investors about cost-effective renovation strategies, including district-based solutions.

Progress

In 2021, the project entered the final phase and started the reporting phase. Due to the COVID-19 pandemic, the progress of the tasks was delayed, but the completion of reports deadline remained as planned in June 2022.
The online interactive map of the collected success stories was completed with fifteen neighbourhoods, and a summary report has been finished that will be published in early 2022. Likewise, the report with the methodological guidelines for cost optimization of district renovation solutions was finished and the online support tool is being refined based on feedback from testing made by the participants.

The methodology has been put into practice by the participating countries, who are now concluding the assessment of eight case studies (based on real districts) and six generic districts (virtual districts characterised according to the local typical housing characteristics).
Stakeholder interviews and the assessment of district renovation examples have been completed, feeding into the stakeholder decision-making guidelines, which are being written. Thirty-eight in-depth interviews were conducted with relevant stakeholders in Austria, Belgium, Germany, the Netherlands, Portugal, Spain, Switzerland, and Sweden. The analysis of these interviews and the results of the district assessments form the basis of the Guidelines for Policy Instruments and Stakeholder Dialogue, enabling the identification of effective policies and business models targeted to urban contexts.

In November 2021, a joint Interreg 2 Seas Triple-A / IEA EBC Annex 75 workshop took place at Delft University of Technology of with the theme 'Social innovation for sustainable housing renovation in districts'. In May 2021, a paper on the project analysis of successful district renovation examples in Europe was published in a peer-reviewed indexed scientific journal (Sustainable Cities and Society Journal).

Meetings

In 2021, two online meetings were convened:
- The 9th Expert Meeting was held in March 2021.
- The 10th Expert Meeting was held in September 2021.

Project duration
2017–2022

Operating Agent
Manuela Almeida, University of Minho, Portugal

Participating countries
Austria, Belgium, P.R. China, Czech Republic, Denmark, Italy, Germany, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland

Further information
www.iea-ebc.org

Competition and Living Lab Platform

EBC ANNEX 74

The success story of the Solar Decathlon Events (SDE) forms the background to this project. The Solar Decathlon is an ongoing series of international competitions for students based on an initiative of the U.S. Department of Energy that started in 2002. In each competition, universities are challenged to design, build and operate solar-powered houses. It is the only student competition worldwide addressing the realisation and performance assessment of buildings and not only the design. During the final phase of an edition of the competition, each interdisciplinary team assembles its house in a common 'Solar Village'. The final phase includes a public exhibition, monitoring, and 10 competing teams, which is the reason why the competition was named a 'Decathlon'.

Twenty-one competitions have been conducted up to the end of 2021 of which nine took place in the US, four in Europe, three in China, two in Columbia, two in Middle East (UAE) and one in Africa (Morocco). Due to the worldwide pandemic, the 2020 editions in the US and Middle East have been performed in 2021, the 2021 European edition was postponed to June 2022. With the United Arab Emirates and Morocco - two countries with hot climates - recently held competitions. Many of the experimental houses are used for education or research when transferred back and reassembled in their home countries. The European 2022 event in Germany will coincide with the 20th anniversary of the SDE movement.

Objectives

The project forms the EBC-based platform for mapping and linking the competition and living lab experiences worldwide and working towards improving competition formats. It intends to stimulate technological knowledge, scientific and architectural quality within future competitions and living labs based on the development of a systematic knowledge platform, and to link to knowledge from previous and current IEA activities. Furthermore, the project aspires to increase the impact of competitions and living lab formats worldwide by means of communication and development of educational material.

Main parts of the project have been linked to an EC project running parallel to document the results and lessons learned, especially from the European Solar Decathlon edition and communicate these within the Smart City Information System. The project was finished by the end of 2020 under the service contract ENER/C2/2016-502/SER/SI2.763962. The final report is made available by the project coordinator: https://www.egen.green/news/solar-decathlon-europe/

Deliverables

The following project deliverables are being produced:

- a web-based competition knowledge platform;
- a technology and innovation evaluation report;
- a post-competition and living lab scenarios report,
- monitoring and documentation templates;
- guides for competition rules, criteria and organisation;
- educational material.

Progress

The online knowledge platform was continuously improved and new material was uploaded: www.building-competition.org.

A large part of the deliverables has been produced and reviewed during 2021. The main report of one of the project tasks included two chapters with a review of the European editions of the Solar Decathlon between 2010 and 2019. It is supplemented by three focus reports:

- The report 'Monitoring Data Visualization' contains for a better overview the graphical processing of the measurement data collected within four past Solar Decathlon competitions.
- The report 'Topical Papers' contains a set of eleven thematic in-depth papers that link typical topics of the Solar Decathlon with research and practice issues, pointing out connections to IEA research networks.
- The report 'Project Facts Template' presents a

Impression of the Solar Village at SDE 2012, held in Madrid, Spain.
Source: Solar Decathlon Europe

newly developed data collection structure for the quantitative data of buildings in a competition.

The reports provide important background knowledge for future competitions. Impulses have been already applied for the next SDE edition in 2022 in Germany. More information is available from the competition's online portal under www.sde21.eu
Based on this material, a comprehensive journal paper was published titled "Solar Decathlon Europe – A review on the energy engineering of experimental solar powered houses".

The second project task acts as the 'think tank' for the creation of innovative and useful competitions and living lab formats. For this, the evolution of past competition such as the Solar Decathlon and the has been systematically analysed. The report, finalised in 2021, provides knowledge on the real impacts and performances of past competitions held around the world, as well as the organisation of the events involved. These impacts and performances have been measured in an objective and quantifiable way, allowing a qualitative and quantitative analysis, as a basis for identifying key indicators, key drivers, lessons learned, etc. in order to improve them in the future and bring the actual performances closer to the desired ones.

A systematic worldwide survey was developed to measure the impact and performance of the various editions. Dozens of semi-structured interviews were conducted to complement the raw data of the surveys and to enrich the analysis. More than 70 interviews were conducted with students, professors and researchers, professionals, companies, and the various organising teams and key people involved in the development of the competition since its origins. These interviews have helped to understand the relationship between objectives, strategies, achieved performance, key drivers, lessons learned, and suggestions for future improvement.

Based on this material, a comprehensive journal paper was published under the title 'Participatory Research for the Evaluation of Satisfaction with Solar Decathlon Competitions: A Survey Analysis'.

Meetings
The final meeting within the working phase took place in May 2021.

Project duration
2018–2022

Operating Agents
Karsten Voss, University Wuppertal, Germany, and
Sergio Vega, Technical University of Madrid, Spain

Participating countries
Belgium, P.R. China, Germany, the Netherlands, Spain, Switzerland, USA
Observers: Hungary, United Arab Emirates, Colombia, Morocco

Further information
www.iea-ebc.org

Towards Net Zero Energy Resilient Public Communities

EBC ANNEX 73

Until recently, most planners of public communities addressed energy systems for new facilities on an individual facility basis without consideration of community-wide goals relevant to energy sources, renewables, storage, future energy generation needs and resiliency aspects. Moreover, building-centric planning falls short of delivering community-level solutions for energy efficiency and energy resilience. For example, many building code requirements focus on hardening to specific threats for the 'mission-critical' buildings in a multi-building community. Disruptions of electrical and thermal energy supplies may degrade critical mission capabilities and cause significant economic impacts at military and civilian installations. Thus, sustainable community projects should consider and combine efficiency and resiliency targets. Significant energy savings would reduce heating, cooling and power needs, and thus contribute to increased energy security.
The status quo in planning and execution of energy-related community projects does not support the attainment of current energy goals, or the minimisation of costs for providing energy security. In the future, primary and end-use energy, as well as carbon footprint targets, must be made available by transformation from single-building target-based frameworks.

Objectives

The project scope includes the decision-making process and computer-based modelling tools for achieving net zero energy resilient public-owned communities. The goal is to develop guidelines and tools that support the planning of net zero energy resilient public communities and that are easy to understand and execute. Specific objectives are to:

- collect, analyse, and document information about best practice community-wide energy master planning processes and find out how they can be improved;
- develop energy, cost, and resilience targets and constraints;
- develop a database of power and thermal energy generation, distribution and storage technologies, and system architectures;
- develop guidance for 'Energy Master Planning for Net Zero Energy Resilient Public Communities';
- collect and describe the business and financial aspects and legal requirements and constraints that can be used for implementation of energy master plans for public communities in participating countries;
- integrate the targets, constraints, enhanced system architectures, the technology database, and resilience analysis into an interactive modeling and optimization tool.

Deliverables

The project has produced the following deliverables:

- Energy Master Planning toward Net Zero Energy Resilient Public Communities Guide.
- a book of case studies.
- the Energy Resilience of Interacting Networks (ERIN) tool.

Progress

One part of the project was to collect and investigate case studies of community energy master planning and to find out how it can be improved. Thirty-two case studies of community master planning for military camps, universities, research institutes, hospitals, small communities, towns, and large cities in participating countries were chosen, studied, and analysed. These studies were documented and published in a case studies book, which includes detailed information on the drivers, goals and methods used for planning, implementation and financing, and the results and lessons learned by the project owners.

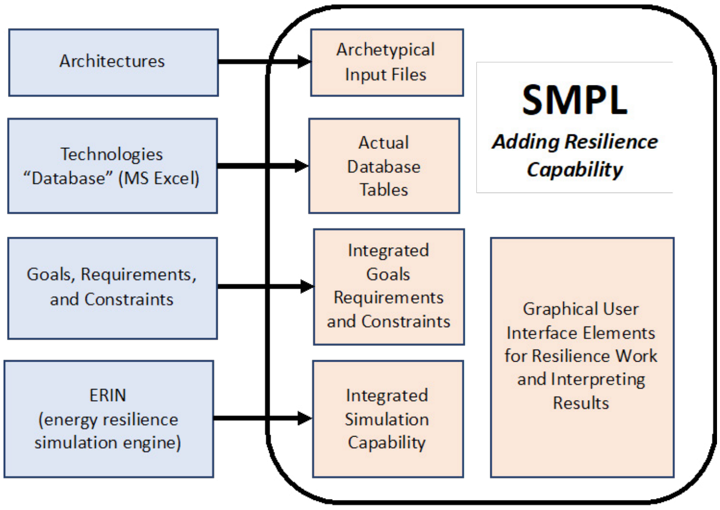
The project also investigated and analysed framing goals and constraints for building and community energy projects that must be considered when energy master planning is conducted. They cover energy use; emissions; sustainability; resilience; regulations and directives; and regional and local limitations such as available energy types, local conditions, costs of energy supply to the community and stakeholders, and individual project requirements.

Energy system resilience is one of the most important goals used to select and design energy systems. Design and evaluation of system resilience measures should be based on requirements established by mission operators. The project research developed the framework for such requirements.

The project team generated a list of more than sixty power and thermal energy system architectures and developed a database of more than four hundred technologies they employ. This information can then be used to do a detailed analysis of the energy master plan baseline and of different alternatives.
The Energy Resilience of Interacting Networks (ERIN) tool has been developed to support an energy master planning process that allows for the assessment of the resilience of energy supply systems to various design-basis threats.

The Guide briefly discusses the application of ERIN in conjunction with a web-based application called the Simple Master Planner (SMPL) Tool, created by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) for energy managers, master planners, and policymakers. The SMPL tool provides a graphical interface that allows users to evaluate energy, water, waste, and stormwater scenarios for military installations, districts, and campuses.

The project has achieved the following progress in 2021:
- Finalised all deliverables
- As a spin-off of the main deliverables, the project has developed an additional 'Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates' (Published by ASHRAE) and is finalizing the first draft of the 'Guide for Resilient Thermal Energy Systems Design in Hot and Humid Climates'.
- Developed 6 pilot projects demonstrating developed methodology and the ERIN tool (to be included in the Book of Pilot Projects)



Integration of the ERIN tool into the SMPL Tool. Currently, the ERIN engine and parts of the technologies database have been integrated into SMPL.
Source: EBC Annex 73

Meetings

The following meetings took place in 2021:
- A technical paper session during the 2021 Cold Climate HVAC and Energy Conference in Tallinn, Estonia.
- The 7th Working Meeting (virtual) in April 2021.
- The 8th Working Meeting (virtual) in October 2021

Project duration
2018–2022

Operating Agents
Alexander Zhivov, US Army Engineer Research and Development, USA, and
Rüdiger Lohse, KEA - Climate protection and energy agency of Baden - Württemberg GmbH, Germany

Participating countries
Australia, Austria, Denmark, Finland, Germany, Norway, UK, USA

Further information
www.iea-ebc.org

Assessing Life Cycle Related Environmental Impacts Caused by Buildings

EBC ANNEX 72

This project is providing the basis and tools to support decision makers and designers to minimise environmental impacts of buildings during their entire life cycle. To achieve this goal the project is providing rules and recommendations on methodological questions (i.e. definition of net zero greenhouse gas emission buildings), application of tools in different design stages and on how to develop national / regional databases to assess the environmental impacts of buildings.

Objectives

The project objectives are to:

- establish a harmonised methodology guideline to assess the life cycle based environmental impacts caused by buildings;
- establish methods for the development of specific environmental benchmarks for different types of buildings;
- derive guidelines and tools (building design and planning tools such as BIM and others) for design decision makers;
- establish a number of case studies;
- develop national/regional databases with regionally differentiated life cycle assessment (LCA) data tailored to the construction sector.

Deliverables

The following deliverables are planned:

- a report on harmonised guidelines on the environmental LCA of buildings;
- a report on establishing environmental benchmarks for buildings, including case study examples;
- a report on national LCA databases used in the construction sector;
- a report on guidelines for design decision makers on optimization using building assessment workflows and tools;
- a report on building case studies on the application of LCA in different stages of the design process;
- a report on how to establish national / regional LCA databases targeted to the construction sector.

Progress

The focus in 2021 was on drafting the final reports and guidelines based on the background reports and establishing a general structure for all project deliverables.

The contents and remaining unresolved issues of the report on 'Context-specific methods for the assessment of life cycle related environmental impacts caused by buildings' were discussed in view of a set of rules and recommendations. Discussions focused on an appropriate typology of net zero greenhouse gas emissions buildings as well as on an appropriate approach to model biogenic carbon intermediately stored in buildings. Linked to this, a scientific paper has been submitted on the life cycle related environmental impacts of a prefabricated wooden residential building (social housing project) erected in Montréal, Quebec, Canada.

An LCA strategy for design decision makers was defined to handle and analyse uncertainty in different design phases. A categorisation for building LCA tools that are currently available for design decision makers is being proposed. A survey was sent to tool providers and users to obtain necessary information for the assessment of available tools. The goal is to support designers and architects in the choice of a tool to assess the environmental impacts of a building in different design phases.

Experts from seven countries participated on a round-robin test of different typical building information modelling to life cycle assessment (BIM-LCA) workflows based on the same BIM model. This activity allows the assessment of differences in extracted bills of quantities and LCA results.

Guidelines on establishing environmental benchmarks for buildings are being drafted. An extensive survey about existing benchmarks and benchmark systems served as an important basis. The final draft of the

PAL 6 prefabricated wooden residential building (social housing project), erected in Montréal, Quebec, Canada; 15 expert teams around the world assessed its life cycle related environmental impacts.
Source: Groupe de ressources techniques (GRT) Action-Habitation

report on optimisation strategies to reduce the life cycle related environmental impacts of new buildings and refurbishments during the design process was completed.

The guidelines for establishing an easy-to-use national LCA database for the construction sector are being drafted. The report covers technical aspects (LCA-related scoping, modelling and data issues), recommendations regarding the governance structure and a roadmap on how to establish such a sectoral database.

During the final IEA EBC Annex 72 expert meeting the Monte Verità Declaration on a built environment within planetary boundaries (IEA EBC Annex 72 experts 2021) was adopted and signed by more than 40 scientists from 20 countries. One of its key recommendations - addressed to governments and administration - is the introduction of legally binding requirements to limit greenhouse gas (GHG) emissions of new constructions and of refurbishments by 2025 latest with a roadmap to net zero emissions by 2035. The recommendation is to enlarge the regulation of GHGs from operational energy to include embodied emissions from the supply chain and to cover the full life cycle of the building.

Meetings

In 2021, the following meetings were held:

– The 8.5th Expert Intermediate Meeting was held online in February 2021.
– The 9th Expert Meeting was planned at Czech Technical University in May 2021 in Prague, Czech Republic, but the meeting was held online.
– The 10th Expert Meeting was held in October 2021 in Monte Verità, Ticino, Switzerland.

Project duration
2016–2022

Operating Agent
Rolf Frischknecht, treeze Ltd., Switzerland

Participating countries
Australia, Austria, Belgium, Canada, Czech Republic, P.R. China, Denmark, Finland, France, Germany, Italy, R. Korea, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, UK, USA
Observers: Brazil, Hungary, India, Slovenia

Further information
www.iea-ebc.org

Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale

EBC ANNEX 70

Building energy epidemiology is the study of energy use among a population of buildings to better understand the trends and drivers that result in variations in building energy performance across the stock. This approach can be used to study and describe the mechanisms of energy demand, as well as the determinants of conditions that lead to different levels of demand.

An energy epidemiology approach is well-suited to dealing with uncertainty using methodological tools and analysis techniques. These include: common definitions and metrics; population selection techniques; study designs for data collection, comparison and analysis; approaches to dealing with bias; guidelines for working towards identifying causal relationships, and systematic approaches to reviewing evidence.

The project is focused on identifying, reviewing, evaluating and producing leading edge methods for studying and modelling the building stock, including data collection techniques on energy use, building features and occupant features; building morphology; analysis of smart meter energy data, building systems and occupant behaviour; modelling energy demand among sub-national and national building stocks.

The results facilitate the use of empirical energy and building stock data in undertaking international energy performance comparisons, policy reviews, national stock modelling, technology and product market assessments and impact analyses. The deliverables will promote the importance and best practices for collecting and reporting of energy and building stock data.

Objectives

The project objectives are to:

- support countries in developing realistic decarbonisation transitions and develop pathways by facilitating better available empirically derived energy and buildings data;
- inform and support policymakers and industry in the development of low energy and low carbon solutions by evaluating the scope for using empirical building stock and energy use data;
- develop best practice in the methods used to collect and analyse data related to real building energy use, including building and occupant data;
- support the development of robust building stock data sets and building stock models through better analysis and data collection.

Deliverables

The following project deliverables are being created:

- a register of energy and building stock data among participating countries and more widely;
- a register of energy and building stock models;
- a data schema for energy and building stock data for developing countries and emerging economies;
- guidelines for energy and building stock model reporting and metrics for stock model comparisons;
- a series of reports on: stakeholder key issues on needs and uses of data; best practice use cases for energy and buildings data; classification for energy and buildings stock data; classification of energy and buildings stock models; stock model uncertainty and sensitivity tests.

Progress

During 2021, the project was in the reporting phase. Each project task has finalised each of its activities and was editing the final report covering the efforts focused on user engagement (needs and provisions), data mechanisms and foundations, and building stock modelling and analysis.

An Energy and Buildings Stock Data Users and Needs survey was completed with over 800 responses from across the project member countries. The survey provides information on what energy and building data a range of stakeholders need and use to support

Topic	Subtopic	Guiding questions
Overview	Aim and scope	What is the overall aim and scope of the model? What are the main use cases addressed?
	Modelling	What is the general modelling approach and how is it structured? What are the main model parts and components and how do they relate to each other? What are the key steps in the modelling workflow?
	System boundary	What are the system boundaries (temporal, geographical, building types, energy services, economic sectors, etc.) of the model?
	Spatio-temporal resolution	What is the spatio-temporal resolution on which energy demand calculations are performed? What are common spatial and temporal aggregations on which outputs are reported in relation to use cases?
Model components	Building stock	How are buildings and the building stock represented and characterized in the model? What building attributes are used to characterize buildings on either an individual or archetype basis?
	People	How are people (e.g. occupant behavior) represented in the model?
	Environment	How is the environment (e.g., climatic, policy, economic, context) represented in the model? How does the model account for spatial differences in these environmental aspects?
Input and output	Energy	How are energy demand (useful, final, primary) and related performance indicators (e.g., GHG emissions) assessed?
	Costs	How are costs (capital and/or operational) assessed?
	Dynamics	How are building stock dynamics (i.e., changes of the stock over time) modeled? Which of the above aspects are modeled dynamically? Which of these dynamics are endogenously defined, what is modeled endogenously?
	Other aspects	Are there other relevant aspects of the model not covered by the above?
Quality assurance	Data sources	What are the primary data sources used for the model and how they are structured?
	Data processing	How has the data been cleaned, matched or otherwise processed to become input into the model?
	Key assumptions	What are the main input assumptions made to address any information gaps in the data and/or model system?
	Scenario	What model inputs are introduced or modified to describe a scenario?
	Output parameters	What are the main model outputs? At what levels of aggregation and in which formats are they available?
	Calibration	With what method(s) and sources of information has the model been calibrated? What was the outcome?
	Validation	With what method(s) and sources of information has the model been validated? What was the outcome?
	Limitations	What are the (current) limitations of the model and its results? How do modelling assumptions or data limitations affect the model application and/or interpretation of the model results?
	Uncertainty	What are key sources of uncertainty in the model? With what method(s) or sources of information has the uncertainty of the model and results been assessed? What was the outcome?
	Sensitivity	With what method(s) and sources of information has the sensitivity of the model and results been assessed? What was the outcome?
Additional information	Implementation	What software, programming language, packages, libraries or other models are used in or necessary for the model to be used? Who owns the model?
	Access	To whom and under what licence/condition is the model and the necessary data available?
	Funding and contributors	How has the model development and/or underlying research been funded?

Structure and guiding questions of different aspects of the reporting guideline.
Source: Nägeli, C., Camarasa, C., Delghust, M., Fennell, P., Hamilton, I., Jakob, M., Langevin, J., Laverge, J., Reyna, J. L., Sandberg, N. H., & Webster, J. (2022). Best practice reporting guideline for building stock energy models. Energy and Buildings, 260, 111904. https://doi.org/https://doi.org/10.1016/j.enbuild.2022.111904

their energy and buildings analysis and modelling, and decision-making to address carbon emissions and improve building energy performance. A systematic literature review described the ways in which published literature describes data use and how these efforts have changed over time. Lastly, case studies describing the use of energy and buildings data from across members illustrate the latest approaches to using, analysing and modelling with energy and buildings stock data. These activities were used in the energy and building stock data and model registry.

An Energy and Building Stock Data Registry was built under the guidance of the International Energy Research Centre in Cork, Ireland. The registry provides an online platform for identifying, describing and sharing energy and building stock data. In 2021 the registry contains information on over 1000 datasets across the themes of energy, buildings, people, environment, and other important data for energy and buildings analysis. The registry provides a resource that will continue to be updated with key data attributes and information resources for the research and policymaking community. In addition, a set of best practice guides focused on remote sensing, user surveys, energy metering data, and geospatial energy and buildings data are provided.

Finally, a model classification was developed that forms the basis of the online Energy and Building Stock Model Registry, which enables researchers to describe building energy stock models. The project task has published guidelines for reporting energy and building stock models led by Chalmers and project members and offers a framework for reporting models in peer-reviewed journal articles. Finally, a set of common exercises and guidance for undertaking model uncertainty and sensitivity tests was produced.

Meetings

The following meetings took place in 2020:

- the fourth reporting phase meeting took place online in July.
- Project Subtask meeting took place in November 2021.

Project duration
2016–2022

Operating Agent
Ian Hamilton, University College London, UK

Participating countries
Australia, Austria, Belgium, Canada, P.R. China, Denmark, Germany, Ireland, Japan, the Netherlands, Portugal, Norway, Sweden, Switzerland, UK, USA

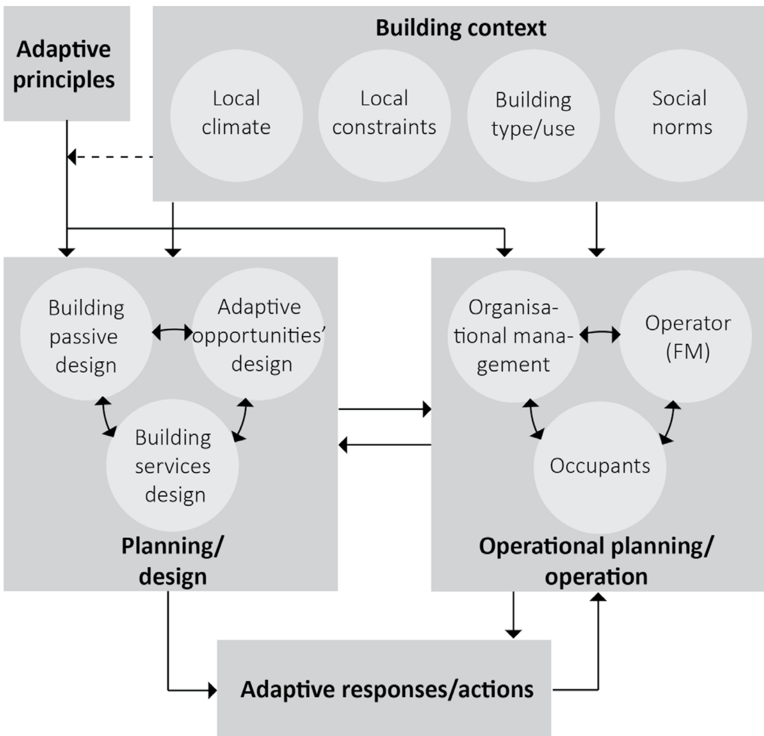
Further information
www.iea-ebc.org

Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings

EBC ANNEX 69

Adaptive thermal comfort has been identified as a key point to establish the balance between reducing building energy use and providing a comfortable indoor environment for occupants. Evidence has shown that strict indoor temperature control can result in high energy costs and greenhouse gas emissions and may not always be beneficial to the comfort and health of the occupants. The development of adaptive thermal comfort provides criteria and inspiration for the design and operation of low energy buildings. There is notable variance in acceptable ranges of indoor temperature across climate zones and seasons, and in the adaptive responses of occupants to thermal discomfort.

If indoor temperature is maintained within an acceptable range, people can achieve thermal comfort through three kinds of adaptive methods: physiological, psychological and behavioural response mechanisms. A stable indoor thermal environment based on the Predicted Mean Vote (PMV) model is not always capable of signifying the actual thermal demand of all the occupants. In order to overcome difficulties in building energy-saving technology, it is important to determine the actual thermal demand of the occupants and their thermal adaptation mechanisms. Moreover, adaptive thermal comfort provides occupants with opportunities to control their personal environment, which can improve occupants' satisfaction with indoor



Framework for adopting the adaptive principles in planning and operation of buildings.
Source: Reprinted from Energy and Buildings, 205/109476, Hellwig, RT; Teli, D.; Schweiker, M; Choi, JH; Lee, MCJ; Mora, R; Rawal, R; Wang, Z; Al-Atrash, A, (2019), 'A Framework for adopting adaptive thermal comfort principles in design and operation of buildings', copyright (2019), with permission from Elsevier.

thermal environments beyond the levels normally achieved through strict adherence to the PMV.

Therefore, it is essential to conduct systematic and profound research on adaptive thermal comfort. If the building's services systems could be running in a 'part-time and part-space' mode determined by its occupants' individual demand instead of the 'whole-time and whole-space' mode prevalent in many buildings today, energy use could be reduced.

This project aims to develop an analytical and quantitative description of occupants' adaptive thermal comfort in buildings. It provides appropriate design strategies, assessment methods and control algorithms for the indoor environment. The fundamental issue is to balance the maintenance of a comfortable indoor environment with building energy efficiency.

Objectives

The objectives of this project are to:

- establish a global thermal comfort database with quantitative descriptions of adaptive responses;
- propose revised indoor environmental standards based on the adaptive thermal comfort concept;
- apply the adaptive thermal comfort concept for achieving low energy use intensities in buildings;
- provide guidelines for developing personal thermal comfort systems with perceived-control adaptation.

Deliverables

The expected deliverables of project include:

- a global thermal comfort database with user interface;
- an adaptive thermal comfort model and criteria in case study buildings;
- guidelines for low energy building design based on the adaptive thermal comfort concept;
- guidelines for personal thermal comfort systems.

Progress

In 2021, the project has moved towards its final phase. The whole team focuses on completing the deliverables and final report.
The review of the deliverable 1 (database with user interface), deliverable 2 (adaptive thermal comfort model and criteria), deliverables 3 and 4 (guidelines) were completed. The final report of EBC Annex 69 was completed and is under review.

Further, a call for Papers of Special Issue 'Diversity of thermal comfort in the real world' in the Journal of Energy and Buildings was concluded. Seventeen submissions were accepted in this special issue.

All the outcomes from the EBC Annex 69 project are expected to be finished in early 2022.

Meetings

No meetings were held in 2021.

Project duration
2015–2022

Operating Agents
Yingxin Zhu, Tsinghua University, P.R. China
Richard de Dear, University of Sydney, Australia

Participating countries
Australia, Canada, P. R. China, Denmark, Germany, Japan, R. Korea, The Netherlands, Norway, Sweden, UK, USA
Observers: India

Further information
www.iea-ebc.org

Air Infiltration and Ventilation Centre

EBC ANNEX 5

EBC Annex 5 'Air Infiltration & Ventilation Centre' has been running since 1979. Its principal goal is to provide reference information on ventilation and air infiltration in the built environment regarding efficient energy use and good Indoor Environmental Quality (IEQ). Whereas in the early years, the focus was more on 'technical ventilation expertise', during the last decade increased emphasis has been given to 'ventilation networking' and 'advanced and innovative dissemination strategies.'

Objectives

The objectives of the AIVC are to:

- identify emerging issues on ventilation and infiltration in new and renovated buildings;
- facilitate better design, implementation, hand-over and maintenance of ventilation systems;
- provide discussion platforms, including conferences, workshops and webinars.

Deliverables

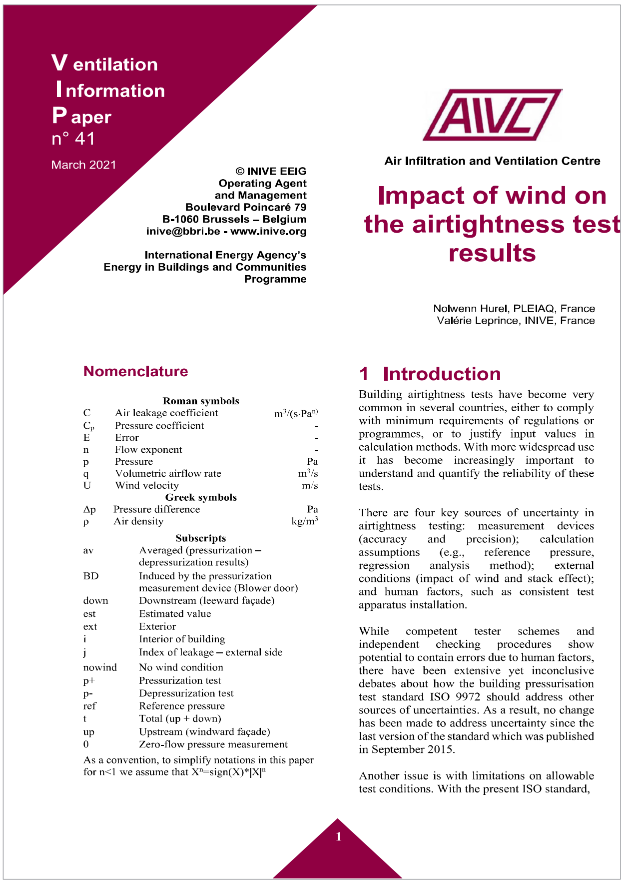
- Events: annual conference, one to two workshops per year on specific topics, and one to two webinars per year;
- Publications: conference and workshop proceedings, technical notes and contributed reports (one per year), and a biannual newsletter

Progress

In 2021, the AIVC focused its work mainly on fourteen projects, five of which were initiated in 2021. Due to the COVID-19 pandemic it was not possible to organise in-person events, including the annual AIVC Conference and planned workshop. Instead, this resulted in the organisation of ten webinars. Furthermore, the AIVC facilitated remote discussions and dissemination activities for EBC Annex 80 'Resilient Cooling of Buildings' and EBC Annex 86 'Energy Efficient Indoor Air Quality Management in Residential Buildings'.

The recently launched AIVC projects are entitled 'Energy recovery ventilation', 'Personalized environmental control systems (PECS)', 'Impact of IoT on ventilation systems', 'Airtightness status at country level' and 'Ventilation status at country level'.

Previously launched projects which were still running in 2021 include: 'Ventilation, airtightness and COVID-19', 'Temperature take-back effect in the context of energy efficient ventilation strategies', '40 Years of AIVC', 'Rationale behind ventilation requirements and



The AIVC Ventilation Information Paper Number 41 on the impact of wind on airtightness test results was published in March 2021.
Source: EBC Annex 5

regulations', 'Integrating uncertainties due to wind and stack effect in declared airtightness results', 'Indoor air quality metrics', 'Residential cooker hoods', 'Competent tester schemes for building airtightness testing' and 'Air cleaning as alternative for ventilation'.

During 2021, the AIVC published four Ventilation Information Papers: 'VIP 41: Impact of wind on the airtightness test results' in March; 'VIP 42: The concept for substituting ventilation by gas phase air cleaning' in April; 'VIP 43: Residential ventilation and health' in July and; 'VIP 44: Residential cooker hoods' in September. Moreover, in the framework of the AIVC's 'COVID-19' project, two AIVC newsletter special issues were published in February and July 2021. The first special issue was published in November 2020. The project '40 years of AIVC', is now close to completion following the delivery of two Technical Notes '40 years to build tight and ventilate right: From infiltration to smart ventilation' and '40 years to build tight and ventilate right: History of the AIVC', highlighting the progress and outcomes over these 40 years with contributions from various AIVC Board experts. The publications are soon to be published in the first quarter of 2022. The project 'Rationale behind ventilation requirements and regulations' is coming to the end, and a Technical Note will be published in 2022.

The AIVC organized ten webinars over the course of 2021 including one webinar on 'Building airtightness databases' (in the UK, Flanders and France) in January 2021; four webinars on 'Building ventilation & SARS-CoV-2 transmission', 'IAQ and ventilation metrics' and 'Big data, IAQ and ventilation' (part 1, part 2) in April 2021; one webinar on 'Resilient ventilative cooling' in June 2021; one webinar on 'Smart materials' in October 2021 and; three webinars on 'Smart ventilation,' 'Impact of wind on airtightness test results' and the 'Inspection of ventilation systems' in November 2021.

To gain more interaction with related organizations and a stronger societal impact, the AIVC is a founding member of the Indoor Environmental Global Alliance (www.ieq-ga.net). There is also ongoing close collaboration with the TightVent platform (www.tightvent.eu) and the Venticool platform (www.venticool.eu).

The Advisory Board of Practitioners, is also a new initiative from EBC Annex 80, AIVC and Venticool, launched in March 2021 and seeking to establish a format for regular exchange between EBC Annex 80 scientists and practitioners and planners as well as representatives from relevant industries.

Editions of the AIVC newsletter were published in 2021 as listed below:

- March 2021
- September 2021
- February 2021 (Special Issue on COVID-19)
- July 2021 (Special Issue on COVID-19)

Meetings

The AIVC Board organized two board online meetings in 2021, in March and October.

Project duration
1979–2026

Operating Agent
Peter Wouters, INIVE EEIG, Belgium

Participating countries
Australia, Belgium, P.R. China, Denmark, France, Greece, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Republic of Korea, Spain, Sweden, UK and USA

Further information and reports
www.iea-ebc.org

AIVC

www.aivc.org

Completed Research Projects

CITIES AND COMMUNITIES
(EBC WORKING GROUP)

INTEGRATED SOLUTIONS FOR DAYLIGHTING
AND ELECTRIC LIGHTING

(EBC ANNEX 77 - SHC TASK 61)

DEEP RENOVATION OF HISTORIC BUILDINGS
TOWARDS LOWEST POSSIBLE ENERGY DEMAND AND CO_2 EMISSION

(EBC ANNEX 76 - SHC TASK 59)

BUILDING ENERGY PERFORMANCE ASSESSMENT
BASED ON IN SITU MEASUREMENTS

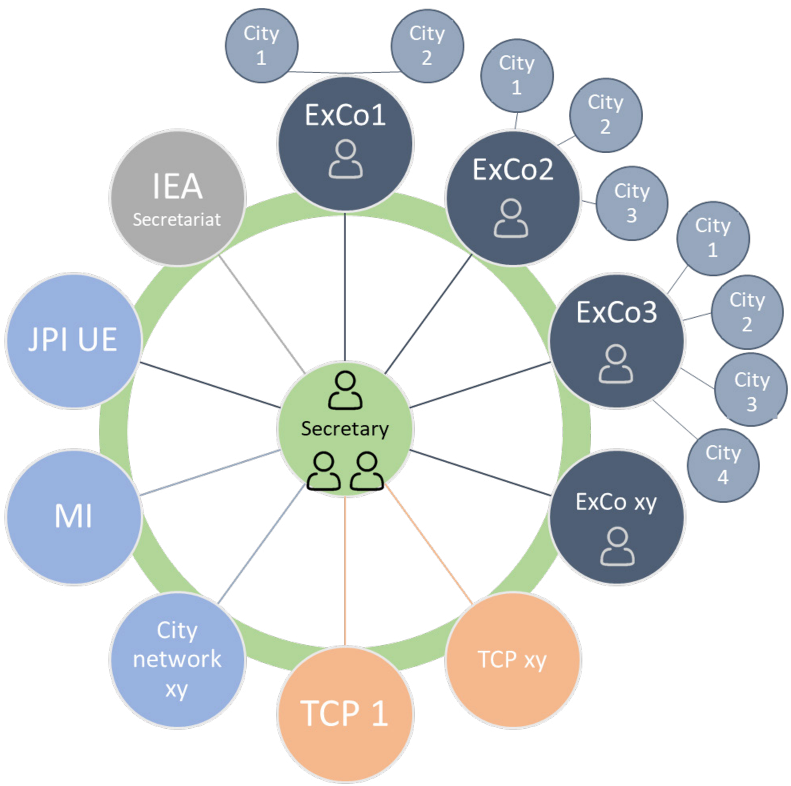
(EBC ANNEX 71)

Cities and Communities

EBC WORKING GROUP

Cities face extensive challenges when it comes to transformation processes of their energy and mobility systems. The generation of suitable decarbonisation strategies and the selection of the best-fit solution for the cities' specific framework conditions requires comprehensive skills, knowledge, and resources, which smaller communities often lack. In addition, these decision-making and planning processes take place in a highly dynamic environment with many further requirements that often have higher priorities. This complexity often leads to uncoordinated decision-making within cities but also within different stakeholder groups. While solutions are mostly provided at a strategic level, decisions at the urban scale can have substantial impacts on individual approaches and technologies.

The Working Group on Cities and Communities therefore aimed to improve the situation by integrating these "urban issues" into research within the IEA Technology Collaboration Programmes (TCPs), including the EBC TCP. This open project was a hosted, single-leadership, delegating structure that shared information across multiple TCPs and cities in a bidirectional approach, in which information was provided and received in both directions. The Working Group was also linked to existing IEA Co-ordination Groups and other structures, either directly, through the EBC Executive Committee Chair or through nominated experts and fed into various IEA publications and workshops.



Organisational structure of the Cities TCP that aims to foster in-depth exchange between different IEA TCPs, city intermediaries and other city-relevant initiatives (e.g. Mission Innovation, JPI Urban Europe, etc.).
Source: Salzburg Institute for Regional Planning and Housing (SIR), 2020

Achievements

The goal of the Working Group was to contribute to an essential step in IEA TCP research to meet cities´ non-technical needs that extends well beyond providing technical solutions for energy systems.

The Working Group activities clearly highlighted the benefits of exchange activities between the different actors working in and with cities. Several models for an establishment of an exchange platform within the IEA framework were discussed, and finally, the Working Group members conjointly decided to develop a new TCP, called Cities TCP.

This Cities TCP aims to provide:

- scientific and evidence-based information, tools, and recommendations to support urban decarbonization efforts, and
- an international forum and communication channel for researchers and city experts with a strong focus on innovation-related projects on urban energy and mobility system transformation and the exchange between TCPs to share innovation in each field as well as between TCPs and practitioners to share best practices and to pool resources.

The relevant documents for establishment of a new TCP were developed. The strategic plan contains information on the relevant deliverables and the organisational structure of the TCP. The Program of Work gives an outlook on the main topics for the first working period.

These documents were finalised in 2021 and the new TCP was recommended by the CERT at its meeting in October 2021. The Governing Board finally approved the TCP at its meeting on the in November 2021. The Implementing Agreement of the 39th TCP within the IEA network called 'Decarbonisation of Cities and Communities' (Cities TCP) formally entered into force in January 2022, after receiving the signature pages of three countries (Austria, Norway and the Netherlands).

Publications

The Final Report has been published including the following:

- Annex I Cities' needs (presentation document),
- Annex II Cities TCP Strategic Plan,
- Annex III Cities TCP Program of Work.

Meetings

No meetings were held in 2021

Project duration
2017–2021

Operating Agent
Helmut Strasser, Salzburg Institute for Regional Planning and Housing (SIR), Austria

Participating countries
Austria, Canada, Denmark, Finland, France, Germany, Italy, Ireland, Japan, P.R. China, the Netherlands, Norway, Sweden, Switzerland, UK, USA

Further information
www.iea-ebc.org

Integrated Solutions for Daylighting and Electric Lighting

EBC ANNEX 77 - SHC TASK 61

This project focuses on the creation and development of strategies to combine daylighting and appropriate lighting control systems to enable highly energy-efficient lighting schemes with emphasis on user comfort.

This project brought together more than 50 international experts and companies involved in dynamic daylighting, lighting and their controls. The main objective was to foster the integration of daylight and electric lighting solutions to benefit user satisfaction concurrent with energy savings. The work focused on four main topics:

- User perspective and requirements.
- Integration and optimisation of daylighting and electric lighting.
- Design support for practitioners.
- Lab and field study performance tracking.

Achievements

Improvement of the understanding of human lighting requirements as target for integrated lighting design:

A comprehensive overview of users' lighting needs was compiled, based on a literature overview of more than 100 articles. It discusses four main categories, including 28 criteria on the perception of light; visual comfort; psychological aspects of lighting and non-image forming aspects.

'Personas' - a new way to describe the user's impact - were developed. The consumption of energy for lighting depends very much on the way people interact with the build environment. For representative building types, typical user groups were identified, and their behaviour analysed. This was aggregated into 26 'personas'. Rather than describing users only with numbers and statistics, a single persona reflects a group and is presented with a narrative.

Controls are the key to integrated lighting solutions

A survey of 100+ professionals suggests that the two main reasons for the implementation of lighting control systems are to reduce electric lighting load and to increase the user's well-being, thereby reducing complaints from the users.

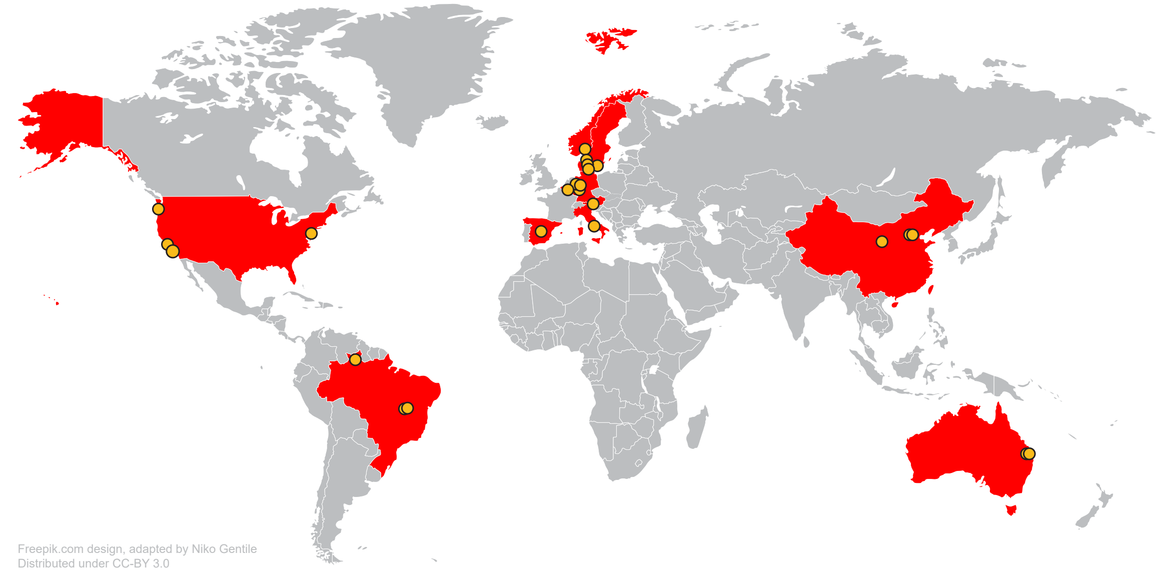
The status of control system technology was documented. General principles and different types of daylight and electric lighting control strategies with altogether 16 specific lighting control protocols (wired and wireless) were analysed. The findings may support designers in system layout and optimization. Human-Machine Interfaces were analysed.

Future research plans focus on simplifying user interaction with lighting systems. Challenges in new systems lie in the multi-criteria optimization of lighting preferences and other building needs such as controlling solar gain. Integrating control systems directly into workstations would enable easy user control of electrical- and daylighting. Three new approaches to this from leading brands were examined and discussed.

New design processes for bringing integrated lighting solutions onto designers' desktops

Typical workflows for planning integrated lighting were collected and discussed based on three state-of-the-art buildings in Austria, Germany and China. Workflows rely strongly on the use of software tools. For this, the key features of 12 tools were compared.

- Photometric models: The current state of the art in the characterisation of daylighting and shading systems by bidirectional scattering distribution functions (BSDFs) was summarised and quality-assured in round-robin tests. Spectral sky measurements and existing models were reviewed and merged into a simplified model for practical applications, extending classical monochromatic sky models.
- Integrated energy rating: A generic, hourly-based rating method for the energy demand of integrated lighting solutions was developed. Close alignment



Sites of the 25 case studies.
Source: EBC Annex 77 / SHC Task 61

with building automation and control systems (BACS) definitions allows an integrated workflow for lighting design and commissioning. Implementation of ISO 10916 - on the impact of daylight utilisation on the energy demand - is under way. Core functionality of the hourly rating model has been implemented through a simple web-based tool and widely-used freeware lighting software environment: DIALux EvoAdditionally, the capabilities of virtual reality-based presentations of integrated lighting scenarios were demonstrated.

Lessons learned from field assessments of integrated lighting solutions

To properly assess the performance of integrated lighting solutions in the field, a new monitoring protocol was developed. The protocol covers the assessment of lighting energy use; visual effects; non-visual effects (circadian potential) and user observations. Based on the protocol, experiences from 25 case studies across 12 countries were gathered, verifying and sometimes showing drawbacks in applied integrated approaches. Others showed that energy demand for lighting can drastically be reduced. Annual lighting energy use as low as 3-4 kWh/m^{2}a are now possible, but are still far from standard.

Publications

The EBC Annex 77: 'Integrated Solutions for Daylighting and Electric Lighting' reports have been published, including: 'Literature review – Energy saving potential of user-centred integrated lighting solutions', October 2021; 'Analysis and evaluation of BSDF characterization of daylighting systems', October 2021; 'Standardisation issues related to lighting and daylighting control systems', October 2021; 'Review of new systems and trends', October 2021; 'User perspective and requirements – Personas', October 2021; 'User perspective and requirements - Use cases', October 2021; 'Evaluating integrated lighting projects - A Procedure to Post-Occupancy Evaluation of Daylight and Electrical Lighting Integrated Projects', September 2021; 'Integrating daylighting and lighting in practice: Lessons learned from international case studies', June 2021; 'Spectral sky models for advanced daylight simulations', June 2021 'User Interfaces', February 2021; 'Review of lighting and daylighting control systems', February 2021; 'Survey on opportunities and barriers in lighting controls', February 2021; 'BSDF generation procedures for daylighting systems - White paper', January 2021; 'Literature review of user needs, toward user requirements', September 2020 'Workflows and software for the design of integrated lighting solutions', November 2019, and 'Daylighting of Non–Residential Buildings - Position Paper', January 2019.

Meetings

Three Task Meeting meetings were held online in March, May and October 2021.

Project duration
2018–2021

Operating Agent
Jan de Boer, Fraunhofer Institute for Building Physics, Germany

Participating countries
Australia, Austria, Belgium, P.R. China, Denmark, Germany, Italy, Japan, the Netherlands, Norway, Slovakia, Sweden, Singapore, Switzerland, USA
Observers: Brazil

Further information
www.iea-ebc.org

Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions

EBC ANNEX 76 - SHC TASK 59

In many countries historic buildings represent a significant share of existing building stock. They are distinctive features of numerous cities and many may only survive if maintained as living spaces. To preserve this heritage, it is necessary to find conservation-compatible energy retrofit approaches and solutions that retain historic and aesthetic values while improving comfort, lowering energy costs and minimising environmental impacts.

Completed examples have shown that reducing the energy demand by up to 75% may be possible for some historic buildings while preserving their heritage value. A considerable reduction in demand - together with optimised use of passive solar design - opens the possibility of proceeding with an effective solar contribution towards a net zero energy building (NZEB). In this context, the opportunities for using solar energy in historic buildings are far more substantial than one might initially expect, especially if solar panels / collectors are compatible in colour and design, are integrated sympathetically with the aesthetic of the building, and if their installation is reversible.

The main target groups addressed by the outcomes are building owners, architects and planners, real estate developers, and administrative professionals (urban planners, urban renewal officials, conservation officers).

Achievements

The IEA Solar Heating and Cooling Technology Collaboration Programme (TCP) SHC Task 59 was working on the project with the EBC Annex 76 at a 'Moderate Level Collaboration', and with the Photovoltaic Power Systems TCP at a 'Minimum Level Collaboration'.

The key results are as follows:

- The website on best practices, the Historic Building Energy Retrofit Atlas (HiBERATLAS), www.hiberatlas.com, has been an online beta version since October 2019 with the last modifications and changes made in 2021.
- HiBERATLAS will continue after the project ends, so major emphasis was placed on developing a user-friendly backend for adding cases, user management, and the integrated process of gathering IP and privacy forms. The integrated platform with tools for holistic retrofit of historic buildings supports the planning process towards conservation compatible net zero energy buildings.
- HiBERtool was developed, combining the assessment and docu¬mentation of solutions with writing common papers. HiBERtool helped to explore and find solutions for energy-efficient retrofit of historical buildings including windows, walls, ventilation, heating and solar renewable systems. Many solutions are part of a fully documented best practice example.
- Significant work was done on the Assessment of the European standard EN 16883 Conservation of cultural heritage — Guidelines for improving the energy performance of historic buildings. This work will feed into a proposal for improving the standard. The analysis was based on three case studies and information from experts from different countries.

Publications

The following EBC Annex 76 / SHC Task 59: 'Renovating Historic Buildings Towards Zero Energy' reports have been published:

- 'Knowledge transfer and dissemination - Final Report on Communication and Dissemination - Summary of Activities, Outcomes and Analysis'
- 'Renovation strategies for historic buildings'.
- 'Conservation compatible energy retrofit technologies - Part I: Introduction to the integrated approach for the identification of conservation compatible retrofit materials and solutions in historic buildings'.
- 'Conservation compatible energy retrofit technologies - Part II: Documentation and assessment of conventional and innovative solutions for conservation

Image of the HiBERtool.
Source: EBC Annex 76 / SHC Task 59

and thermal enhancement of window systems in historic buildings'.

- 'Conservation compatible energy retrofit technologies - Part III: Documentation and assessment of materials and solutions for wall insulation in historic buildings'.
- 'Conservation compatible energy retrofit technologies - Part IV: Documentation and assessment of energy and cost-efficient HVAC-systems and strategies with high conservation compatibility'.
- 'Conservation compatible energy retrofit technologies - Part V: Documentation and assessment of integrated solar thermal and photovoltaic systems with high conservation compatibility'.
- 'Planning energy retrofits of historic buildings - EN16883:2017 in practice'.
- 'An Evaluation of the Usability of EN 16883:2017 - Suggestions for enhancing the European guidelines for improving the energy performance of historic buildings'.
- 'Case Studies Assessment Report'.

Meetings

No meetings were held in 2021.

Project duration
2017 – 2021

Operating Agent
Alexandra Troi, Eurac Research, Italy

Participating countries
Austria, Belgium, Denmark, France, Germany, Ireland, Italy, Spain, Sweden, Switzerland, UK, USA
Observer: Türkiye

Further information
www.iea-ebc.org

Building Energy Performance Assessment Based on In-situ Measurements

EBC ANNEX 71

It is essential that the energy-efficient technologies used in buildings do more than simply satisfy regulations based on theory; they must make genuine differences in real-world applications. Building owners, investors and governments need to know that the investments they make are delivering as expected. Therefore, it is critical to ensure that real performance matches design performance.

Recently, statistical methods and system identification techniques showed to be promising tools to characterise and assess the as-built performance of buildings. So far, though, the studies remain dispersed and are often based on dedicated tests making use of extensive monitoring techniques. A thorough analysis of the applicability of the methods, investigating the balance between cost of data gathering versus achieved precision and reliability is lacking.

This completed project evaluated and improved replicable methodologies embedded in a statistical and building physical framework to characterize and assess the actual energy performance of buildings. The project explored for residential buildings the development of characterisation methods as well as quality assurance methods. Characterisation methods aim to translate the (dynamic) behaviour of a building into a simplified model that can be used in model predictive control, fault detection, etc. Quality assurance methods aim to pinpoint some of the most relevant actual building performance metrics, such as the overall heat loss coefficient of a building, or its solar aperture.

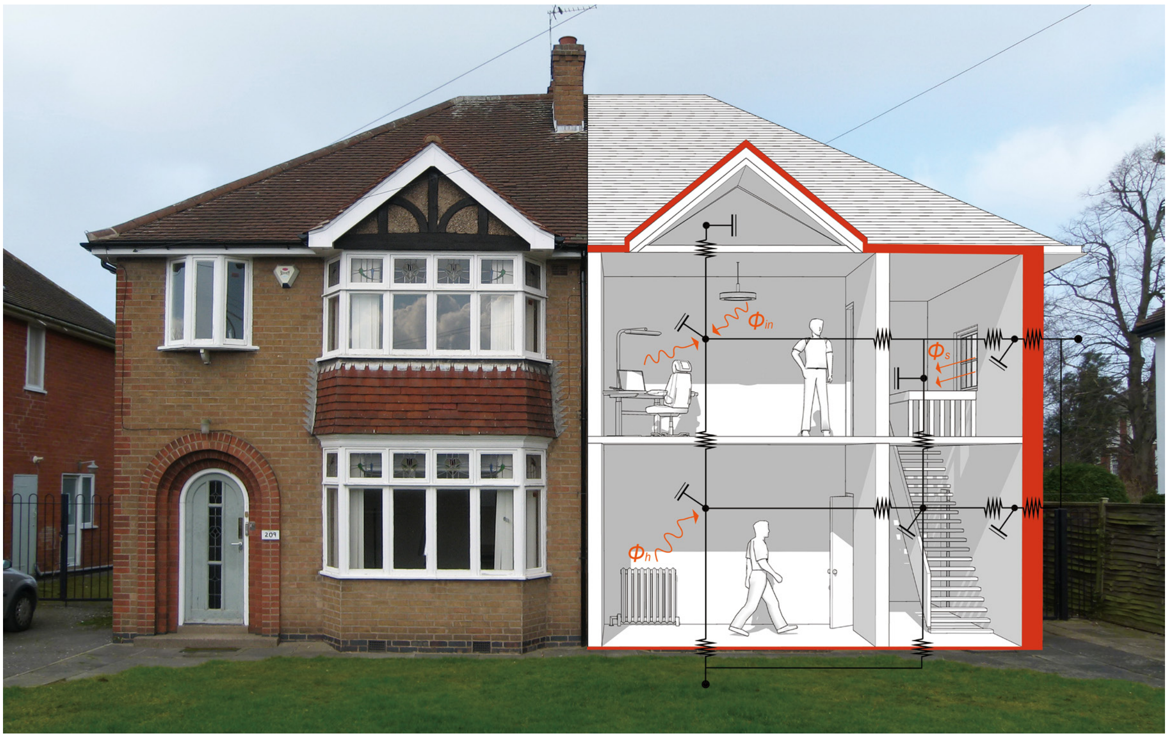
Achievements

Assembling the knowledge, tools, and skills to reliably determine the heat transfer coefficient (HTC) of a dwelling was one of the main drivers for EBC Annex 71. An extensive survey, carried out amongst our different stakeholders, revealed the interest of the building industry for such methods. However, research has been carried out in this area for several years. What set this work apart, was the idea of measurement of the HTC using cost effective data collection methods, such as smart meters and on-board devices such as thermostats, using complex analyses. Together with international examples of quality guarantees in the building sector, this resulted in a report presenting the general framework of this project.

Two additional reports examine in detail the suitability of different statistical methods for building behavior identification and quality assessment. Investigated applications regarding building behavior identification focused on model predictive control (MPC) and fault detection and diagnosis (FDD). Regarding quality assessment, the focus was on the on-site characterization of the overall heat loss coefficient of a building. On-site measured data in artificially- and actually-occupied dwellings have been used to explore and optimize statistical methods.

A final report describes a new building energy simulation (BES) validation exercise, that was set-up in the project as a follow up of the BES-validation exercise completed within the EBC project Annex 58. In the current project, real measured data on a test house, heated with a real heating system and occupied by artificial users has been used to validate common BES-models.

The project deliverables were completed in cooperation with the Dynastee-network (www.dynastee.info). This network of excellence on full scale testing and dynamic data analysis organises events on a regular basis, such as international workshops, annual training courses and helps organisations interested in full scale testing campaigns. This has enhanced the network and continues the promotion of reliable building energy performance characterisation based on full scale dynamic measurements.



Visualisation of a simplified RC-model fitted to on-site measured data to be used in building behaviour identification, or quality assessment procedures.
Source: drawing of Xiang Zhang (KU Leuven, Belgium) on a picture of the Loughborough test houses (Loughborough University, UK)

Publications

The following reports have been published:

- EBC Annex 71: Building energy performance assessment based on in-situ measurements: Challenges and general framework.
- EBC Annex 71: Building energy performance assessment based on in-situ measurements: Building behaviour identification.
- EBC Annex 71: Building energy performance assessment based on in-situ measurements: Physical parameter identification.
- EBC Annex 71: Building energy performance assessment based on in-situ measurements: Description and results of the validation of building energy simulation programs.

Meetings

Two meetings were organized in 2021:

- The 10th expert meeting took place in April 2021. Due to the pandemic the meeting was hold online.
- A closing meeting with outreach activities was held in September 2021 and was hosted by the University of Salford, UK.

Project duration
2016–2021

Operating Agent
Staf Roels, KU Leuven University of Leuven, Belgium

Participating countries
Austria, Belgium, Denmark, France, Germany, Norway, Spain, Switzerland, the Netherlands, United Kingdom
Observers: Estonia

Further information
www.iea-ebc.org

Background Information

EBC AND THE IEA

RECENT PUBLICATIONS

EBC EXECUTIVE COMMITTEE MEMBERS

EBC OPERATING AGENTS

PAST PROJECTS

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 over 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.

EBC PARTICIPATING COUNTRIES

Australia
Austria
Belgium
Brazil
Canada
P.R. China
Czech Republic
Denmark
Finland
France
Germany
Italy
Ireland
Japan
R. Korea
New Zealand
The Netherlands
Norway
Portugal
Singapore
Spain
Sweden
Switzerland
Türkiye
UK
USA

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 R&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, including Annexes and strategic planning, with all IEA buildings-related TCPs through collaborative projects and through the BCG (Buildings Coordination Group), constituted by the IEA Energy End Use Working Party (EUWP) Vice Chair for Buildings and the Executive Committee Chairs of the following IEA Technology Collaboration Programmes:

– 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)

Beyond the BCG meetings, EBC meets 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 Technology Collaboration Programmes 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 CO_2 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 22,000 records on air infiltration, ventilation and related areas, Web based, updated every 3 months

AIVC Conference Proceedings

– 40th AIVC Annual Conference, held Ghent, Belgium, October 2019

Ventilation Information Papers

– VIP 40: Ductwork airtightness - A review, 2020
– VIP 41: Impact of wind on the airtightness test results, 2021
– VIP 42: The Concept for Substituting Ventilation by Gas Phase Air Cleaning, 2021
– VIP 43: Residential ventilation and health, 2021
– VIP 44: Residential Cooker Hoods, 2021

Design and Operational Strategies for High IAQ in Low Energy Buildings – EBC Annex 68

– Subtask 1: Defining the Metrics, 2017
– Subtask 2: Pollutant Loads in Residential Buildings (Common Exercises), 2020
– Subtask 3: Modelling of Energy Efficiency and IAQ - Review, Gap analysis and Categorization, 2020
– Subtask 4: Current Challenges, Selected Case Studies and Innovative Solutions Covering Indoor Air Quality, Ventilation Design and Control in Residences, 2020
– Subtask 5: Field Measurements and Case Studies, 2020
– Subtask 5: Field Measurements and Case Studies - Appendix to Final Report: Case Studies, 2020

Building Energy Performance Assessment Based on In-situ Measurements – EBC Annex 71

– Physical Parameter Identification, 2021
– Building Behaviour Identification, 2021
– Challenges and General Framework, 2021
– Description and Results of the Validation of Building Energy Simulation Programs, 2021

Renovating Historic Buildings Towards Zero Energy – EBC Annex 76 / SHC Task 59

– Knowledge transfer and dissemination - Final Report on Communication and Dissemination - Summary of Activities, Outcomes and Analysis, 2021
– Renovation strategies for historic buildings, 2021
– Conservation compatible energy retrofit technologies - Part I: Introduction to the integrated approach for the identification of conservation compatible retrofit materials and solutions in historic buildings, 2021
– Conservation compatible energy retrofit technologies - Part II: Documentation and assessment of conventional and innovative solutions for conservation and thermal enhancement of window systems in historic buildings, 2021
– Conservation compatible energy retrofit technologies - Part III: Documentation and assessment of materials and solutions for wall insulation in historic buildings, 2021
– Conservation compatible energy retrofit technologies - Part IV: Documentation and assessment of energy and cost-efficient HVAC-systems and strategies with high conservation compatibility, 2021
– Conservation compatible energy retrofit technologies - Part V: Documentation and assessment of integrated solar thermal and photovoltaic systems with high conservation compatibility, 2021
– Planning energy retrofits of historic buildings - EN16883:2017 in practice
– An Evaluation of the Usability of EN 16883:2017 - Suggestions for enhancing the European guidelines for improving the energy performance of historic buildings, 2021
– Case Studies Assessment Report, 2021

Integrated Solutions for Daylighting and Electric Lighting – EBC Annex 77 / SHC Task 61

– Workflow and Software for the Design of Integrated Lighting Solutions, 2019
– Literature review - Energy saving potential of user-centred integrated lighting solutions, 2021
– Analysis and evaluation of BSDF characterization of daylighting systems, 2021
– Standardisation issues related to lighting and daylighting control systems, 2021
– Review of new systems and trends, 2021
– User perspective and requirements - Personas, 2021
– User perspective and requirements - Use cases, 2021
– Evaluating integrated lighting projects - A Procedure to Post-Occupancy Evaluation of Daylight and Electrical Lighting Integrated Projects, 2021
– Integrating daylighting and lighting in practice: Lessons learned from international case studies, 2021
– Spectral sky models for advanced daylight simulations, 2021
– User Interfaces, 2021
– Review of lighting and daylighting control systems, 2021
– Survey on opportunities and barriers in lighting controls, 2021
– BSDF generation procedures for daylighting systems - White paper, 2021
– Literature review of user needs, toward user requirements, 2021
– Workflows and software for the design of integrated lighting solutions, 2021
– Daylighting of Non–Residential Buildings - Position Paper, 2021

Working Group on HVAC Energy Calculation Methodologies for Non-residential Buildings

– Final Report, 2020

Working Group on Cities and Communities

– Final Report, 2020

Working Group on Building Energy Codes

– Building Energy Codes and Other Mandatory Policies Applied to Existing Buildings, 2021

EBC Executive Commitee Members

CHAIR
Dr Takao Sawachi (Japan)

VICE CHAIR
Prof Paul Ruyssevelt (United Kingdom)

AUSTRALIA
Stanford Harrison
Department of Climate Change, Energy, the Environment and Water
stanford.harrison@dcceew.gov.au

AUSTRIA
DI (FH) Isabella Warisch
Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology
Isabella.Warisch@bmk.gv.at

BELGIUM
Dr Peter Wouters
Belgian Building Research Institute (CSTC – WTCB)
peter.wouters@buildwise.be

BRAZIL
Gustavo Santos Masili
Ministério de Minas e Energia
gustavo.masili@mme.gov.br

CANADA
Meli Stylianou
Natural Resources Canada
meli.stylianou@canada.ca

P.R. CHINA
Prof Yi Jiang
Tsinghua University
jiangyi@tsinghua.edu.cn

CZECH REPUBLIC
Hana Rambousková
Ministry of Industry and Trade
rambouskova@mpo.cz

DENMARK
Søren Østergaard Jensen
The Danish Energy Agency
snjn@ens.dk

FINLAND
Dr Ala Hasan
VTT Technical Research Centre of Finland
Ala.Hasan@vtt.fi

FRANCE
Marjorie Musy
CEREMA
marjorie.musy@cerema.fr

GERMANY
Katja Riess
Forschungszentrum Juelich
k.riess@fz-juelich.de

IRELAND
Conor Hanniffy
Sustainable Energy Authority of Ireland
conor.hanniffy@seai.ie

ITALY
Michele Zinzi
ENEA - UTEE ERT
michele.zinzi@enea.it

JAPAN
Dr Eng Takao Sawachi (Chair)
Building Research Institute, Japan
tsawachi@kenken.go.jp

REPUBLIC OF KOREA
Dr Seung-eon Lee
Korea Institute of Construction Technology
selee2@kict.re.kr

NETHERLANDS
Daniël van Rijn
Netherlands Enterprise Agency
daniel.vanrijn@rvo.nl

NEW ZEALAND
Michael Donn
Victoria University of Wellington
michael.donn@vuw.ac.nz

NORWAY
Harald Rikheim
Norges Forskningsråd
hri@forskningsradet.no

PORTUGAL
João Mariz Graça
Direção-Geral de Energia e Geologia
Joao.Graca@dgeg.gov.pt

SINGAPORE
Noel Chin
Building and Construction Authority
Noel_CHIN@bca.gov.sg

SPAIN
María José Jiménez Taboada
CIEMAT-Plataforma Solar de Almería
mjose.jimenez@psa.es

SWEDEN
Dr Jörgen Sjödin
Swedish Energy Agency
jorgen.sjodin@energimyndigheten.se

SWITZERLAND
Andreas Eckmanns
Bundesamt für Energie BFE
andreas.eckmanns@bfe.admin.ch

TÜRKİYE
Assoc. Prof Dr. Gülsu Ulukavak Harputlugil
Çankaya Üniversitesi
gharputlugil@cankaya.edu.tr

UK
Prof Paul Ruyssevelt (Vice Chair)
University College London
p.ruyssevelt@ucl.ac.uk

USA
Marc LaFrance
US Department of Energy
marc.lafrance@ee.doe.gov

EBC Executive Committee Support and Services Unit (ESSU)
Malcolm Orme
essu@iea-ebc.org

IEA Secretariat
Ksenia Petichenko
Ksenia.Petichenko@iea.org

EBC Operating Agents

Air Infiltration and Ventilation Centre (AIVC) – EBC Annex 5
Dr Peter Wouters
INIVE EEIG, Belgium
info@aivc.org

Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings – EBC Annex 69
Prof Yingxin Zhu
Tsinghua University, P.R. China
zhuyx@tsinghua.edu.cn

Prof Richard de Dear
University of Sydney, Australia
richard.dedear@sydney.edu.au

Building Energy Epidemiology: Analysis of Real Building Energy Use at Scale – EBC Annex 70
Dr Ian Hamilton
University College London, UK
i.hamilton@ucl.ac.uk

Building Energy Performance Assessment Based on In-situ Measurements – EBC Annex 71
Prof Staf Roels
University of Leuven, Belgium
staf.roels@bwk.kuleuven.be

Assessing Life Cycle Related Environmental Impacts Caused by Buildings – EBC Annex 72
Rolf Frischknecht
treeze Ltd., Switzerland
frischknecht@treeze.ch

Towards Net Zero Energy Resilient Public Communities – EBC Annex 73
Dr Alexander M. Zhivov
Energy Branch US Army Corps of Engineers, USA
Alexander.M.Zhivov@erdc.usace.army.mil

Rüdiger Lohse
KEA-Climate protection and energy agency of Baden-Württemberg GmbH, Germany
ruediger.lohse@edlhub.org

Competition and Living Lab Platform – EBC Annex 74
Prof Karsten Voss
University Wuppertal, Germany
kvoss@uni-wuppertal.de

Prof Sergio Vega
Technical University of Madrid, Spain
sergio.vega@sdeurope.org

Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables – EBC Annex 75
Dr Manuela Almeida
University of Minho, Portugal
malmeida@civil.uminho.pt

Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions – EBC Annex 76 / SHC Task 59
Dr Alexandra Troi
EURAC Research, Italy
Alexandra.Troi@eurac.edu

Integrated Solutions for Daylighting and Electric Lighting – EBC Annex 77 / SHC Task 61
Dr-Ing Jan de Boer
Fraunhofer Institute for Building Physics, Germany
jan.deboer@ibp.fraunhofer.de

Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications – EBC Annex 78
Prof Bjarne Olesen
Technical University of Denmark
bwo@byg.dtu.dk

Dr Pawel Wargocki
Technical University of Denmark
paw@byg.dtu.dk

Occupant-centric Building Design and Operation - EBC Annex 79
Dr Liam O'Brien,
Carleton University
liamobrien@cunet.carleton.ca

Prof Andreas Wagner
Karlsruhe Institute of Technology
wagner@kit.edu

Resilient Cooling of Buildings - EBC Annex 80
Dr Peter Holzer
Institute of Building Research and Innovation
peter.holzer@building-research.at

Data-Driven Smart Buildings – EBC Annex 81
Dr Stephen White
CSIRO, Australia
Stephen.D.White@csiro.au

Energy Flexible Buildings towards Resilient Low Carbon Energy Systems – EBC Annex 82
Dr Rongling Li
Technical University of Denmark
liron@byg.dtu.dk

Søren Østergaard Jensen
Technical University of Denmark
sosje@dtu.dk

Positive Energy Districts - EBC Annex 83
Dr Francesco Reda
VTT Technical Research Centre, Finland
Francesco.Reda@vtt.fi

Demand Management of Buildings in Thermal Networks - Annex 84
Dr Anna Marszal-Pomianowska
Aalborg University, Denmark
ajm@build.aau.dk

Indirect Evaporative Cooling - Annex 85
Dr Xiaoyun Xie
Tsinghua University, P.R. China
xiexiaoyun@tsinghua.edu.cn

Energy Efficient Indoor Air Quality Management in Residential Buildings - Annex 86
Prof Jelle Laverge
Ghent University, Belgium
jelle.laverge@ugent.be

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

Dr Ongun Berk Kazanci
Technical University of Denmark
onka@byg.dtu.dk

Prof Bjarne Olesen
Technical University of Denmark
bwo@byg.dtu.dk

Communities and Cities EBC Working Group

Helmut Strasser
Salzburg Institute for Regional Planning and Housing, Austria
helmut.strasser@salzburg.gv.at

Building Energy Codes EBC Working Group

Michael Donn
Victoria University of Wellington
michael.donn@vuw.ac.nz

Meli Stylianou
Natural Resources Canada
meli.stylianou@canada.ca

Meredydd Evans
Pacific Northwest National Laboratory , USA
m.evans@pnnl.gov

Past Projects

Annex 1 Load Energy Determination ofBuildings
Annex 2 Ekistics and Advanced Community Energy Systems
Annex 3 Energy Conservation in Residential Buildings
Annex 4 Glasgow Commercial Building Monitoring
Annex 6 Energy Systems and Design of Communities
Annex 7 Local Government Energy Planning
Annex 8 Inhabitants Behaviour with Regard to Ventilation
Annex 9 Minimum Ventilation Rates
Annex 10 Building HVAC System Simulation
Annex 11 Energy Auditing
Annex 12 Windows and Fenestration
Annex 13 Energy Management in Hospitals
Annex 14 Condensation and Energy
Annex 15 Energy Efficiency in Schools
Annex 16 BEMS 1-User Interfaces and System Integration
Annex 17 BEMS 2-Evaluation and Emulation Techniques
Annex 18 Demand Controlled Ventilation Systems
Annex 19 Low Slope Roof Systems
Annex 20 Air Flow Patterns within Buildings
Annex 21 Thermal Modelling
Annex 22 Energy Efficient Communities
Annex 23 Multi Zone Air Flow Modelling (COMIS)
Annex 24 Heat, Air and Moisture Transfer in Envelopes
Annex 25 Real time HEVAC Simulation
Annex 26 Energy Efficient Ventilation of Large Enclosures
Annex 27 Evaluation and Demonstration of Domestic Ventilation Systems
Annex 28 Low Energy Cooling Systems
Annex 29 Daylight in Buildings
Annex 30 Bringing Simulation to Application
Annex 31 Energy-Related Environmental Impact of Buildings
Annex 32 Integral Building Envelope Performance Assessment
Annex 33 Advanced Local Energy Planning
Annex 34 Computer-Aided Evaluation of HVAC System Performance
Annex 35 Design of Energy Efficient Hybrid Ventilation (HYBVENT)
Annex 36 Retrofitting of Educational Buildings
Annex 37 Low Exergy Systems for Heating and Cooling of Buildings (LowEx)
Annex 38 Solar Sustainable Housing
Annex 39 High Performance Insulation Systems
Annex 40 Building Commissioning to Improve Energy Performance
Annex 41 Whole Building Heat, Air and Moisture Response (MOIST-ENG)
Annex 42 The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
Annex 43 Testing and Validation of Building Energy Simulation Tools
Annex 44 Integrating Environmentally Responsive Elements in Buildings
Annex 45 Energy Efficient Electric Lighting for Buildings
Annex 46 Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47 Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48 Heat Pumping and Reversible Air Conditioning
Annex 49 Low Exergy Systems for High Performance Buildings and Communities
Annex 50 Prefabricated Systems for Low Energy Renovation of Residential Buildings
Annex 51 Energy Efficient Communities: Case Studies and Strategic Guidance for Urban Decision Makers
Annex 52 Towards Net Zero Energy Solar Buildings (NZEBs)
Annex 53 Total Energy Use in Buildings – Analysis and Evaluation Methods
Annex 54 Integration of Microgeneration and Other Energy Technologies in Buildings
Annex 55 Reliability of Energy Efficient Building Retrofitting – Probability Assessment of Performance and Cost
Annex 56 Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation
Annex 57 Evaluation of Embodied Energy and Carbon Dioxide Equivalent Emissions for Building Construction
Annex 58 Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurement
Annex 59 High Temperature Cooling and Low Temperature Heating in Buildings
Annex 60 New Generation Computational Tools for Building and Community Energy Systems
Annex 61 Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62 Ventilative Cooling
Annex 63 Implementation of Energy Strategies in Communities
Annex 64 LowEx Communities – Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65 Long-term Performance of Super-insulating Materials in Building Components and Systems
Annex 66 Definition and Simulation of Occupant Behavior in Buildings
Annex 67 Energy Flexible Buildings

Annex 68	Indoor Air Quality Design and Control in Low Energy Residential Building
Annex 71	Building Energy Performance Assessment Based on In situ Measurements
Annex 76	Deep Rrenovation of Historic Buildings towards Lowest Possible Energy Demand and CO2 Emission
Annex 77	Integrated Solutions for Daylighting and Electric Lighting