ANNEX 86

EBC

Energy in Building and Communities Programme

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

Project Summary Report

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international cooperation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is 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. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.).

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely ‘Objectives’ and ‘Means’. These two groups are distinguished for a better understanding of the different themes.

Objectives: The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of ‘low tech’, robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible; the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means: The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from ‘living labs’ to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the ‘objectives’ themes are final goals or solutions (or part of) for an energy efficient built environment, while the ‘means’ themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
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 HVAC 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 (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)

Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
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 Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (*)
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale (*)
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements (*)
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings (*)
Annex 73: Towards Net Zero Energy Resilient Public Communities (*)
Annex 74: Competition and Living Lab Platform (*)
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables (*)
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions (*)
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting (*)
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications (*)
Annex 79: Occupant-Centric Building Design and Operation (*)
Annex 80: Resilient Cooling (*)
Annex 81: Data-Driven Smart Buildings (*)
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems (*)
Annex 83: Positive Energy Districts
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Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
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Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: EBC Annex 90 / SHC Task 70 Low Carbon, High Comfort Integrated Lighting
Annex 91: Open BIM for Energy Efficient Buildings
Annex 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings
Annex 93: Energy Resilience of the Buildings in Remote Cold Regions
Annex 94: Validation and Verification of In-situ Building Energy Performance Measurement Techniques
Annex 95: Human-centric Building Design and Operation for a Changing Climate
Annex 96: Grid Integrated Control of Buildings
Annex 97: Sustainable Cooling in Cities
Annex 98: Flexibilization and Optimization of Heat Pump Systems in Existing Buildings through Secondary-Side Digitalization
Annex 99: Air Cleaning for Sustainable and Resilient Buildings

Working Group – Energy Efficiency in Educational Buildings (*)
Working Group – Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group – Annex 36 Extension: The Energy Concept Adviser (*)
Working Group – HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group – Cities and Communities (*)
Working Group – Building Energy Codes

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Summary Report

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

The IEQ-Global Alliance (IEQ_GA) defines Indoor Environmental Quality (IEQ) as encompassing four core dimensions: the thermal environment, indoor air quality (IAQ), lighting, and the acoustic environment experienced by occupants. Among these, IAQ has, as showcased by the recent IAQ focused event at the UN general assemby, emerged as a central concern, both for its direct impact on health and its significant interaction with energy performance. While ventilation remains the primary strategy for IAQ management, complementary technologies such as advanced air filtration and air cleaning systems are increasingly available. However, despite this growing diversity of approaches, no coherent framework currently exists for systematically assessing and comparing the performance of different IAQ management strategies.

IEA-EBC Annex 86 was established to address this gap. Its central focus has been to assess performance trade-offs, identify optimal solutions, and develop the methodological foundations required to achieve maximum energy efficiency while guaranteeing high levels of indoor air quality across new, renovated, and existing residential buildings. The Annex does not propose a single prescriptive tool, but rather a **coordinated framework of interoperable components**—a suite of methodological "building blocks" designed to strengthen confidence in performance-based assessment. This cooperative structure enables stakeholders to adopt, test, and refine performance-based approaches in a mutually reinforcing way, fostering the evolution of a robust, evidence-driven ecosystem for IAQ management.

The emerging **IAQ performance-based ecosystem** explored in Annex 86 is structured along three key dimensions: **methodology, application, and implementation**.

- **Methodology:** Building upon the advanced simulation methods developed in earlier Annexes 23 and 68, Annex 86 first established metrics applicable across diverse IAQ technologies (Subtask 1) and compiled reliable input datasets to support accurate modeling and simulation (Subtask 2).
- **Application:** On the opposing ends of the technology readiness spectrum, the Annex explored innovative solutions such as smart materials designed for targeted pollutant removal—from basic research through proof-of-concept demonstrations (Subtask 3). In parallel, long-term performance assessments of smart ventilation systems in the field were conducted, examining the mechanisms that sustain high performance over extended periods (Subtask 4).
- **Implementation:** To facilitate real-world deployment, the Annex conducted "common exercises", collaborative efforts applying the developed metrics to smart ventilation systems under different national regulatory contexts (Subtask 4) and investigated how the Internet of Things (IoT) can enhance monitoring, control, and feedback mechanisms in performance-based IAQ management (Subtask 5).

The outcomes of Annex 86 are captured in four primary **deliverables**, collectively forming a reference framework for future policy, design, and implementation efforts.

- **Deliverable D.3** serves as the integrated synthesis, compiling the most significant methods and tools developed across the Annex into a single, accessible report. It provides concise summaries of each Subtask, complemented by references for deeper exploration.
- **Deliverable D.1** presents a comprehensive literature list for those looking for more in-depth reading, available as plain text as well as 4 different common reference manager formats, and is disseminated through AIVC.
- **Deliverable D.2** details the open-access datasets created under Subtask 2, including the *Pandora* database for emissions and source characterization, and repositories on GitHub and Zenodo for exposure analyses.
- **Deliverable D.4** showcases applications of the Annex's methods through practical demonstrations of tools, and documentation of joint exercises and outreach webinars.

A central insight emerging from this collective work is that **indoor air quality exerts a direct and measurable influence on human health**, yet most building regulations still address ventilation in isolation—without integrating explicit objectives, criteria, or indicators that define and assess IAQ performance. Annex 86 fills this critical policy and technical gap by developing and testing **new performance-based methods** to quantify the health, functional, and economic consequences of exposure to indoor air contaminants.

One of the most significant achievements of the Annex is the adoption of **Disability-Adjusted Life Years (DALYs)** as a common metric for quantifying the health burden of exposure to contaminants in indoor air. This enables the comparison of different contaminants on a unified scale and supports prioritization based on actual harm. Particulate matter and formaldehyde were identified as the dominant contributors to this health burden. The developed methodology underpins **the world's first harm-based compliance pathway incorporated into ASHRAE Standard 62.2**, representing a major advancement in the alignment of building standards with public health objectives.

Beyond health metrics, the Annex developed and tested a set of metrics for **multi-criteria assessment frameworks** that evaluate IAQ management strategies across multiple performance dimensions, including energy efficiency, cost, resilience, and robustness. Simulation studies explored how different system types perform against different metrics under typical constant and variable, dynamic conditions, while a resilience framework was created to assess system responses to shocks such as outdoor pollution events, indoor emission peaks, and power outages. These approaches enable decision-makers to assess not only average system performance but also reliability under stress.

The Annex further quantified the **economic and social costs of poor IAQ**, revealing that productivity losses associated with Sick Building Syndrome constitute the largest share of the total burden, followed by chronic disease impacts primarily linked to particulate matter exposure. Case studies demonstrated that interventions such as the use of low-emission materials, filtered ventilation, and optimized airflow rates can substantially reduce these costs, strengthening the case for performance-based regulation.

Because simulation plays a pivotal role in implementing performance-based methods, a second major achievement was the creation of **two open datasets compiling global literature on pollutant sources, typical exposure levels, and concentration distributions**. These datasets are supported by analytical tools that allow modelers to perform uncertainty and sensitivity analyses, ensuring the robustness of their results. The underlying data schemas accommodate both small-scale experimental data and large-scale IoT-based data collection, enabling scalable and adaptive modeling approaches. The datasets and associated algorithms, publicly accessible through the *Pandora* and *Global IAQ* databases, form a critical foundation for future data-driven IAQ management.

A third major contribution lies in the **proof-of-concept development of novel smart materials** as active components in IAQ management strategies. The Annex identified **Metal–Organic Frameworks (MOFs)** as a particularly promising class of materials for indoor pollutant removal. Experimental studies demonstrated that MOFs can outperform conventional sorbents by up to an order of magnitude and can be engineered for easy regeneration and targeted performance. Simulation models were subsequently developed to incorporate these materials into integrated IAQ design frameworks. The research findings directly inform the objectives of **IEA-EBC Annex 92**, focused on advancing smart materials for heating, cooling, and air quality control in residential buildings.

Finally, the Annex assessed the **implementation potential of performance-based IAQ approaches** through surveys, simulation exercises, and field investigations of smart ventilation systems. The results underscore the importance of continuous verification throughout a system's life cycle. Regulatory frameworks should therefore provide not only performance criteria and indicators but also mechanisms for verification, validation, and stakeholder support across all stages — from design to operation. Participants in Annex 86 continue to advance this approach through their contributions to **CEN TC 156 WG 25** and **ISO TC 205/163 JWG 4**, ensuring its integration into emerging European and international standards.

Taken together, these achievements constitute a **comprehensive toolkit** for an ecosystem that supports policymakers, designers, and industry leaders seeking to transition from prescriptive to performance-based approaches in IAQ management. The results of Annex 86 demonstrate that by combining robust metrics, transparent data, innovative materials, and adaptive regulatory frameworks, it is possible to simultaneously enhance energy performance, protect occupant health, and promote a resilient, future-ready building stock.

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