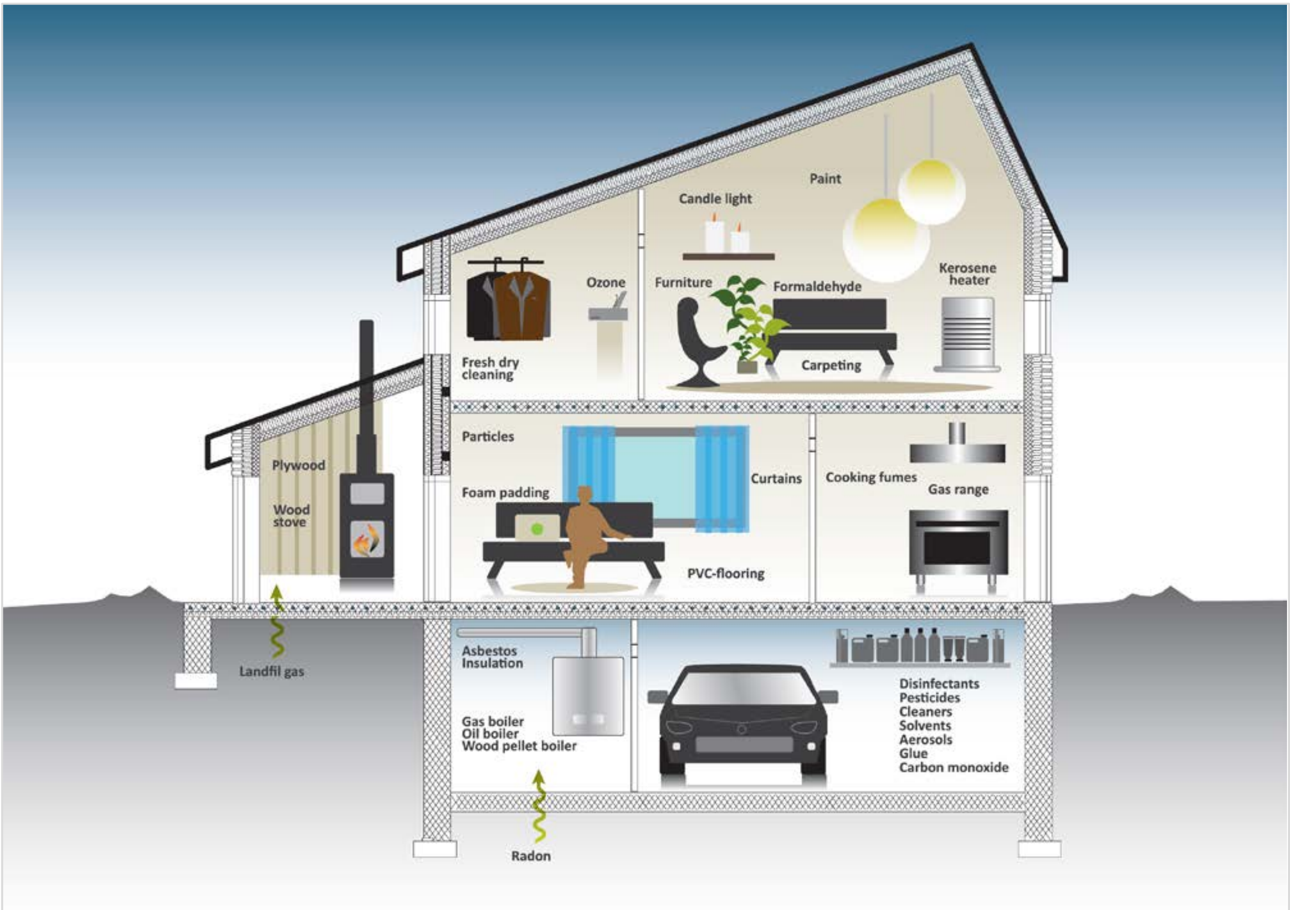
Final report

1. Project details

Project title	Coordination of IEA EBC Annex 68
File no.	64015-0062
Name of the funding scheme	EUDP – Energy efficiency
Project managing company / institution	DTU Civil Engineering
CVR number (central business register)	30 06 09 46
Project partners	Danish Building Research Institute, SBi, Aalborg University (AAU Build). Danish Technological Institute.
Submission date	14 December 2020



Source, ICIEE, DTU Civil Engineering

2. Summary

Summary (in English)

New dwellings or deeply renovated existing dwellings are designed to be energy efficient, and have airtight structures. This leads to a risk of high indoor pollutant loads due to activities and emissions from materials in contact with indoor air. Ventilation must be dosed at the right volume of clean air with proper scheduling in order to keep indoor pollutant concentrations low, while not increasing the energy need. The target group are stakeholders involved in design, construction and maintenance of buildings.

Relevant indoor air quality (IAQ) indicators are documented in a report that gathers state of the art information and presents the indicators in a “dashboard” that considers the combination of the most significant pollutants and also visualizes the energy use.

A main result of the project is an easy to understand and practically applicable collection of experiences with design and operational strategies for achieving optimal energy performance and high IAQ in residential buildings.

Furthermore, the project presents a modelling framework and design tools, suitable for integrated and coordinated design of buildings with low energy consumption and high IAQ.

With regards to pollutants in buildings, data and models have been applied on sources and sinks of pollutant emissions to estimate the net pollutant loads over time under realistic environmental conditions. This is supported by databases on the properties of materials with respect to pollutant emissions.

Finally, field tests and case studies were documented for different climatic zones as well as methodologies to carry out such testing. Specifically, this activity targeted industry partners, building owners and operators.

An important lead from the project to policy makers is to facilitate possibility by legislation that residential buildings may be operated flexibly and intelligently with regards to demand control of ventilation in a manner that considers realistic hygrothermal and pollutant loads in buildings.

Resumé (in Danish)

Nye boliger eller renoverede eksisterende boliger er designet til at være energieffektive og har lufttætte strukturer. Dette fører til en risiko for høje indendørs belastninger med forurening på grund af aktiviteter og emissioner fra materialer, der er i kontakt med indeluften. Ventilation skal doseres med den rette mængde ren luft med korrekt styring for at holde koncentrationen af forurenende stoffer lavt, samtidig med at energibehovet ikke øges. Målgruppen er personer involveret i design, udførelse og vedligehold af bygninger.

Relevante indendørs luftkvalitetsindikatorer er dokumenteret i en rapport, der samler aktuel viden og præsenterer indikatorerne i et "kontrol panel" over kombinationen af de mest betydningsfulde forurenende stoffer og som også visualiserer energiforbruget.

Et hovedresultat af projektet er en letforståelig og praktisk anvendelig samling af erfaringer med design- og driftsstrategier til opnåelse af optimal energimæssig ydeevne og høj indeluftkvalitet i boliger.

Desuden præsenterer projektet et sæt designværktøjer, der er velegnet til integreret og samordnet design af bygninger med lavt energiforbrug og høj IAQ.

Med hensyn til forurenende stoffer i bygninger er der anvendt data og modeller om afgivelse og absorbering af forureninger for at estimere forurenings-belastningen over tid under realistiske miljøforhold. Dette understøttes af databaser om materialernes egenskaber med hensyn til emission af forurenende stoffer.

Endelig blev feltundersøgelser og casestudier dokumenteret for forskellige klimazoner samt metoder til at udføre sådan tests. Denne aktivitet har specifikt været målrettede industripartnere, bygningsejere og driftspersonale.

Et vigtigt hint fra projektet til beslutningstagere er, at der lovgivningsmæssigt bør være mulighed for, at boliger kan drives fleksibelt og intelligent med hensyn til behovsstyring af ventilation, der betragter realistiske hygrotermiske og forureningsmæssige belastninger i bygninger.

3. Project objectives

Objective and setting of the national EUDP project

The objective of the EUDP project has been to be managers of the international IEA EBC Annex 68 project, which should establish the basis for design and operational strategies for buildings that have very low energy consumption and maintain a high standard of indoor environment based on control of supply, removal and flows of heat, air, moisture and contaminants under in-use conditions.

The international project had participation from researchers and a few company representatives from some 39 organizations from 15 countries, see Table 1. In addition, national stakeholders had occasion to interact with the project when semi-annual working meetings were arranged by differing hosts among the participating countries. Participation from these international partners was funded by them-selves nationally, and the purpose of the Danish EUDP project was to facilitate the international coordination. This also means that the production of research results from the project was mainly relying on the contributions and resources from the different international partners.

Table 1 A total of 39 institutions from the below 15 countries have contributed to the project. The table lists only the 19 organizations with whom an official Letter of National Participation has been signed.

Country	Organization
Austria	Universität Innsbruck
Belgium	Ghent University
Canada	British Columbia Institute of Technology
China	Nanjing University
Czech Republic	Czech Technical University of Prague
Denmark	Technical University of Denmark
Estonia (observing country)	Tallinn University of Technology
France	LaSIE, Université La Rochelle LOCIE, Université de Savoie Saint-Gobain Recherche
Germany	TU Dresden
Korea	Korea Institute of Civil Engineering & Building Technology
The Netherlands	TU Eindhoven
New Zealand	Building Research Association of New Zealand
Norway	Norwegian University of Science and Technology Norwegian Institute for Wood Technology Norwegian University of Life Sciences
United Kingdom	University College London
USA	Syracuse University

Professor Carsten Rode, Department of Civil Engineering, Technical University has been the so-called “Operating Agent” of the international project. Associate Professors Menghao Qin, Jakub Kolarik and Pawel Wargocki have been subtask leaders (Qin and Kolarik) and co-subtask leaders (Wargocki) on the international project’s Subtasks 2, 4 and 1, respectively. These leadership tasks were supported by the EUDP project, whereas research results were based on other activity from the research portfolio of the researchers and colleagues from their groups.

Based on the EUDP project, also Senior Researcher Henrik N. Knudsen from the Danish Building Research Institute (now “Build”, Aalborg University), and Senior Specialist Thomas Witterseh from the Danish Technological Institute have contributed with results from their research portfolio – although without having particular leadership tasks.

The research theme of the project is certainly of interest for Danish energy policy and for commercial stakeholders (who were also interacting with the project along the way), but it has obviously had interest from participants from many parts of the world.

Representation of Danish stakeholders in the project were by the companies Rockwool International A/S, Exhausto A/S, COWI A/S, NIRAS A/S, VELUX A/S, Isover Scandinavia, and Cenergia Energy Consultants (later Kuben Management) and the trade organization VELTEK. They had opportunity to participate as visitors at two occasions at International expert meetings hosted in Denmark, at other information meetings and regular communication on a personal basis with representatives from these companies.

Concluding on the objectives from the perspective of the Danish EUDP project has been to use this organizational setting as a means to lead and coordinate an important international effort and thus being able to direct a considerably larger set of activities than what would be possible in a national project alone. Each participating country was committed to deliver 3 man-months of labour per year, which is altogether a comprehensive effort.

Objective of the International IEA EBC Annex 68 project

The international Annex project has focused on design options and operational strategies, which can be used to enhance energy performance of new and refurbished residential buildings, for instance demand controlled ventilation and improvement of the building envelope by tightening and selecting better insulating products. These methods should be studied with a view to finding optimal solutions for good energy performance and high Indoor Air Quality (IAQ).

A central hypothesis of the Annex has been that high IAQ buildings can only be achieved by carrying out a multi-facetted optimization. Specifically, a handful of technology areas have been dealt with as outlined in the paragraphs below, which also pertain to the subtask division that is explained in the next section.

A major obstacle to integrating energy and IAQ strategies in building design and optimization has been the lack of a quantitative measure of the IAQ benefit in comparison with the benefit of energy saving and reduction of greenhouse gas emissions. The project should collect existing correlations between IAQ and productivity, and healthcare related costs should be reviewed. An approach should be developed of relevance for residential buildings to enable proper consideration of both energy and IAQ benefit in building design and operation.

Another obstacle to integrating energy and IAQ strategies has been the lack of reliable methods and data for estimating pollutant loads in buildings in the way heating/cooling loads are routinely estimated. The project should collect existing data and to some extent establish new data about properties for transport, retention and emission of chemical substances in new and recycled materials under the influence of heat and moisture conditions where such correlations are not sufficiently known. Collection of results from lab tests on material and room level should be part of this study. Specifically, results should be collected and analysed from tests of emission of harmful compounds under various temperature, humidity and air flow conditions, since only a limited number of such data under combined exposures exist.

It was also anticipated that manufacturers of building materials and inventory products should be involved regarding testing and possible co-development of products that have minimal emission of harmful substances or which may have function to absorb indoor pollutants.

Furthermore, the project should address the inadequacy of existing knowledge to predict the combined effects of hygrothermal conditions and chemical reactions on the indoor pollution species and concentrations in light of recent revelations of the importance of secondary emissions such as ozone-initiated indoor air and surface chemistry in affecting the indoor air quality. The approach of modelling the effects of combined heat, air, moisture and pollutant (CHAMPS) transport and their impact on energy and IAQ is needed. A task should be to collect and develop guidelines about use of contemporary whole building analysis tools and methods to predict the hygrothermal conditions, absorption and transport of humidity and chemical substances, and energy consumption within buildings. Focus should be on methods to predict the emission and absorption of chemical compounds from materials under realistic in-use conditions regarding the CHAMPS-exposure in buildings. It should be a high priority that the methods also facilitate prediction of the energy consumption associated with the operation of buildings, such that the tools can be used to optimize for the minimal energy consumption that satisfies the needs with respect to indoor environmental quality.

Using the metrics, models and databases developed in the project, another task should be to devise optimal design and control strategies for the operation of buildings, not least with regards to ventilation requirement and ventilation mode (e.g. intermittent vs. continuous ventilation), such that the building energy performance, user comfort and health conditions could be optimized. A focus point has been on strategies that benefit both energy and IAQ, including developing new paradigms for multi-scale and local thermal and air quality management, and demand controlled ventilation that consider the transport of chemical compounds to and from the indoor atmosphere. Studies of buildings should be conducted such that the developed strategies could be validated.

Cooperation was anticipated with building designers and with companies that provide ventilation systems and controls.

Finally, field tests and analyses should be carried out on a variety of residential buildings to test and verify the findings of the previous elements of the project. Buildings located in several sites/climates should be studied, and the field tests should include buildings, which are declared as “green”. Both new and refurbished older buildings should be comprised in the case studies. The field tests should focus on testing and demonstrating in practice which low energy operational strategies can be applied to provide amenable indoor environments.

The field tests should be carried out in cooperation with industry partners from the previous subtasks and with building owners, and should involve engineers and building owners/operators from the studied buildings.

The Annex project should put emphasis on ensuring that the knowledge developed in the project could be brought to companies and associations which are in the market. Therefore, the Annex should cooperate closely with and form ties with industry and working groups such as the AIVC on ventilation, university and industry groups working on chemical emissions from building products, building physicists and practitioners regarding hygrothermal conditions in buildings and their materials, and building simulation communities (e.g. IBPSA) on modelling of buildings.

Energy technology developed and demonstrated in the project

Technology areas covered by the project are defined according to the subtasks in which the work was executed:

Subtask 1 Defining the metrics

A major obstacle to integrating energy and IAQ strategies in building design and optimization has been the lack of a single index (marker) which would quantitatively describe the IAQ and allow comparison with the indices describing energy use. Such an index would allow to quantify the benefits of different methods for achieving high IAQ and compared in parallel with consequences for energy and greenhouse gas emission.

In this subtask, existing correlations between IAQ and health care related costs were reviewed as the index was considered useful to enable proper consideration of both energy and IAQ benefit in building design and operation. In particular, the index should include additional energy consumption needed to improve IAQ in comparison with standard practice such as increased fan consumption induced by air change rates or additional particle/gas filters, or use of air cleaners.

Subtask 2 Pollutant loads in residential buildings

An obstacle to integrating energy and IAQ strategies has been the lack of reliable methods and data for estimating pollutant loads in residential buildings in the way heating/cooling loads are routinely estimated. This subtask has been to collect existing data and to a limited extent provide new data about: properties for transport, retention and emission of chemical substances in new and recycled materials, and particle transport in residential buildings under the influence of heat, airflow and moisture conditions. Collection of results from laboratory tests on material and room level were part of this study. Specifically, results should be collected and analysed from tests of emission of harmful compounds under various temperature, humidity and airflow conditions, since such data under combined exposures generally have been very scarce before this project.

From a theoretical point of view, a so-called similarity approach was to be adopted to analyse how emission transport of pollutants from building products, particularly in the form of Volatile Organic Compounds (VOC) and their transport properties could be calculated based on well-known transport models and properties for water vapour transport.

Subtask 3 Modelling - review, gap analysis and categorization

In the past, many models have been developed in the field of building performance simulation (e.g. building design, life cycle analysis and energy retrofit). However, existing knowledge has still been inadequate for predicting the combined effects of hygrothermal conditions and chemical reactions on indoor pollution and its concentrations. In light of recent revelation of the importance of secondary emissions such as ozone-initiated indoor air and surface chemistry, a modelling approach of the effects of combined heat, air, moisture and pollutant simulation (CHAMPS) and its impact on energy and IAQ was needed.

The target of Subtask 3 has been a review, gap analysis and categorization of existing models and standards. The task was to collect and develop validated reference cases by using contemporary whole building analysis tools and methods to predict the hygrothermal conditions, absorption and transport of humidity and chemical substances, and energy consumption in buildings. The whole-building perspective was to be realized by integral consideration of indoor air and building envelope, building users and the building services systems. The feasibility of implementing reduced order models for prediction of IAQ within existing Building Energy Simulation tools should be investigated.

Subtask 4 Strategies for design and control of buildings

This subtask was to apply the results of the previously mentioned subtasks (Indoor Air Quality metrics, pollution/emission models and databases developed in Subtasks 1, 2 & 3 and experiences from the field studies of Subtask 5) together with existing knowledge to devise optimal and practically applicable design and control strategies for high IAQ in residential buildings. The strategies should take into account requirements for IAQ based on current standards as well as newly developed metrics based on health effects. Optimal strategy should be understood as one that takes into account building energy performance, user comfort and health conditions. A matrix of different strategies were to be created to evaluate possibilities for win-win solutions (excellent IAQ at low energy consumption) as well as other alternatives that will ensure high IAQ.

Use of models and databases developed under the Annex should enable addressing new paradigms for multi-scale and local thermal and air quality management including demand-controlled ventilation that consider the transport of chemical compounds to and from the indoor atmosphere. The subtask should take into account recent advances in sensor technology to identify ways to optimize IAQ without compromising on the energy efficiency. On the energy account, the subtask should seek to establish correlation factors between on one side, pollutant loads in buildings and methods to mitigate these loads, and on the other side, energy consumption.

The subtask had the initial intention to develop a guidebook with advice on technologies to ensure the intended optimal operational conditions and controls to ensure good IAQ at low energy use. However, since it became clear during project execution that it would be difficult with a collaborative activity, such as an IEA Annex project, to really have authority to issue such a guide book that would have validity in all EBC member countries and to ensure it covered all relevant aspects. Therefore, it was decided to change the scope of the subtask to merely produce a comprehensive collection of examples and cases that represent state of the art solutions carried out or gathered by the subtask participants.

Subtask 5 Field measurements and case studies

Subtask 5 was to investigate and identify relevant case studies through a literature survey and running some measurement campaigns in well-known field test buildings, and to provide data for investigation and validation in Subtask 1-4. Several sites/climates were proposed, and the field tests included buildings declared as being energy efficient, or recently refurbished to become so. The field tests should focus on testing and demonstrating in practice which low energy operational strategies can be used, which will provide amenable indoor environments. Subtask 5 was to, as far as possible, test buildings with the ventilation strategies that represent both current and novel solutions, as identified in Subtask 4.

The tests were to include studies of new ventilation patterns in highly energy efficient residential buildings based on improved airtightness, increased insulation, use of materials, and possibly also new residential behaviour. The field tests were to be carried out in cooperation with industry partners from the previous subtasks and with building owners.

Each of the above-mentioned subtasks were executed as individual “projects in the project”, but with coordination and links between the activities as planned at the joint working meetings, and with some overlaps between the subtask participants. Figure 1 gives an overview of the subtasks and the intended ties between them.

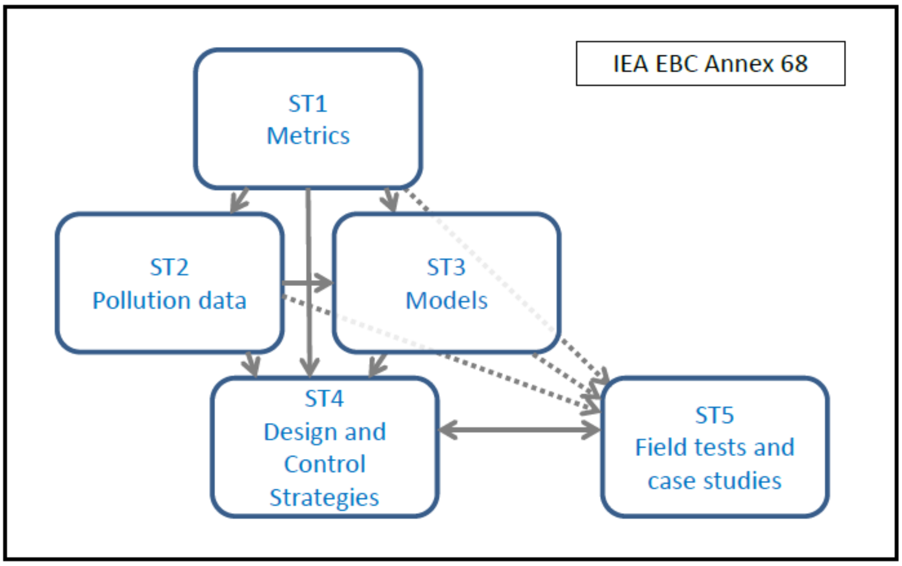


Figure 1 Schematic overview of the subtasks and their relations.

Overall, all subtasks have fulfilled their ambitions. It leads too far to represent their results here, but each subtask is reported in some final reports, about 100 pages each, and sometimes with appendices. A Project Summary Report, however, gives in 14 pages (according to the draft final edition) an overview of some of the important results. An overview with links to the reports is given in Section 8 of this report. The final report from Subtask 1 (published in 2017) and Subtask 4 (2020), have been co-published with the Air Infiltration and Ventilation Centre (AIVC), which ensures further dissemination to a wide international audience with interest in ventilation technology.

4. Project implementation

How the project evolved

The Annex project started in the beginning of 2015 after having been approved by IEA's so-called Technology Collaboration Programme (TCP) for Energy in Buildings and Communities (EBC) at its meeting in November 2014. The project was planned with the year 2015 as a preparation phase, 2016-2018 for the working phase and 2019 for reporting.

Risks associated with conducting the project

Main risk of executing the project is if the international project participants did not deliver on their expectations. The operating agent has no power to ensure the continued delivery of activity and results from the international participants other than to report about the status at the semi-annual meetings with EBC's Executive Committee. Reality is that participants from some countries have been considerably more active than others, and only with such dedicated contributions has it been possible overall to deliver on the project.

Development of project implementation as foreseen and according to milestones

Overall, the project developed as anticipated and according to the laid plan.

However, due to delayed start of some "Common Exercise" activities in several subtasks, it became necessary in May 2018 to ask for permission from the EBC Executive Committee (ExCo) to extend the completion of the project's working phase by 6 months with subsequent delay of the completion of the reporting phase/termination of the project. This was granted by the EBC ExCo for the International project at the ExCo meeting on 20-21 June 2018, and subsequently by the EUDP for the Danish project (on 24 Sept. 2018).

During the reporting phase, final subtask reports were submitted to the ExCo essentially on time in January 2020 for review and approval. The last ExCo reviews of all subtask reports from were received only during June 2020, and required minor modifications of the reports. It was therefore not possible to close the project as anticipated at the ExCo meeting in June 2020. Instead, a further extension until the ExCo meeting in November 2020 was granted by the ExCo. The extension was sanctioned by the Danish EUDP programme on 23 July 2020.

The two extensions incurred no budgetary modifications apart from a small change that permitted conversion of the unused travel budget (11,428 DKK) to salaries.

Experiences of problems not expected?

The project experienced no other serious problems.

5. Project results

Fulfilment of the project objective

Generally, it can be stated that the project objectives have been accomplished. The results are documented predominantly by the main reports from the different subtasks but also by articles in scientific journals, conference papers and a few other deliverables, such as a webinar on sensor technology to measure VOC's.

The next subsection gives a short presentation of the themes that constitute the main results from the project.

Description of technological results from the project

The project has focused on new and existing residential buildings, although it should be underlined that many findings may also be relevant to other building types.

The IAQ indicators that need to be studied are documented in the report from the project's Subtask 1, *Defining the metrics*, that collects state of the art information and suggests a principle in the form of a "Dashboard" on how to balance the combination of the most significant among many pollutants to be considered. See Figure 2. The dashboard also highlights the energy performance aspect.

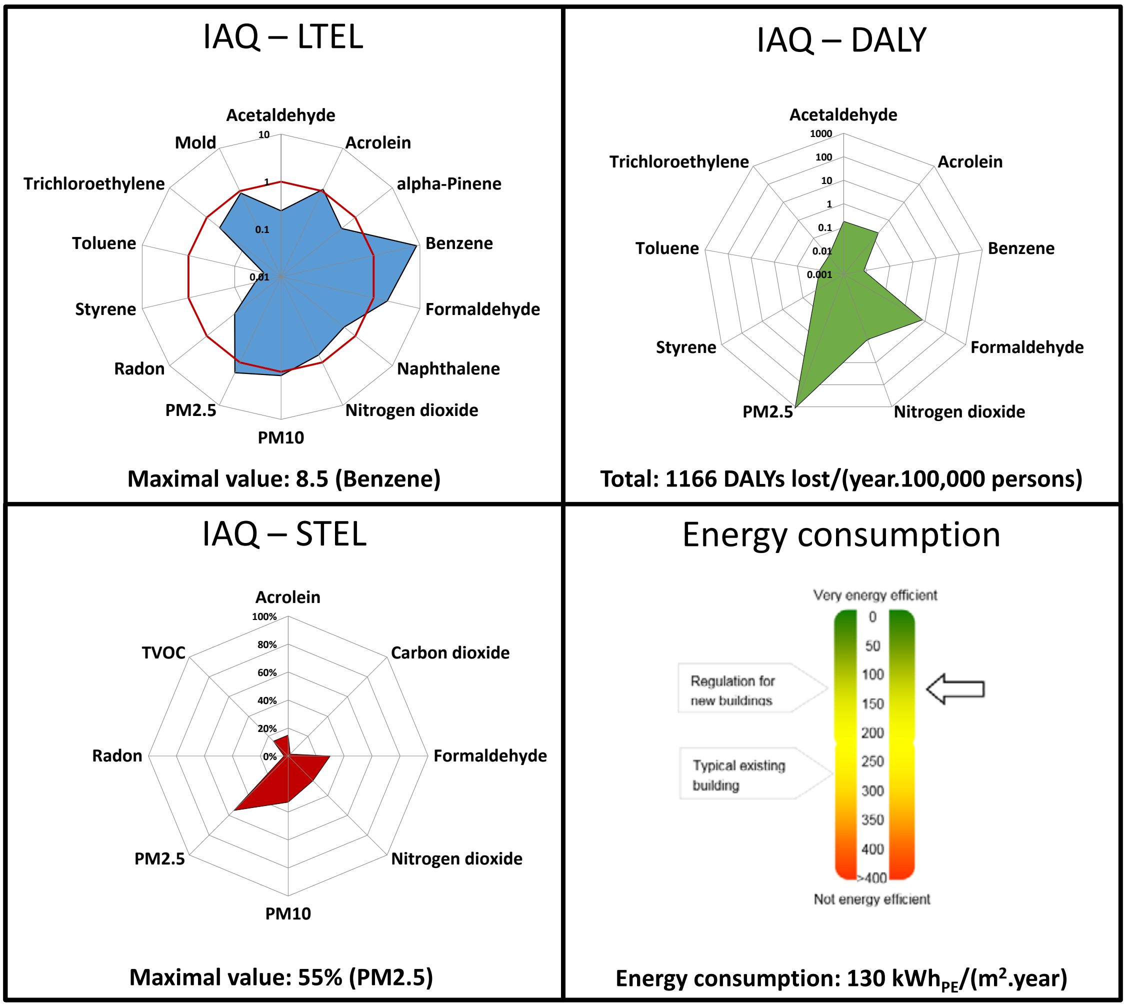


Figure 2 An example of IAQ/Energy signature for low-energy residential buildings (data represented here are just for display and do not represent an actual situation).

One of the main results of the project is an easy to understand and practically applicable collection of case studies with experiences on design and operational strategies for achieving optimal energy performance and high IAQ in residential buildings. This is the result of the project's Subtask 4, *Strategies for design and control of buildings*, see Figure 3. The collection is intended for stakeholders involved in design, construction and maintenance of buildings.

With respect to energy technologies developed in the project, we here give a replicate of the list of items from the collection of case studies with experiences. Each of the topical case studies were always described based on:

- Objectives, description & methodology
- Results and findings
- Conclusions, lessons learned for practice
- Further reading
- References

		Design			Construction, Comissioning & Operation	
Chapter	Case study	Assessment methods	Assessing ventilation concepts	Novel ventilation solutions	Quality assurance	Assessing in-use performance
3.1	Alternative ducting options for balanced mechanical ventilation systems in multifamily housing			Spatial requirements / Refurbishment		
3.2	Ambient air filtration in highly energy efficient dwellings with mechanical ventilation		Health & Comfort			
3.3	Development of a compact ventilation system for facade integration			Spatial requirements / Refurbishment		
3.4	Volatile Oorganic Compounds exposure due to Floor heating systems versus Radiator heating	Health & Comfort				
3.5	Control strategies for mechanical ventilation in Danish low-energy apartment buildings		Health & Comfort / Cost & Energy consumption			
3.6	Response of commercially available Metal Oxide Semiconductor Sensors under air polluting activities typical for residences			Comissioning		
3.7	Impact of multi zone air leakage modelling on ventilation performance and indoor air quality assessment in low-energy houses		Health & Comfort			
3.8	Towards a better integration of indoor air quality and health issues in low-energy dwellings	Health & Comfort				
3.9	List of key pollutants for design and operation of ventilation in low-energy housing	Health & Comfort				
3.10	Definition of a Reference Residential Building Prototype for Evaluating Indoor Air Quality and Energy Efficiency Strategies	Health & Comfort				
3.11	Temperature dependent emissions of Volatile Organic Compounds from building materials	Health & Comfort				
3.12	Detailed modelling of Indoor Air Quality to improve ventilation design in low energy houses		Health & Comfort			
3.13	Mechanical ventilation system in deep energy renovation of a multi-story building with prefabricated modular panels			Spatial requirements		
3.14	Simplifying Mechanical Vventilation with Heat Recovery systems			Health & Comfort / Refurbishment		
3.15	Design of room-based ventilation systems in renovated apartments			Comissioning / Refurbishment		
3.16	Introduction to the Coupled Heat, Air, Moisture and Pollutant Simulation CHAMPS modeling platform	Health & Comfort / Cost & Energy consumption				
4.1	House owners' experience and satisfaction with Danish Low-energy houses - focus on ventilation					User satisfaction
4.2	Development and test of quality management approach for ventilation and indoor air quality in single-family buildings				Quality of installation	
4.3	Applications of the Promevent protocol for ventilation systems inspection in French regulation and certification programs				Comissioning	
4.4	Long-term durability of humidity-based demand-controlled ventilation: results of a ten years monitoring in residential buildings				Quality of installation	
4.5	Practical use of the Annex 68 Indoor Air Quality Dashboard					Health & Comfort
4.6	Performance evaluation of Mechanical Extract Ventilation (MEV) systems in three 'low-energy' dwellings in the UK					Quality of installation
4.7	Indoor air quality in low energy dwellings: performance evaluation of two apartment blocks in East London, UK					Quality of installation
4.8	Continuous-commissioning of ventilation units in multi-family dwellings using controller data				Quality of installation	Comissioning

Addressed topics:
- Health & Comfort
- Spatial requirements
- Cost & Energy consumption
- Refurbishment
- Comissioning
- Quality of installation
- User satisfaction

Figure 3 Overview about topics/challenges addressed and their relation to design, construction and operation in Chapters 3 and 4.

Furthermore, the project presents a modelling framework and design tools, suitable for integrated and coordinated design of buildings with low energy consumption and high IAQ. This modelling framework came out of the project's Subtask 3, *Modelling - review, gap analysis and categorization*, see Figure 4.

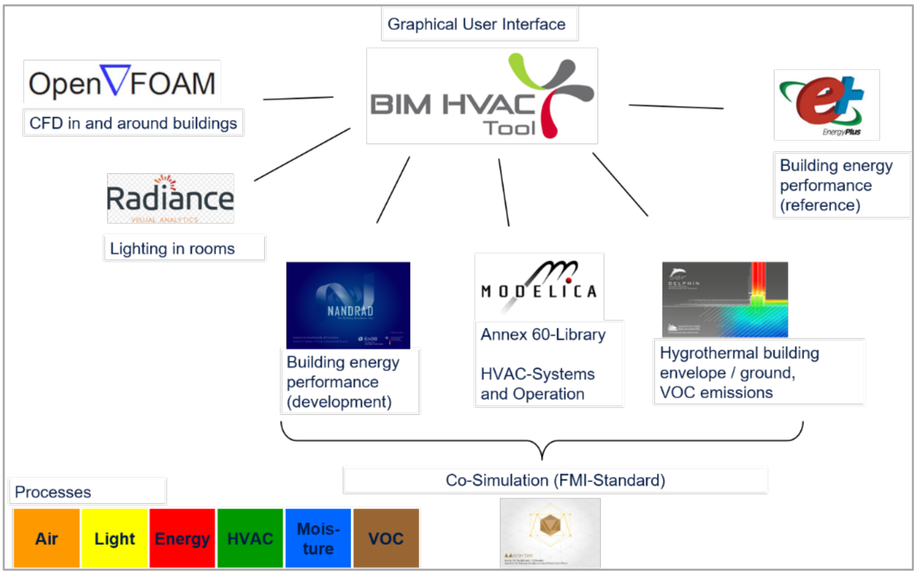


Figure 4 Multi-scale and multi-disciplinary CHAMPS modelling platform.

With regards to pollutants in buildings, data and models have been applied on sources and sinks of pollutant emissions to estimate the net pollutant loads over time under realistic environmental conditions. This is supported by databases on the properties of materials with respect to pollutant emissions. This is reported by the project's Subtask 2, *Pollutant loads in residential buildings*. An example of a specific research output from this subtask can be seen in Figure 5.

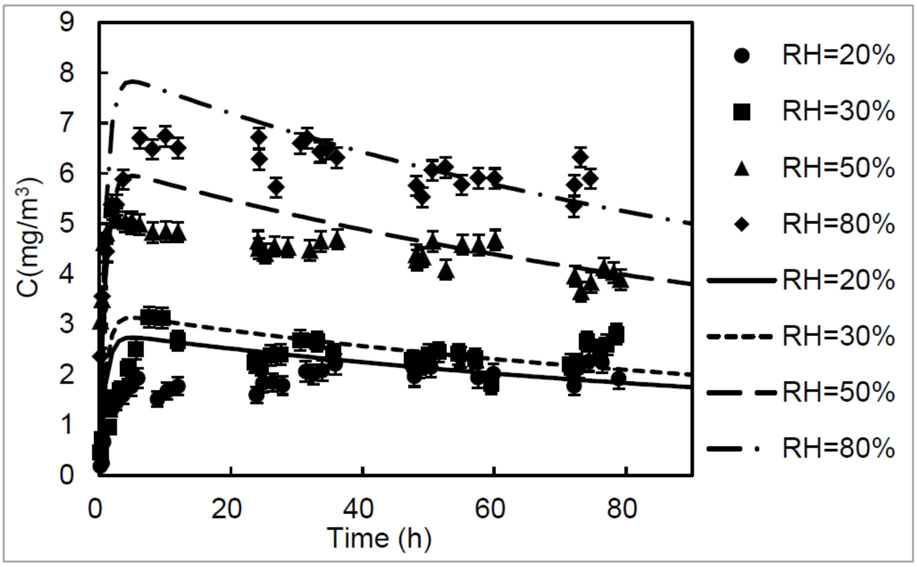


Figure 5 Time-varying formaldehyde concentrations emitted from an MDF panel to the air of a measuring chamber at different humidity levels.

Finally, field tests and case studies were documented for different climatic zones as well as methodologies to carry out such testing. This was carried out in the project's Subtask 5, *Field measurements and case studies*. Specifically, this activity targeted industry partners, building owners and operators. An example of how results from case studies was presented can be seen in Figure 6.

Project Title:	Lodenareal

Contributor	Name	Gabriel Rojas
	Country	Austria
	Institution	University of Innsbruck

General	Building Location	Innsbruck, Austria		
	Building Type	Multi-Unit Low-rise	ground + 5 topfloors	
	Year of Construction	2009		
	Major Renovation Year (if applicable, for older buildings)			
	Building Floor Area (m2)	26000	354 apartments (apt)	
	Reference: URL or Citation: Report, Journal, Conference	https://doi.org/10.1080/17512549.2015.1040072 https://passivehouse-database.org/index.php?lang=en#d_1225		
Building Description	Building envelope	Construction type	mass wall construction	
		Window to Wall ratio (%)		
		Above Grade Wall R-value (K.m2/W)	7.7	0.13
		Below Grade Wall R-value (K.m2/W)		
		Roof R-value (K.m2/W)	9.1	0.11
		Slab on grade R-value (K.m2/W)	7.7	0.13
		Window U-value (W/K.m2)	0.72	
		Airtightness (ACH at 50 Pa)	0.18	
	Interior finishing		Type	
		Interior paint		
		Flooring	Wood laminat	
		Window cover (fabric, plastic, wood etc.)	plastic	
	Mechanical systems		Terminal unit	Equipment/Source
		Heating	underfloor heating	wood pellets, gas boiler and solar t
		Cooling	no	
		Heat/Energy recovery	Heat Recovery	
		Humidity control	No	
	Ventilation		Ventilation type	Ventilation strategy
		Heating season	Mechanical Ventilation	Continious
		Cooling season	Hybrid	Continious
		Shoulder seasons	Mechanical Ventilation	Continious

Figure 6 Example of a data collection sheet for one of the case studies of the project – this case is from Austria.

The project was carried out with contributions from researchers from some 38 research institutions from 15 countries worldwide, plus one participant that was a global enterprise that supplies building products and solutions in many areas. Several local stakeholders such as consultants and HVAC manufacturers and associations have been visitors to the project when expert meetings were held semi-annually in different countries. Meetings were usually planned to be held in conjunction with relevant conferences such as by AIVC, ASHRAE but also Indoor Air, IBPC and IAQVEC conferences. The project has also fostered input to meetings in the interest group "CHAMPS" on Combined Heat, Air, Moisture and Pollutant Simulation, which convenes annually in different places of the world.

An important lead from the project to policy makers is to facilitate possibility by legislation that residential buildings may be operated flexibly and intelligently with regards to demand control of building ventilation in a manner that considers realistic hygrothermal and pollutants loads in buildings. Also cascade ventilation (room to room) may in some cases be permissible.

Commercial results obtained

The project did not intend to produce any direct commercial results per se. However, the academic results were anticipated to have interest among stakeholders from the ventilation and construction industry, building designers and building operators, and through the AIVC. There have been good examples of communication with these industry branches, and the project has thereby established the foundation for commercial deployment of its results.

Target group and added value for users

The most obvious target group are consultants who may use results from Subtask 3, the modelling platform, as tools in their business. Consultants and manufacturers of ventilation and control systems may also take advantage of the case studies and technology implementations that have been described in Subtask 4

Overview of dissemination of the project results

The project has resulted in 10 peer reviewed scientific journal articles, 20 conference papers and 38 presentations, 2 articles for professional/technical magazines, 1 webinar and 1 tool. Links to these deliverables are given in Section 8 of this report.

In addition, contributions to newsletters, factsheets and annual reports have been contributed to the IEA EBC Technology Collaboration Programme and to AIVC newsletters (see the sub-section on External collaborations under Section 6 of this report).

Minutes of the semi-annual expert working meetings are publically available on the project homepage www.iea-ebc-annex68.org, where also the above-mentioned scientific journal articles and conference contributions etc. from the project can be found.

6. Utilisation of project results

Future use of technological results

It is anticipated that the results listed in the catalogue of technology cases made by Subtask 4 will be studied and taken into use by consultants and providers of HVAC and control technology. Furthermore, the set of tools gathered in Subtask 3 may be used by academic persons working in the field, e.g. PhD-students and by advanced users among consultants in building energy technology. Results from Subtasks 2 and 5 will be used by academic users and by consultants with specialized knowledge in the field of indoor air chemistry or interest to gather experiences from field case studies.

Furthermore, there is currently an increasing interest in and use of sensors for logging indoor air quality and energy use. A sub-activity to Subtask 4, has been to investigate this market, and a webinar on this topic was held on 4 September 2018. It is anticipated that the near future will continue to see an increased interest in sensors, and that the finding produced in this project will be studied and used.

The technological results will be used in the new follow-up IEA EBC Annex 86 on *Energy Efficient IAQ Management in residential buildings*, which will focus on practical and intelligent implementation of ventilation systems in residential buildings by use of smart components and materials.

Use of commercial results from the project

Results from the project are not of a nature that make them directly ready for sale and commercial use, neither as tangible products nor as intellectual results. However as described in the previous section, it is up to the commercial partners with whom there has been contact through the project to take the results and use them for their products and services.

Characterization of the competitive situation in the market

The project has no close feeling with the competitive situation in the market for advanced ventilation technology and its control and design. However, it may be assumed that knowledge and products within the field dealt with in this project will contribute to improving the competitive situation of commercial providers of solutions and knowledge if they can offer solutions on pollution control and smart ventilation to their customers.

Entry or sales barriers

Again, this is a topic that has been treated directly within this project. However, while it must be realized that the building sector is a rather conservative trade area, where new solutions can have a hard time enter and penetrate a market, it can be hoped that good dissemination of results from this project can be influential. It must be realized also that legislative incentives or difficulties play an important role, and it is important therefore that building codes permit the use of smart control in ventilation and building operation, e.g. such that cascaded principles of ventilation can be used, and such that it may be permissible that only very small rates of ventilation can be used under certain conditions of low pollution loads and no or only limited occupancy.

The project's contribution to energy policy objectives.

Compliance with Danish Energy Policy

Roughly 40% of the energy use in society is spent in buildings, and 10-40% of the electricity use of buildings is spent on ventilation (https://sparenergi.dk/offentlig/varme-og-koling/ventilation). Energy efficiency remains to be a prioritized topic in Danish energy policy (https://ens.dk/ansvarsomraader/energibesparelser), and the building sector, households, and heating and ventilation are mentioned as dedicated areas for making further efforts. Thus, there is no doubt that results from a project like this can contribute to fulfilling objectives in energy policy.

Compliance with strategic plans of the IEA EBC Technology Collaboration Programme

The project has sought to contribute to the following themes of the *IEA EBC Strategic Plan 2014-19*:

- Theme #1: Integrated planning and building design, e.g. regarding establishment of knowledge about the design process for zero or low energy buildings with integrated information about the function of building envelopes (e.g. the materials) and the building energy systems (e.g. ventilation systems)
- Theme #2: Building energy systems concerning the optimal operation considering building / user / system interactions
- Theme #3: Building envelope regarding design and multiple function of the envelope.

From the *IEA EBC's Strategic Plan 2019-2024,* the "Means" section mentions the topic: *Improving smart control of building services technical installations, including occupant and operator interfaces*.

Thus, this project contributes to fulfilling ambitions of both the past and the new strategic plans of IEA EBC.

External Collaborations for the purpose of collaboration and dissemination of Annex 68 results

AIVC

As operating agent of Annex 68 Carsten Rode has participated as a visitor to some of the semi-annual board meetings of the *Air Infiltration and Ventilation Centre*, namely the following:

- 17 March 2014, Brussels, Belgium (participation as part of planning to establish the Annex project)
- 18 March 2015, Lund, Sweden
- 26 May 2016, Aalborg, Denmark
- 15 March 2017, Brussels, Belgium
- 15 September 2017, Nottingham, UK
- 17 September 2018, Sophia Antipolis, France
- 14 & 16 September 2020, online (Teams)

Annex 68 expert working meetings have at several occasions been planned such that they were held nearby AIVC conferences, such as Madrid, Spain, September 2015; Syracuse, NY and Alexandria, VA, USA, September 2016; and Nottingham, UK, September 2017. At these occasions Annex 68 results have been presented and topical sessions arranged at the conferences. In addition, a topical session on Annex 68 was held in conjunction with the AIVC conference in Ghent, Belgium in September 2019 (w/o an expert working meeting at that time and place).

Two of the Annex 68 final subtask reports (Subtask 1 and 4) have been co-published with the AIVC.

An AIVC Webinar on *Using MOS sensors to measure VOC for ventilation control* was planned and given by Annex 68 partners on 4 September 2018.

Articles on Annex 68 given in the Newsletters of the AIVC published in March 2017 and September 2019.

CHAMPS

CHAMPS is an international interest group working on *Combined Heat, Air, Moisture and Pollutant Simulation*, which meets about annually to discuss advances in such simulations. The group started collaboration in 2004 and was a predecessor to the formulation and start-up of the Annex 68 project. During the execution of the Annex 68 project, CHAMPS workshops have been arranged in conjunction with Annex 68 expert working meetings at these occasions:

- Syracuse, September 2016
- Dresden, March 2017 (Combined with a so-called ENTOOL workshop)
- Syracuse, September 2018

The CHAMPS workshops have functioned as open meetings where it was possible to invite a local technical audience and people from practice to participate and discuss/make mutual presentation on advances in numerical assessments of the combined transport phenomena.

Other conferences

Annex 68 has also been represented and arranged technical sessions for audiences at the following conferences:

- Indoor Air 2016, Ghent, Belgium, 3-8 July 2016
- ASHRAE IAQ, Alexandria, VA, USA, 12-14 September 2016 (joint with the AIVC Conference)
- International Building Physics Conference, IBPC2018, Syracuse, NY, USA, 23-26 September 2018
- IAQVEC 2019, Bari, Italy, 5-7 September 2019

7. Project conclusion and perspective

The project has led to main results in the following areas:

- A clear identification of indoor pollutions most worthy of consideration when assessing the impacts of chemical emissions and other pollutants in dwellings. The presentation balances these considerations with a presentation of the energy of performance of a building under study.
- A tool has been provided to guide in collecting of the most relevant indoor pollutant sources according to the selections elected in the activity on Definition of indicators and presenting the graphically on a “Dashboard” for overview and prioritization.
- New data on chemical emissions from building products as they are influenced by temperature and humidity. A paradigm has been developed according to a so-called “similarity approach” whereby data from for instance moisture transfer performances of building products can be used also in estimation of their properties for storage and emissions and chemical compounds.
- Three common exercises were described and documented with relation to chemical emissions from building product and modelling thereof. Data from these exercises have value in their own right, but can also be used in training of future experts (and PhD and master students) in estimating and assessing the coupled transport phenomena involved with pollution processes in indoor environments.
- A platform has been provided for modelling/simulation of whole building performance of the complex and interacting processes of energy/thermal assessment of buildings with their moisture, airflow and chemical/atmospheric conditions. The platform was tested and documented by its use in a common exercise whereby conditions in a so-called PASSYS reference test cell were computed.
- A survey has been carried out comprising a varying set of stakeholders (architects and ventilation designers, facility managers, property developers and representatives of public authorities) who have expressed their opinions on challenges and desirable possibilities for designing and implementing advanced ventilation systems and their control for optimal operation with respect to energy use and provision of good indoor environments. A total set of 24 themes have been discussed in this respect - many of which represented solutions that were exemplified as realized cases studies from which learnings could be collected.
- An overview of test methodologies to use in measurements campaigns/experiments to assess indoor climate and ventilation performance.
- A collection of field tests of indoor climate performance of test chamber, and controlled field tests where emissions of pollutants and hygrothermal conditions were studied under varying exposures and operational conditions with regards to materials and ventilation.
- A collection of studies from high performance buildings in seven places spread in different geographies of the world. Apart from energy use and standard indoor climate parameters, the buildings were also characterised for their chemical indoor environment. The cases are indexed as an archive from which valuable data can be retrieved for research.

Most predominantly, it is anticipated that results from the project will lead to the implementation of smarter paradigms for demand-controlled ventilation whereby ventilation schemes are adjusted with close consideration of the pollutant emission and occupancy schedule of buildings. Without compromising the indoor air quality in periods and rooms when and where occupants are present, this will prevent the need for continuous operations of buildings at a standard level for ventilation. By turning down the level of ventilation in unoccupied periods or rooms, if the pollutant level is low, considerable energy savings can be achieved.

In addition, the project has studied transport processes of chemical compounds in materials that are used in contact with indoor air. This fundamental knowledge can be used in development of less indoor polluting materials, or even materials that may have an air-cleaning function.

Overall, it is our own opinion that the project has succeeded to accomplish the targets it set out to do, and that it has successfully done so by combining the competences of a varied and international group of experts – as it was needed and intended to achieve the goals.

While Annex 68 has concentrated on collecting fundamental inputs in its field of research, it has led to the formulation of a new Annex 86 project, which will take the Annex 68 results further with a focus on practical and intelligent implementation of ventilation systems in residential buildings by use of smart components and materials.

8. Appendices

The project has the homepage www.iea-ebc-annex68.org.

The homepage has a Results section with links to:

- Final subtask reports
- Journal articles
- Conference papers
- Presentations
- Webinar
- Tool

Furthermore, a section of the homepage describes Events with relation to the project:

- The semi-annual expert working meetings
- AIVC Conferences and workshops
- CHAMPS workshops
- Other conferences

Throughout the project execution, the project has also delivered information and status papers to periodic reports (Newsletters and Annual Reports) from the EBC Technology Collaboration Programme, namely the following:

- June 2015 Newsletter. Information on Annex 68 as “New Project”
- November 2015: Factsheet on Annex 68
- Annual Report 2015. On Annex 68 as “Ongoing Project”
- Annual Report 2016. On Annex 68 as “Ongoing Project”
- November 2017 Newsletter: Information on EBC Annex 68 as “Current Project”
- Annual Report 2017. On Annex 68 as “Ongoing Project”
- Annual Report 2018. On Annex 68 as “Ongoing Project”
- November 2019 Newsletter: Information on “The Guide” from IEA EBC Annex 68
- November 2019: Factsheet on Annex 68
- Annual Report 2019. On Annex 68 as “Ongoing Project”

Presentations have been given to EBC Technical Days at the following occasions:

- 7 June 2017, London, UK
- 21 November 2018, Wellington, New Zealand
- 10 November 2020, Webinar