Energy in Buildings and
Communities Programme

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IEA EBC Annex 67 Energy Flexible Buildings

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The foreseen large deployment of renewable energy sources may seriously affect the stability of energy grids. It will be necessary to control energy consumption to match instantaneous energy production. The built-in Energy Flexibility in buildings may be utilized for stabilizing the energy grids and allow for a larger roll out of renewable energy sources as buildings can be controlled in order to shift energy demand in time.

The Energy Flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs and grid requirements. Energy Flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding grids.

Currently there is no overview or insight into how much Energy Flexibility different building types and their usage may be able to offer to the future energy systems. The aim of the Annex is thus to increase knowledge on and demonstrate the Energy Flexibility buildings can provide for the energy grids, and to identify critical aspects and possible solutions to manage this Energy Flexibility.

In-depth knowledge of the Energy Flexibility that buildings may provide is important for the design of future Smart Grids and buildings. The knowledge is, however, not only important for the utilities it is also necessary for companies when developing business cases for products and services supporting the roll out of Smart Grids. It is further important information for policy makers and government entities involved in the shaping of the future energy systems.

1. Background and Justification

The last decades increasing global energy demand, a foreseen reduction of available fossil fuels and increasing evidence for global warming have generated a high interest in renewable energy sources. However, energy sources, such as wind and solar power, have an intrinsic variability that can seriously affect the energy system stability if they account for a high percentage of the total generation. Therefore: *future high penetration of variable renewable energy sources forces a transition from generation on demand to consumption on demand in order to match the instantaneous energy generation*. In practice this means that the energy consumption needs to become flexible.

The end use of electricity is not located in the high voltage transmission level but in the low voltage parts of the grid, which have different requirements and constraints. Traditionally, only the power demand has guided the design of grids. The challenge with large scale application of buildings which not only consume but also generate energy - commonly called prosumers or DERs (Distributed Energy Resources) - is that the grid has to be designed with respect to the power (both heat and electricity) demand as well as the local energy generation and to the way these coincide in order to avoid creating stress on the grid. If not considered, it may result in limits on the amounts of exported energy for building owners to avoid power quality problems, e.g. Germany has already enforced restrictions on private PV generation exported to the grid. Furthermore, today the distribution grid is often dimensioned based on houses heated by sources other than electricity e.g. oil or gas burners. However, the transition to a renewable energy system will in many areas lead to an increase in electrical heating - by e.g. heat pumps or resistance heaters – even if the foreseen reduction in e.g. the space heating demand via energy renovation is realized. The expected penetration of electrical vehicles may further increase the loads in the distributed grids but may also be used for peak shaving using their batteries. All these factors will in many distribution grids call for major reinforcement of the existing grids or a more intelligent way of consuming electricity. The intelligent way is Smart Grid (or Smart Energy Networks when energy carriers other than electricity are also considered) where both demand and local production in the distribution grid are controlled in order to stabilize the grid. Buildings are expected to have an important role in future Smart Grids/Energy networks.

In most developed countries energy use in buildings accounts for 30-40 % of the total energy consumption, and is used for heating, cooling, ventilation and lighting of rooms, heating of domestic hot water as well as for appliances used by occupants. A large part of the buildings' energy demand may be shifted in time and may thus significantly contribute to increasing flexibility of the demand in the energy system. In particular, the thermal part of the energy demand, e.g. space heating/cooling, ventilation, domestic hot water, but also hot water for washing machines, dishwashers and heat to tumble dryers can be shifted. A Danish study on large scale implementation of heat pumps in individual homes outside areas with district heating showed increased utilization of excess power generation from wind turbines and reduced use of fuels during periods with low electricity production by utilizing storage in e.g. the constructions of buildings or in water tanks. The study showed that excess power generation could be reduced by up to 20% - excess power that else would be wasted or sold at a low or even negative price. The most cost-effective solution was to utilise the buildings thermal mass as heat storage even if only a small part of the total thermal capacity can be exploited by existing technologies. A similar approach may be used in communities with district heating or community heating (common heating system for a limit number of buildings). Excess renewable energy generation (e.g. wind power) may be utilized for heating in the district/community heating plant. However, in order to be able to store sufficient heat the thermal mass of the buildings connected to the district/community heating grid may be utilized in the same way as in buildings with heat pumps or resistance heaters.

All buildings have thermal mass embedded in their constructions, which makes it possible to store a certain amount of heat. Depending on the amount, distribution, speed of charging/discharging, etc. of the thermal mass it is possible to postpone heating or cooling for a certain period of time without jeopardizing the thermal comfort in the building. And if a building is excess pre-heated/cooled within the comfort range of the room temperature prior to a shutdown of heating/cooling it is possible to prolong the shutdown period. The time constant of buildings is - depending on the amount and exploitability of the thermal mass together with the heat loss, internal gains, user pattern and the actual climate conditions - typically between a few hours to several days. Many buildings may also contain different kinds of discrete storages (e.g. water tanks and storage heaters) that may add to the energy demand flexibility of the buildings. One such typical storage is the domestic hot water tank, which might be excess pre-heated before a low energy level situation. The excess heat may be utilized for space heating but may also be used for white goods such as hot-fill dishwashers, washing machines and tumble dryers in order to decrease and shift their electricity need.

Although various investigations of buildings in the Smart Grid context have been carried out, research on how Energy Flexibility in buildings can help stabilize the future energy system and thereby facilitate large penetration of renewable energy sources is still in its early stages. The investigations have mainly focused on how to control a single component – often simple on/off controlled - and not on how to optimize the Energy Flexibility of the buildings themselves.

There is currently no overview or insight into how much Energy Flexibility different building types and their usage may be able to offer to the future energy systems.

No previous IEA annexes or tasks have dealt directly with the above issues. However, several IEA annexes and tasks have carried out investigations and have obtained results that will be relevant to this Annex – e.g.:

EBC Annex 51	Energy Efficient Communities. The developed energy strategies on a community level or municipal quarter level are interesting when looking at aggregated Energy Flexibility.
EBC Annex 52	Towards Net Zero Energy Solar Building where load match and grid interaction indicators for net zero energy buildings where investigated.
EBC Annex 54	Integration of Microgeneration and related Technologies in Buildings from where demand load profiles and models for components are valuable.
EBC Annex 58	Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements where utilization of dynamic building characterisation for optimising smart grids is investigated.
EBC Annex 64	“LowEx” Communities - Optimized Performance of Energy Supply Systems with Exergy Principles. The aim is to improve the energy conversion chains on a community scale and are thus interesting when looking at aggregation of Energy Flexibility.
SHC Task 32	Advanced Storage Concepts for Solar and Low Energy Buildings. The results from investigations on new or advanced solutions for storing heat will be utilized in the Annex.
PVPS Task 14	High Penetration of PV Systems in Electricity Grids. The identified constraints and solutions for PV integration are important knowledge when investigating Energy Flexibility at prosumer level.
ECES Annex 23	Energy Storage Applications in Low-Energy Buildings. Different important storage technologies were investigated e.g. water tanks and PCM.
ECES Annex 28	Integration of Renewable Energies by Distributed Energy Storage Systems. The annex investigates overall storage properties and their impact on the integration of renewable energy. ECES Annex 28 welcomes input from EBC Annex 67.

ECES Annex 31 Energy storage with net zero energy buildings and districts: optimisation and automation. The Annex will investigate integration, control and automation of energy storage from a grid point of view. Cooperation between the two Annexes has already been discussed.

1.1 Research issues

An important part of the Annex is to develop a methodology for characterization of the Energy Flexibility of buildings. This includes investigations of energy storages, load management, on-site generation, user behavior and user acceptance. Control strategies and algorithms for obtaining Energy Flexibility in buildings will be investigated and developed. Based on simulations, laboratory tests and demonstrations in real buildings example cases will be investigated and documented.

2. Objectives and Limitations

The aim of the project is to increase the knowledge, identify critical aspects and possible solutions concerning the Energy Flexibility that buildings can provide and the means to exploit and control this flexibility. This knowledge is important in order to be able to incorporate the Energy Flexibility of buildings in the future Smart Energy systems and thereby facilitate energy systems being entirely based on renewable energy sources. The obtained knowledge is also important when developing business cases that will utilize building Energy Flexibility in future energy systems – hereunder that utilization of Energy Flexibility in buildings may reduce costly upgrades of distribution grids.

2.1 Objectives

To fulfil the aims of the Annex and to facilitate future Energy Flexible Buildings the Annex focuses on the following specific objectives:

- Development of common terminology and definition of “Energy Flexibility in buildings” and a classification method (STA)
- Investigation of user comfort, motivation and acceptance associated with the introduction of Energy Flexibility measures in buildings (STA and STC)
- Investigation of the Energy Flexibility potential in different buildings and contexts, and development of design examples, control strategies and algorithms (STB)
- Investigation of the aggregated Energy Flexibility of clusters of buildings and the potential effect on energy grids (STB)
- Demonstration of Energy Flexibility in buildings through experimental and field studies (STB and STC)

2.2 Scope and Demarcation

The Annex will focus on analysis of the potential Energy Flexibility in buildings and how to control this flexibility without loss of comfort for the users in the buildings. The building technologies with special focus will be storage of heat in building constructions and in water tanks (e.g. DHW tanks), control of HVAC systems (e.g. heat pumps, air conditioning and ventilation) but also the interaction between the building load and on-side energy production based on renewable energy will be investigated.

Other electricity loads (e.g. lighting) and storage in batteries may also be included in the work within the annex.

The Annex will address both residential and non-residential buildings, however, these two sectors will be treated separately because the issues, challenges and possible solutions are different. The Annex will address both new constructions and renovation of buildings. Renovation of buildings is of special importance because the majority (75 %) of buildings existing today will still be there by 2050, and it is important from a cost point of view to consider Energy Flexibility as part of a renovation process.

All energy demands of and storage possibilities in buildings are in principle included in the scope of the Annex. However, only demands which can be controlled and can contribute significantly to the Energy Flexibility in buildings will be included in the investigations. Different ways of storing energy in buildings will be investigated, especially focussing on storage methods that is considered to already be or soon may become economical feasible.

The Annex will focus both on single buildings and clusters of buildings as the grids mainly are influenced by buildings at an aggregated level. It is, therefore, also important to investigate the aggregated flexibility given by pooling of several buildings within the same distribution grid.

Although interoperability is mandatory when deploying Energy Flexibility of buildings for stabilization of energy grids, this is not a direct focus area of the Annex, but will be considered where important.

The knowledge generated by the Annex is important when trying to develop business cases that will include the utilization of building Energy Flexibility in future energy systems. However, business cases and the future interaction between buildings and the grid are not directly part of the project. The aim is to provide information that will facilitate such developments.

3. Means

3.1 Methodology

To address the specific Annex objectives the research and development work in the Annex will be divided into three subtasks, each of which is further divided into a number of research activities.

3.2 Subtasks

The Annex will comprise the following subtasks:

- Subtask A: Definitions and Context
- Subtask B: Analysis, Development and Testing
- Subtask C: Demonstration and User Perspectives

The main part of the activities will be carried out in parallel.

Subtask A: Definitions and Context

As Energy Flexibility in buildings for grid stabilization is a new research area the subtask will develop a terminology and definition of the term Energy Flexibility in buildings that can be understood not only within the building sector but also at the grid managing level. Further a methodology for characterization of Energy Flexibility in buildings will be developed in order to make the potential flexibility operational for both the building and grid side, especially for the aggregators who will aggregate the flexibility of many buildings and offer this on a flexibility market. However, as buildings are occupied it is also important to understand how the behavior and acceptance of the users of the buildings will influence the actual obtainable Energy Flexibility in buildings.

The subtask will be divided into the following research activities:

Activity A.1. Common terminology and definition of Energy Flexibility in buildings

Activity A.2 Methodology for characterization of Energy Flexibility in buildings

Activity A.3. User needs, motivation and barriers for application of Energy Flexibility in Buildings

Activity A.4. Market analysis

Subtask B: Analysis, Development and Testing

In this subtask different storage, generation and control options for achieving and optimizing Energy Flexibility in buildings will be investigated and documented. The investigations in the subtask will be carried out using both simulations and laboratory tests. Control strategies and algorithms will be developed and together with components and systems these will be tested in controlled environments. Based on the investigations and input from Subtask C, example cases will be selected and documented. Simulations will be carried out for the example cases under realistic energy prices, weather conditions, user behavior and load profiles.

The subtask will be divided into the following research activities:

Activity B.1. Simulation of Energy Flexibility in single buildings and clusters of buildings

Activity B.2. Control strategies and algorithms

Activity B.3. Laboratory tests of components, systems and control strategies

Activity B.4. Example cases and design examples

Subtask C: Demonstration and User Perspectives

The work in Subtask A and B is mainly theoretical work. However, in order to be able to convince policy makers, energy utilities, grid operators, aggregators, the building industry and consumers about the benefits of buildings offering Energy Flexibility to the future energy systems, proof of concept based on demonstrations in real buildings is crucial. A number of real buildings will be selected and provided with equipment for controlling the flexibility of the buildings. The measurements will provide important input to Subtask B on the actual accessible flexibility in real buildings under real use. The subtask will also provide real load profiles and monitored data on storage and generation systems. This knowledge may be utilized for calibration of the simulation models of the example cases in Subtask B. The demonstrations will further deliver important knowledge on user motivation and acceptance of Energy Flexibility in buildings.

The subtask will be divided into the following research activities:

Activity C.1. Measurements in existing buildings

Activity C.2. Demonstration of Energy Flexibility in real building

Activity C.3. User motivation and acceptance

4. Results and deliverables

The results of the Annex will be documented example cases, definition of Energy Flexibility in buildings, a methodology for characterization of Energy Flexibility, control strategies and algorithms for optimizing Energy Flexibility, user perspectives and test procedures.

The resulting knowledge is also important when developing business cases that will benefit from the utilization of building Energy Flexibility in the future energy systems.

Recommendations for future work on building Energy Flexibility labeling will be given.

4.1 Official deliverables

The EBC deliverables are listed below:

	Official deliverables	***Target group***	***Related subtask***
D1	Source Book: Principles of Energy Flexible Buildings	Research community and associates. DSOs, TSOs and aggregators, building industry, policy makers	STA, STB, STC
D2	Technical report: Terminology, definition and Flexibility indicators for characterization of Energy Flexibility in buildings	Research community and associates. DSOs, TSOs and aggregators, Building industry, architects, consulting engineers. Policy makers	STA with input f STB and STC
D3	Technical report: Guidelines on modelling of Energy Flexibility in buildings	Research community and associates. Building industry, consulting engineers, ICT industry and aggregators	STB
D4	Technical report: User perspectives	Building industry, architects, consulting engineers, ICT industry, aggregators, Policy makers	STA and STC
D5	Technical report: Control strategies and algorithms	Building industry, consulting engineers, ICT industry	STB

D6	Technical report: Test procedures and results	Building industry, consulting engineers, DSOs, TSOs and aggregators, ICT industry Policy makers	STB
D7	Technical report : Design examples on optimization of Energy Flexibility in buildings	Building industry, architects, consulting engineers, aggregators, ICT industry	STB with input from STC
D8	Project Summary Report	Research community and associates + EBC Programme	STA, STB, STC

All deliverables will be published electronically.

4.2 Annex beneficiaries and outreach activities

The Annex beneficiaries will be:

- The building research community and associated specialists will gain important knowledge on the future requirements for buildings
- DSOs (District System Operators), TSOs (Transmission System Operators) and aggregators (aggregating the Energy Flexibility of many buildings and offering this on a flexibility market) will gain important knowledge on how buildings may contribute to stabilize the future energy system
- Architects and design companies, engineering offices and consultants in building physics, energy, HVAC and sustainable construction are advised on how to design and construct energy flexible buildings
- Building component and HVAC-system developers and manufacturers will gain knowledge on how to control their product in order to obtain flexibility
- ICT developers and manufactures will gain insight in control algorithms for creating energy flexibility in buildings
- Policy makers and experts involved in shaping the future energy system will obtain important information on the possibilities that energy flexible buildings create
- Educational institutions obtain firsthand knowledge and insight into future requirements for buildings

Outreach activities will be planned and carried out in the form of:

	Outreach activities	***Target group***
O1	Internet site and Annex newsletter	Research community and associates, DSOs, TSOs and aggregators, building industry EBC Programme
O2	Active internet seminars	Depending on the scope of the seminars: Building industry, architects, consulting engineers, DSOs, TSOs and aggregators, ICT industry, Policy makers

O3	Conferences and seminars	Depending on the conferences/seminars: Building industry, architects, consulting engineers, DSOs, TSOs and aggregators, ICT industry, Policy makers
O4	Proceedings of international events	Depending on the scope of the events: Building industry, architects, consulting engineers, DSOs, TSOs and aggregators, ICT industry, Policy makers
O5	Summer School	PhD students

5. Preliminary Current State Assessment

In relation to the objectives defined in the Annex and the work defined in the subtasks, the project can be broken down to the following three areas that need to be assessed:

1. Application of Energy Flexibility in Buildings
2. Solutions to manage Energy Flexibility in Buildings
3. Users acceptance of activated Flexibility in Buildings

Fifteen countries have evaluated the three areas for their specific countries. A summary of the evaluation is given in the below table. When a current readiness level (CRL) for an area has been given as a range the mean value is used in the below table.

It is seen that in mean the CRL is for all three areas between 3.2 and 3.6 meaning at an Analytical and experimental level however including some validation in laboratory. The range is between 1 and 6 - i.e. between Basic principles observed and reported and Engineering / pilot-scale, similar (prototypical) system validation in relevant environment.

The reason for the low mean values for the CRLs is that although acknowledge as an important issue there is still no real market for Energy Flexibility. The rather large range between CRLs for the different counties is due to difference in the foreseen necessity of utilization of Energy Flexibility in the near future.

Some areas/techniques are rather mature like remote control of electrical water heaters in Norway. Many demonstration projects have been or are being carried out in Denmark on control of heat pumps, however, mainly exploring “half” of the obtainable Energy Flexibility using a simple on/off control which do not allow for excess pre-heating before a low energy level period.

The research and developed solutions have mainly focused on how to control a single component – often simple on/off controlled – and not on how to optimize the Energy Flexibility of the buildings themselves. Advanced control using e.g. forecast of demand, weather and prices are still in its early beginning.

Investigations on user motivation and acceptance have mainly been carried out in connection with well-defined demonstration projects not necessarily giving a correct picture with regards to a major role out of utilization of Energy Flexibility in Buildings.

Country	CRL technology			Confidence
	1	2	3	
Spain	1	4	2	3
Denmark	4	4	4	5
Switzerland	3	4	3	3.5
UK	4.5	4	2	3.33
Italy	1.5	3.5	3	3
Netherlands	3	3	2	4
Austria	3	4	3	3
Belgium	5	4	2	4
Germany	3	4	4	5
Ireland	3	3	2	3
New Zealand	4	5	4	3
Norway	6	2	6	5
Portugal	2	3	3	4
Czech Republic	5	3	4	4
Canada	3	3	4	3
Finland	3	6	3	4
mean	3.4	3.7	3.2	3.7
lowest	1	2	2	3
highest	6	6	6	5

6. Management of the Annex

The Annex is managed by the Operating Agent assisted by subtask leaders and co-leaders.

6.1 Operating agent

The Operating Agent is responsible for the overall performance and the time schedule of the Annex, for reporting, and for information dissemination activities. The operating agent is Søren Østergaard Jensen, Danish Technological Institute, Denmark assisted by Anna Joanna Marszal-Pomianowska, Aalborg University, Denmark – both funded by the Danish Energy Agency.

6.2 Subtask leaders

The Subtask leaders shall be participants who bring a high level of expertise to the subtask they manage and who undertake substantial research and development in the field of the subtask. They are nominated by the Annex participants and approved by the IEA EBC ExCo. Duties of the subtask leaders are:

- Co-ordinate the work performed under the subtask;
- Assist the Operating Agent in preparing the detailed work plans and editing the deliverables of the Annex;
- Direct the technical workshops of the subtask and provide the Operating Agent with the workshop results;
- Coordinate the technical reports resulting from the Subtask;

Subtask and co-subtask leaders are:

Subtask A:	Subtask leader:	Roberto Lollini and Wilmer Pasut, EURAC, Italy and Armin Knotzer, AEE Institute for Sustainable Technologies, Austria
	Co-subtask leader:	Daniel Aeleni, Universidade Nove de Lisboa, Portugal
Subtask B:	Subtask leader:	Peter Engelmann, Fraunhofer ISE, Germany
	Co-subtask leader:	Bart Bleys, BBRI, Belgium Igor Sartori, SINTEF / NTNU, Norway
Subtask C:	Subtask leader:	Anne Stafford, Leeds Becket University, UK
	Co-subtask leader:	Wim Zeiler, Technische Universiteit Eindhoven, The Netherlands

7. Time Schedule

The duration of the Annex's working phase will be three years (starting June 2015) followed by one year of reporting. Two meetings will be held every year. The Operating Agent will organize semi-annual plenary Annex meetings at varying locations, each time hosted by one of the participating countries. In connection with the plenary Annex meetings, a semi-annual subtask leaders meeting will be organized. If needed, the participants and subtask leaders of each subtask may decide to organize separate meetings. In such cases, they must inform the Operating Agent of the meeting and its results. A fourth year will be used to finish reports.

8. Funding and Commitment

The work is divided into three subtasks. Each participant shall work in at least one of the subtasks. All participants are also required to deliver information and written material to the final reports. Each participant shall individually bear their own costs incurred in the Annex activities. Funding is expected to cover labour costs, consumables and investments (including eventual overhead costs) associated with the execution of activities defined in paragraph 3 and 4, and to cover traveling costs for participating in at least two expert meetings per year during the four-year duration (including one year of reporting) of the Annex. The working meetings shall be hosted by one of the participants. The costs of organizing and hosting the meeting shall be borne by the host participant.

All participating countries have access to the workshops and results of all subtasks. Each participating country must designate at least one individual (an active researcher, scientist or engineer, here called the expert) for each subtask in which they decide to participate. It is expected that the same expert attends all meetings and acts as technical contact regarding the national subtask contribution. A minimum commitment of four person-months of labour for each year of the Annex term will be required for the participating countries. For the subtask coordinators funding shall allow for additional two person-months per year for Annex activities. For the Operating Agent, funding shall allow for additional four person-months per year for Annex activities including the attendance at the two ExCo meetings per year. The Operating Agent may allow for a reduced country participation if the obtainable input to the annex is important.

Participating countries:

Country	Position
Austria	Leader of Subtask A
Belgium	Co-leader of Subtask B
Canada	
China	
Denmark	Operating Agent and Co-Operating Agent
Finland	
France	
Germany	Leader of Subtask B
Ireland	
Italy	Leader of Subtask A
The Netherlands	Co-leader of Subtask C
Norway	Co-leader of Subtask B
Portugal	Co-leader of Subtask A
Spain	
Switzerland	
UK	Leader of Subtask C

9. Intellectual Property

Each Annex participant retains ownership of any knowledge brought into or developed within the Annex by that participant. Knowledge resulting from the work of more than one participant may only be published with the consent of all participants involved.

When presenting Annex related work at congresses and meetings outside the Annex, publishing in journal papers and reports the Annex shall be acknowledged as one of the vehicles that assisted in carrying out the work.

The Operating Agent will hold all intellectual property rights on the deliverables from the Annex on behalf of the participants in accordance with the EBC Implementing Agreement.