Energy Flexible Buildings
IEA EBC Annex 67

Operating Agent
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IEA EBC Technical day
Golden, November 12, 2019
Common understanding that we need to replace fossil fuels with renewable energy
Example: Denmark
Goal: 50 % wind in power grid by 2020 and only RES in the total energy system by 2050

Denmark has just got a new minority government. Together with the three centrum-left supporting parties the government has agreed to reduce the CO₂ emission in 2030 with 70 % compared to 1990, which is a considerable increase compared to the former government’s goal of an only 40 % reduction.
Solutions to large share of RES in the energy systems

Large interconnectors - export/import
Heat pumps in district heating
Generation of hydrogen and upgrading of biogas
RES based fuel factories

Demand response - industry and buildings
Most buildings have the ability to become energy flexible
Commercial buildings

ventilation systems

cooling systems

supermarkets

pumps
Electricity demand in households

- Heat pumps (aircondition)
- EVs
- Ventilation systems
- White goods
Example

Load profile for 0.4 kV feeder

- existing load
- max allowed load
Example

Load profile for 0.4 kV feeder

- 40% homes with EV
- Heat pumps
- Existing load
- Max allowed load

KV

Hours

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Example

Load profile for 0.4 kV feeder

- 40% homes with EV
- Heat pumps
- Existing load
- Max allowed load

Intelligent charging of EVs
Temperature rebound
Free floating
Excess preheating

Hours

kV
Prosumers
Voltage problems

max.

230 V

min.

with PV

without PV
Smart Readiness Indicators in EBPD (Energy Performance in Buildings Directive)

- The introduction of a smart readiness indicator rating the readiness of the building to adapt its operation to the needs of the occupant and the grid, and to improve its performance
- The smart readiness indicator should be used to measure buildings’ capacity to use ICT and electronic systems to optimise operation and interact with the grid
Smart readyness indicator in EPBD

Annex 67 has written a Position paper

There is a need for an approach that takes into account the dynamic behavior of buildings rather than a static counting and rating of control devices. It is further important to minimize the CO$_2$ emission in the overall energy networks rather than optimize the energy efficiency of the single energy components in a building.

Grid-interactive Efficient Buildings

**GEB Key Characteristics**

**EFFICIENT**
Persistent low energy use minimizes demand on grid resources and infrastructure

**CONNECTED**
Two-way communication with flexible technologies, the grid, and occupants

**SMART**
Analytics supported by sensors and controls co-optimize efficiency, flexibility, and occupant preferences

**FLEXIBLE**
Flexible loads and distributed generation/storage can be used to reduce, shift, or modulate energy use

IEA EBC Annex 67
Energy Flexible Buildings

June 2014 – June 2015: Preparation phase: done
June 2018 – November 2019: Reporting phase: nearly final

A follow-up annex is being considered:
Preparation workshop, September 19-20, 2019
Possible new workshop: Week 14, 2020 in Barcelona
Annex 67 work plan

Subtask A: Definitions and Context
- Common terminology and definition of Energy Flexibility in buildings
- Methodology for characterization of Energy Flexibility in buildings
- User needs, motivation and barriers for application of EF in building
- Market analysis

Subtask B: Analysis, Development and Testing
- Simulation of Energy Flexibility in single buildings and clusters of buildings
- Control strategies and algorithms
- Laboratory tests of components, systems and control strategies
- Example cases and design examples

Subtask C: Demonstration and User Perspectives
- Measurements in existing buildings
- Demonstration of Energy Flexibility in real buildings and clusters
- User motivation and acceptance
Participating countries

- Austria
- Belgium
- Canada
- China
- Denmark
- Finland
- France
- Germany
- Ireland
- Italy
- Norway
- Portugal
- Spain
- Switzerland
- The Netherlands
- UK
Residual loads 2030
Grid optimized performance

Specific heating and cooling load and grid-optimal trajectories

Alberta, Austria, Belgium, Switzerland, Germany, Denmark, Greece, Spain, France, Great Britain, Italy, Netherlands, Norway, Portugal, Sweden

Heating load, January
Grid-optimal, January
Cooling load, July
Grid-optimal, July

Hour of the day
Currently there is no overview or insight into how much Energy Flexibility different building types and their usage may be able to offer to 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 Energy systems 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 Energy networks. Furthermore, it is important information for policy makers and government entities involved in the shaping of future energy systems.

Read more about Annex 67, click here
Website

annex67.org

Publications

Here you can find publications connected to the project.

- Articles
- Conference papers
- Position paper
- Reports
- Software
- Deliverables
- Seminar
Deliverables from Annex 67

- **Principles of Energy Flexible Buildings** summarizes the main findings of Annex 67 and targets all interested in what Energy Flexibility in buildings is, how it can be controlled, and which services it may provide.
- **Characterization of Energy Flexibility in Buildings** presents the terminology around Energy Flexibility, the existing indicators used to evaluate the flexibility potential and how to characterize and label Energy Flexibility.
- **Stakeholder perspectives on Energy Flexible buildings** displays the viewpoint of different types of stakeholders towards Energy Flexible Buildings.
- **Control strategies and algorithms for obtaining Energy Flexibility in buildings** reviews and evaluates control strategies for Energy Flexibility in buildings.
- **Experimental facilities and methods for assessing Energy Flexibility in buildings** describes several test facilities including experiments related to Energy Flexibility and draws recommendations for future testing activities.
- **Examples of Energy Flexibility in buildings** summarizes different examples on how to obtain Energy Flexible Buildings.
- **Project Summary Report** brief summary of the outcome of Annex 67.
International Energy Agency

Examples of Energy Flexibility in Buildings

Energy in Buildings and Communities Programme
Annex 67 Energy Flexible Buildings
September 2019
Energy Flexibility of buildings

Building Energy System (BES)

Legend
- Gas
- Thermal energy
- Electricity

Gas grid

Power grid

fixed electric load/generation

battery

fuel switch

CHP
Boiler
Heat pump
Chiller

thermal storage

building mass

net power load

net power demand

heat+cold generation

heat+cold delivery

effect on energy networks
### Examples

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## Examples

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Examples
What is the possible Energy Flexibility in buildings?

It depends

- type of building and energy service systems
- use of the building
- climate
- time of the day and the year
- occupants
- control possibilities
- state of storage (constructions, tank, battery, ...)
- physical max vs. cost optimal energy flexibility
- surrounding grids
- energy tariffs
- ...

...
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Characterization of Energy Flexibility in Buildings

Energy in Buildings and Communities Programme
Annex 67 Energy Flexible Buildings
October 2019
Definition of Energy Flexibility in buildings

• 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.
Characterization and labelling of Energy Flexibility in buildings

control signal, penalty signal, reward signal, disturbance signal
Expected Flexibility Saving Index

![Graph showing demand change and penalty over time for Building 1, Building 2, and Building 3.]

<table>
<thead>
<tr>
<th>Building</th>
<th>Wind (%)</th>
<th>Solar (%)</th>
<th>Ramp (%)</th>
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Flexibility Index

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## Expected Flexibility Saving Index vs. Flexibility Index

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Energy Flexibility in buildings

characterizing the energy flexibility of buildings and districts.

Could be used for labeling of energy flexibility.

Model Predictive Control
Time series analysis

International Energy Agency

Control strategies and algorithms for obtaining energy flexibility in buildings

Energy in Buildings and Communities Programme
Annex 67 Energy Flexible Buildings
September 2019
### Examples on control

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## Examples on control

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<tr>
<td>1</td>
<td>Multi-objective genetic algorithm for model predictive control in buildings</td>
<td>University of Southern Denmark</td>
<td>Denmark</td>
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<td>2</td>
<td>Deep reinforcement learning for optimal control of space heating</td>
<td>Enervis and KU Leuven</td>
<td>Belgium</td>
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<td>A Model Predictive Controller for Multiple-Source Energy Flexibility in Buildings</td>
<td>Technical Research Centre of Finland Ltd</td>
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<td>Model predictive control for carbon emissions reduction in residential cooling loads</td>
<td>Catalonia Institute for Energy Research</td>
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<td>Investigation of the energy flexibility of a residential net-zero energy building involved with the dynamic operations of hybrid energy storages and various energy conversion strategies</td>
<td>The Hong Kong Polytechnic University</td>
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<td>Rule-based load shifting with heat pumps for single family houses</td>
<td>Fraunhofer IEE</td>
<td>Germany</td>
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<td>Predictive rule-based control to perform heating demand response in Norwegian residential buildings</td>
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<td>CO₂-aware heating of indoor swimming</td>
<td>Technical University of Denmark</td>
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<td>Economic model predictive control for demand flexibility of a residential building</td>
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<td>Aggregation of energy flexibility of commercial buildings</td>
<td>University College Dublin</td>
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</table>
Simple rule based example

**Daily load profiles divided on sectors**

- **Grid losses**
- **Public enterprises**
- **Trade and services**
- **Industry**
- **Agriculture**
- **Residential**

**Figure 1.** Typical load profiles in the Danish power grid.

**Single family house – 150 m²**

Heat pump in a single family house

Set point and room temperatures - April 10

Set point and room temperatures - April 11

Power to and from heat pump - April 10

Power to and heat from heat pump - April 11
Hongkong: Building, PV, wind, battery and EV
One control strategy

Program start

- \( t = 0 \)
- \( t = t + \Delta t \)

On-site renewable electricity generation, \( G_{\text{RE}}(t) \)
- Electricity in the battery storage, \( P_{\text{storage}}(t) \)

Basic electric load of the building, \( L(t) \)

- \( P_{\text{storage}}(t) - L(t) > 0 \)

On-site REs, \( P_{\text{storage}}(t) = L(t) - P_{\text{storage}}(t) \)

Vehicles' discharging, \( P_{\text{discharge}}(t) = P_{\text{storage}}(t) - P_{\text{ACST}}(t) \)

Yes

- \( P_{\text{storage}}(t) > 0 \)

Yes

- \( P_{\text{discharge}}(t) > 0 \)

- \( P_{\text{storage}}(t) > 0 \)

Yes

- \( P_{\text{discharge}}(t) > 0 \)

Excess REs - DHW recharging
- \( P_{\text{discharge}}(t) = P_{\text{storage}}(t) - P_{\text{ACST}}(t) \)

- \( P_{\text{discharge}}(t) > 0 \)

Yes

- \( P_{\text{storage}}(t) > 0 \)

Excess REs - ACST recharging
- \( P_{\text{discharge}}(t) = P_{\text{storage}}(t) - P_{\text{ACST}}(t) \)

- \( P_{\text{discharge}}(t) > 0 \)

Yes

- \( P_{\text{storage}}(t) > 0 \)

Excess REs - SCST recharging
- \( P_{\text{discharge}}(t) = P_{\text{storage}}(t) - P_{\text{ACST}}(t) \)

- \( P_{\text{discharge}}(t) > 0 \)

Yes

- \( P_{\text{storage}}(t) > 0 \)

Battery charging
- \( P_{\text{discharge}}(t) = P_{\text{storage}}(t) - P_{\text{ACST}}(t) \)

- \( P_{\text{discharge}}(t) > 0 \)

Yes

- \( P_{\text{storage}}(t) > 0 \)

Export to the grid

- \( P_{\text{storage}}(t) > 0 \)

Import from the grid

End
Example of a EMPC controller

Test house at Grundfos: indirect control, price signal, forecast, EMPC
Simulation with 48 h prediction horizon using perfect forecasts.
Savings: 30 % in DKK but 8 % larger energy demand.

Results from test in the test house during January-May 2014 utilizing 24 h forecast: 16 % cost saving with dynamic tariffs and 8 % cost saving with flat tariffs.

Modeling and Control for Price Responsive Electricity Loads. Jacopo Parvizi
International Energy Agency

Experimental facilities and methods for assessing energy flexibility in buildings

Energy in Buildings and Communities Programme
Annex 67 Energy Flexible Buildings
June 2019
Hardware-in-the-loop test facilities, where parts of a system are physical components while others are virtual, establish a bridge between cheap simulation and expensive tests in real buildings. Systems and energy flexibility strategies are usually developed through simulations, so there is a need for validation through tests under dynamic, real (or as close as possible to real) operating conditions. Hardware-in-the-loop test facilities represent, therefore, an important tool where researchers and industry can test, under controlled conditions, the performance of new systems before they are implemented in real buildings and/or field tests.
### Test facilities

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<td>Tarragona, Spain</td>
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<tr>
<td>NZEB Emulator</td>
<td>Aalto University</td>
<td>Espoo, Finland</td>
</tr>
<tr>
<td>OPSYS test rig</td>
<td>Danish Technological Institute (DTI)</td>
<td>Taastrup, Denmark</td>
</tr>
<tr>
<td>ZEB Living Lab</td>
<td>NTNU / SINTEF</td>
<td>Trondheim, Norway</td>
</tr>
<tr>
<td>Energy Research Lab</td>
<td>Institute Energy in Building, FHNW</td>
<td>Muttenz, Switzerland</td>
</tr>
<tr>
<td>Semi-Virtual Laboratory</td>
<td>Polytechnique Montréal</td>
<td>Montréal, Canada</td>
</tr>
<tr>
<td>EnergyVille labs</td>
<td>EnergyVille (VITO, KU Leuven, IMEC)</td>
<td>Genk, Belgium</td>
</tr>
<tr>
<td>Test Lab Heat Pumps and Chillers</td>
<td>Fraunhofer Institute for Solar Energy Systems</td>
<td>Freiburg, Germany</td>
</tr>
<tr>
<td>Energy Smart Lab</td>
<td>IREC - Catalonia Institute for Energy Research</td>
<td>Barcelona, Spain</td>
</tr>
</tbody>
</table>

**REAL SYSTEM**

**Emulation laboratory facilities:**
- real equipment operated to respond to energy demand from the virtual building model
- integration of thermal and electrical energy sources and loadings

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**VIRTUAL SYSTEM**

**SCADA integrated with dynamic building simulation model:**
- climatic conditions
- 3D building design
- building occupancy and user behaviour
- simulation of thermal and electrical loadings
Results from IRAC
Results DTI, Denmark

Set point and room temperatures - December 21

Power to and from heat pump - December 21
Stakeholders’ perspectives on Energy Flexible Buildings

Energy in Buildings and Communities Programme
Annex 67 Energy Flexible Buildings
September 2019
The perspective of the stakeholders

Stakeholder acceptance and behaviour are crucial to the success of strategies for energy flexibility in buildings. Without careful design and implementation, introducing energy flexibility has the potential to disrupt occupant lifestyles, building systems for thermal comfort and health, as well as potentially increasing cost or energy consumption.

Stakeholder acceptance and behaviour may also be a barrier, but this can be reduced, or overcome entirely, if the related stakeholders are informed about flexibility measures and support any measures that are introduced.
The perspective of the stakeholders

There is a wide range of different stakeholders who may be affected by energy flexibility measures:

At the building level: end-users (occupants of buildings), building owners, facility managers, Energy Service Companies (ESCOs), developers, architects, contractors, and product/system suppliers.

The energy flexibility is ultimately useful for aggregators, DSOs (District System Operators of both power and district heating and cooling networks) and TSOs (Transmission System Operators).

It is important to establish a comprehensive understanding of acceptance, behaviour, and motivation at different levels of involvement for the relevant stakeholders.
Research by Annex 67

16 studies bases on questionnaires and/or interviews have been carried out among:

- Building managers – both campus and retail buildings
- Occupants – households, office and campus buildings
- Industrial consumers
- Energy suppliers
- Aggregators
- Technology providers
- Building energy analytics and consulting
- National regulation authority
## Occupants

based on 922 completed questionnaires by employees in offices in the Province of Bolzano, Italy

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Survey sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>39 % male, 61 % female</td>
</tr>
<tr>
<td>Age (years old)</td>
<td>Secondary school or lower: 3 %, High school: 53 %, University level: 39 %</td>
</tr>
<tr>
<td>Educational level</td>
<td>Ph.D.: 5 %</td>
</tr>
<tr>
<td></td>
<td>Employee: 77 %, Manager: 13 %, Intern: 0.4 %</td>
</tr>
<tr>
<td></td>
<td>PhD/researcher: 0.1 %, Team leader: 6 %, Team member: 2 %</td>
</tr>
<tr>
<td></td>
<td>Other: 2 %</td>
</tr>
<tr>
<td>Position</td>
<td>Single office: 42 %, Shared office with another colleague: 40 %</td>
</tr>
<tr>
<td></td>
<td>Shared office with two other colleagues: 7 %, Shared office with 3 or more</td>
</tr>
<tr>
<td></td>
<td>Other colleagues: 6 %, Open space: 2 %, Other: 2 %</td>
</tr>
<tr>
<td>Office typology</td>
<td></td>
</tr>
</tbody>
</table>
Results

Importance of using renewables instead of fossil fuels

Familiarity with smart grid
### Results

<table>
<thead>
<tr>
<th>Appliance</th>
<th>1 Not willing at all</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 Really willing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dishwasher</td>
<td>13.4%</td>
<td>17.8%</td>
<td>10.4%</td>
<td>8.8%</td>
<td>22.9%</td>
</tr>
<tr>
<td>Printer/copier</td>
<td>14.4%</td>
<td>21.5%</td>
<td>16.1%</td>
<td>8.0%</td>
<td>20.1%</td>
</tr>
<tr>
<td>Air conditioning</td>
<td>16.1%</td>
<td>10.4%</td>
<td>9.8%</td>
<td>8.0%</td>
<td>22.6%</td>
</tr>
<tr>
<td>Smart heating system</td>
<td>15.5%</td>
<td>8.0%</td>
<td>9.8%</td>
<td>8.0%</td>
<td>24.0%</td>
</tr>
<tr>
<td>Electric vehicle</td>
<td>8.8%</td>
<td>13.4%</td>
<td>20.4%</td>
<td>17.5%</td>
<td>39.5%</td>
</tr>
</tbody>
</table>

Willingness to let some smart appliances be remotely controlled by the electricity utility
Results

Conditions to accept the remote control of some appliances by the electricity utility:

- Not compromising privacy: 75%
- Possibility to override, at any time, that control: 78%
- Not interfering with the work activities: 68%
- Only if needed to ensure electricity supply: 17%
- Environmental advantages: 74%
- Effective electricity bill savings: 68%
- Be informed of the control actions and savings generated: 46%
- Other: 3%
Conclusions

• It is essential to understand stakeholders’ needs and behaviour, not only regarding comfort and energy requirements, but also regarding their possible position within business models, in order to be able to develop feasible market access strategies for different types of actors.

• Although ‘consumer driven/centred’ approaches have been emphasized in recent years, policy makers are still the lead stakeholders for strengthening opportunities and eliminating barriers in the energy system. To establish and realize the markets for energy flexible buildings, decentralization of the power hierarchy is necessary, especially for international collaboration and trading.
Possible new IEA EBC annex:

Energy flexible buildings towards resilient low carbon energy systems
Research topics for a new annex

• Scaling from single buildings to clusters of buildings
• Flexibility and resilience in a multi carrier energy system
• Stakeholder acceptance and engagement
• Development of business models
Other related IEA activities
Thank you for your attention