Project Summary Report

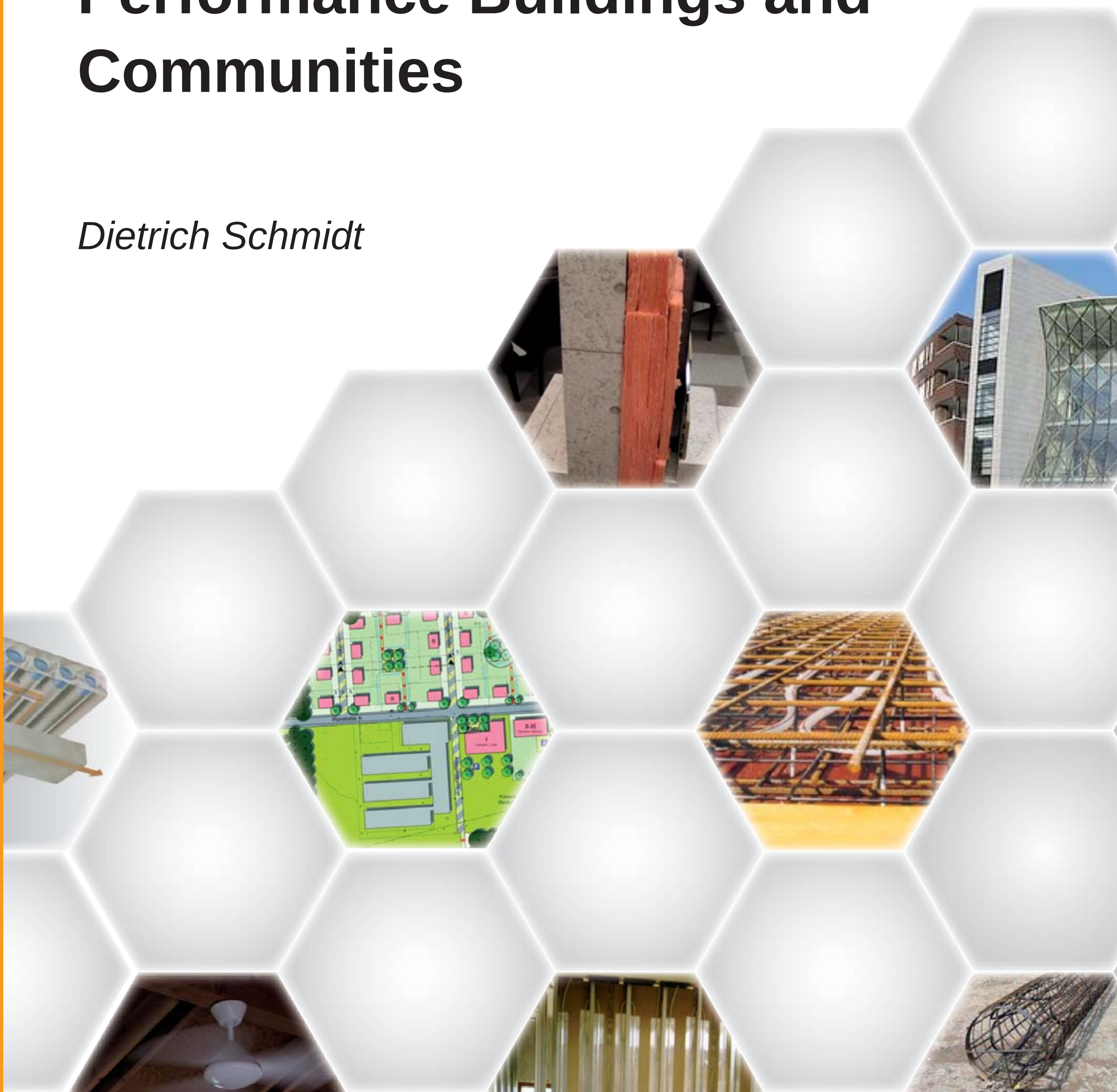
EBC

Energy in Buildings and Communities Programme

EBC Annex 49

Low Exergy Systems for High Performance Buildings and Communities

Dietrich Schmidt



Energy in Buildings and Communities Programme

EBC Annex 49

Low Exergy Systems for High Performance Buildings and Communities

Project Summary Report

Dietrich Schmidt

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Contents

About EBC

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-eight IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy in Buildings and Communities

The IEA co-ordinates research and development in a number of areas related to energy. The mission of one of those areas, the EBC - Energy in Buildings and Communities Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)
The research and development strategies of the EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshop, held in April 2013. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas of R&D activities:

– Integrated planning and building design
– Building energy systems
– Building envelope
– Community scale methods
– Real building energy use

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified in grey):

Annex 1:	Load Energy Determination of Buildings
Annex 2:	Ekistics and Advanced Community Energy Systems
Annex 3:	Energy Conservation in Residential Buildings
Annex 4:	Glasgow Commercial Building Monitoring
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities
Annex 7:	Local Government Energy Planning
Annex 8:	Inhabitants Behaviour with Regard to Ventilation
Annex 9:	Minimum Ventilation Rates
Annex 10:	Building HVAC System Simulation
Annex 11:	Energy Auditing
Annex 12:	Windows and Fenestration
Annex 13:	Energy Management in Hospitals
Annex 14:	Condensation and Energy
Annex 15:	Energy Efficiency in Schools
Annex 16:	BEMS 1- User Interfaces and System Integration
Annex 17:	BEMS 2- Evaluation and Emulation Techniques
Annex 18:	Demand Controlled Ventilation Systems
Annex 19:	Low Slope Roof Systems
Annex 20:	Air Flow Patterns within Buildings

Annex 21: Thermal Modelling
Annex 22: Energy Efficient Communities
Annex 23: Multi Zone Air Flow Modelling (COMIS)
Annex 24: Heat, Air and Moisture Transfer in Envelopes
Annex 25: Real time HEVAC Simulation
Annex 26: Energy Efficient Ventilation of Large Enclosures
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems
Annex 28: Low Energy Cooling Systems
Annex 29: Daylight in Buildings
Annex 30: Bringing Simulation to Application
Annex 31: Energy-Related Environmental Impact of Buildings
Annex 32: Integral Building Envelope Performance Assessment
Annex 33: Advanced Local Energy Planning
Annex 34: Computer-Aided Evaluation of HVAC System Performance
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT)
Annex 36: Retrofitting of Educational Buildings
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx)
Annex 38: Solar Sustainable Housing
Annex 39: High Performance Insulation Systems
Annex 40: Building Commissioning to Improve Energy Performance
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings
Annex 48: Heat Pumping and Reversible Air Conditioning
Annex 49: Low Exergy Systems for High Performance Buildings and Communities
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings
Annex 51: Energy Efficient Communities
Annex 52: Towards Net Zero Energy Solar Buildings
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)
Annex 56: Cost Effective Energy & CO2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO2 Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long-Term Performance of Super-Insulation in Building Components and Systems

Working Group - Energy Efficiency in Educational Buildings
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings
Working Group - Annex 36 Extension: The Energy Concept Adviser

General Information

Project leader: **Dietrich Schmidt, Fraunhofer Institute for Building Physics, Kassel, Germany**

Project duration: **2005 - 2009**

Further information: **www.iea-ebc.org**

Buildings sector is responsible for about one third of the total energy end use and a major contributor to carbon dioxide (CO_2) emissions. A major fraction of total energy is used for heating and cooling of room spaces, in which the required temperature levels are comparably low and in turn the required energy 'quality' to satisfy these demands is low too. The objective of the project **'Annex 49: Low Exergy Systems for High performance Buildings and Communities'** was to show ways of supplying indoor spaces with the required energy, without using high quality sources, such as fossil fuels or electricity. Based on the thermodynamic concept of 'exergy', new solutions for space conditioning was identified and analysed.

The outcome from the project is a Guidebook, intended to present the state of the art related to exergy analyses for buildings. It investigates the benefits of applying the exergy concept to the design and optimisation of energy supply systems for buildings and communities. Two versions of the Guidebook are available:

- The full extended version is oriented to scientists and researchers working in the field of energy efficient building systems. The technical background and thermodynamic concepts related to the exergy analysis in building systems are explained thoroughly in a clear and detailed way. This report is intended to be a reference for further analyses so that comparability can be guaranteed between results of exergy analyses of different building case studies.

- The short summary version is intended to introduce the concepts of and methodology behind exergy analysis to building decision makers and planners. The technical basis behind the exergy concept is explained in a simplified, applicable manner by focusing on the outcomes of exergy analysis and the importance of this concept for building and community systems design.

What is Exergy?

Exergy expresses the quality of an energy source in terms of the potential for useful work extraction it is able to derive from a system.

Tools for exergy performance assessment

One of the core aims of the project was to bring the exergy approach to the attention of building planners, decision makers and architects. For this purpose, the development of user-friendly open-platform software for exergy based building design and performance assessment is essential.

Within the research activities, six different assessment tools have been developed. These tools are focused on different parts of the energy supply chain, ranging from component analysis, to community systems assessment and to building systems design. Thereby, the whole scope of energy supply in buildings is covered for the benefit of the wider audience relating to energy systems and building design. The exergy calculation tool DPV (Design Performance Viewer) has been implemented within a building information model (BIM) and developed for building designers and architects.

Case studies on buildings and community systems

To show the benefits of exergy analysis on buildings, several case studies on building and community energy supply systems have been analyzed. An example of a building system is a heat recovery system for grey water. This is used as an energy source in the thermodynamic cycle of a heat pump supplying space heating and domestic hot water demands, significantly increasing the coefficient of performance of the machine. In this way, a low temperature heat flow usually considered as waste within buildings is

Participating Countries:

Austria
Canada
Denmark
Finland
Germany
Italy
Japan
Poland
Sweden
Switzerland
The Netherlands
USA

Table 1. Summary of community case studies for exergy analysis.

Community	Country	LowEx highlights
Alderney Gate	Canada	Sea water cooling coupled with borehole thermal energy storage
Andermatt	Switzerland	Geothermal energy systems
Heerlen	Netherlands	Low temperature emission systems, low temperature district heat from old coal mines
Letten	Switzerland	Geothermal energy systems
Minnesota	USA	Co-generation and district heating
Oberzwehren	Germany	Utilisation of waste heat from CHP as low exergy supply source
Okotoks	Canada	Solar thermal heating systems coupled with seasonal ground thermal energy storage
Parma	Italy	Low temperature heating systems coupled with efficient ventilation systems
Ullerød	Denmark	Low energy district heating, ground source heat pump (GSHP) and air-to-water heat pump (AWHP)

recovered and allows significant exergy savings in the energy supply of buildings.

Table 1 gives an overview of the analyzed community level case studies within the project. The main technologies used are shown, as along with the countries in which they are located.
To compare the exergy performance of the different community case studies with each other qualitatively, diagrams characterizing their energy and exergy performance in a simple and graphical manner have been developed. Figure 1 shows, as an example, such a diagram for a community case study, namely Oberzwehren (Germany).

In Figure 1, the good exergy performance of low temperature district heating supply as compared to the other options considered can be seen. As a consequence, this was the supply option chosen for this particular project.

The project has delivered a strong scientific basis for the development of models and tools for the wider implementation of exergy analyses for buildings and communities, supported by a collection of innovative case studies. The Guidebook is a valuable source book for future work within this field and opens an excellent opportunity for new activities within the development of more efficient energy use and supply structures for buildings and communities.

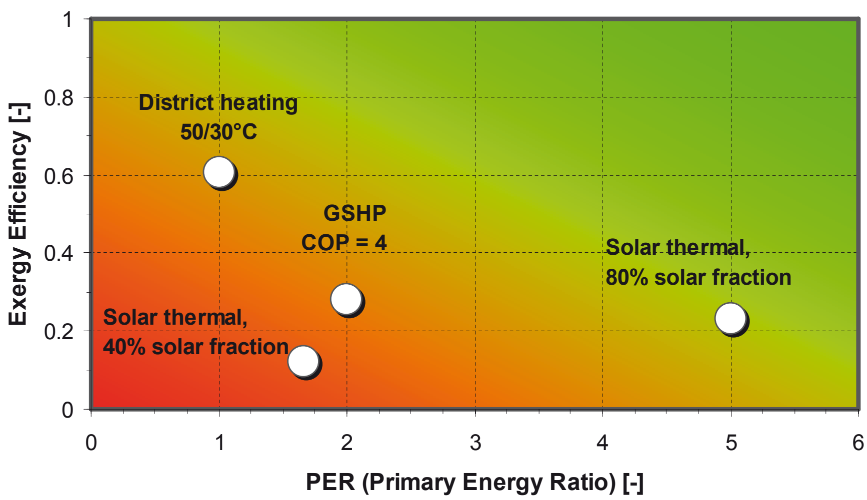

Figure 1. Primary energy ratio versus exergy efficiency diagram for the energy supply options considered for the community of Oberzwehren, Germany.

Project Outcomes

Project leader: **Dietrich Schmidt, Fraunhofer Institute for Building Physics, Kassel, Germany**
Project duration: **2005 - 2009**
Further information: **www.iea-ebc.org**

Much of the energy used in the buildings sector is required to maintain constant room temperatures, usually around 20°C to 25°C. So, in industrialized countries the buildings sector is responsible for about one third of the total energy end use and a major contributor to carbon dioxide (CO2) emissions. A major fraction of total energy is used for heating and cooling of room spaces, in which the required temperature levels are comparably low and in turn the required energy 'quality' to satisfy these demands is low too. The objective of the project **'Annex 49: Low Exergy Systems for High performance Buildings and Communities'** has been to show ways of supplying indoor spaces with the required energy, without using high quality sources, such as fossil fuels or electricity. Based on the thermodynamic concept of 'exergy', new solutions for space conditioning have been identified and analysed.

The outcome from the project is a Guidebook, intended to present the state of the art related to exergy analyses for buildings. It investigates the benefits of applying the exergy concept to the design and optimisation of energy supply systems for buildings and communities. Two versions of the Guidebook are available:

- The full extended version is oriented to scientists and researchers working in the field of energy efficient building systems. The technical background and thermodynamic concepts related to the exergy analysis in building systems are explained thoroughly in a clear and detailed way. This report is intended to be a reference for further analyses so that comparability can be guaranteed between results of exergy analyses of different building case studies.

- The short summary version is intended to introduce the concepts of and methodology behind exergy analysis to building decision makers and planners. The technical basis behind the exergy concept is explained in a simplified, applicable manner by focusing on the outcomes of exergy analysis and the importance of this concept for building and community systems design.

Guidebook for Low Exergy Systems

The main objectives of the project were:

- develop design guidelines regarding exergy metrics for performance and -sustainability

- create open-platform exergy software for building design and performance assessment

- show best practice examples for new and retrofit buildings and communities

- document benefits of existing and developed demonstration projects

- set up a framework for future development of policy measures and pre-normative work including the exergy concept

The topics mentioned are treated in detail within the guidebook in chapters:

- Following the introduction the guidebook gives a detailed description of the first unitary methodology for performing dynamic exergy analysis on building systems. Fundamental concepts and the thermodynamic background of the exergy approach are highlighted, as well as detailed equations for the analysis of several building systems.

- In the following the tools developed within the project are presented. A detailed description of the main features, calculation approach and usability of each tool is also given.

- Than, the guidebook highlights and summarises main strategies for optimised exergy design of buildings and community systems.

- The main parameters developed or used for characterising exergy performance of any building or community are presented. Based on these parameters, first discussions and bases for setting pre-normative proposals which include the exergy concept are also included.

- The guidebook shows the main building and community case studies analysed within the research activities of the project.

Tools to facilitate exerg analysis of buildings and communities

In building design, both the energy and exergy performance of the building and its building systems should be taken into account. As a part of the work done, a variety (in total six different tools) of software tools have been developed to facilitate the use of exergy analysis in building design. These tools have different levels of complexity and can be used in various applications. They are at the forefront of the use of exergy in the building sector, providing a unique viewpoint that simple analysis based on energy balances alone might overlook. These tools provide designers with a range of options for producing results pertaining to the exergetic performance of a particular design.

Excel pre-design tool

The concept and structure of the tool are based on the MS-Excel tool developed within a previous project (it can be downloaded at www.lowex.net) and represent a further development of that tool. Main newly implemented features are:

- two different energy sources, or energy supply systems for DHW and space heating demands can be combined, e.g. solar thermal collectors and heat pumps, boilers, etc.
- renewable energy flows are accounted for, both in energy and exergy terms, in the generation and primary energy transformation subsystems.
- renewable and fossil energy and exergy flows are regarded separately, allowing good traceability of different energy sources in the energy supply chain.

Cascadia tool

A MS-Excel based tool for community analysis, called “Cascadia”, has been developed. The model implemented in this tool represents the building as a simple thermal load and emphasises more, the form of the energy supply

What is Exergy?

Exergy expresses the quality of an energy source in terms of the potential for useful work extraction it is able to derive from a system. The exergy content of energy sources required to satisfy the demands for heating and cooling of buildings is very low. Nevertheless, high quality energy sources like fossil fuels are commonly used to satisfy these small demands for exergy. Therefore, **low exergy (LowEx) systems** for buildings and communities are desirable. These are designed to make use of low quality energy sources for heating and cooling.

To achieve this matching between the quality levels of the energy demand with that supplied, new advanced technologies have to be implemented. For instance, the use of low temperature (and quality) heat sources, such as waste heat, ground heat or solar heat for providing space heating demands requires the use of low temperature heating systems such as floor heating or thermally activated systems within the building. For the cooling situation innovative technologies such as **phase change material (PCM)** systems allow reduced peak cooling loads and supply cooling demands at a high temperature level (i.e. low quality and therefore exergy efficiently).

At the same time as the use of high quality energy for heating and cooling is reduced, there is more reason to apply an integral approach, which includes all other processes where energy / exergy is used in buildings and in community systems.

Project Outcomes

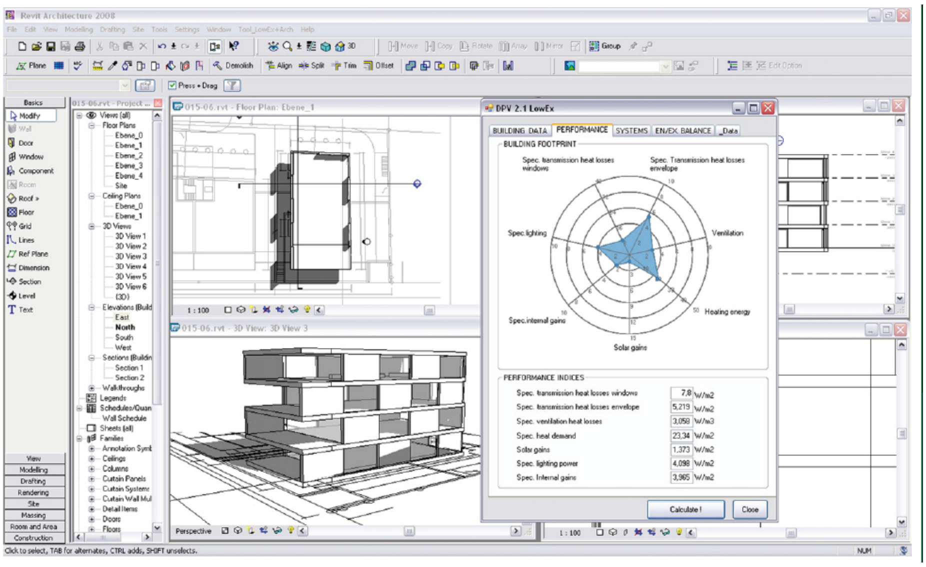

Figure2: Screenshot from DPV tool with spider graph for comparing the performance of different parts of a building design.

and its distribution network. For the evaluation process the district energy supply temperature has been selected, based upon the capabilities of the supply technology. Five technologies were included within the model:

- a medium efficiency gas fired boiler
- a high efficiency, condensing gas fired boiler
- a reciprocating gas fired engine based co-generation system
- an electrically driven ground source heat pump
- lat plate solar thermal collectors

SEPE an Excel calculation tool for exergy-based optimisations

SEPE, or “Software for Exergy Performance“ is a MS-Excel based software that utilises the iteration features of Excel to perform steady-state exergy evaluations and optimisation of different cooling and heating systems. The tool provides insight on the exergy processes at the component level of building supply systems.

Design Performance Viewer (DPV)

For the first time, a building exergy calculation has been implemented in a Building Information Modelling (BIM) tool. A new energy and exergy tool called the Design Performance Viewer (DPV) has been developed based on the Excel tool. The tool, which is integrated with Autodesk Revit software, allows planners, designers, and architects to obtain an easy-to understand graphic display of the energetic and exergetic performance of their buildings.

Benchmarking for components of building systems and communities

To assess different system layout options in the design the benchmarks have been developed. The benchmarking proposals from the project are based on the following parameters:

- The exergy expenditure figure is calculated as the ratio between the exergy input (effort) required to supply a given energy demand and the energy demand itself (use). Auxiliary energy for operating the component is also included as input (i.e. effort) in the parameter. Exergy expenditure figures can be used to characterise the performance of components in energy supply systems. This figure can be seen as an enhanced version of the quality factors (exergy to energy ratio), where both the energy and exergy losses in a certain energy conversion unit are depicted.
- Quality factors are defined as the ratio between the exergy and energy of a

given energy system. They indicate the convertibility of an energy flow into mechanical work, i.e. high valued energy with high exergy content. Thereby they characterise and distinguish high exergy sources and demands from low exergy sources and demands. They allow a simple but thermodynamically correct representation of the matching in the quality levels between energy supplied and demanded, and are used for this purpose in the “arrow diagrams” used to depict the performance of community case studies.

- Exergy efficiency defined as the ratio between the obtained output and the input required to produce it. Exergy efficiencies help identifying the magnitude and point of exergy destruction within an energy system. Therefore they quantify how well the potential in the energy and exergy inputs to the system are used.

- Primary energy ratio (PER) is calculated as the ratio between the useful energy output, i.e. the energy demand to be supplied, and the fossil energy input required for its supply. High PER values indicate that the proportion of fossil energy in the supply is low, thereby meaning that a greater share of renewable energy sources is present in the supply.

- Based on the last three parameters two diagrams for depicting the performance of community supply systems have been developed:

- The arrow diagram shows the matching between the quality levels of the energy supplied and demanded. The diagram is a qualitative representation of the quality and quantity of energy demands and supply in buildings. The position of the arrows on the Y-axis (i.e. “Energy quality, q”) represents the quality factor of the energy supplied and demanded and thereby depicts the exergy content of the energy flow. On a scale from zero to one, quality factors for different energy flows are represented. The thickness of the arrows represents the amount of energy demanded or supplied. In this way, both the quality and quantity of the different regarded energy flows is shown. Thus the matching between the quantity and quality levels of the energy supplied and demanded can be seen.

- The (PER)-exergy efficiency diagram characterises the exergy performance and use of renewable energy in the supply of a

Figure3. Example of an arrow diagram showing a match betwen the energy quality of demand and supply.

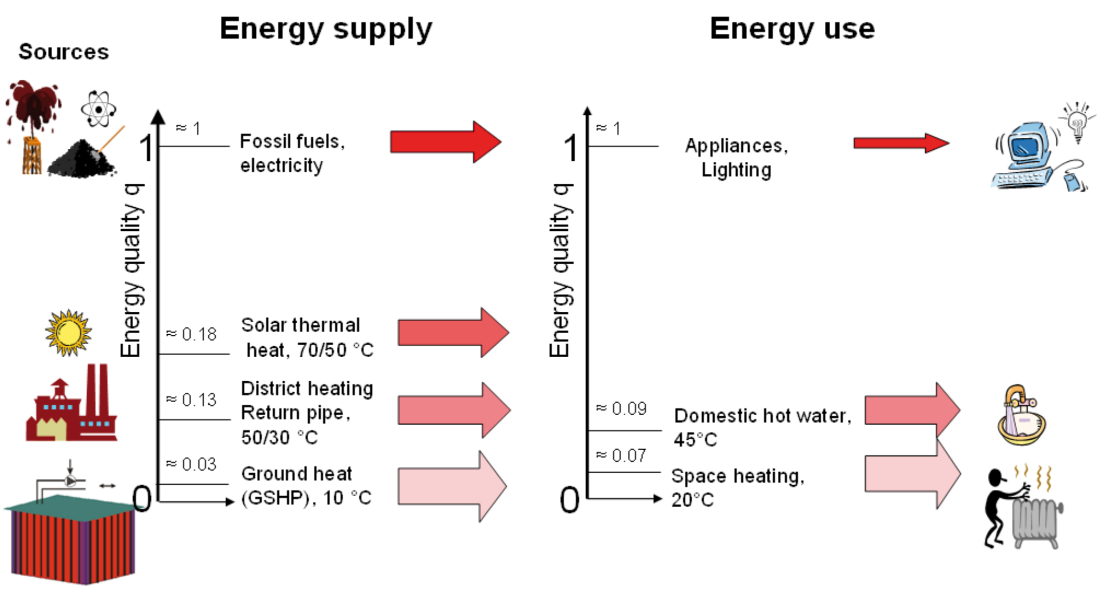

Table 2a. Summary of building components and systems case studies for exergy analysis.

	Main building components	Relevance as Low-exergy technology
1	Exergy efficient air-conditioning systems and appliances in buildings	By using outdoor dry air as the driving force, the indirect evaporative chiller is aimed at providing a novel air-conditioning concept for public buildings in dry regions. It takes advantage of the use of "wet" exergy contained in liquid water to produce cool exergy and subsequently cool the air or water as a cool carrier. It produces cold water with a temperature between 16°C and 18°C without usage of electricity, as standard chillers. The use of water strongly contributes to lowering exergy losses, with respect to airborne systems, due to better heat vector behaviour.
2	Temperature and humidity independent control (THIC) air-conditioning system	This system allows the control of both humidity and temperature by splitting the management of them into two independent systems. Due to the increased temperature for cooling from 7°C to 18°C, much better performances in terms of exergy can be obtained. Referred to an outside reference environment at 25°C, the exergy content is respectively 6.4% and 2.4% of the produced and delivered heat. Similarly, a chiller ideally working in the same environment would perform almost three times more effectively. Consequently, relevant amounts of exergy can be saved, while still assuring good comfort conditions in the cooled areas.
3	Adjustment of the ventilation rates based on the variation in time of the actual needs	Energy use for air circulation in air unit systems is a relevant part of the overall energy balance. To overcome the pressure drops in air ducts, which implies slight exergy destruction, electricity-driven fans are needed as their exergetic efficiency is very low. This approach limits the electricity consumption for air circulation by making use of the natural pressure differences in the environment that would be otherwise supplied. Furthermore, active systems, such as chillers, can be switched off to maintain IAQ comfort requirements. As a result, in intermediate seasons, it is possible to cut off the electricity consumption, that is exergy, and make use of available environmental sources.
4	Seasonal heat storage with ground source heat pump system	The main precondition to the exploitation of many renewable sources is the possibility to store energy, due to their inconsistent availability. The exploitation of renewable sources is considered as a low exergy approach. Even though solar radiation has a theoretically great exergy potential, the exergy destruction of the solar radiation would take place anyway, regardless of human exploitation, and its use replaces high-exergy fossil fuels. Seasonal heat storage has a two-fold positive effect on exergy consumption in buildings: it allows the massive exploitation of solar energy in an efficient way – thus collecting freely available exergy - and it improves the performance of active, electricity-driven systems, such as heat pumps.

Table 2b. Summary of building components and systems case studies for exergy analysis.

	Main building components	Relevance as Low-exergy technology
5	Shallow ground heat storage with surface insulation	This technology opens up the possibility of providing heating and cooling with low exergy supply. The reduced heat loss to the ground is also a way to minimize exergy losses in the system. However, special care will probably be needed to control the moisture from the ground.
6	Exergy recovery from wastewater in small scale integrated systems	In this study case, the recovery of waste energy has a strong influence on the performance of the heat pump, By increasing the source temperature, and consequently the COP, the demand of electricity decreases.
7	Innovative configuration for cooling purposes: series design for chillers	The industry standard design is to provide a single temperature chilled water supply. Water cooled chillers are normally configured with evaporators in parallel and condensers in parallel. The supply to return temperature differential for both evaporator and condenser water chiller flows is typically between 5.6°C and 6.7°C. The industry large scale chiller plants average approximately 0.267 system kWelectric/kWcooling at 24.2 °C ambient temperature. The improvement potential achievable with an innovative chiller design consisting on a series connection of several chillers is investigated. The forecasted electrical energy demand for the chillers is then reduced from the conventional value of 0.267 kWelectric/kWcooling to 0.135 kWelectric/kWcooling at 24.2°C ambient air temperature. Ideal exergy efficiencies for both configurations amount 8.33 and 12.14 respectively. This represents an improvement of 47%.

community. An example of such a diagram can be seen on Figure 4. White dots show both parameters for different supply concepts, characterising the performance of the case study. Dots in the upper right corner indicate good exergy performance and high use of renewable energy sources. Consequently, these supply concepts correspond to “LowEx” community concepts. In turn, dots close to the lower left corner depict case studies with low exergy efficiency and high fossil fuel share on the energy supply.

Case studies of innovative building design strategies

Seven case studies of innovative concepts or technologies were investigated in the project. The summary of these case studies with short description on their relevance as low-energy technology is shown in Table 2.

Innovative community case studies

In many of the community case studies the performance of possible supply options are considered at the beginning and in the planning phase of the project. Table 3 shows the summary of community case studies.

The simple benchmarking diagrams developed within the project and presented above are used to show, how suitable the different supply options are. Figure 4 shows, as an example, the PER exergy efficiency diagram for the case study of Oberzwehren. The great exergy performance of low temperature district heating supply as compared to the other options can be easily seen.

Project Outcomes

Community	Country	LowEx highlights
Alderney Gate	Canada	Sea water cooling coupled with borehole thermal energy storage
Andermatt	Switzerland	Geothermal energy systems
Heerlen	Netherlands	Low temperature emission systems, low temperature district heat from old coal mines
Letten	Switzerland	Geothermal energy systems
Minnesota	USA	Co-generation and district heating
Oberzwehren	Germany	Utilisation of waste heat from CHP as low exergy supply source
Okotoks	Canada	Solar thermal heating systems coupled with seasonal ground thermal energy storage
Parma	Italy	Low temperature heating systems coupled with efficient ventilation systems
Ullerød	Denmark	Low energy district heating, ground source heat pump (GSHP) and air-to-water heat pump (AWHP)

Table 3. Summary of community case studies for exergy analysis.

Following, this was the supply option chosen for the project. However, in terms of primary energy the performance of district heating supply could still be improved by using renewable energy fuels to power the CHP units providing waste heat to the district network. This was done for example in the city of Parma. The target was to transform Parma into a renewable city by the year 2050, adopting today's best available technologies. A renewable-fuelled CHP unit was therefore also considered.

Summary

The exergy demand of buildings is one of the most important variables of exergy analysis in buildings. The exergy demand represents the minimum amount of work that would need to be provided to the building in order to maintain acceptable conditions in the indoor environment. Within the project, two different approaches have been developed for determining the exergy demand of buildings:

- simplified approach, suitable for analysing the efficiency and performance of building systems, and
- detailed approach suitable for analysing the performance of the building design and envelope.

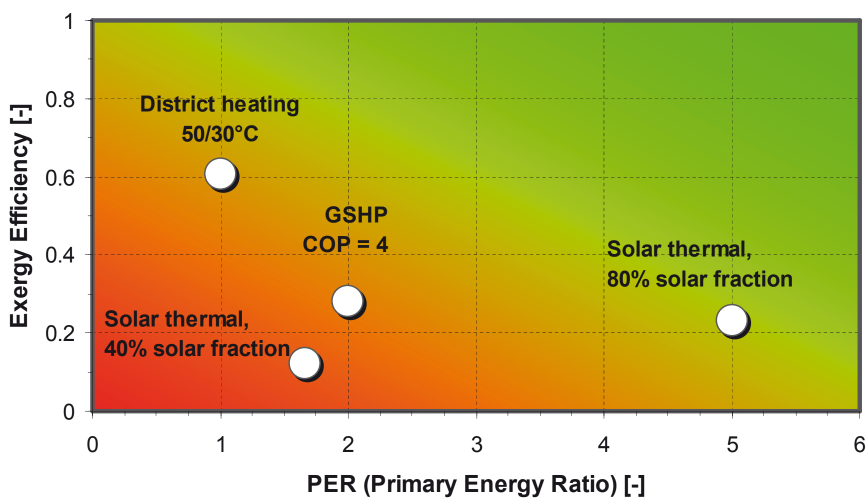

Figure 4. Primary energy ratio versus exergy efficiency diagram for the energy supply options considered for the community of Oberzwehren, Germany.

Project Outcomes

The project has delivered a strong scientific basis for the development of models and tools for the wider implementation of exergy analyses for buildings and communities, supported by a collection of innovative case studies.

The Guidebook is a valuable source book for future work within this field and opens an excellent opportunity for new activities within the development of more efficient energy use and supply structures for buildings and communities. Additionally a report on the exergy aspects of the human body and thermal comfort was published. This report describes an application of one of the core concepts of thermodynamics, "exergy", to the human-body thermoregulatory system in order to have a better understanding of thermal comfort in the built environment.

Project Outcomes

Further Information

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and Thermal Comfort, Annex 49 Working Report

Dietrich Schmidt and Herena Torío, Annex 49 Midterm Report, A framework for exergy analysis at the building and community level, Fraunfofer-IBP, 2009

Herena Torio, Dietrich Schmidt, Exergy Assessment Guidebook for the Built Environment, Annex 49 Summary Report, Fraunhofer Verlag, 2011

Project Reports

www.iea-ebc.org

Project Participants

Category	Organisation
Austria	Vienna University of Technology
Canada	Sustainable Buildings & Communities & Natural Resources Canada
Denmark	Technical University of Denmark
Finland	VTT Technical Research Centre of Finland
Germany	Fraunhofer-Institute for Building Physics
Italy	University of Padova
Japan	Tokyo City University Nihon Sekkei
The Netherlands	Cauberg-Huygen R.I. B.V. Delft University of Technology SenterNovem
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