International Energy Agency
Energy Conservation in
Buildings and Community
Systems Programme

Project Summary Report

Heating & Cooling

with a Focus on

Increased Energy Efficiency

& Improved Comfort

Energy Conservation in Buildings & Community Systems Programme

ECBCS
Annex 37

Heading and Cooling with a Focus on Increased Energy Efficiency and Improved Comfort

ECBCS Annex 37 Project Summary Report

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Preface

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). The IEA co-ordinates research and development in a number of areas related to energy.

Energy Conservation in Buildings and Community Systems Programme

The mission of the IEA Energy Conservation for Building and Community Systems 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.

The research and development strategies of the ECBCS Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Building Forum Think Tank Workshop, held in March 2007. 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 three focus areas of R&D activities:

- Dissemination
- Decision-making
- Building products and systems

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 by (*)):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)

Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time 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)
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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: Analysis of Micro-Generation & Related Energy Technologies in Buildings
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO)

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - Energy Efficient Communities

(*) – Completed

Contents

1. Introduction

Annex 37 "Low Exergy Systems for Heating and Cooling of Buildings" (LowEx) of the IEA ECBCS implementing agreement has embraced the concept of exergy and explored its relevance to low temperature heating and high temperature cooling of buildings. The Annex has brought together world-wide experience and understanding of exergy to promote the use of energy sources in the most appropriate way for the required end use in building services.

The Annex has produced a Guidebook[1] of more than 280 pages that deals in great deal with the concept of exergy and its relevance to building services and human comfort within them. It provides a comprehensive list of systems that work together with the LowEx concept and gives example buildings that demonstrate the systems. A major product of the work of the Annex is the development of pre-design calculators that assist with LowEx design of buildings and their services. All that information and the tools are available in the Guidebook.

The aim of this report is to introduce architects and building design engineers to the concept of exergy. The report has the following sections:

- Exergy – an explanation that provides a basic insight into the concept of exergy and shows how this can be applied to providing the heating and cooling of buildings.
- Exergy Pre-design Analysis Tools – a spreadsheet tool for optimising the exergy use in buildings
- LowEx Systems for Buildings – a compendium of heating and cooling systems that can be used to minimise the loss of exergy in heating and cooling systems
- Example case study buildings – two of the 30 case studies reported by the Annex.

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[1] "Low exergy systems for heating and cooling of buildings - Guidebook" is available as a CD version and also freely available as a PDF version on the internet (www.lowex.net). The CD version, however, offers a more reader friendly environment and some additional information.

2. Exergy and LowEx Heating and Cooling in Buildings

In the realm of energy use in buildings the most commonly used expressions are “energy use”, “energy conservation”, and “energy consumption”. Whilst these have value and are widely understood they do not address the fact that energy is ‘converted’, rather than used or consumed, and it is rather better said that the energy changes its ability to do work. It is the ability of energy to do useful work that underpins the concept of exergy.

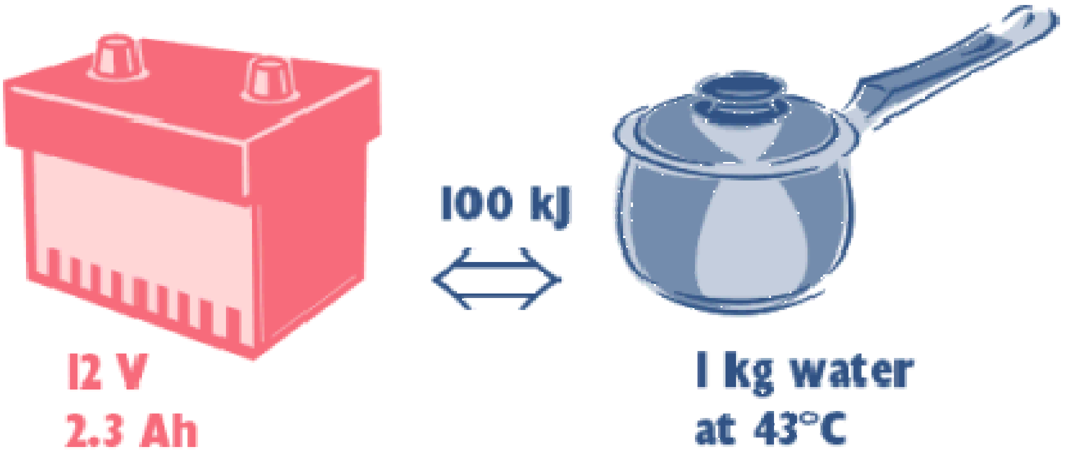
Exergy is a term that has been in existence for more than a century and has been used to describe the ‘quality’ of energy; by which we mean the ability to do work with respect to a final end state. The form in which “energy” is available to do work is fundamental to the development of the LowEx concept.

2.1. Exergy an Explanation

The normal analysis of energy use in a building will rely on the First Law of Thermodynamics that says that energy must be conserved. Hence we express the performance of the building in terms of energy conservation. For example, converting the chemical energy of gas to heat by combustion within a boiler cannot lose energy: that which does not get transferred to the water leaves via the flue with the combustion products or is lost from the boiler casing to the local environment. This description fulfils the requirement of the First Law and the ‘energy efficiency’ in everyday terms is the ratio of useful heat in the water to energy in the ingoing gas.

However, it can be seen that the value of the ‘energy’ has been degraded from a chemical form in the gas to heat at a low temperature from which it little or no mechanical work can be derived. Alternatively, if the gas had been used to power an engine to generate electricity, which has a greater ‘value’ than heat in terms of its ability to do work, then the ‘potential’ of the energy is maintained. The theory of exergy takes this decrease in availability to do useful work as the means of establishing the exergy content of an energy source.

As an example, consider a battery and a container of hot water as in the picture below. Each contains the same 100 kJ of energy but the value of the energy is quite different. Simplistically, the battery can be used for a wide range of functions such as driving motors, running a computer or providing light from a lamp - it can even be used to produce hot water at 43^0C. The hot water however, has more limited usefulness but could adequately contribute to an underfloor heating system, or other similar LowEx system.



Exergy is therefore the expression of the ‘quality’ of energy that is lost when energy moves between either temperature levels or changes of state. It is a measure of the availability of energy to do useful work. It follows that when energy is expressed only in terms of heat then the loss of exergy is linear with temperature, however, when a change of state occurs, either chemical or mechanical, then the relationship is not linear but more of a discontinuity with a consequential loss in exergy not entirely dependent on the temperature levels of the process.

To determine this change in exergy ‘Quality Factors’ are used that compensate for the dissipation of exergy when energy moves from one state to another. The exergy of an energy resource is therefore expressed as the product of its energy content and an appropriate Quality Factor for that energy state.

exergy = energy x quality factor

Quality factors vary from 1.0 for electrical energy and mechanical energy to 0.9 for fossil fuels and 0.06 for thermal energy at 40^{o}C. As in the battery example above an appropriate final thermal end-point is defined and for quality factors this is taken as thermal energy at 20^{o}C. Hence the quality factor of thermal energy at 20^{o}C is 0.00.

It follows from this that a key aim in any energy process is to minimise the loss of exergy in the system as this leaves available exergy for other functions. In practice this can simply mean using low temperature heat sources for heating and high temperature heat sources for cooling, but a full analysis of the exergy use of a system will provide insights beyond this simple assumption.

It is not only the mechanical services aspects of providing heating for a building that can benefit from the exergy approach. As explained more fully in the LowEx Guidebook adopting the exergy concept as part of the overall design philosophy of the building is important so that the basic building is designed to reduce the exergy burden it imposes on the energy conversion processes.

The exergy concept can be applied to human comfort and it can reveal benefits in both thermal comfort for the building occupants as well as the reduction of exergy loss. Recent studies suggest that a combination of lower air temperature and higher environmental radiant temperatures lead to the optimum human thermal comfort. Such a combination further benefits the LowEx concept.

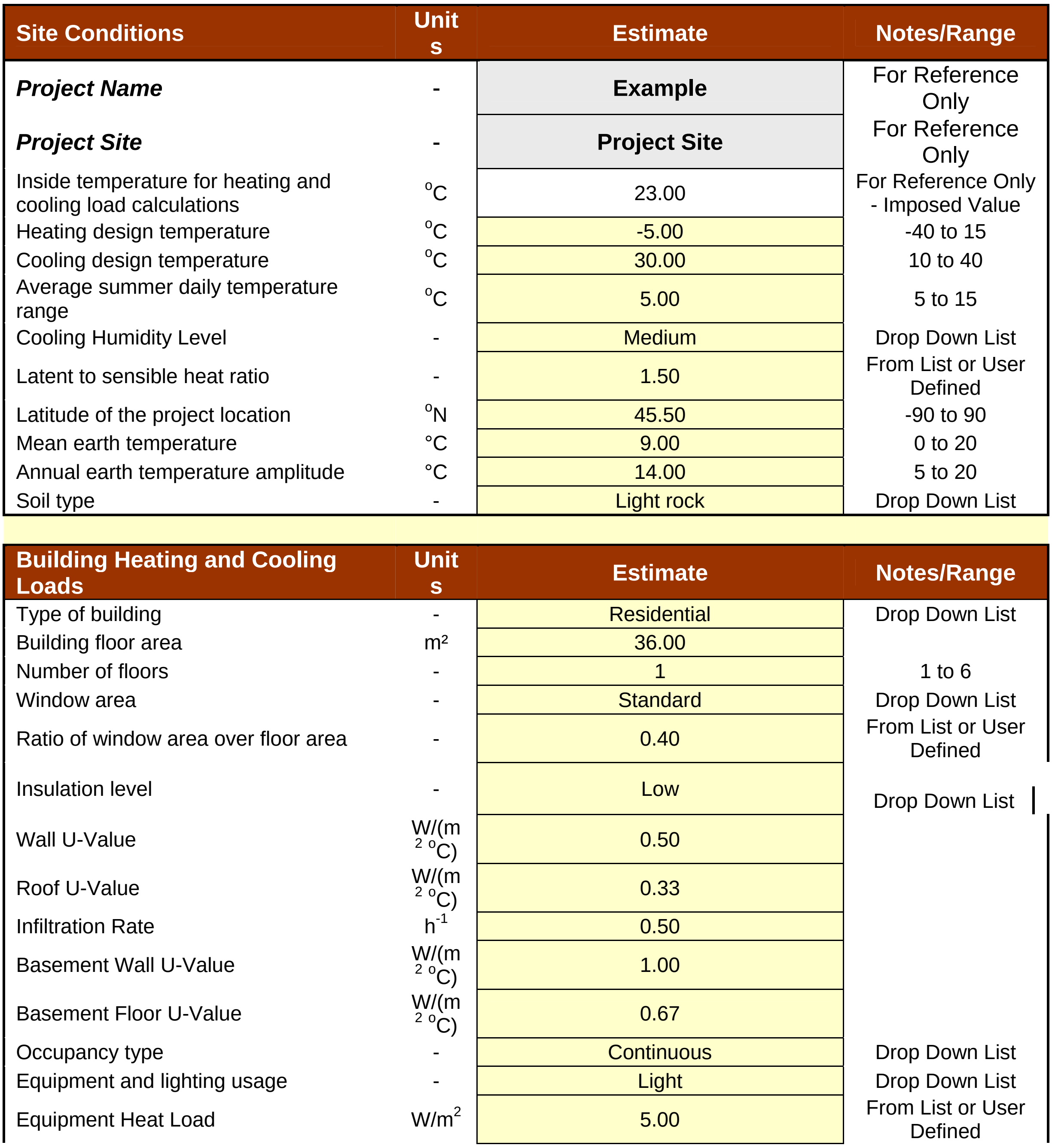
Based on the above theories the LowEx Annex of the IEA has developed a tool that analyses the exergy flows in building heating and cooling systems and provides guidance on the selection of appropriate systems to minimise the loss of exergy.

3. LowEx Pre-Design Analysis Tools

The Annex developed a spreadsheet tool for analysing the exergy change for all steps of the energy chain for heating and cooling buildings - from the primary energy source, via the building, to the sink (i.e. the ambient environment). The tool is based on calculations under steady state design conditions rather than annual energy use calculations.

The tool is built up from sub-systems for all the important steps in the energy chain and has a range of inputs that covers all components of the system including building construction and building services equipment. Heat losses in the different components are calculated, as well as the auxiliary electricity required for lighting, pumps and fans. On the primary energy side, the inputs are differentiated between fossil and renewable sources. The key input and output parameters are shown in the table below. The resulting exergy loss by conditioning the building is given as the result of the calculations.

Figure 1: Example of spreadsheet tool



Site Conditions	Units	Estimate	Notes/Range
Project Name	-	**Example**	For Reference Only
Project Site	-	**Project Site**	For Reference Only
Inside temperature for heating and cooling load calculations	°C	23.00	For Reference Only - Imposed Value
Heating design temperature	°C	-5.00	-40 to 15
Cooling design temperature	°C	30.00	10 to 40
Average summer daily temperature range	°C	5.00	5 to 15
Cooling Humidity Level	-	Medium	Drop Down List
Latent to sensible heat ratio	-	1.50	From List or User Defined
Latitude of the project location	°N	45.50	-90 to 90
Mean earth temperature	°C	9.00	0 to 20
Annual earth temperature amplitude	°C	14.00	5 to 20
Soil type	-	Light rock	Drop Down List

Building Heating and Cooling Loads	Units	Estimate	Notes/Range
Type of building	-	Residential	Drop Down List
Building floor area	m²	36.00	
Number of floors	-	1	1 to 6
Window area	-	Standard	Drop Down List
Ratio of window area over floor area	-	0.40	From List or User Defined
Insulation level	-	Low	Drop Down List
Wall U-Value	W/(m^2 °C)	0.50	
Roof U-Value	W/(m^2 °C)	0.33	
Infiltration Rate	h^{-1}	0.50	
Basement Wall U-Value	W/(m^2 °C)	1.00	
Basement Floor U-Value	W/(m^2 °C)	0.67	
Occupancy type	-	Continuous	Drop Down List
Equipment and lighting usage	-	Light	Drop Down List
Equipment Heat Load	W/m^2	5.00	From List or User Defined

Lighting Heat Load	W/m^2	5.00	From List or User Defined
Foundation type	-	Slab on grade	Drop Down List

System Description - Heating Application	**Units**	**Estimate**	**Notes/Range**
Generation System	-	LNG condensing boiler	Drop Down List
Storage System	-	No storage	Drop Down List
Distribution System			
Placement	-	Generator inside heated space	Drop Down List
Insulation level	-	High insulation	Drop Down List
Mean design temperature	-	High, T <= 80 °C	Drop Down List
Design temperature drop	-	Low	Drop Down List
Emission System	-	HT radiators (DIN 255: 55/45)	Drop Down List

System Description - Cooling Application	**Units**	**Estimate**	**Notes/Range**
Cooling Technology	-	Vapor Compression Chiller	Drop Down List
Estimated Coefficient Of Performance (COP)		***Assumes a second order polynomial function of ambient temperature***	
Constant parameter	-	4.00	From List or User Defined
First order parameter	-		User-Defined
Second order parameter	-		User-Defined
Electrical auxiliary power	W$_{elec}$/ kW$_{heat}$		From List or User-Defined
Cold Energy Source	-	Refrigerant	Drop Down List
Quality factor	-	0.70	From List or User-Defined
Storage System	-	No storage	Drop Down List
Distribution System			
Placement	-	No distribution	Drop Down List
Insulation level	-	No distribution	Drop Down List
Mean design temperature	-	No distribution	Drop Down List
Design temperature drop	-	No distribution	Drop Down List
Cooling Emission System	-	Heat Exchanger-Evaporator	Drop Down List
Efficiency	-	1.00	From list
Supply temperature	°C	-7.00	From list
Return temperature	°C	-5.00	From list
Electrical auxiliary power	W$_{elec}$/ kW$_{heat}$		From list
Maximum cooling load emission	W/m^2	100.00	From list

Building Design Heating and Cooling Loads	Units	**Estimate**	**Notes/Range**
Design heating load	kW	2.063	
	hp	2.800	Conversion Units
Design cooling load	kW	2.652	
	ton (cooling)	0.800	Conversion Units

Building Heating and Cooling Energy Demands on an Annual Basis	Units	**Estimate**	**Notes/Range**
Building heating energy demand	MWh	2.693	
	kWh	2,693.000	Conversion Units
Building cooling energy demand	MWh	4.893	
	kWh	4,893.000	Conversion Units

4. LowEx Systems for Buildings

Well designed buildings, that are highly insulated, have air-tight building envelopes, and adequate solar protection can still benefit from the use of low temperature heating and high temperature cooling systems. Applying low-exergy design principles to minimise the temperature difference between the heating and cooling source and the room conditions can result in maximum savings of high quality exergy sources. The table below provides a list of the LowEx technologies applicable for building heating and cooling systems and information on the typical heating and/or cooling temperature range.

LowEx Technology	Cooling temp. [^oC]	Heating temp. [^oC]
Surface heating and cooling		
Floor heating		
Embedded coils in slabs	10-15	25-30
Coils in surface layers	16-20	28-35
Hollow core slabs	15-18	25-30
Suspended floors	16-20	30-40
Phase Change in floor heating	-	25-50
Wall heating and cooling		
Pipes in surface layers (wet/half wet,mounted)	10-15	25-50
Pipes in surface layers (half-dry embedded)	10-15	25-50
Pipes in surface layers (wet, embedded)	10-15	25-50
Pipes in surface layers (dry systems)	10-15	25-50
Double walls	15-18	25-35
Dynamic Insulation		25-30
Capillary tubes	10-15	25-30
Ceiling cooling and heating		
Radiative panel	10-15	25-50
Cooling beams	10-15	25-50
Ceiling integrated system	10-15	25-50
Evaporative roof surfaces	15-20	-
Ceiling panel cooling by double-roofing with		
Local heaters		
Low temperature radiators/convectors	-	30-50
Radiators integrated in the interior design		
High Temperature Radiators	10-20	20-40
Base board heaters	-	80-130
Transparent insulation	-	40-95

LowEx Technology	Cooling temp. [^{o}C]	Heating temp. [^{o}C]
Air heating and cooling		
Air to air heat exchanger		
Sensible Only Heat Exchangers /		40-95
Counter flow air to air heat exchanger/	10-15	20-50
Total (Latent) Heat Exchangers / Regenerator		25-50
Altering Heat Exchangers		40-95
Water to air heat exchanger		
Supply air conditioning	-	40-90
Fan coil units	10-15	25-30
Steam / vapour to air heat exchanger		
Supply air conditioning		100-120
Other heat exchanger		
Supply air façade	-	20-100
Evaporative cooling		-
Passive system		
Atria		
Solar chimneys		
Generation / conversion of cold and heat		
Boilers		
Condensing boilers	-	
Pulsating gas boiler	-	50-80
Ground heat		
Ground coils	8-18	-
Bore hole	8-18	18-22
Slab on ground	14-22	16-22
Heat pumps		
Compressor heat pumps	10-15	25-50
Absorption heat pumps	10-15	-
Solar collectors		
Flat plate collectors	-	20-80
Evacuated tube collector	-	20-120
Unglazed flat-plate collector	-	20-80
Combined heat and power generation		
Cogeneration units with gas motor	-	80-90
Cogeneration units with microturbines	-	
Cogeneration units with Stirling motor	-	

Fuel cells		
Fuel cells	-	
Biological systems / Metabolic		
Bacteria	-	20-60
Animals	-	20-35
Plants	20-25	-
Thermal storage		
Seasonal storage		
Ground / rock storage	8-20	40-100
Earth duct storage	10-15	45-75
Hot water storage	-	35-95
Phase change thermal storage		
Short term storage		
Buffer storage tank	5-15	40-90
Domestic hot water tank	-	45-60
Distribution		
Transfer medium		
Air	-	
Water		
Thermera® heat carrier		
Glycol		
Community system		
District heating	-	65-115
District cooling	6-10	

A more complete description of all these systems; their benefits and risks, how they are specified, installed, and used is given in the LowEx Guidebook. Information on typical costs and the range of application in either residential or commercial buildings is also provided.

5. Example Buildings

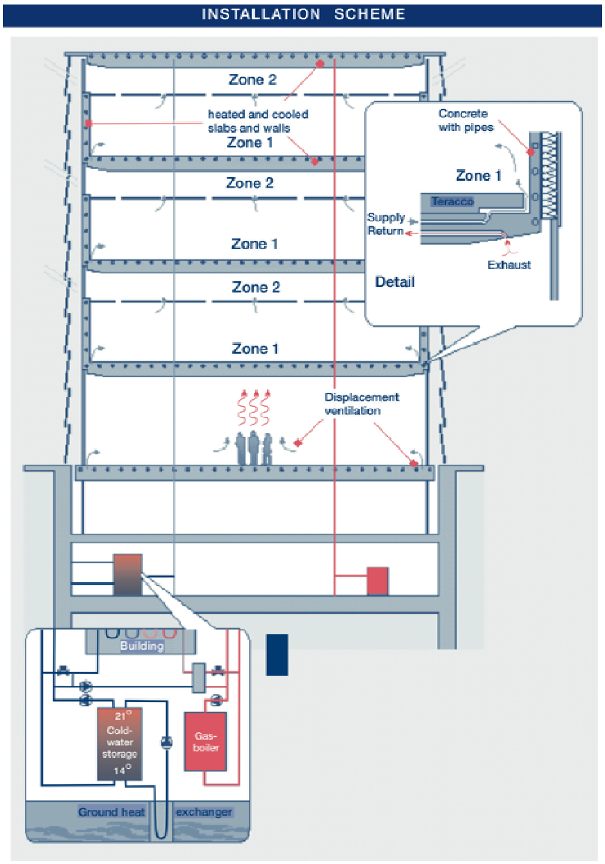
The Annex studied a total of 30 case study buildings including new and retrofit situations in both residential and commercial buildings. A wide range of LowEx technologies were studied including emission systems in floors, walls and ceilings and numerous combinations of other system types.

The full reports of the case studies including energy and exergy analysis, together with human comfort and occupant satisfaction reports are given in the Guidebook. Two example case studies are given here as an indication of the success of using LowEx systems in commercial and residential buildings respectively.

5.1. Bregenz - Art Museum

The four storey art museum building in Austria has a double skin external envelope with an outer openable glass wall. The space heating is provided with a hydronic system embedded in the building structure. The dynamic coupling of the concrete enables heating and cooling of the room climate to be carried out using the building mass. In addition, two-zone displacement ventilation provides a minimum of outside air that no longer has to perform the tasks of heating and cooling - its only function is that of ventilation for indoor air quality.

The energy and operation costs are more than 50 % lower in comparison with other fully air-conditioned art museums.



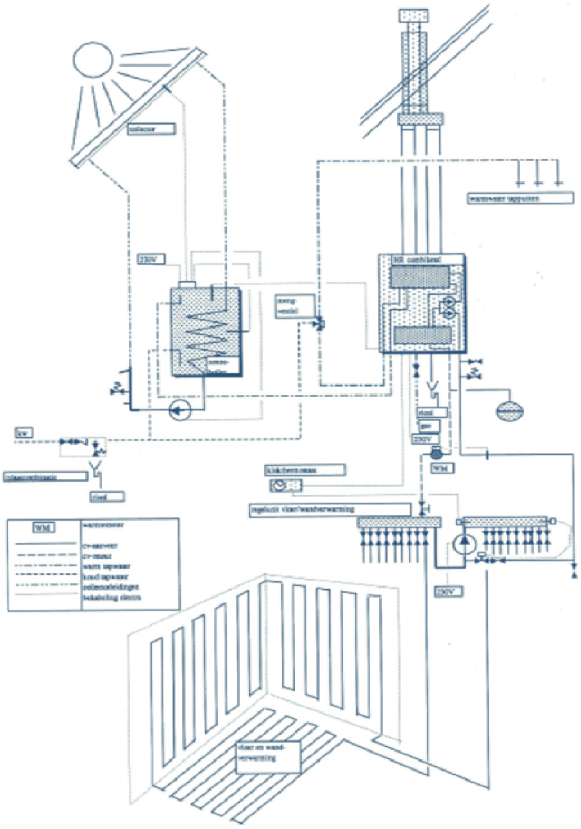
Museum in Bregenz with pipes embedded in walls and concrete slabs for heating and cooling. Details right show the displacement ventilation and the generation system for cooling and heating.

5.2. Ecological Dwellings “Amboise” Maastricht, the Netherlands

Amboise is a demonstration project for the Dutch Low Temperature heating programme. It contains 18 semi-detached houses, and is situated in the city of Maastricht. There are two orientations: 9 dwellings face south and 9 dwellings face north. The floor plan is identical. Having identical dwellings with different low temperature heating emission systems offers the opportunity to compare both systems in terms of energy, thermal comfort and the users’ experience.

The occupants’ response to the dwellings is generally favourable and those with the wall heating system would accept a lower air temperature than with the radiator system: confirming the assumption that the radiation effect of the wall heating can provide increased thermal comfort at lower air temperatures. The heat-up times were perfectly adequate for the occupants and temperatures were very stable in the wall-heated homes.

Installation Scheme – south facing dwelling



Every south-facing dwelling has a condensing gas boiler for space heating as well as for the domestic hot water (dhw) supply. A solar collector preheats the dhw. There is a wall heating system with a maximum flow temperature of 55°C and a return temperature of 40°C. The bathroom and the kitchen have additional floor heating. The houses are mechanically ventilated.

North-facing houses were supplied with radiators for heating (70/50°C). The dhw is heated by a heat pump together with a storage tank using exhaust air as the heat source.

International Energy Agency (IEA)
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The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has co-ordinated various research projects associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA co-ordinated research.

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