International Energy Agency

Technical Synthesis Report

Annex 36

Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures

Energy Conservation in Buildings and Community Systems

36

Technical Synthesis Report Annex 36

Retrofitting in Educational Buildings -
Energy Concept Adviser for Technical Retrofit Measures

Edited by Richard Barton

Annex 36 information based on the final reports of the project.
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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-four 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 Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation in Building and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation. The objectives of collaborative work within the ECBCS R&D programme are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

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 (ongoing projects are shown in **bold**):

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 Built Environments and Communities
Annex 50: Prefabricated Systems for Low Energy / High Comfort Building Renewal

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

Annex 36: Retrofitting in Educational Buildings – Energy Concept Adviser for Technical Retrofit Measures

This summary report concentrates on Annex 36: Retrofitting in Educational Buildings – Energy Concept Adviser for Technical Retrofit Measures.

In many IEA countries educational buildings such as kindergartens, schools, training centres and universities share many similar design, operation and maintenance features. Unfortunately they also often share the characteristic of high energy consumption resulting in the need to retrofit energy saving measures. Studies have shown these retrofit measures are not usually applied due to a lack of knowledge of both the amount of investment required and the efficiency of the potential energy saving measures. This can result in the wrong decisions being made and inappropriate energy saving measures being applied. The lack of knowledge is often compounded by the lack of assessment methods giving a quick, but accurate estimation of the levels of investment required before more detailed analysis is undertaken.

The development of an 'energy concept adviser' for use during the planning and implementation phases of a project would help decision makers not only to optimise the energy saving measures to be applied, but avoid exaggerated expectations. The adviser should be applicable throughout the entire project to ensure that the calculated energy savings and cost both meet expectations.

Following analysis of the various facets of energy efficiency in educational buildings a software tool (the Energy Concept Adviser) has been developed, providing advice on energy-efficient retrofit measures, for use by administrative decision makers.

The work was structured into **four subtasks**.

Subtask A was the selection and analysis of existing information on exemplar retrofit projects in educational buildings in the IEA member countries. The work mainly focused on requirements, guidelines, building types, technologies, benchmarks and decision criteria.

Subtask B was the identification of case studies in the IEA participating countries. The case studies included educational buildings, with innovative energy saving measures and advanced control systems. Measured performance data and user acceptance of environmental conditions formed part of the assessment of the case study buildings.

Subtask C was the development of software and methods of analysis. A range of design tools, in use, ranging from simple spreadsheets to advanced computer programs were assessed.

Subtask D was the development of documentation and its dissemination to potential users by means of newsletters and practice articles both in print and on the internet and does not form part of this report.

The countries participating in Annex 36 were Finland, France, Denmark, Germany, Greece, Italy, Norway, Poland, U.K., and U.S.A.. The Annex 36 Operating Agent was the Fraunhofer Institute for Building Physics (IBP), Stuttgart.

Scope

This report contains a summary of the work of Annex 36 the formal duration of which was from 1999 to 2003. The report is mainly based upon the principal documentation of Annex 36 listed under References.

Contents

1. Introduction

In order to improve the current practices of energy control the E.U. passed a directive on the Energy Performance of Buildings on the 4 January 2003. The directive will lead to increased co-ordination of legislation and building codes in European countries. It proposes a common methodology for calculating the integrated energy performance of buildings and the application of minimum standards on energy performance to new buildings and to certain existing buildings when they are renovated.

The education sector would benefit from such a calculation tool for use by decision makers when considering energy efficient improvements to educational buildings. Currently there is often a lack of understanding of what needs to be done and inappropriate energy efficiency choices can be made during the retrofit process.

The aim of Annex 36 is to develop such a tool for the education sector so that the energy saving potential of different measures can be fully appreciated and appropriate action taken during retrofit projects.

2. Subtask A: Selection and analysis of existing information

2.1 Introduction

Subtask A was separated into two activities in order to provide the required information on the state of the art of knowledge in the field of retrofitting in participating countries.

2.2 Building envelope

Improving the thermal properties of the existing building envelope is, in many cases, a logical step in order to reduce building energy consumption. As a consequence this is one of the most important strategies when considering retrofitting to a building. The main aspects of the envelope of a building with the potential for improvement through retrofitting are:

1 - Windows are the least insulating part of the thermal envelope with a heat loss coefficient, a U-value, typically 4-10 times higher than other thermal elements.

The heat loss coefficient of a window is significantly higher than that of other thermal envelope constructions, but at the same time windows allow solar energy to pass through into the building. These two properties of windows are named the U-value and g-value respectively and a balance is required between them. Other factors for determining the choice of window used include orientation, shading conditions, thermal mass of the building and internal heat load. Assessment and calculation, in terms of its energy characteristics, will be required to achieve the optimum choice of window.

Techniques currently used to reduce heat transmission through windows include:-

- Sealed glazed units: Two or more layers of glass are joined together in a single frame.
- Low emissivity coatings: Low E coatings reduce heat transmission in connection with radiation
- Gas fillings: Filling the space between the frames with a gas of lower thermal conductivity than air.
- Edge sealing: Less conductive edge seals are being used in the U.S.A. and Canada, but are less common in Europe due to cost.

Replacing wooden frames with frames manufactured from materials with a low maintenance factor has not always had the desired thermal effect. A commercially accessible frame construction that significantly improves the insulating properties of the window unit is not yet available.

Research and development into window design has concentrated on new super insulated glazing, improved insulation of frame construction, and increased g-value.

2 - High levels of insulation, with a minimum of thermal bridging and air leakage paths, are key components in improving the thermal performance of a building envelope. Without the right combination of these factors, simply adding more insulation may extenuate thermal discontinuities within the building envelope. To be cost effective the degree of retrofit should be carefully considered as, for example the law of diminishing returns applies to each successive layer of insulation simply added to the envelope of the building. A more expensive over-cladding system with integral windows may be more cost effective. The main factor to check when choosing a new insulating system is its suitability for the proposed application. Alternative insulation materials are now being used more frequently and examples of these are shown below in Table 1.

Products	Raw Materials	Product Types
Cellulose fibres	Paper granulate/cellulose fibres Borax (+boric acid) (Aluminium hydroxide	Granulate Soft boards Hard boards
Cork	Natural or expanded cork granulate from the cork oak	Granulate Hard boards
Fibre boards	Wood chips and wood waste (Aluminium sulphate)	Soft boards Hard boards
Wood concrete boards	Wood chip Cement/magnesite	Hard boards
Flax fibres	Flax fibres Ammonium phosphate (boric salt) Polyester fibres	Soft boards Rolls
Sheep's wool	Cleansed sheep's wool Boric salt, insecticides (Polyester fibres)	Soft boards Rolls
Coconut fibres	Coir fibres (from the coconut shell) Fire retardant	Soft boards Hard boards
Cotton	Cotton Boric salt	Soft boards Rolls
Polyester fibres	Synthetic (recycled) Polyester fibres	Soft boards

Table 1 List of raw materials for alternative insulation products and product types

3 - Post-insulating the exterior of the building, can if detailed correctly, reduce thermal bridges. Post-insulating the interior of the building can also be an effective thermal remedy, but must be detailed very carefully to avoid interstitial condensation and can affect the thermal response of the internal surfaces. Another factor to take into account when considering retrofitting an internal post-insulation system is the possible disruption to activities within the school.

4 - Solar walls are an alternative to traditional external post insulation of walls with a southerly orientation where the solar radiation on the walls is used for heating the rooms behind and/or reducing ventilation losses.

5 - Post insulation of roofs can be an economical way of placing additional insulation in one of the main elements of the building. Additional floor insulation can be applied in a similar way to walls, but attention is required to the floor/wall interface.

6 - When looking at a comprehensive retrofit programme, including windows and doors and a new heating and ventilation system the use of **an overcladding system** is often an effective choice to improve the thermal performance of the external envelope.

7 - Doors: Heat loss through doors can be prevented by draught sealing and also by thermal insulation. Main entrances to schools should always be lobbied to prevent large heat losses due to the frequent movement of people in and out of the building. It may be difficult to provide lobbies for other doors, due to space restrictions. Revolving doors can be fitted in larger institutions, but secondary access for disabled persons will be required. Door closers can be a low cost energy saving option, but the force required to open them might create problems for small children and the disabled.

2.3 Heating systems

Improving the heating system can play a crucial role in the overall benefits accruing from a retrofit programme in educational buildings. As shown in Table 2, a number of heating systems are suitable for use in educational buildings.

	Transfer system				Distrib. system	Central generation system				Central ventilation system		Domestic hot water system			primary efficiency factors	end efficiency factors
Nr.	Heating appliance 90/70°C	Heating appliance 70/55°C	Heating appliance 55/45°C	Floor heating 35/28°C	Horizontal distribution	High-temp. boiler	Low-temp. boiler	Cond. boiler	District heating	Natural ventilation	Outside/ discharge air WRG: 80%	non system	Central system	Central system, bivalent with solar energy	2500m² 7500m² 30000m²; 40 / 120 / 240	2500m² 7500m² 30000m²; 40 / 120 / 240
0	O				O	O				O		O			1,56/1,33/1,29	1,40/1,20/1,17
1		O			O		O			O		O			1,43/1,26/1,22	1,28/1,14/1,11
2			O		O			O		O		O			1,32/1,17/1,14	1,18/1,06/1,04
3				O	O			O		O		O			1,25/1,13/1,10	1,11/1,02/1,00
4		O			O		O				O	O			1,59/1,31/1,25	1,28/1,14/1,11
5			O		O			O			O	O			1,27/1,16/1,13	0,99/1,00/1,00
6				O	O			O			O	O			1,22/1,12/1,10	0,93/0,96/0,97
7			O		O				HKW f	O		O			1,44/1,35/1,33	1,10/1,04/1,02
8			O		O				KWK f	O		O			0,79/0,73/0,72	1,10/1,04/1,02

Table 2. Examples of both ventilation and heating systems suitable for educational buildings

Heating systems are evaluated by comparing benefit and expenditure as it is done for other technical systems. The functioning of an effective heating system comprises the suitable selection, dimensioning and arrangement of heating appliances in any particular space, known as the 'room system'.

For the purpose of providing default systems in educational buildings the Energy Concept Adviser distinguishes five historical time periods. Typical systems are described for each of these periods. Estimated values are given for their efficiency factors as a function of the building type characterised by the heat demand as shown in Figure 1.

Domestic hot water used mainly for cleaning purposes makes use of two resources, water and energy and therefore any retrofitting strategy should include a proper DHW system installation.

When considering heating systems it is necessary to differentiate between conventional energy and renewable energy sources. Conventional, traditional, energy sources are generated from fossil fuels, i.e. oil, gas or coal. Renewable energy is usually associated with sustainable resources, but can also include heat transfer and the combustion of renewable materials.

An efficient control system in a building and HVAC plant is necessary for achieving an energy efficient building. In general, in any building, there is a strong interaction between the energy producing plant and control system. In buildings

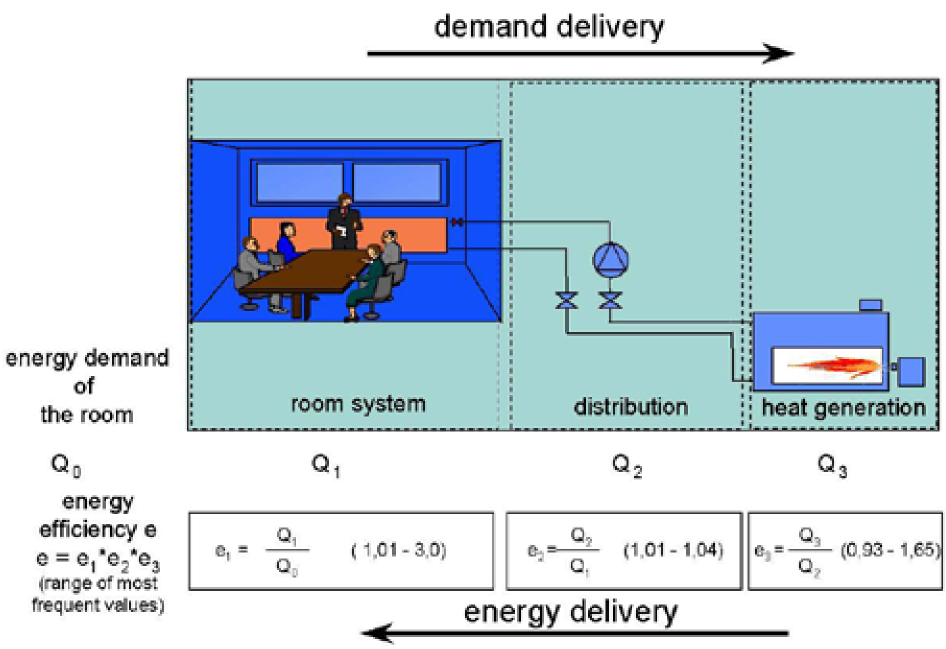


Figure 1. Demand and energy delivery

with active components, the envelope is included and it is important that the design team, architects, HVAC engineers and control engineers, work together to optimise the control strategy. Control systems range in complexity from thermostatic radiator valves to ‘intelligent buildings’ where all the systems are managed for optimum efficiency.

Building Energy Management Systems (BEMS) usually consist of one or more self contained computer based ‘outstations’ which not only control energy consuming plant and equipment, but also monitor and report on the performance of these items. Outstations can be linked together and can communicate not only with one another, but also with a central operator’s terminal.

Advanced control strategies can control and optimise several parameters and the most advanced of these can be self-learning. Because advanced control strategies are very complex and time consuming to commission, currently they have not been widely used in the buildings.

2.4 Ventilation systems

One of the most important factors when considering the modernisation of educational buildings is applying retrofit measures, resulting in low energy consumption, without having a negative impact on indoor air quality. This became an important consideration at an early stage in the work of Annex 36. As shown in Table 2, a number of ventilation systems are suitable for use in educational buildings.

Although indoor air contains about 3000 different elements and compounds, carbon dioxide is the most important factor influencing air quality. The flow rate of air supplied to a space will vary with the use of the space and the need to remove impurities and each of the participating countries have building codes which determine the air change rate, the positioning of air supply and exhaust units and indoor air quality.

The use of mechanical ventilation has increased since the middle of the last century. Latterly, over the last fifteen years, natural ventilation has been tried out again and has also been combined with mechanical ventilation in hybrid systems.

The aim of air conditioning is to create, on demand, an acceptable indoor climate, optimising temperature, indoor air quality and moisture. Ventilation is a significant energy consumer in a building. It therefore follows that the large savings and reasonable payback times can be gained from improving a building’s ventilation system.

Selecting an air handling system is an important and complex process in the retrofitting of an educational building, because the energy efficiency of the system can be affected at many stages during the selection process. The most important decisions, however, will be made at the design stage of this selection process.

Natural ventilation is the most common ventilation system in older building stock relying on the operation of opening components, for example windows, in the external envelope of the building.

When renovation is being considered it is likely that choices will have to made between mechanical and natural ventilation. It is possible to combine the best features of each system to create a hybrid ventilation strategy known as ‘boosted natural ventilation’.

Mechanical ventilation is generally found in larger, multi-storey educational buildings where it can provide the required air change and air flow in each room. It is divided into two main types :

- mechanical air supply and exhaust ;
- mechanical ventilation with heat recovery.

The latter can provide optimal air quality and energy efficiency if properly designed, operated, controlled and maintained.

A significant part of the heat content of exhaust air can be recovered by the use of heat exchangers in the ventilating unit. In terms of retrofitting existing educational buildings it should be borne in mind that the heat recovery unit will require additional plant area.

Hybrid ventilation, combining natural and mechanical ventilation, is a relatively new technology with possible retrofit applications in many existing educational buildings. Currently, with careful design, it can produce good indoor air quality (IAQ) and thermal comfort, but is not as effective in achieving outstanding energy performance.

A retrofit project optimising the ventilation control system in an educational building, in terms of both IAQ and energy efficiency requires continuous monitoring of the system by means of a control and information system.

2.5 Solar control and cooling systems

Ideal shading devices should reduce solar radiation whilst admitting diffuse radiation as daylight and allowing an outside view. This selective mode of radiation control is difficult to attain, because all shading devices reduce daylight availability. The approaches to control sunlight and prevent glare can be classified into the following:

- Selection of appropriate orientation, tilt and size of the openings
- Obstruction of solar radiation by use of envelope appendices or shading devices
- Selection of internal or external shading devices according to their solar optical properties (external is optimal)

Shading systems and glare protection: When retrofitting a building, designers and decision makers should be aware that the performance of a shading assembly might be different from that established in standard tests. Parameters such as differences in fixed solar incidence or direct solar radiation may vary from those given by the manufacturer, see Table 3.

Type of Shading Device	**Shading Coefficient**	**Daylight Transmittance**
Screens (outside position) (ref:Hexcel Lyverscreen Satin 525)	0.14 grey 0.20 yellow 0.26 white	5% grey 18% yellow 25% white
Screens (inside position) (ref: Hexcel Lyverscreen Satin 525)	0.48 grey 0.36 yellow 0.37 white	5% grey 18% yellow 25% white
Reflective film inside (ref: DTI reflective with a 4 mm clear glass)	0.26 argent 20 0.42 argent 35	20% argent 20 35% argent 35
Ionised film inside (ref: DTI Sputter with a 4 mm clear glass)	0.67 inox 50 0.41 inox 75 0.46 bronze 50 0.26 bronze 75 0.49 XH50	50% inox 50 23% inox 75 45% bronze 50 22% bronze 75 45% XH50
Sealed blinds (for a chosen blades tilt)	depends on sun elevation, no data	No data

Table 3. Examples of shading coefficient given by manufactures for some shading devices

Cooling systems: There are five categories of cooling system:

- Natural cooling is effective in mild and coastal climates. Systems are simple to install, with little maintenance and a simple payback period of 8 to 10 years.
- Evaporative cooling is effective in warm and dry climates where higher indoor temperatures are acceptable during hot periods. Installation costs are more than a typical A/C system, but the operating cost is significantly less.
- Direct expansion
- Chilled water systems can be effective in larger educational buildings where long service, i.e. duct, runs become unmanageable. Chilled water is piped around the building and connected to air handling units.
- Geo-exchange utilises the ground around an educational facility to serve as a heat and/or cooling source. The cost of these systems is normally 10-15% more than a conventional system, but will result in a 20-50% reduction in energy costs and a 30% reduction in maintenance costs. The payback for a typical geo-exchange system ranges from 5 to 10 years.

When considering any of these methods for retrofitting in educational buildings it is necessary to look at appropriate climatic zones for use, cost effectiveness, benefits and operation and maintenance.

Air conditioning installation in the retrofit of educational facilities is dependent on many elements including use of space, size of facility and climate. Various air conditioning options are available and each has advantages and disadvantages when used in educational buildings.

Today a large variety of glazing or selective coatings is available from manufacturers and can be used to protect internal spaces from excessive light and reduce brightness, glare and solar radiation through glazing. Some solar control technologies are still under development and so may be difficult to install and justify economically for the retrofit of educational buildings.

An important advantage of fixed shading devices (examples are shown in Table 4), is that they are passive. They do, however, change the aesthetic character of facades and must be robust enough to resist snow loading and strong winds. Orientation, inclination and geometry of fixed shading devices must also be carefully analysed.

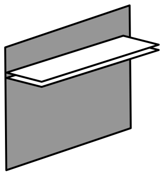
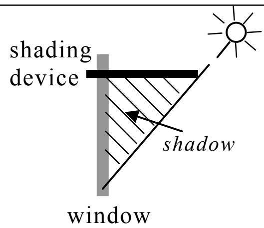
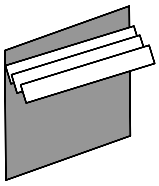
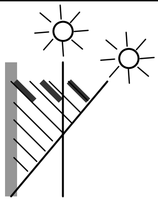
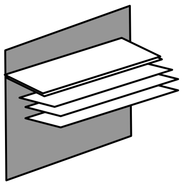
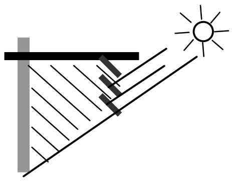
		Horizontal overhang is more efficient around southern orientation.
		Louvers parallel to the wall allow air to circulate. Slanted louvers offer better protection.
		Where protection is needed for low sun angles, louvers hung from horizontal overhang are more efficient.

Table 4. Examples of fixed shading devices and their protection against direct sunlight

Movable shading control systems: Although more responsive than fixed shading devices responsive systems can present installation and maintenance problems. A combination of movable outdoor shading devices and indoor light blinds offer the best opportunities to control solar gains throughout the year.

2.6 Lighting and electrical appliances

Learning and teaching both rely on good lighting of indoor spaces. In existing educational buildings that are in need of retrofitting it is not sufficient to simply replace old lighting equipment. Innovative lighting designs are also needed to meet new requirements and to reduce energy consumption.

Natural lighting or daylighting uses natural sunlight to supplement or replace artificial light. Although it is difficult to achieve when retrofitting buildings it should be considered when, for example, a school undergoes significant remodelling or when new structures are added.

Direct sunlight is variable and for this reason it is excluded for design purposes and window sizing. Instead an overcast sky with a specified luminance distribution is chosen. The final window design will be a compromise between the requirements for a view, avoidance of glare and an even spread of daylight indoors.

As in daylighting there are many options when designing electric lighting. The areas that need to be considered are the type of installation, the luminaire, the lamps and the controls. Apart from the need to look at best efficacy in the choice of lamps, energy savings can be obtained through task lighting, instead of general lighting and smart control of lighting, and careful design of the overall room.

A large variety of lamps and luminaries can be used from very low cost to more expensive, but very efficient equipment. The most energy efficient solution may not always provide the best visual amenity. The use of task lighting or accent lighting can be an effective alternative.

A comparison of efficacy values, the lumens per Watt of electricity, can give a good indication of ways of upgrading the energy performance of an obsolescent lighting system. The payback periods for each type of lamp vary depending on the hours of use and daylight availability of an educational building.

Table 5 provides an overview of the qualitative performance of a range of luminaire types.

Daylighting technologies: A good daylighting strategy provides adequate lighting levels and a visually attractive environment. When retrofitting for daylighting, many key design features, for example the size of windows, cannot be changed while new daylighting systems can be applied easily. It should be borne in mind, however, that daylighting systems require the integration of many design aspects.

Control systems: Well planned lighting controls can save energy by making good use of available daylight and ensuring that electric lights are switched off when a space is unoccupied. There are a wide range of automatic lighting control systems available, some of which are complex and too expensive for retrofit in typical educational buildings.

2.7 Management

Improving the energy efficiency of equipment and systems requires significant resources to either retrofit or replace, whilst improvement in the management of energy systems and their use requires little or no resources. A further benefit of using low/ no cost energy efficient measures is that there is no need for new equipment to be installed which can be time consuming and disruptive within

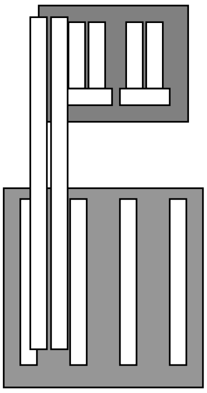
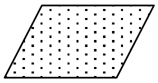
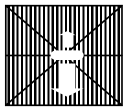
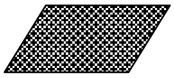
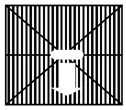
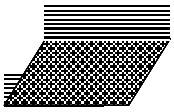
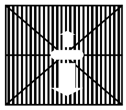
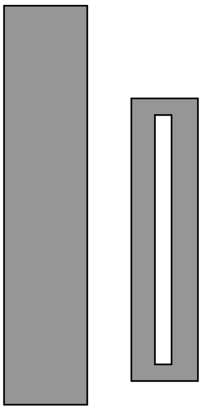
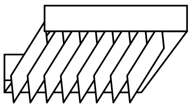
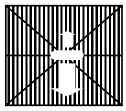
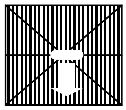
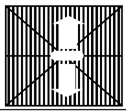
Luminaire type		Distribution/mounting	Performance
	Diffuser 	Semi-direct 	Good utilisation factor for large high reflectance rooms (LHR) Risk of glare for large low reflectance rooms (LLR).
	Prismatic 	Direct 	Middle utilisation factor even for LHR rooms Little risk of glare for LLR rooms.
Modular	Prismatic controller 	Semi-direct 	Good utilisation factor for LHR rooms Little risk of glare for LLR rooms.
	Transverse louver 	Semi-direct 	Middle utilisation factor even for LHR rooms Little risk of glare even for LLR rooms.
	Low brightness reflector with transverse louver	Direct 	Good utilisation factor for LHR rooms No risk of glare even for LLR rooms.
	Direct/indirect 	Direct – Indirect 	Middle utilisation factor for LHR rooms No risk of glare even for LLR rooms.

Table 5. Range of luminaire types

an educational facility. Management strategies when properly implemented can reduce energy use and costs with minimal expenditure. Most low cost/no cost items when implemented can reduce energy usage from 10-15%.

Auditing entails making an inventory of the energy systems and equipment in an educational establishment and benchmarking energy use, and is further discussed under Subtask C.

Commissioning addresses the system performance as designed and constructed. Re-commissioning should be undertaken periodically to insure that the performance of equipment and systems is maintained at design levels. Further work has been undertaken on commissioning in Annex 40.

Education and training of the users, occupants and maintenance staff is essential to insure proper use and levels of maintenance of the energy systems in the facility.

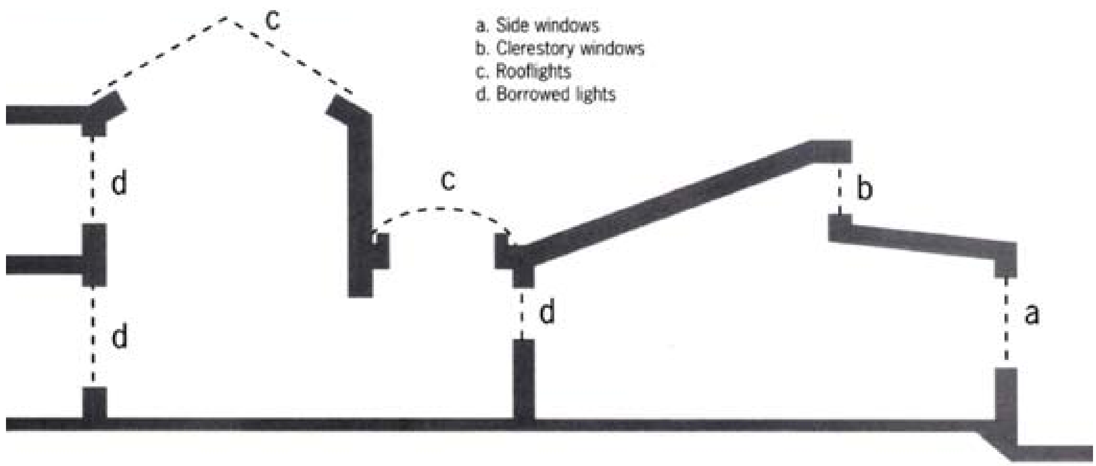


Fig 2. Windows provide a considerable benefit to school buildings: consider skylight, sunlight, views out and other related matters

Non-investment measures like scheduled maintenance and preventative maintenance reduces energy costs and usage.

3. Subtask A: State of the art overview: questionnaire evaluations

Following a review of the current retrofitting measures available in the participating countries, the second part of Subtask A dealt with the collection of information, through the use of questionnaires, on a number of topics related to energy efficiency and retrofit projects in existing educational buildings.

3.1 Evaluation of the questionnaire on the energy consumption of educational buildings

All ten participating countries provided input into the questionnaire. The questions on energy demand were divided into educational buildings as a whole, universities, schools and nursery schools. The responses made to the questionnaires suggest the following:

- The weather data from participating countries was found not to be comparable.
- The range of heating energy consumption is very broad for all types of educational building and in all countries.
- Electric power consumption needed for lighting, equipment and HVAC systems for all educational buildings differs between participating countries and is highest for Norway where hydro electric power is used for heating as

shown in Figure 3.

- The ratio of air conditioned buildings ranged from 1% in Italy to 50% in Finland and the USA.

It was concluded that the climatic influence on the energy consumption, both heating and electricity (including cooling), is significant. In some countries the use of mechanical ventilating or cooling systems results in significantly higher electrical power consumption.

The broad range of heating energy consumption values in each country shows a common need for retrofit. Since some countries also have other intentions, when retrofitting an educational building, besides reducing the energy demand e.g. improving the indoor air quality, the targets for the retrofit in Annex 36 should vary with each country and any existing special problems.

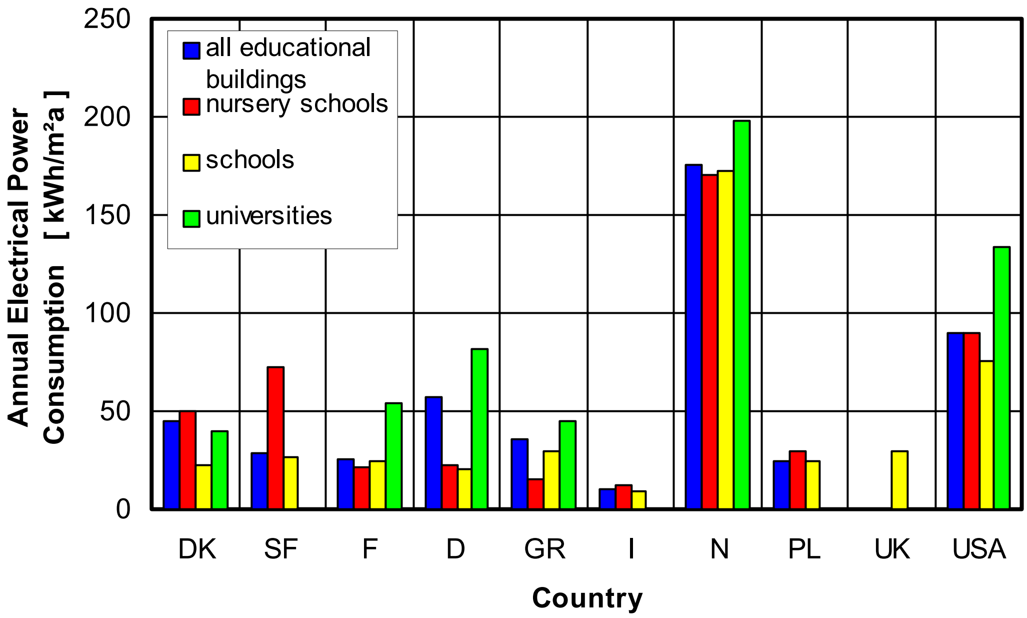


Fig 3. Average electrical power consumption for all building types and countries

3.2 Review of national requirements and design guidelines for energy and environmental issues in the refurbishment of educational buildings

Information from the participating countries was obtained through a series of questions and tables asking for basic information on national requirements and guidelines. There are a large number of requirements and guidance documents covering works to educational buildings in all ten participating countries.

3.3 Evaluation of the questionnaire on economic calculation procedures

Three factors were identified as important when choosing from a range of specific retrofitting measures: They were

- Basic economic information: Methods of economic analysis, existing incentives for retrofitting, rate of return, rate of inflation, rate of depletion.
- Investment cost factors: Average cost of thermal insulation, windows, technical equipment.
- Operating cost factors: Average cost of primary energy in terms of natural gas, liquid gas, oil, electricity, district heating.

It was concluded from the responses to the questionnaires that the economic efficiency of retrofitting for educational buildings is one of the most important factors influencing the decision makers, including school managers and local authority members, in choosing specific measures. In order to achieve comparable results, for economic efficiency calculations, common methods have to be employed.

Considering the experience of different countries, see Table 6, the net present value (NPV) calculation seems to be the most effective method for creating the economic criterion for the quality of retrofitting process.

	Austria	Denmark	Finland	France	Germany	UK	USA	Poland
NPV	no	yes	yes	yes	yes	yes	no	yes
IRR	no	no	no	yes	yes	sometimes	yes	yes
OTHER	Life Cycle Cost - ONORM 7140	Simple Payback	Target Price Method	Simple payback time: Inv/y. savings	Additional Costs to Benefit Ratio		Life Cycle Costing	Life Cycle Costing

Table 6. The methods of calculating economic efficiency

The national economic factors, rate of discount, primary energy cost, investment cost coefficients, etc. may significantly vary from country to country. This can result in the same retrofitting project having a significantly different rate of profit in different countries.

When comparing different retrofitting projects, decision makers have to be aware of the influence of national economic factors on the final result of NVP calculations.

Economic factors were also considered as part of Subtask C.

3.4 Evaluation of the questionnaire on short-term energy monitoring procedures

The evaluation of the completed questionnaires showed that in the participating countries, no short-term energy monitoring tests, for example fan pressurisation tests, thermography etc., are well established.

The completed questionnaires showed a general concurrence between the kind of information provided by short-term energy monitoring tests, for example fan pressurisation tests, and the information respondents would wish to obtain from these types of performance / validation tests. Existing methods can also be applied in cost, and time frames were also acceptable to respondents.

Within the scope of Annex 36 this cost effective monitoring approach could provide an inexpensive and useful insight into the effectiveness of a range of retrofit projects. Short-term monitoring could be promoted to decision makers and designers as an inexpensive way of guaranteeing the retrofit measures to be employed. Its implementation through the use of design or concept advice software would also receive a favourable reception. On the basis of this, suitable methods could be selected and improved or further developed.

The methodology could be integrated as a user-friendly stand-alone software package, integrated into the concept adviser software as part of a building assessment procedure, for validation of the design (retrofit) process. The algorithms, methods, test set-up, test protocol, evaluation and application examples could be documented. The retrofit measures in the case study buildings could be validated and there would be an option of incorporating monitored data into the database.

3.5 Evaluation of the questionnaire on calculation tools

The purpose of this questionnaire was to clarify the ‘state-of-art’ of calculation tools within the participating countries.

According to the questionnaire, different calculation tools are most commonly utilized in Sweden, UK, and Finland. This might be due to a longer period of use and therefore more positive attitudes towards these tools in these countries.

Lists of the most important and commonly used calculation tools varied widely in different organizations and participating countries. Traditional TRNSYS, DOE-2, and ESP-r are used in many countries, but there are considerable numbers of other existing and new tools

Most of the participating countries have developed or are involved in the development of calculation tools. For this reason there is awareness about the practical application of calculation methods as research tools.

Figure 4 shows frequencies of utilizing calculation tools among different professions in different participating countries. Based on this questionnaire, it seems there are no suitable calculation tools available especially for architects.

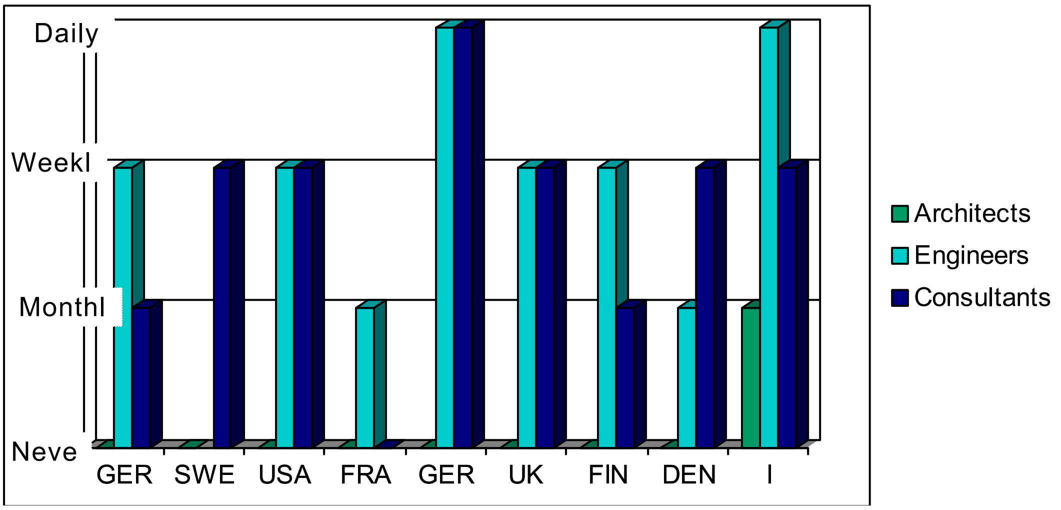


Fig 4. Frequencies of utilizing calculation tools amongst different professions in the participating countries

Attitudes among client organisations seem to be quite positive towards calculation tools. This attitude, however, depends to some extent on the client organisations themselves.

The existence of a public certification system, noticeable development projects and administration of calculation tools varies between the participating countries. Certification systems exist in Germany and U.K. and there are development projects going on in all participating countries.

Answers to the calculation tools questionnaire received from the participating countries indicate the importance of calculation methods as valuable tools in building research work. There were several parallel development projects going on and a large number of different simulation tools are being used. The results of the questionnaire confirmed the need for better international co-ordination.

4.0 Subtask B: Case studies

As part of Annex 36 one of the sub-tasks identified was to collect a group of energy retrofit projects carried through in different countries and under different constraints.

4.1 Introduction

A group of 25 case studies of energy efficient renovations comprising 17 schools, 7 universities and 1 day care centre form the basis of Subtask B. A variety of climates, building types and energy conservation principles and technologies were represented in these case studies.

4.2 Typologies

Educational buildings cover a wide range of learning activities and schools can generally fit one of these categories:

The village school (19th century)
The multi-storey town or urban school (19th century)
The single or two storey central corridor school (20th century)
The side corridor school (late 19th century to mid 20th century)
The pavilion school (early 20th century)
The main hall school (1930s, Central Europe)
The comb-shaped school (1950s)
The open-plan school (1960s)
The cluster school (1970s until 1990s in Denmark)

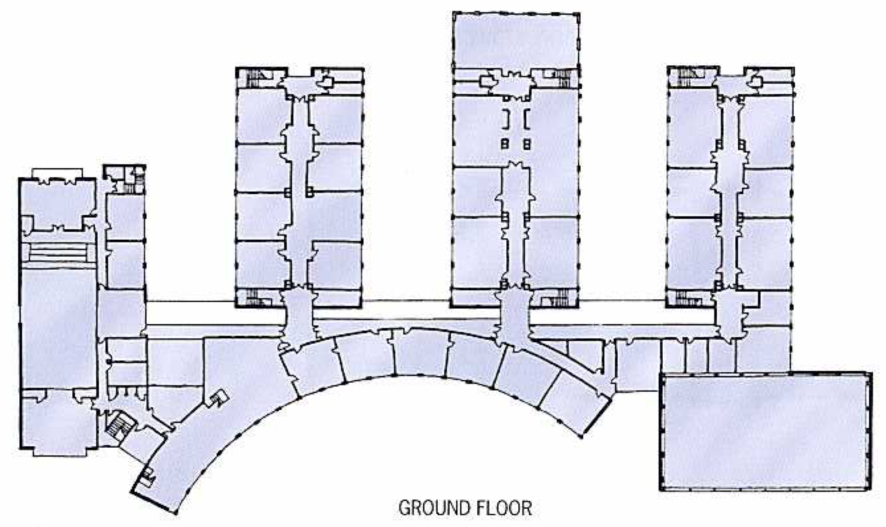


Fig 5. Ground floor plan of a two storey central corridor school

Most university buildings fall into one of the following categories:

The college-type university building (middle ages)
The early university building (until 1850)
The palace university building (19th century)
The functional university building (20th century)
The mega structure university building (1960s-1980s)
The eco-university building (1990s onwards)
The science park university building (1990s onwards)
The conversion of industrial buildings (1970s onwards)

The schools chosen as case studies have been categorised according to the predefined typology framework listed above. Most of the projects are from the periods 1950-1970 and after 1970. One of the projects chosen was built before 1910 and four projects are from between 1910-1950. Most of the projects included as case studies are 'central corridor' or 'side corridor' types. The rest of the school projects are equally divided between the 'central school', the 'comb-shaped school', the 'open-plan school' and the 'cluster' school'.

University buildings: All except one of the university case study buildings belong to the 'functional' and to the 'mega-structure' type. Three projects are engineering faculties, two case studies are liberal arts facilities, one case study includes natural-science and medical facilities and one project includes a central facility.

Day care centre: A Finnish day care centre was selected to represent this type of building.

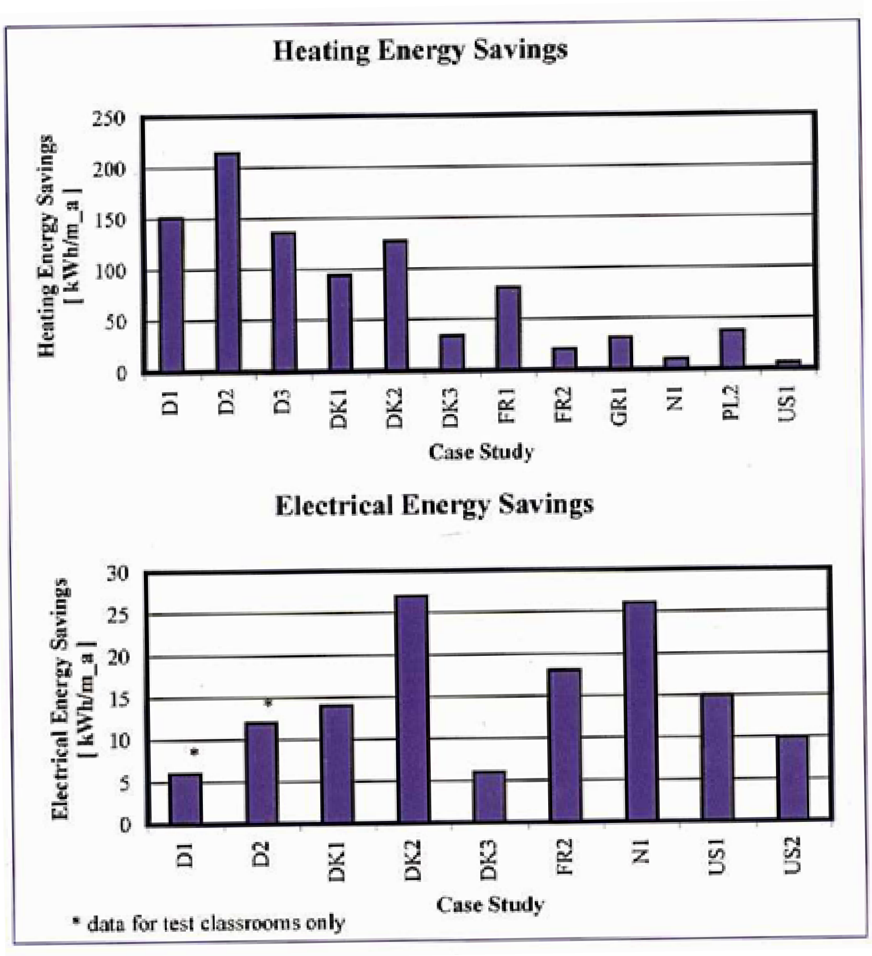
4.3 Technologies

The energy retrofit technologies of the projects have been categorised in Table 7 to present an overview of their distribution. The traditional energy conservation technologies that have been employed most often are weather-stripping, added insulation, low-e windows, new efficient artificial lighting (and control thereof), renewal and control of the heating system and installation of a building energy management system (BEMS). More recent concepts such as natural (hybrid) ventilation and demand and controlled ventilation have been implemented in more than 30% of the projects. In approximately 25% of the projects daylighting principles and improved control of the artificial lighting systems have been implemented. The rest of the technologies, preheating of the ventilation air, innovative insulation systems, passive solar design, atria, a number of passive cooling technologies, active solar, PV and other principles, have only been implemented in a few projects.

The technologies traditionally accepted as economically viable are the most dominant in the case studies. The newer, less established technologies, demonstrated in the case studies, add important knowledge with respect to the design, construction and control of these technologies.

4.4 Energy saved

The energy savings reported are, for some projects, quite considerable. For example heating energy consumption for the German and Danish projects before retrofit were 200-280 kWh/m2.year and after the retrofit these were reduced to 50-90 kWh/m2.year. The savings percentages of the different projects range from 75% heating and 100% electricity to 0% heating and 15% electricity. A number of projects (primarily from Denmark and Germany) report quite large savings 55-75% heating and 30-40% electricity. At the other end of the scale the projects in UK and the US report rather modest savings of 8-20% heating and around 15% electricity savings. Examples of these savings are shown in Tables 7 and 8.



Tables 7 & 8. Heating and electrical savings amongst a sample of the case studies

The projects showing higher savings are generally demonstration projects, in which several energy saving technologies have been implemented together, where relatively long payback times have been less critical. In contrast, the projects showing relatively smaller savings are projects where fewer technologies have been implemented and more emphasis has been on a cost effective approach. This has resulted in fairly low payback times of the order of 5 years. In some projects the main emphasis has been on the improvement of indoor comfort, air quality or lighting comfort and the energy savings have been considered as a positive side effect.

4.5 Case study

It was decided early on to collect the case studies in two rounds, existing and new case studies. Figure 6 is a list of all the case studies organised by country which can be cross referenced with the information in Table 9.

Of the 25 case studies one, Egebjerg School, Ballerup, Denmark, has been selected to provide an example of the implementation of technology as part of the total retrofit concept.

The project illustrates the implementation of ventilation technologies as part of the total retrofit concept. Egebjerg School, built in the seventies in the municipality of Ballerup (see Figure 7) is an open plan school. The overall aim of the project was to demonstrate that an energy efficient and ecological refurbishment of a common school of the seventies, could be carried through to obtain a healthy indoor climate at a reasonable cost. Heating and ventilation technology was combined with carefully chosen materials, natural ventilation and active solar heating.

The project at Egebjerg School concerned a selected part of the school, areas C1 and C2, containing classrooms, connecting corridors and two double height common area rooms. The project was completed in 1998. The retrofit concept focused on replacing the existing mechanical ventilation system with a natural ventilation system and reducing heat losses through reduced U-values in roof, facades and windows. A completely new sloping roof construction replaced the original flat roof. An average of 20 cm of mineral wool was added, giving 30 cm thick insulation overall. All facades were completely renewed including 20 cm of mineral wool insulation. All the windows in the selected sections of the school were replaced by new low energy windows with a U-value of 1.7 $W/m^2.K$.

A completely new natural ventilation system was designed. Fresh air is taken in through air ducts to a crawl space below the classrooms. From the crawl space, the air is led into each classroom behind convector radiators, which have been

A total of25 case studies have been reported: 5 from Germany (D) and the UK, 3 from Denmark (DK) and the US, 2 from Finland (SF), France (FR), Greece (GR) and Poland (PL) and 1 from Norway (N). The projects are listed below ordered country by country.			
D1	Exemplary Retrofitting of a School in Stuttgart (EROS)	GR1	Chemical Engineering Building, NTUA, Athens
D2	Bertolt-Brecht-School in Dresden	GR2	University of Ioannina
D3	Paul-Robeson-School in Leipzig		
D4	University of Stuttgart	N1	Kampen School
D5	University of Ulm		
		PL1	Secondary School in Swarzedz
DK1	Egebjerg School, Ballerup	PL2	Poznan University of Technology
DK2	Enghojskolen, Hvidovre		
DK3	Vridsloselille School, Albertslund	UK1	William Parker Community Secondary School
		UK2	Hadley Junior School
SF1	Elementary School of Oulujoki	UK3	Grove House Refurbishment
SF2	Vihaistenkari Day Care Centre	UK4	George Tomlinson School, Bolton, Lancashire
		UK5	Ketley Town Junior School
FR1	Louise LABE Secondary School		
FR2	GAMBETTA Professional High School	US1	Wausau West High School, Wisconsin
		US2	Akard Elem. School, Sullivan County, Tennessee
		US3	University of New Hampshire

Figure 6. List of case studies

designed to further preheat the air. Air leaves the classroom through corridors to the double height common assembly room, at the roof of which a combined stack effect, wind and solar chimney is placed. The chimney is designed to work by a combination of wind pressure and ordinary stack effect. Two separate chambers are heated as solar air collectors and are opened when the temperature increases to such a degree that a considerable driving force is established. This feature is primarily designed for summer operation. A fan is located in the crawl space to generate a slight over- pressure in case the natural driving forces are too weak to generate the necessary ventilation. A type of solar air collector called a “Canadian Solar Wall” is installed on the south facade of the double-height building. From the collector, air is taken into the crawl space instead of from the earth ducts, whenever it is preheated to a higher temperature.

Energy technologies by case study	D 1	D 2	D 3	D 4	D 5	DK 1	DK 2	DK 3	FR 1	FR 2	GR 1	GR 2	N 1	PL 1	PL 2	SF 1	SF 2	UK 1	UK 2	UK 3	UK 4	UK 5	US 1	US 2	US 3	Total
Building Envelope																										
Windows	●	●	●			●	●		●	●	●			●	●			●		●		●	●		●	15
Insulation mareral & systems	●	●	●			●	●	●	●	●	●				●			●				●	●			13
Over-clading systems																		●								1
Doors	●	●	●						●	●					●											6
Heating systems																										
Heating insulation	●	●							●	●										●	●	●	●			8
Domestic hot water	●	●							●	●														●		5
Energy sources	●		●						●	●			●	●						●	●	●	●	●		11
Control systems	●	●	●	●	●	●			●	●				●	●					●	●	●		●		14
Ventilation systems																										
Natural ventilation systems				●	●	●	●	●	●	●	●	●								●						10
Mechanical ventilation systems			●	●	●				●	●						●	●						●			8
Hybrid ventilation systems		●		●	●	●		●			●		●													7
Control & information systems			●	●	●	●		●	●	●	●	●	●							●			●			12
Solar control & cooling																										
Shading & glare protection	●	●	●						●	●	●	●	●													8
Cooling systems				●	●								●							●				●		5
Air conditioning systems				●	●																		●			3
Control systems	●	●		●	●																		●			5
Lighting & Electrical appliances																										
Lighting systems	●	●				●			●	●	●								●	●	●			●	●	11
Electrical applances	●			●	●				●	●	●			●												7
Daylighting technologies	●	●				●		●	●	●	●	●														8
Control systems	●			●	●	●			●	●	●								●	●					●	10
Management																										
Energy auditing techniques	●	●							●	●	●	●														6
Commissioning											●															1
Education and training		●									●															2
Non-investment measures		●									●															2

Table 9. Case studies distributed by implemented energy conservation technologies

The energy consumption before and after were measured to be:

- Heating: Before: 181 kWh/m^2.year after: 87.3 kWh/m^2.year
- Electricity for ventilation and lighting: Before: 36 kWh/m^2.year, after: 22 kWh/m^2.year

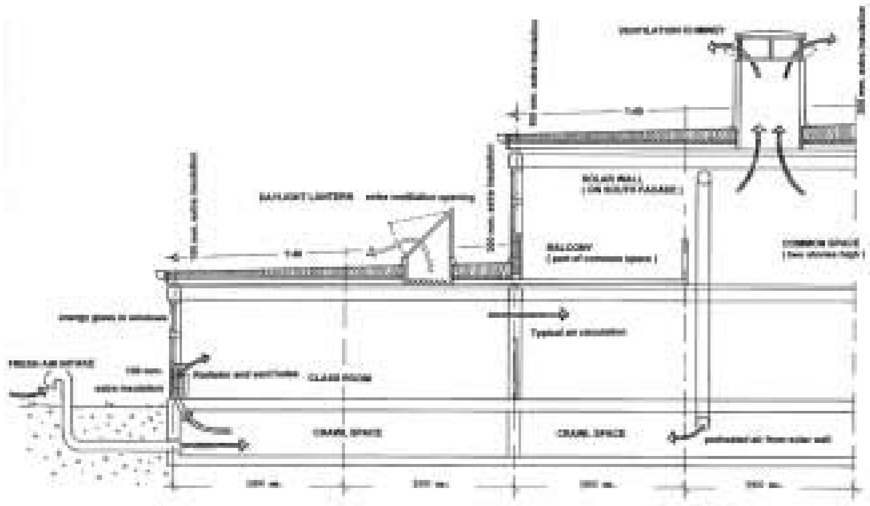


Figure 7 A photograph of the school (north view) and diagram of the school showing the principles of the ventilation system.

Area C1 was defined as a reference case for the qualitative user evaluation of C2. All pupils and teachers in the two sections answered a questionnaire developed by the Stockholm office of statistics and research in Sweden. In all 8 teachers and 120 pupils from the C2 section and 9 teachers and 72 pupils from the C1 section participated. The questionnaire had 17 main questions and several sub-questions. Figure 8 shows the results of one of the main questions concerning air quality. The histogram very clearly shows a “shift” in perceived air quality from acceptable to quite good and from poor to acceptable as a result of the refurbishment of the school. The general picture of all questions is an overall improvement of the indoor comfort quality compared to the reference.

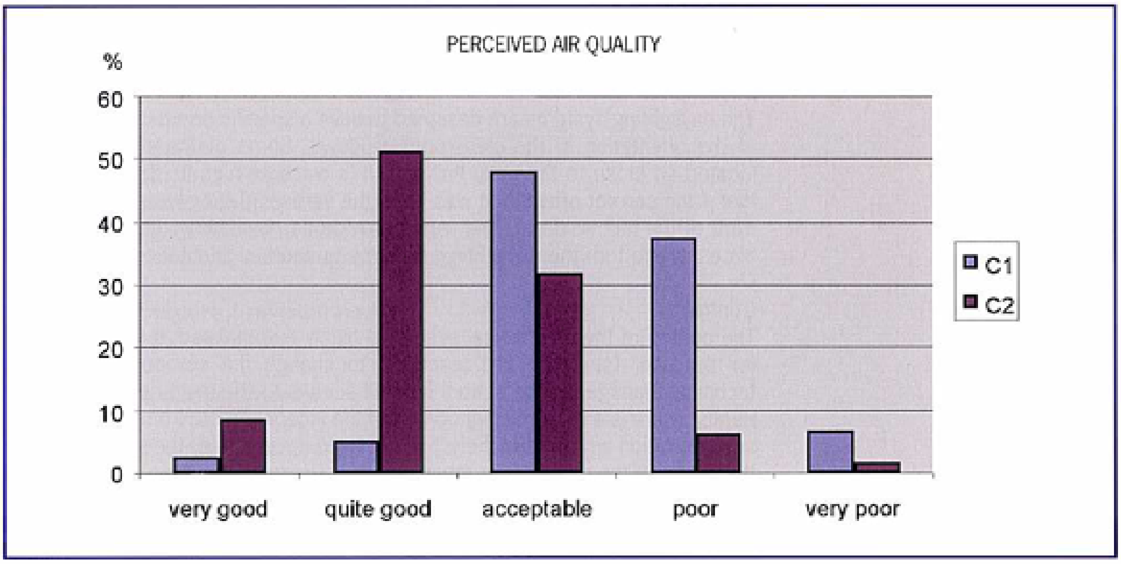


Figure 8. Perceived air quality within Egedjerg School

4.6 Lessons learned

A number of observations have resulted from the 25 case studies indicating energy efficiency measures, which can be integrated into the work of Annex 36. These have been grouped under the same categorisation as used for the energy technologies, examined in Subtask A as follows:

- Building envelope
- Heating systems
- Ventilation systems
- Solar control and cooling
- Light and electrical appliances
- Management

In general though the following was found to be the case:

- An integrated retrofit concept including the building envelope and the service installations leads to better cost-effectiveness.
- In current construction practice, a goal-oriented implementation process is hindered by the dividing up of responsibility for implementation of the indoor climate among too many parties.
- Pre-contract surveys are important, e.g. the discovery of asbestos during a project led to large additional costs.
- Noise from automatic mechanical shading or ventilation dampers can be a problem and should be avoided.
- Substantial energy reductions can be achieved by simple low-cost measures such as new paint and voluntary work by the pupils (e.g. insulation of the roof).

- Increased ceiling height, use of materials with greater storage capacity for heat and air pollution, users motivated to share responsibility for the quality of the indoor climate and understandable and responsive buildings and installations are key issues in improving the indoor climate and reducing energy consumption in schools.
- New technology is not always the answer to a problem. Existing technology may provide the necessary result without additional costs. Existing equipment and strategies configured to maximize their capabilities can achieve the desired result. This can be done without the need to introduce new devices and equipment, which require staff training to use.

The sample of case studies for energy efficient renovation of educational buildings, presents some of the new advanced technologies, such as preheating of the ventilation air, innovative insulation systems, passive solar, atria, a number of passive cooling technologies, advanced HVAC, active solar and PV. It also includes the more traditional technologies such as: added insulation, low-e windows, building energy management systems and new lighting systems.

The latter technologies are represented in the majority of the case studies showing that there is still a need for more demonstration projects implementing and verifying the viability of the newer, less established technologies.

- The energy savings reported range from quite large savings of 55-75% heating and 30-40% electricity to more modest savings of 8-20% heating and around 15% electricity. This can be interpreted as three different strategies:

    1. Implement several technologies as part of a holistic approach aiming at high energy savings and accepting long payback times;
    2. Focus on the technologies with an immediate return on the investment resulting in smaller savings, but with very short payback periods;
    3. Focus on the improvement of indoor climate, air quality or lighting comfort and consider energy savings as additional benefits.

5.0 Subtask C: Software development and analysis methods

5.1 Introduction

The work of Subtask C was divided into two activities, the first reporting on audit procedures and the second reporting on calculation tools, including both those for analysis and monitoring.

5.2 The role of calculation tools for retrofitting in educational buildings

Typical steps in proceeding with a retrofit project are as follows:

- Undertake an energy audit of the existing building. Tools, for example those supporting energy audit procedures, are useful at this stage in the project.
- Determine the retrofit measures required. Simple calculation tools can be used to evaluate measures in regards to their efficiency.
- Detailed planning. The Energy Concept Adviser would not provide much information at this stage in the process, as design specialists develop their plans.
- Commissioning. Rules for commissioning are being developed in a separate annex (Annex 40).
- Evaluation of operation. At this stage tools able to compare expected and actual consumption data are useful.

All these steps can be supported by the review of existing retrofit activities (Subtask A), by case studies (Subtask B) and by computational tools (Subtask C).

5.3 Role of models

Different models can be used to describe the same reality and each is valid only in a defined context. All results of simulations based on a model are limited to this context. Usually a reduction in the model's limitations can be achieved by increasing its complexity.

An analysis of the energy efficiency of the building can reveal what measures are required to reduce the energy demand of the building and in order to start modelling a thermal model of the building has to be selected.

The co-ordination of the user behaviour, the system operation and the energy demand will reveal measures to reduce energy consumption. Therefore the thermal model of the building has to be supplemented by a user model and a model describing system behaviour.

To be able to select possible measures to be used on the building it is necessary to have the ability to evaluate the possible measures. Very often economic criteria are of the greatest importance and economic calculation procedures should also be discussed in the context of the ECA modelling.

To make the energy savings sustainable, continuous control of the energy consumption and management of the energy system are necessary as shown in Figure 9. Tools that can collect and evaluate consumption and other energy relevant data are therefore of great importance.

All the tools used have to be simple enough to give effective support to the decision makers and other parties involved in energy saving in schools. More complex tools are only desirable or even necessary if buildings with high levels of energy consumption, for example universities, are considered or if specialists require more detailed results to solve a particular problem.

The results produced through the ECA tools must be easy to understand. The tool should concentrate on integral values (e.g. energy consumption per year) and comparisons on a more or less qualitative basis (e.g. measure A will reduce energy consumption by a% and have a medium payback time).

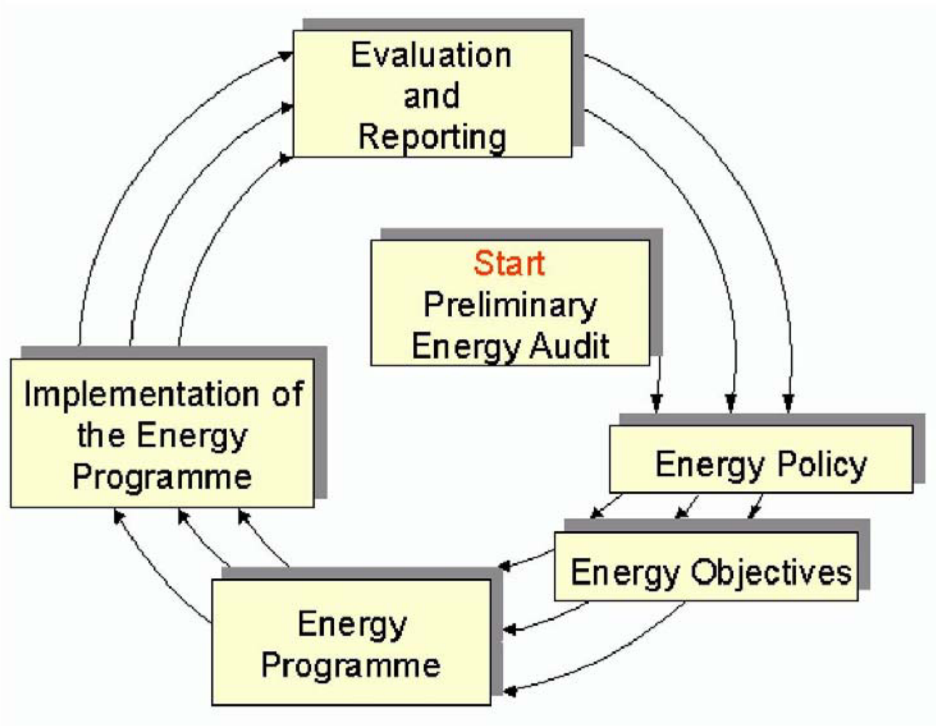


Figure 9. The management of energy use at schools is a continuous process (from MOTIVA).

5.4 Energy demand and consumption

Energy demand is usually calculated through energy balances using standard energy inputs and losses as shown in Figure 10. All the processes of input and loss are dependent on both the system in use and the way it is operated.

To predict consumption is more difficult than predicting demand. Reasons for

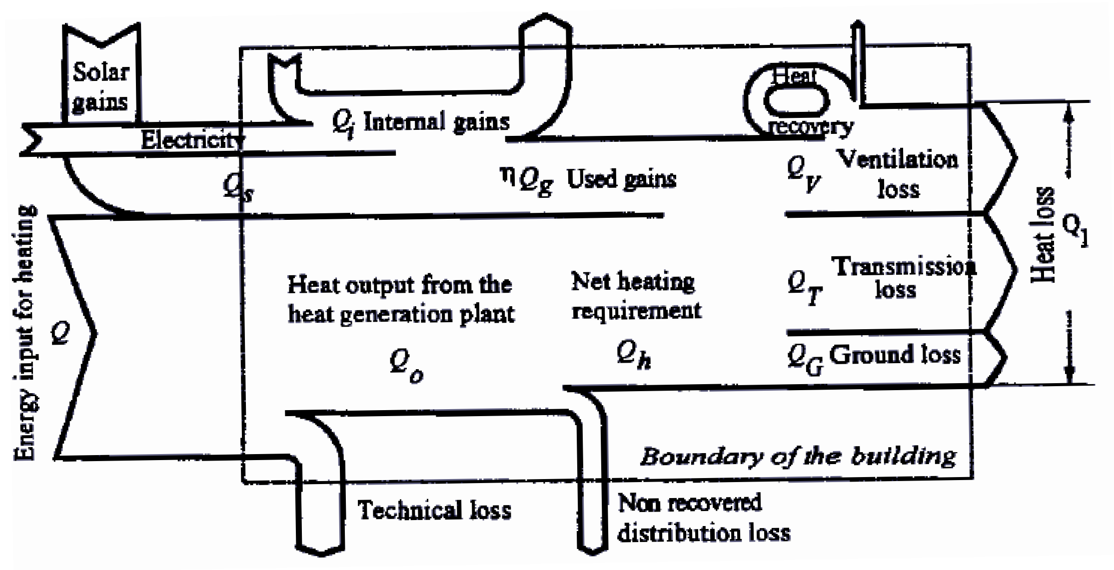


Figure 10. Energy balance associated with a building according to EN832

this include possible changes in usage due to additional lectures, changes in vacation times or changes in user behaviour. Changes in system operation due to system faults or uncontrolled operation will also have an effect on consumption. The meteorological conditions, which cannot be known in advance can also have an effect on consumption.

5.5 Economic calculation procedures

Often economic criteria are of the great importance when choosing retrofitting measures. Depending on the calculation method there are several approaches to derivation of the economic criteria. The two most commonly used methods in the participating countries are:

Net Present Value (NPV)
Simple Payback Time(SPBT)

The NPV calculation is more suitable for ranking the retrofitting alternatives according to their financial efficiency, for decision makers in financial institutions. The SPBT method provides quick recommendations on the choice of retrofitting to be undertaken.

It should be borne in mind, however, that the economic performance of retrofitting projects is highly dependent on national economic factors and the same retrofitting project in two different countries can have different economic outcomes.

5.6 Control and management

Without proper knowledge about where and how energy is being used in buildings, real management or improvement of current activities is not possible. Optimising energy consumption depends on the attitudes and habits of a building's occupants and on the motivation and knowledge of those responsible for the operation and maintenance of the building. Monitoring and targeting is an effective tool for obtaining reliable information on energy consumption and for motivational and training purposes.

Accurate information on actual energy consumption is also necessary for the validation and verification of calculations and simulations used in the design and construction phases of a retrofit project.

Numerous codes exist for yearly and monthly balance calculations. Only a few codes to simulate energy behaviour of buildings with a higher time resolution are available on the market.

Simple calculation and monitoring tools suitable for installation on PCs for use by a wider audience have been developed. One such tool is 'KULU' developed by the Technical Research Centre of Finland (VTT) for use by caretakers, service personnel and other building users who directly influence energy consumption within the building they occupy.

5.7 Models selected for the Energy Concept Adviser (ECA)

In selecting models for the ECA the following were considered:

- Target group: These are likely to be decision makers without a great technical knowledge of energy.
- Basic geometrical model: A single zone model with a simplified heat balance equation is preferable.
- Time resolution: A monthly basis should be used.
- Structure of calculation part of the ECA: Three steps comprising input, calculation engines and output form the method of calculation is preferable.
- Limitations – What the concept adviser cannot do. To keep the tool as simple as possible a number of limiting criteria should be introduced.

For the ECA a one zone model with a simplified heat balance equation was used. Its main components are shown in Figure 11.

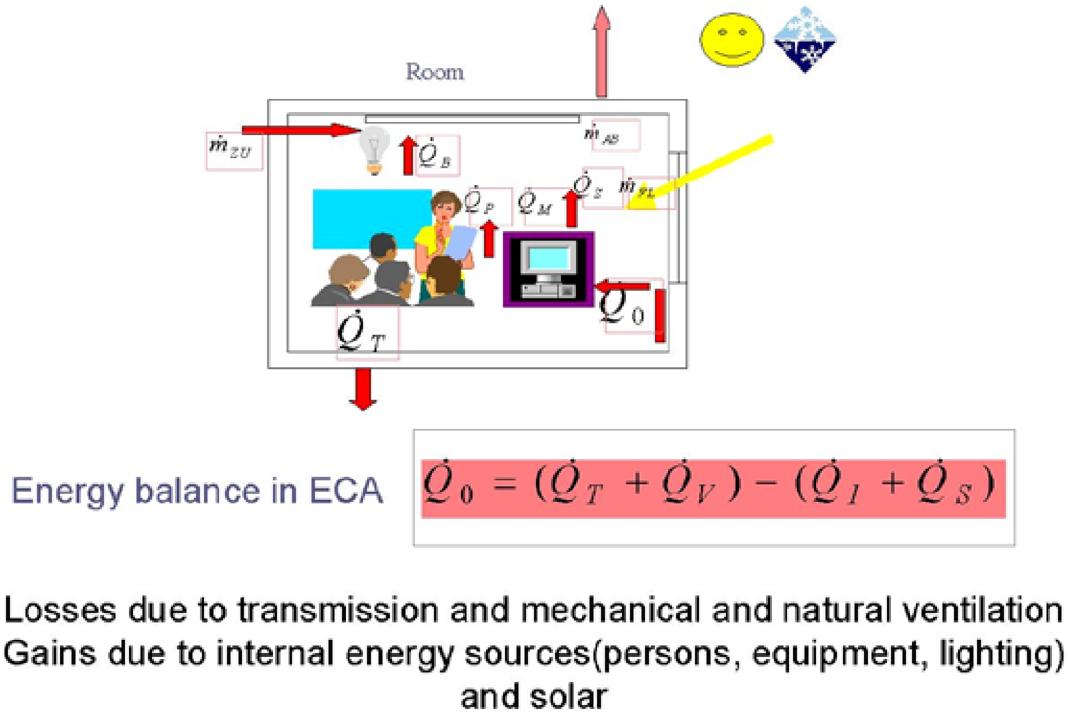


Figure 11. A simplified model for calculating heating demand and cooling needs in the ECA

5.8 Calculation methodology for energy calculation of the Energy Concept Adviser

The main concept behind the ECA was to keep it as simple a tool to use as possible. The calculation methodology of European standard EN832, offering simplified calculation methods to determine the required heat energy needed to maintain a set-point internal temperature by balancing heat gains and losses, has been used for the energy calculation of the ECA. Though it is an information rather than a design tool, some simplifications were made, due either to performance reasons or missing information.

The calculation procedure takes into account the French Thermal Regulation 2000, the *norm* NF-EN-410 and the *norm* NF-X35-103. The purpose of this method is to calculate the energy consumption for lighting of educational buildings. External lighting, lighting of car parks, emergency lighting and display lighting should not be taken into account during the application of this method.

5.9 Adaptation of ECA models to schools

- Monthly balance methods are applicable for schools:
- All the methods to be implemented in the ECA have to be adapted to the

Economic factor	**Alternative A**	**Alternative B**	**Alternative C**	**Alternative D**
Annual energy savings for space heating - ΔE_{SH} [kWh/a]	68300	29250	23100	120600
Annual cost savings [Euro/a]	2.200,-	940,-	740,-	3.860,-
SBPT [a]	**5,7**	**4,7**	**34,9**	**11,1**
Annual cost savings [Euro/a]	2.200,-	940,-	740,-	3.860,-
Annual fixed cost C_{FIX} (10% of investment cost) [Euro/a]	220,-	100,-	70,-	400,-
Annual variable cost C_{VAR} [Euro/a]	0,-	0,-	0,-	0,-
Annual cash flow of the project CF_I [Euro/a]	1.600,-	685,-	540,-	2.815,-
NPV_{10} [Euro]	**-245,-**	**890,-**	**-21.800**	**-21.250,-**

Table 10. Examples of economic calculations for different countries

operating conditions of the educational buildings under consideration. This includes the integration of the new calculation methods as well as the adaptation of certain parameters.

Unfortunately energy demand cannot be correlated directly to energy consumption. The ECA enables reductions to be made in differences between, for example the building or weather conditions, and the model by allowing the input of more detailed information. If after the input of more detailed information major differences still occur between measured and calculated consumption then they are assumed to be due to non-optimal operation of systems.

The validation of the simulation part of the ECA was undertaken in several steps.

1. A set of general parameters to describe educational buildings for the ECA was derived from theoretical considerations.
2. Based on the above a model was derived and, following experimentation with several calculation programs, the results agreed.
3. Profiles describing the usage of typical schools were defined and following experimentation with hourly codes good agreement was found between ECA and hourly determinations of the energy demand.
4. Following use in the 34 school project of the City of Ludwigshafen the agreement between measured and predicted energy consumption seemed acceptable.

5.10 Selection of calculation methods in the ECA

The work within this part of Subtask C showed that monthly balances allow a reasonable estimation of potential energy savings for schools, but need adaptation of average parameters to school conditions. Dynamic calculations use less conservative assumptions resulting in lower energy demands. Such methods, however, should be used only by experts, due to the great number of parameters which have to be adapted to the actual situation.

All the methods implemented in the ECA have to be adapted to the operating conditions of the educational buildings under consideration. This includes the integration of new calculation methods as well as the adaptation of certain parameters.

Unfortunately energy demand cannot be correlated directly to energy consumption, but the ECA allows a reduction in some of the differences due to the inputting of more detailed information.

6 Energy Audit procedures

An energy audit is the key procedure to thoroughly identify the energy saving potential of buildings to be retrofitted. It can underline the need to start the retrofit process and can give indications about which measures to focus on. Recorded energy performance values can then serve as reference for the savings likely to accrue from retrofit measures. Moreover, audits can be used during commissioning and after completion of the retrofit process to validate the implemented measures and to track building performance over the whole building life cycle.

Audit methods include:

- Analysis of the building envelope as an overall system down to air leakage tests and component analysis using thermography. Short-term and long-term based approaches can be used;
- Analysis of commission and survey HVAC system behaviour, on a short-term and long-term basis;
- Analysis of lighting electricity consumption and identification of appropriate potential savings;
- Undertake remote energy surveillance for larger numbers of buildings, for example on a university campus, to obtain an almost real time overview of consumption and to compare the behaviour of similar units and to label monitored consumption according to defined ratings.

These procedures are currently specific to individual countries, but nevertheless might be applicable to other projects as performance indicators.

6.1 Overall building performance analysis

Comprehensive monitoring exercises, giving detailed information, require at least two years to complete and require a large number of sensors and are expensive. This may not be suitable for an environment such as a school. An alternative is to undertake a short-term exercise.

Short-term methods usually require no more than a portable data acquisition system and up to about 25 sensors. There are a number of approaches as shown in Figure 12.

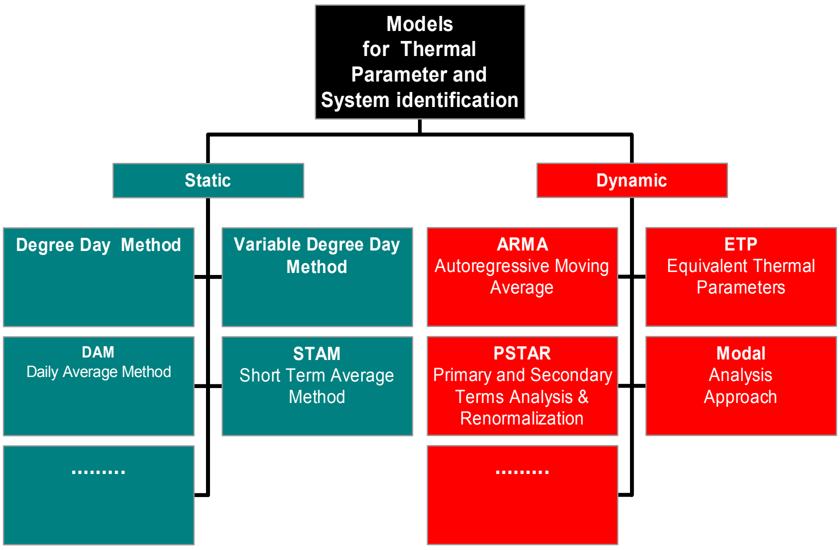


Figure 12. Selection of a number of different methods used for energy prediction of dwellings and non-residential buildings on a short term basis

Comprehensive energy audit methods require a tool, which can be used for detailed energy and water benching marking in schools. The tool should have a detailed means of describing the facilities that a school has and the times of day that the school is being used.

To carry out the audit it is necessary to survey the school and note, in the paper based audit form, all energy and water using equipment. The data is then entered into the database, which calculates the total energy and water used and the energy and water use by facility, end use or excluding out of hours use.

Long term monitoring of the thermal behaviour of the building is performed to collect detailed information, see Figure 13 on the quality of the building envelope, to acquire information on the user behaviour and therefore the user impact on the building's energy behaviour. High installation and maintenance costs

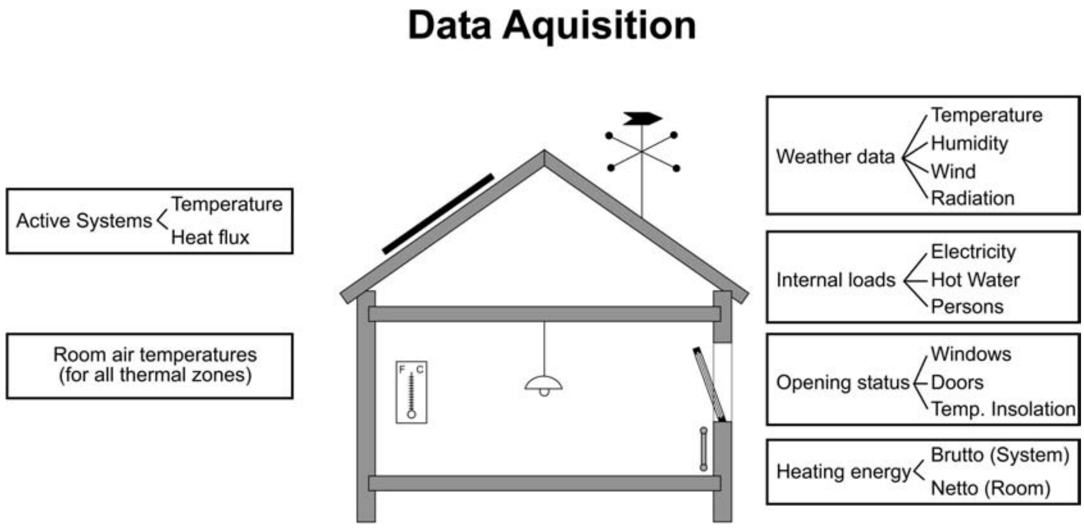


Figure 13. Quantities recorded for detailed analysis of the thermal building behaviour

normally restrict these monitoring campaigns to research projects.

The visual energy centre (VEC) is an example of a tool supporting both building energy analysis and system management during all phases of the building lifecycle. Single schools as well as whole campuses might be considered.

6.2 Component analysis using thermography

To assess energy saving measures based on benchmarking and energy auditing, it is necessary to determine the thermal performance of the constructions. In many cases when trying to consider retrofit measures the original drawings showing constructional information, i.e. what the envelope comprises, are not available. The most effective method for monitoring the thermal performance of the building envelope is using an infrared camera. This will highlight thermal discontinuities in the external envelope of the construction, which cannot be detected by any other means.

6.3 Airtightness and airtightness testing

An appropriate supply of controlled ventilation is necessary for the wellbeing of the occupants. However a certain amount of unwanted and uncontrolled air will 'leak' through gaps and cracks in the building. In buildings where no specific airtight design methods have been included then this can have a significant effect on the energy consumption of the building. The thermal comfort of the occupants can also be affected, for example gaps below raised floors can result in localised cold spots, particularly in cellular office accommodation.

It is not possible to ascertain the air leakage characteristics of a building by visual inspection alone. Air pressurisation of a building using a single or multi fan arrangement, in conjunction with the use of hand held smoke tubes or smoke machines is required to identify and record air leakage around the building. By undertaking, what is in effect, an air leakage audit, a comprehensive picture of the main air leakage areas around a building can be obtained. When combined with thermogarphy, airtightness testing can also be used to check for thermal discontinuity in areas too high for safe access.

An air pressurisation test can also be used to quantify the amount of air leakage through the external envelope of the building.

6.4 Lighting analysis

According to the room function, the technological choices for lighting are guided by a series of priorities including absence of glare, colour and lighting direction, colour rendering and lighting uniformity.

A lighting analysis procedure aims to evaluate on site lighting environment quality in educational buildings for refurbishment. The main procedures for evaluating the quality of the lighting environment in educational buildings to be refurbished generally follow three steps as shown in Table 11.

Steps	Description
1. Recording existing situation	Site characteristics
	Daylight description
	Electric lighting description
	Lighting control system description
	Furniture description
2. Measurements, monitoring	Visual comfort
	Daylight availability
	Installed power
	Management controls
3. Analysis	Visual comfort
	Energy consumption

Table 11. Lighting analysis procedure

Using simple measuring equipment, this procedure, in three steps, provides a pragmatic approach to lighting diagnosis. It records the existing situation, takes measurements and monitors given elements for reducing installed electric lighting whilst ensuring sufficient luminances.

6.5 Labelling

Although currently only mandatory in Denmark, energy labelling of buildings has been developed in a number of forms. Eco-labelling has also been developed to give a profile of a building's environmental characteristics.

7 Conclusions

All Subtasks provided their results as input to the joint working group. Based on the results the joint working group developed an electronic interactive source book (Energy Concept Adviser). A central database includes all Annex results and allows the user later on to get extensive information, according to their individual focus of interest, on design inspirations, design advice, decision tools and design tools. Therefore the user is able to increase his knowledge in the respective field of interest quickly and reliably. The user has the choice of analysing design scenarios and/or use the pool of experience gained in the case studies projects to access information on energy saving potentials and requirements. Appendix 2 contains a brief introduction to the Energy Concept Adviser (ECA).

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Appendix 1 Participating Organisations

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Appendix 2 Energy Concept Adviser (ECA)

The Energy Concept Adviser is a new internet based information tool for decision makers and their technical staff that have to decide about retrofit projects in educational buildings. It offers a set of tools to assist decision makers through the whole process of thinking about refurbishment. It is easy to use and it can be used at all stages without a detailed knowledge of the actual building.

Structure of the Energy Concept Adviser (ECA)

The Energy Concept Adviser offers tools for every stage of the process of a refurbishment.

If there is an existing problem with the building, a possible solution can be found in the **'Problem Related Recommendations'**. There are over 600 possible solutions for more than 25 different problems. The solutions are not restricted to a particular building type. It suggests possible solutions to existing problems.

The next step is a huge information database. It deals on the one hand with the description of some representative refurbishments in the **'Case Study Viewer'** and on the other hand with the technologies for refurbishments in the **'Retrofit Measure Viewer'**. All other elements of the Energy Concept Adviser are linked to this information database, so there is always the possibility to get more background information to the current stage.

Up to this stage, it is quite building independent. If we are now interested in how our building performs in comparison to others, the **'Performance Rating'** gives an answer. The consumption of energy (and for some countries also the consumption of water) is compared to a national stock of buildings. This results in advice as to whether or not it is worth considering for energy efficient refurbishment.

The **'Energy Concept Development'** is a powerful, but easy to use tool that allows us to develop energy efficient retrofit concepts. The different possibilities for refurbishment can be either explored using a common building or a building that fits an existing building. Finally five different concept can be compared regarding the energy relevant values as well as economic calculations.

The last step is the **'Auditing and Monitoring'** of a refurbishment. To help in this there is the software tool called 'KULU' and several reports available.

The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

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 sponsored various research annexes 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 sponsored research.

www.ecbcs.org