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

SUBTASK A REPORT

Overview of Retrofitting Measures

edited by:
Tomasz M. Mróz
Poznan University of Technology
Poznan, Poland

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IEA ECB&CS Annex 36
Retrofitting in Educational Buildings
Energy Concept Advisor for Technical Retrofit Measures

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1. FOREWORD

One of the most important questions that has to be answered concerning the modernization of educational buildings is: how to retrofit the building to provide low energy consumption without getting negative impact on the indoor air quality. It was one of the aims that had risen at the very early stage of co-operation within the Annex 36 project.
On the basis of experience of experts from different countries involved within the project and lessons learned during analysis of case studies a database on so called strategies and technologies has been created.
This report presents the results of investigations that have been performed by Annex 36 participants in order to find out what possible strategies of retrofitting process and what are the available technologies that can be utilized to proceed and complete the assumed strategies.
As the result of discussion among the Annex 36 participants the following so called retrofitting measures have been identified and described in the following chapters:

– Building envelope – thermal retrofitting of building envelope is one of the most frequently applied retrofitting measures. It considers the different building elements: windows, insulation systems, over-cladding systems and doors. The state of the art overview of different approaches to the modernization of building envelope focused on the minimization of energy heat demand of educational buildings is presented in the chapter 2, prepared by Kirtsen Eglund Thomsen, Marco Citterio and Richard Daniels.

- Heating systems – the modernization of the heating systems can be a crucial action for the final result of energy conservation related to retrofitting of educational buildings. It refers especially to the well insulated buildings with relatively low heat demand. The overview of heating systems scenarios for retrofitting, include: heating installations, energy sources and domestic hot water systems is given in the chapter 3, prepared by Rahael Haller, Radek Gorzenski.

- Ventilation systems – the knowledge of possible scenarios of retrofitting of ventilation systems in educational buildings is required due to the two important factors being the operation of ventilation systems influences the indoor air quality (IAQ) in the classrooms which is related to the quality of learning and teaching. This can be one of the major items of energy balance of educational building. The description of different ventilation system retrofitting actions referred to natural, mechanical and hybrid ventilation systems is given in the chapter 4, prepared by Timo Kauppinnen and Tomasz M. Mróz.

- Solar control and cooling systems – high solar heat gains appearing in educational buildings might influence both: indoor climate quality (glare problems, overheating problems) and high energy consumption which can result in the required application of mechanical cooling installations. The overview of retrofitting scenarios referring to solar control and cooling techniques, including shading systems, cooling systems and air conditioning systems is presented in the chapter 5, prepared by R. Cantin, G. Guarracino, C. Laurentin, V. Richalet and Lorenz v. Schoff.

- Lighting and electrical appliances – the energy consumption of educational buildings is highly affected by the utilization of artificial lighting and electrical appliances (computers, audio and video systems, etc). The state of the art overview of lighting techniques and electrical appliances, including artificial and day-lighting techniques is given in chapter 6, prepared by R. Cantin, G. Guarracino, C. Laurentin, R. Jakobiak and V. Richalet.

- Management – management of educational buildings may be one of the most cost-effective retrofitting measures concerning the reduction of energy consumption. It covers different activities: energy auditing techniques, commissioning of buildings, education and training of teaching staff, pupils and service institutions. The description of different management retrofitting measures is given in the chapter 7, prepared by Fiona Fanning, Lorenz V. Schoff, Richard Daniels and Euprozine Triantis.

The detailed information concerning the retrofitting measures included in the following report is a source book for energy concept advisor platform (ECA II) and will be available as a pdf-file in the official web page of Annex 36 – www.annex36.bizland.com.

Tomasz Mróz

Annex 36 Subtask A Leader

September 2003

Chapter 2

Building Envelope

by

Kirsten Engelund Thomsen, Marco Citterio

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2.1. Introduction

The building envelope (roof, external walls, windows, doors and floors) serves a number of functions but this chapter focuses on the thermal aspects, the insulation of the building. The climatic differences throughout Europe, for instance, are mirrored in the traditional buildings that range from uninsulated (usually quite heavy) constructions in the south (designed mainly for summer conditions) to fairly well insulated heavy or light constructions in the north, designed primarily to comply with winter conditions.

Improving the thermal properties of existing building envelope is, in many cases, one of the most logical solutions in order to reduce building energy consumption and in consequence this is one of the most important strategies in building retrofit.

In order to achieve good results in this area, the different aspects related to the energy performances of building envelope components and the technologies for their improvement, should be part of the designer's knowledge, in order to clearly define the most appropriate strategies.

The improvement of building envelope energy performance is often the result of an optimisation process and the choice of the correct strategies has to be the result of a general overview of all the necessary options for a building to be retrofitted, usually this will involve windows, doors, walls and roofs and an unbalanced design between different components, can lead to unsatisfactory results.

There are two key components to a super-insulated building shell: high levels of insulation with minimum thermal bridges and airtight constructions. High levels of insulation are accomplished by constructing a thicker than normal wall and filling it with an insulation material. However, by simply adding more insulation does not result in a conventional assembly turning into a high-performance assembly. The wall system and junctions between building components have to be carefully designed to be airtight and avoid thermal bridges or discontinuities. As more insulation is added, the thermal discontinuities become more important.

Cost effectiveness of building envelope intervention is a critical issue so it should be remembered, for example, that the first layer of insulation is the most effective and the law of diminishing returns dictates that each additional layer of insulation is less effective than the previous layer. On the other hand, the adoption of generally considered expensive solutions such as overcladding systems, can be considered a convenient strategy in a comprehensive retrofit scheme, including window and door replacement and the installation of new heating and ventilation systems

This chapter intends to be an overview of the technologies applicable in building envelope retrofit when looking at the different components. The readers will then find described some strategies in order to improve the energy performance of these components, by means of a correct use of the most recent technologies in the fields of windows, insulation, overcladding systems and doors.

2.2. Windows

2.2.1. Introduction

In the following paragraphs the present state of windows is reviewed with emphasis on energy conditions, while special products like solar protection glazing and security glazing are not described. Finally, topical research areas are outlined.
In terms of energy, windows occupy a special position compared with other thermal envelope structures this is due to their many functions: 1) Windows let daylight into the building and provide residents with visual contact with their surroundings, 2) Windows protect against the outdoor climate and 3) Windows transmit solar energy that may contribute to a reduction of energy consumption, but which may also lead to unpleasant overheating.
Windows are still the least insulating part of the thermal envelope with a heat loss coefficient, a U-value, which is typically 4-10 times higher than that of other thermal envelope elements. At one time this led to the use of very small window areas at the expense of the natural daylight level, but concurrently with development of improved insulating glazing**,** the size of typical window areas has increased again.
In the following sections the present state of windows is reviewed with emphasis on energy conditions, while special products like solar protection glazing and security glazing are not described. The final section in this area outlines topical research areas.

2.2.2. Sealed units

Low-emissivity coatings
Sealed glazed units are built up of two or more layers of glass that are joined together at the edge with a spacer that ensures the desired distance between the panes of glass and an almost airtight and moisture proof sealing of the cavity between the glass layers.
Heat transmission in a sealed glazed unit occurs by means of conduction and convection in the cavity and by radiation from the warm glass to the cold glass. In an ordinary double-glazed unit heat transmission by radiation accounts for approximately 2/3 of the total heat transmission between glass layers**.** Therefore research and development (R&D) has primarily been aimed at reducing heat transmission by radiation through low-emission (lowE) coating on one or more glass surfaces. A lowE coating consists of a very thin metallic film that is almost 100% transparent to solar radiation (short-wave radiation). However, the film will radiate only very little heat (long-wave radiation) therefore reducing heat transmission caused by radiation.
Two different kinds of coating exist: 'hard' and 'soft' coatings which are two different methods of applying the coating. The hard coatings are added during production of the glass and are resistant to exterior impacts (thus the name 'hard'), but soft coatings are applied to the finished glass in a vacuum chamber. The latter type of coating is attacked by ordinary humid, atmospheric, conditions in air and is destroyed by mechanical impacts, which is the reason why soft coatings should always face a dry sealed cavity.
The coatings influence the light transmittance and solar energy transmittance of glass as a major amount of short wave radiation is absorbed. This means that the coated glass is heated through solar radiation more than ordinary glass. Therefore lowE coatings should not be applied on layers in between multi-glazed units, as the temperature of the glass can become very high and lead to thermal fractures in the pane. Sunlight refers to the wavelength of the area for visible light while solar energy, in principle, refers to the whole wavelength area covered by solar radiation.

Table 2.1. Typical values for a sealed, argon-filled double-glazed unit coated on the inner pane, depending on the type of coating. Glass distance is 15 mm.

Type of coating	Emissivity	Solar transmission	Solar heat gain	Centre U-value
Hard	0.35	0.73	0.66	1.9
	0.12	0.76	0.64	1.4
Soft	0.09	0.77	0.54	1.3
	0.04	0.75	0.47	1.1

Table 2.1 shows that it is impossible with hard coating to obtain emissivity as low as when using soft coatings. On the other hand the transmittance of light and solar energy is higher.

Gas fillings

The application of lowE coatings reduces heat transmission in connection with radiation by up to approximately 90% and thereby the heat transmission and convection in the sealed cavity become dominate. Heat transmission and convection depend on the glass distance and gas.

By combining several layers of glass, lowE coatings and insulating gases it is possible to construct glazing with a very low U-value, but for every layer of glass and every coating, light transmittance and solar energy transmittance is significantly reduced. For example, by using a triple-glazed unit with 2 lowE coatings and krypton filling a U-value of 0.45 W/(m^2 K) is obtained, but a direct solar energy of only 0.29.

Edge sealing

Traditional the spacer, a part of the edge sealing of the pane, consists of a metal profile of 0.4 mm aluminium or galvanised steel, separated from the glass surfaces only by an approximately 0.3 mm butyl joint. Metal is completely diffusion-resistant against gas and water vapour, while diffusion through the butyl joint is reduced to an almost negligible level owing to the very small cross-section area of the joint and the high diffusion resistance of the butyl mass.

Because of the metal profile, the edge sealing forms a pronounced thermal bridge in relation to the rest of the pane. The thermal bridge is important for surface temperatures at distances of approximately 0.10 m, calculated from the pane edge, to the pane centre. The importance of the thermal bridge for the total U-value of the pane depends on the shape and size of the pane, but typically it gives a U-value for the whole pane that is 5-10% higher than the U-value at the centre of the pane.

USA and Canada are far ahead in the use of other types of spacers based on butyl and silicone foam. The metal profile is replaced by a metallized plastic film thereby reducing the thermal bridge significantly. These new types of spacers have not become popular in Denmark, primarily because of the price, but also because they require introduction of new production technology. However, a few manufacturers offer to supply windows with insulating spacers in the glazed units - typically in cases, where there is an increased risk of condensation. Another possibility of reducing the thermal bridge is by using spacers of stainless steel with a material thickness of approximately 0.15 mm. This type of spacer will not require introduction of new technology and will lead to a reduction of the thermal bridge that approaches the level of non-metals.

2.2.3. Frame constructions

Frame constructions are traditionally made of wood, which is easy to work and has a relatively low thermal conductivity. Wooden windows still make up the major part of the market, but high maintenance costs have brought about the development of plastic and aluminium windows with minimal maintenance costs. Plastic windows insulate less than wooden windows partly because of an inserted metal profile, which is necessary for reasons of strength. For aluminium windows, the exterior and the interior parts of the construction are required to be thermally separated, eg by means of a disruption made of plastic, but the U-value is significantly higher than for wooden windows.

A combination in ever-wider use is the wooden window provided with an externally ventilated aluminium profile combining the low maintenance costs with the good insulating properties of wooden windows.

New frame constructions have been developed that are made of unbroken insulating material such as PU foam covered with aluminium. The insulating properties of the construction are somewhat better than those of a traditional wooden construction, but a commercially accessible frame construction that significantly improves the insulating properties is not yet available.

The U-values for typical frame constructions is approx. 1.4 - 2.0 W/(m^2 K) and are significantly higher than the centre U-value of the most frequently used double-glazed, coated and filled units. As the frame construction often constitutes a large part of the total window area, the higher U-value has a noticeable effect on the U-value of the whole window.

In connection with Danish participation in IEA Task 13 Solar Heating and Cooling Programme - Advanced Solar Low Energy Houses detailed analyses of the total U-value as a function of size and insulating properties of the frame area were performed (fig. 2.1).

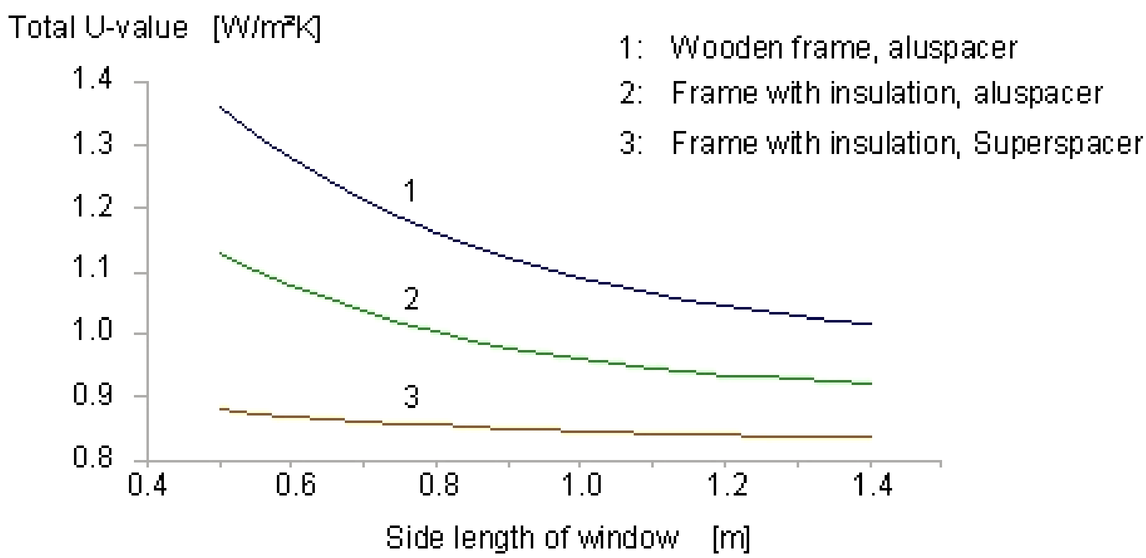


Figure 2.1. Total U-value calculated from a square window with triple glazed, coated and filled units (centre U-value = 0.85 W/(m^2 K)) as a function of the size of the window. Calculations are made with a traditional frame construction of wood (U = 1.6 W/(m^2 K)) and a wooden frame construction with a built-in insulating layer (U = 0.8 W/(m^2 K)) and two different spacers.

An alternative to using improved insulating frame constructions is a minimising of frame dimensions which will lead to lower total U-value for the window if the frame U-value is not changed, but it will also lead to a larger transparent area resulting in added light and solar heat gain in the dwelling.

2.2.4. U-value / g-value

As previously mentioned, the heat loss coefficient of a window is significantly higher than that of other thermal envelope constructions, but at the same time the window allows solar energy to pass through which might be advantageous for the dwelling. The two properties are named the U-value and the g-value, respectively.
In Denmark the U-value is calculated as the weighting of the area of the U-values of the glazed unit and the U-value of the frame construction plus an additional value for the thermal bridge conditions along the perimeter of the glazed unit. This additional value is calculated as the product of the circumference of the pane and the linear transmission coefficient Ψ_g that expresses the extra heat loss per metre edge.
The g-value is a measure of how much of the solar energy that penetrates the exterior of the window and is transmitted to the space behind. This is called total solar energy transmittance. Total solar transmittance contributes with: 1) Direct solar transmittance, and 2) Indirect solar transmittance. The indirect contribution originates from the heating of the glass panes because solar energy is absorbed in the glass and from possible coatings. Part of the absorbed heat will be transmitted to the space behind by means of radiation and convection and thus contributes to covering the heat loss. Therefore the total solar transmittance is higher than the direct solar transmittance.
The concept 'g-value' is used both for glazing and for the finished window and it is important to know which of the two the g-value is referring to. The g-value for a window will typically be much smaller than for the glazing as the frame area does not transmit solar energy, see table 2.2.
For well-insulated glazing, the narrow and less insulating frame construction means that the total U-value is lower than in traditional and better insulating wooden frames because of its larger glass area.

Table 2.2. Examples of various combinations of frame construction and types of panes and their significance for the total U-value and g-value. The exterior measurements are 1 x 1 m^2. The linear transmission coefficient is 0.6 W/(m K).

Frame height	Frame area	Glass area	Pane circumfer ence	Centre U-value	Frame U-value	Total U-value	g-value pane	g-value window
mm	m^2	m^2	m	W/(m^2 K)	W/(m^2 K)	W/(m^2 K)	-	-
110	0.39	0.61	3.12	1.4	1.6	1.66	0.64	0.39
110	0.39	0.61	3.12	1.1	1.6	1.48	0.59	0.36
110	0.39	0.61	3.12	0.45	1.6	1.09	0.39	0.24
55	0.21	0.79	3.56	1.4	2.0	1.74	0.64	0.51
55	0.21	0.79	3.56	1.1	2.0	1.5	0.59	0.47
55	0.21	0.79	3.56	0.45	2.0	0.99	0.39	0.31

However, it is not clear how the U- and g-values should be weighted in relation to each other, as other conditions may be used for determining for the actual choice of glass construction for example the orientation of the window, shading conditions, the thermal mass of the building, internal heat load. In each case an assessment/calculation should be made to find the optimum choice of window in terms of energy.

2.2.5. An overview of existing window solutions

Windows are built up of a number of components (glass type, gas filling, spacer, frame) that can be combined so that in each case the window meets the requirements made to insulating properties, daylight conditions, solar shading, noise reduction etc
Table 2.3 lists typical values for panes for windows. The table includes some solar protection glazing to illustrate the possibilities for limiting solar heat gain.
Well-insulated pane types, ie panes with a centre U-value of less than approximately 1 $W/(m^2 K)$), present an aesthetic problem of condensation on the exterior of the pane. Condensation is primarily present on clear, silent nights but will start to disappear late in the morning or towards noon. Time will show how much this will influence the user's opinion of well-insulated windows.
Today most window glazing manufacturers use 0.4 mm galvanised steel for spacers but in a few cases insulating spacers are used, primarily to avoid condensation on the interior of the pane, while the energy aspect rarely leads to the use of improved spacers.
In the field of frames practically no developments have occurred towards improving insulating constructions, this is due to the main efforts of the manufacturer’s focus on a reduction of maintenance costs. Narrow frame constructions are marketed with a frame height of approximately half of what is found in traditional windows. In contrast the U-value is a considerably higher but this is partly compensated for by a smaller frame area.

Table 2.3. Overview of the most typical values for commercially available types of window panes. The window pane is described by 4-15-*4, for example, which indicates a double glazed unit with a glass thickness of 4 mm and a glass distance of 15 mm and a coating on the inner glass.

Description	Emissivity	Centre U-value			Light transmission	g-value
		Air	Argon	Krypton		
	-	$W/(m^2 K)$	$W/(m^2 K)$	$W/(m^2 K)$	-	-
4-12-4	-	2.9	2.7	2.6	0.82	0.76
4-12-*4	0.09	1.8	1.4	1.2	0.77	0.66
4-15-*4	0.12	1.7	1.4	1.4	0.75	0.71
4-15-*4	0.09	1.6	1.3	1.2	0.77	0.66
4-15-*4	0.04	1.4	1.1	1.0	0.75	0.59
4-12-4-12-*4	0.09	1.4	1.1	0.9	0.70	0.59
*4-12-4-12-*4	0.09	1.0	0.8	0.6	0.66	0.48
*4-12-4-12-*4	0.04	0.9	0.7	0.4	0.62	0.40
*4-12-4 solar shading	0.09	1.8	1.4	1.2	0.56	0.46
*4-12-4 solar shading	0.04	1.6	1.3	1.0	0.65	0.44

2.2.6. Research and development

In Denmark research concerning window centres has concentrated on the development of new superinsulating glazing, improved insulation of frame constructions and increased g-value of the windows.

Superinsulating glazing

1. Vacuum glazing is a double sealed unit where the sealed cavity is evacuated to a pressure below 10 $^{-7}$ atm causing all heat transmission and convection to stop. In order that the outer atmospheric pressure does not cause the glazed unit to collapse, a number of small supports are evenly distributed between the two glass layers. The supports are visible at close range.
   The vacuum pane is very thin, the glass distance is only approximately 0.2 mm, which makes this pane suitable for replacement by single window panes. The theoretical centre U-values is approx. 0.3 W/(m^2 K) but because of the spacers the real centre U-value will also be about 0.5 W/(m^2 K). The g-value will be 0.6 because of the two coatings. The edge sealing must be 100% air tight; which causes a significant thermal bridge along the perimeter of the pane.

2. Aerogel units are double-glazed sealed units where the cavity between the layers is filled with monolithic silica aerogel and evacuated under a pressure of approx. 10 $^{-3}$ atm. Aerogel is a porous material with open pores making up 90% of its volume. The fine pore structure breaks the transmission and convection in the air at an almost vacuum while at the same time making the material impenetrable to heat radiation. Aerogel has a pressure strength that can withstand the load from the outer atmospheric pressure thus preventing the pane from collapsing.

The pane thickness can be randomly chosen but with a glass distance of 20 mm a U-value of 0.4 W/(m^2 K) can be achieved for the pane. The great advantage of an aerogel pane is the high g-value of approx. 0.7. The aerogel pane has not been developed to be at a level that makes it suitable for use in ordinary windows as the aerogel material is translucent. The edge sealing can be made without any noticeable thermal bridge, by means of a special plastic film that has sufficient diffusion resistance to moisture and gas diffusion so that the pane can maintain the vacuum approximately 25 years.

Improved frame construction and g-value

The possibility of obtaining low U-values for the glazing has centred focus on obtaining a reduced thermal bridge effect of the edge sealing and the frame construction. Possible design solutions with regard to the edge sealing are already available by using insulating spacers, and research has therefore concentrated on frame construction. Particularly the development of narrow constructions has a high priority, as the insulating pane will fill in a larger part of the window area. This will also give a larger transparent area to compensate for the often-lower g-value of well-insulated panes.

Other topical research areas are improvement of the g-value of the pane and use of so-called non-ferrous glass where the absorption of sunlight and solar energy in the glass can be reduced by approximately 5%. The use of non-ferrous glass will also mean less colouring of the light. Moreover the glass is surface-treated with an antireflection treatment so that a smaller part of the sunlight is reflected from the surfaces of the pane. Both methods will lead to a significant improvement of the g-value.

In addition methods are being developed in order easily and quickly to assess what combination of the U- and g-values will be optimal in a given situation in terms of energy.

The problem of exterior condensation on well insulated glazing is assessed as a general problem that impedes widespread use of better insulated windows and a more detailed determination of conditions leading to condensation is being worked on as well as the possibilities of reducing this problem.

2.3. Insulation materials and systems

2.3.1. Introduction

There are two key components to a super-insulated building shell: high levels of insulation with minimum thermal bridges, and airtight construction. High levels of insulation are accomplished by constructing a thicker than normal wall and filling it with an insulation material. However, simply adding more insulation does not turn a conventional assembly into a high-performance assembly. The wall system and junctions between building components have to be carefully designed to be airtight and avoid thermal bridges or discontinuities. As more insulation is added, the thermal discontinuities become more important. The building assemblies have to be designed so that all non-insulating building materials (including wood, steel and concrete) are thermally protected by insulation. The first layer of insulation is the most effective in reducing heat loss. The law of diminishing returns dictates that each additional layer of insulation is less effective than the previous layer. The amount of insulation used depends upon the severity of the climate. Mild climates require a wall U-value of 0.2 W/m^2K or loss, whereas harsh climates might necessitate a value of under 0.13 W/m^2K.

2.3.2. Types of insulation materials

The insulating material which dominates most countries markets is mineral wool, but there are a number of other typical insulation materials available for example: aerated concrete, light clinker, cell glass, expanded polystyrene (EPS), extruded polystyrene (XPS), polyurethane, perlite, cellulose fibres, fibre boards and woodcrete. Increased interest in a building process that develops towards more eco-friendly insulation materials has resulted in a group of insulation materials with the common denominator 'alternative insulation materials'. These eco-friendly insulation materials can be agriculturally produced or produced via recycled products. A table below lists the raw materials and product types of the alternative products.

Straw is also used, not only as an insulation material, but also for construction of the carcass of a house. Globally approximately 1000 straw buildings have been built, most of them in the USA. Rot and mould is without doubt the weakest point of straw, so it is necessary to safeguard against water penetration.

Table 2.4. List of raw materials of alternative products and product types.

Products	Raw materials	Products 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

The term 'dynamic insulation' describes insulation materials used as outdoor air filters. As a consequence of underpressure created in a building, the air passes though the insulation material and is heated by transmission loss. Dynamic insulation may be seen as a kind of heat exchanger and the more airtight? the house is, the greater the obtainable energy savings will be. The term 'evacuated insulation' is used as a common denominator for a group of insulation materials with the property in common that a vacuum between two surfaces helps improve the insulating property of an element. The surfaces are separated by filler, which serves additional purposes than to keep the membranes apart, such as a radiation barrier that reduces heat reduction through radiation compared with evacuated elements without a radiation barrier. Conversely, the filler contributes to conduction through the panel, which counteracts this effect. A number of evacuated insulating panels have been developed for refrigerating and cooling cabinets, and for refrigerating trucks and containers in the transportation trade. Compared with ordinary insulation materials, the advantage of evacuated insulation panels is improved overall insulating properties with less wall thickness. A considerable amount of research is going on in many places in the world, but information about advances is limited.
Moreover, mould-cast polystyrene blocks with holes to be filled out with cement are marketed, such as a product from New Zealand called “Formfour wall system”. Every block is made of EPS in with the measurements 1000 mmx250mmx300mm (l x w x h) and has 4 circular holes with a diameter of 160 mm. The product was developed for use in one and two-storey buildings. The term 'transparent insulation' is a material or a construction that has a green house effect like glass or better than glass. The material must have a high solar transmittance, but needs only to be clear as glass if used for windows. The insulating effect is normally caused by air gaps between the actual materials used. The materials can be divided into the following principal types: 1) Plane sheets and foils, 2) Corrugated foils and twin walled plates, 3) Honeyhomb and plastic foam, 4) Granular silica aerogel and 5) Monolithic

silica aerogel. The transparent insulation is the basis for both passive and active use of solar energy for heating.

2.3.3. Post-insulation systems of the thermal envelope

A well-insulated thermal envelope without thermal bridges is a passive way to obtain a low heat demand and improved thermal comfort. A certain thickness of insulation gives the largest effect if applied externally, because the largest possible numbers of cold bridges are broken. Furthermore the importance of air tightness to the heat demand and to the durability of the constructions must not be underestimated. Very few insulation materials are airtight in themselves and their insulating effect is due to still air in small cavities and depends on them being built into airtight constructions. At the same time, air movement through a building construction will transport moisture in much higher contents than possible through diffusion. A higher moisture content in the construction has two major effects, a significantly lower thermal resistance and possible condensation in the colder parts of the construction.
Post-insulation may include many kinds of initiatives, all of which reduce energy consumption for heating, but also cooling loads may be reduced. In this chapter an overall outline is given of the different existing possibilities for post-insulation of the thermal envelope with the main emphasis on the facades (windows are discussed in main chapter 2.2 and overcladding systems in chapter 2.4) and pros and cons of the different methods are given. The existing constructions will of course set some limits eg the sizes of the cavities in the constructions as they may be filled on-site with sprayed foams or granulates.

2.3.4. Internal post-insulation of facades

Internal post-insulation is usually done by mounting lathes on the inside of an existing construction. Insulation material is placed between the lathes and gypsum boards or wood finishes covers? the insulation. The lathes can be made of wood or sometimes a metal profile is used, but in all circumstances the lathes will form a thermal bridge. Dividing the total insulation thickness into two layers can reduce the thermal bridge effect. Letting the lathes of each layer lie perpendicular to each other reduces the thermal bridge to the area where the lathes cross. Internal post-insulation requires a vapour barrier to be mounted on the warm side of the insulation in order to prevent diffusion of moisture to the construction. It is often placed between the finishing internal cladding and the insulation material, but the vapour barriers can be placed approximately a third of the total insulation thickness from the warm side in the case of extensive post-insulation. This leaves the vapour barrier well protected and also leaves room for installation of electrical switches etc without rupturing the vapour barrier.
There are many disadvantages connected with post-insulation. In terms of moisture, internal post-insulation may involve a risk of defects in the construction caused by moisture, as the resulting moisture resistance of the vapour barrier, including any leakage at joint or ductways of installations, is required to be significantly higher than that of the original construction. Internal post-insulation will reduce the thermal bridge effect around the floors and joints between internal partitioning walls and exterior walls only to a limited degree. Post-insulation will moreover reduce the active thermal mass of the room, thus increasing the risk of overheating due to solar radiation. Apart from thermal and moisture disadvantages, internal post-insulation means that the room cannot be used as long as work is in progress and that the inner measurements of the room will be reduced. These many disadvantages are the reasons why internal post-insulation is not commonly used.

2.3.5. External post-insulation of facades

A number of insulation initiatives for facades can be considered external to post-insulation: Mounting of insulation layers on top of existing construction, replacement of windows, solar walls, ventilated solar walls and combinations of the above. Within each group several variations exist of how to carry out post-insulation in practice.
It is assumed that the original wall construction is solid or that cavity wall insulation has already been done in the case of cavity wall structures.

2.3.5.1. Mounting an extra external insulation layer

Extra insulation layers can be mounted on the existing facade without a ventilated layer of air if it is ensured that the external insulation cladding allows water to penetrate the constructions behind. At the same time the cladding must be sufficiently diffusion open to allow moisture diffusing into the construction from the indoor air to be drained off. Alternatively the external post-insulation can be executed with a ventilated layer of air between the insulation material and the finishing facade cladding. In this way moisture diffusing into the construction can be ventilated off.
Post-insulation without a ventilated layer of air is typically done by mounting the insulation material directly on the original facade by means of an adhesive and mechanical fastening such as through-going dowels. On the outside the insulation finishes with a reinforced layer of plaster. This way a surface without joints is achieved which provides the necessary winds and water tightness. In principle the insulation thickness can be freely chosen, but in practice it will depend on the shearing stiffness of the fastening and the insulation material, as in principle there is no support for the insulation material.
The ventilated solution is executed by mounting a profile system fastened to the original facade. The profile system can be built up of wooden lathes or metal profiles and serves to fasten the finishing facade cladding and as a means of fastening the insulation material. The insulation is placed between the mounted profiles and is fastened to the existing wall construction by means of through-going dowels. In some cases fastening is done by means of the metal profile directly. The fastening is to ensure close contact between insulation material and the wall surface behind. Moreover it contributes to maintaining the desired width of the gap between the surface of the insulation material and the finishing cover. The surface of the insulation material, orientated towards the ventilated layer of air, must be diffusion open but windproof and waterproof. This might be achieved either through the properties of the selected insulation material or by mounting a windproof cover. The insulation thickness depends on the strength of the selected profile system, as the system has to transfer the shear strength from the facade cladding to the construction behind. Both types of post-insulation requires special details around windows, doors and projections adapted to each building. If the external post-insulation is combined with replacement of windows, the windows should be pulled forward so that they are level with the post-insulation.
The existing facade should be reasonably smooth and able to absorb the loads from the mounted post-insulation systems. The unventilated solution focuses on the weight of the insulation material and the facade plaster that will result in a load equally distributed over the facade and which originates from bonding and anchoring with dowels. The ventilated solution is different as the weight of the insulation is equally distributed over the facade while the weight of the finishing facade cladding is distributed via the profile system, i.e. in more concentrated areas.

External post-insulation with a diffusion open layer of plaster or with a ventilated layer of air causes moisture problems and moreover it will lead to drying out of the original wall construction. External post-insulation is therefore often used in connection with facade renovation of concrete buildings with incipient attacks on the reinforcements.

External post-insulation makes large energy savings possible, as this type of insulation contributes not only to a reduction of the heat loss through the large wall surfaces but also eliminates the traditional thermal bridges where floor and internal wall are anchored in the exterior wall. The resulting energy savings depend on the insulation thickness and the amount of thermal bridges that occur in connection with the post-insulation.

2.3.5.2. Use of solar walls

Solar walls are alternatives 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 for reducing ventilation loss.

Solar walls have been roughly divided into ventilated and unventilated solar walls. The principle in both cases is to cover the original facade with glass to form a layer of air between the glass and the surface of the wall, which is painted black for greater solar absorption. Solar radiation causes the temperatures on the wall surface and in the layer of air to rise. Depending on its construction, the high temperature can be used in different ways to reduce the heat loss of rooms behind the solar wall.

Unventilated solar walls

The unventilated solar wall is the most primitive form of solar wall as it consists of covering? the facade with a layer of glass. The solar heat is transmitted by heat conduction through the wall to the room behind. The principle is to exploit a phase shift between solar radiation on the external side of the wall and the time when the heat reaches the internal side of the wall and can be supplied into the room.

The unventilated solar wall solution provides no possibility for regulating the heat transfer to the room behind the solar wall, unless it can be covered against solar radiation. This would be necessary in the summer period.

An unventilated solar wall is mounted by first repairing any defects on the existing facade and then by painting it black or adding a coating for improved absorption of the solar radiation. The selective coating can be added by supplying the surface of the wall with a selectively coated metal foil. The coating is characterised by high absorption of solar radiation (short-wave radiation) and low emissivity of heat radiation (long-wave radiation) and thus a major part of solar energy is transmitted into the wall.

Next a transparent cover is mounted on the wall by mounting glass or acrylic boards in a profile system fastened to the original facade. The gap between the cover and the facade should be optimised so that the best possible insulating properties are obtained, which causes a gap of approximately 15-20 mm. In cloudy periods this simple unventilated solar wall does not result in significant reduction of the heat loss through the wall. Alternatively the gap of air can be filled with a transparent insulation material that reduces the heat loss from the wall, also during cloudy periods, while at the same time reducing the amount of solar energy that is

transmitted to the surface of the wall. Transparent insulation materials will typically be constructed as a thin-walled matrix of plastic tubes perpendicular to the surface of the wall, thus transmitting a major part of the solar radiation to the wall. If transparent insulation materials are used in the solar wall, the thermal bridge effect of the profile system should be assessed like traditional external post-insulation. Preferably the profile should have low heat conductivity while at the same time be able to resist the high temperatures that may occur in the solar wall. The combination of a low thermal bridge effect and high temperature stability can be obtained, for example. by using punctured steel profiles. The unventilated solar wall is only suitable for poorly insulating solid constructions as the heat absorbed on the outside of the wall must be supplied by transmission through the wall to the room behind.
The existing facade must be reasonably smooth and the strength of the wall must be able to absorb loads from the added cover, ie the weight of the glass, which is transmitted to concentrated areas via the profile system. It must be ensured that materials close to the wall surface are able to resist temperatures of up to approximately 100 ^{o}C.
When constructing an unventilated solar wall, an almost 100% diffusion tight cover must be mounted on top of the original wall. This might cause moisture problems in the construction and, in spite of the term 'unventilated', a slight ventilation of the layer of the air between the cover and the outside of the original wall must be ensured. In Denmark the suggested size of ventilation openings per m^2 solar wall is a 10 mm whole at the top and also at the bottom. The ventilation openings are considered to reduce the insulating effect by 3%. Mounting of a solar wall will generally result in draining of the original wall construction as its mean temperature will increase at the same time as it is protected against moisture from the outside. It is recommended to paint the outer surface (black paint for improved solar absorption) with a diffusion open paint, so that any accumulated moisture in the wall may diffuse into the slightly ventilated layer of air.

Contrary to the traditional post-insulation, the energy saving potential by using solar walls depends on a number of factors such as the orientation of the surface, shading conditions and internal heat load. The internal heat load is important for the utilisation rate of the heat transported from the solar wall. In general, the use of suitable computer programs is recommended for calculating the energy saving potential in each case. As a rough estimate of the potential energy saving it is important to remember that, in contrast to traditional post-insulation, the use of solar walls will have the effect that during certain periods energy is transmitted through the wall to the room behind it. A precondition for obtaining the calculated energy saving is that the transported energy can be used without causing significant overheating**.** This also means that a doubling of the solar wall area does not necessarily result in a doubling of the energy saving.

Ventilated solar walls

In a ventilated solar wall the air in the gap between cover and wall surface is used as the primary heat transmitting medium, while the heating of the wall itself is of secondary importance. In its simplest form the solar wall works by means of openings located at the top and at the bottom of the wall which facilitates air circulation between the layer of air of the solar wall and the room behind. When the sun shines, the layer of air will be heated up and a thermal driving pressure will occur that will cause circulation of warm air to the room through the top opening and correspondingly cooler room air is driven out through the bottom openings. To avoid air flows in the opposite direction at night, the openings in the wall have been equipped with non-return valves that can work at low differential pressure.

The heat transfer will occur at the same time as solar radiation through windows in the facade, and this might lead to unpleasant overheating. The use of easily operated non-return valves does not allow control of the heat transmission. This can be obtained by using manually controlled or motor-controlled dampers. Solar walls with closed dampers will work as an unventilated solar wall thus delaying the heat transmission. In this way the ventilated solar wall provides a possibility for quick and relatively high heat transmission, if it is required (typically during winter), or a more reduced and split-time heat transmission (typically during spring and autumn).
The simple form of ventilated solar wall does not significantly improve the insulating properties of the wall, which is why energy saving is due to solar heat gain. However, the ventilated solution provides a possibility for combining post-insulation and utilisation of solar radiation. Establishment of external post-insulation means that heat transmission by conductivity through the wall is almost eliminated.

Ventilated solar walls can also be used for the preheating of ventilation air in connection with mechanical exhaust where, instead of circulation of the room air, the outdoor air is sucked in at the bottom of the solar wall. This system can be further improved to become a solar air collector where the energy from the air is transmitted to a central storage where the exploitation of the heat can be controlled by demand. The ventilated solar wall can be used at post-insulation of all types of wall construction as the primary wall transport is independent of the thermal mass and insulating properties of the wall construction.

Construction of ventilated solar walls is like the construction of unventilated solar walls, the ventilation ducts in the facade excepted. The ducts at the top and at the bottom are typically approximately 100 mm high and with a width that corresponds to the modular width of the solar wall. Non-return valves can be designed simply by mounting a frame provided with rough grating and a plastic foil fastened to its surface. During the day the plastic foil will be pressed away from the grating by thermal pressure, thereby allowing air circulation to take place, while the foil will be pressed against the grating during the night and thereby shutting off air flow in the opposite direction.
The existing facade must be reasonably plain? and the strength of the wall must be able to absorb the loads from the added cover, which means that the weight of the glass cover is distributed to concentrated areas via the profile system. It must be ensured that materials incorporated in the construction are able to withstand temperatures of up to approximately 100 ^{o}C.
Ventilated solar walls pose no risk of condensation, since moisture, which may have been supplied to the cavity between the solid part of the solar wall and the cover, will be quickly exhausted by the air flow in the solar wall when the sun is shining. It must be ensured that any moisture from driving rain and heavy condensation on cold nights can be drained away at the bottom of the solar wall. The moisture conditions in the original construction will be improved, as the construction dries out as a result of its higher mean temperature and at the same time it will be protected against moisture from the outside. It is recommended to paint the external wall surface (black paint for improved solar absorption) with a diffusion opening paint so that accumulated moisture in the wall can diffuse into the slightly ventilated layer of air.
Calculation of the energy saving potential for ventilated solar walls is somewhat more complicated for the unventilated solar wall, as there is a complicated connection between the temperature of the air in the gap between cover and solid wall, which is significant for the size of the thermal driving pressure and consequently for how much air circulates in the solar wall.

More ever, the heat transmission coefficient depends on the air flow velocity between the sunlit wall surface and the air in the gap etc The calculations can be performed by an iterative process and are solved by means of computer or pocket calculator programs.

The highest energy savings can be achieved by using the solar wall for preheating of the ventilation air, as a suitably high air velocity can be ensured through the solar wall with the increased heat transmission properties from absorber to air. As the largest part of solar energy is transmitted via ventilation air, this solution may advantageously be combined with post-insulation of the original wall construction. This will achieve energy savings by reduction of the heat loss through the wall even when the sun is not shining. The energy saving potential in Denmark ranges from 150-200 kWh/m^2 per year for a wall oriented towards south.

2.3.6. Post-insulation of roofs and floors

Roofs usually offer the most economical surface for placing thick layer of insulation, often by merely utilising the force of gravity, laying the insulation on top of the ceiling or structural part of the roof. A flat or almost flat roof present a hygrothermal problem as they must have an extremely tight cover to prevent snow and rain penetration as well as an internal vapour barrier. For more information see chapter 2.4 concerning overcladding systems.
The insulation from self-supporting floors is not significantly different from walls. Post insulation of floors is often done for comfort reasons to obtain higher floor temperatures and avoid draughts along the floor. A weak point to which special attention is required is the floor/wall connection for buildings with slab-on-ground constructions.

2.4. Overcladding systems

2.4.1. Introduction

Overcladding system is often the most logical solution to achieve a range of sensible improvements to the thermal performance of the external envelope of buildings,. It is best suited to be used in a comprehensive rehabilitation scheme, including windows and doors replacement and the installation of new heating and ventilation systems.
Overcladding system, in its generic form, is a composite one consisting of three key components:
Insulant (see chapter on Insulant materials and systems)
Fixing or framework
A variety of fixing are used:
- Mechanical fixing - metal or timber batten/rail system or framework and mechanical anchors or dowels
- Chemical fixing - various adhesives
- Mechanical and chemical fixing - a combination of the above fixings, eg chemical anchors.

Finish
There are two generic finishes:
- Wet render - polymer and fibre-reinforced cementitious renders (PMCR), polymeric coatings, insulating renders and cementitious renders
- Dry cladding - rigid boards, panels and tiling in a variety of materials.

2.4.2. Selecting overcladding systems

Overcladding system is appropriate for refurbishment projects when

- The external walls are poorly insulated
- The external walls are deteriorating or insufficiently weather tight, leading to damp, draught and heat losses.
- Wall cavities are bridged or blocked, limiting the possibility for cavity fill insulation.
- The use of internal lining insulation would be too disruptive, would alter critical internal dimensions or make room sizes too small.

General factors to consider in application of overcladding systems:

- overcladding system will involve alteration in various details of the building such as at windows, doors and where services punctuate the external envelope;
- the planning authority should be consulted for all overcladding system refurbishment projects. Overcladding system may not be appropriate where its application may alter the appearance of a sensitive or historic building.

2.4.3. Overcladding systems available

The following generic systems are available to choose from:

- Wet render systems
- Dry cladding systems
- Bespoke overcladding systems

Wet render and dry cladding systems are often proprietary products, developed and tested with third party accreditation for use in particular situations. Bespoke systems are designed by architects or others for particular projects and combine all the elements of proprietary systems.

Advantages of overcladding system

- ✓ Improves thermal performances
- ✓ Improves air tightness
- ✓ Transfers the dew point outside the structural wall element
- ✓ May contribute to improve sound insulation
- ✓ Optimises use of thermal mass
- ✓ Is relatively easy to install, leading to faster construction
- ✓ Ease of quality control as insulation coverage is clearly visible
- ✓ Renews ageing exterior facades
- ✓ Contributes to eliminate internal problems: damp, condensation and mould growth, when accompanied by controlled ventilation
- ✓ Avoids internal building works and can be installed during occupancy
- ✓ Increases life expectancy of buildings
- ✓ Limits disruption to the fabric of the building
- ✓ Does not reduce the size of the rooms
- ✓ Lowers maintenance costs

Drawbacks of overcladding system

- ⇒ Overcladding system finishes are not as robust as solid construction; without attention, damage can lead to dampness and weathering problems
- ⇒ Critical detailing requires knowledgeable design and care during installation
- ⇒ Approved installers must be used for proprietary systems
- ⇒ Guarantees are only provided if a proprietary system is used, otherwise performance becomes the designer liability
- ⇒ Small project demand the same level of technical support from system manufacturers as larger projects, hence they are relatively more expensive
- ⇒ Overcladding system is not suitable where an existing substrate is structurally unsound or cannot be repaired
- ⇒ Overcladding system may not be suitable for listed or sensitive historic buildings

2.4.4. Wet render systems

There is a wide range of wet render systems on the market. As insulation and fixing components are common to most systems, the component that distinguishes a high performance wet system from a low-performance wet system is the thickness and quality of the render. Wet render system consists of:

- Insulant
- Adhesive mortar and/or mechanically fixings, eg mushroom-headed dowels; fixing materials include polypropylene, nylon, stainless steel and plated steel
- Profiles and edgings in galvanised steel, stainless steel, plastic or aluminium, used on corners, at damp-proof course (DPC) level, window reveals, verges and copings
- Base-coat render, incorporating a glass fibre, plastic or metal mesh
- Top coat render with or without a finish

2.4.5. Use of wet render systems

Traditional render and PMCRs can be used on both low rise and high rise buildings. Polymer helps to make the render more workable on site, and in higher quantities provides weather protection and elastic flexibility in the render. Thin polymeric coatings can be used on both low-rise and high- rise buildings. The reduced weight of the render can be found to be advantageous in high-rise buildings. Polymeric coatings are relatively new on the market.

2.4.6. Critical detailing - Wet render systems

For wet systems, there are standard details and methods of application that must be followed according to manufacturers' recommendations. Particular care should be taken in the following areas:

- Fire spread and fire barriers - all systems must meet the current standards and regulations. Note that in multi-storey buildings, unless mineral wool insulation is used, fire breaks will be required in the overcladding system to prevent the spread of flame externally.
- Fixings to substrate - must take into account the nature and condition of the substrate, dead and imposed loads (wind pressure and dynamic suction), corrosion of fixings, and the movement of the system, with or isolated from, the building fabric.
- Render specification - to ensure weather protection, resistance to cracking, durability, aesthetic requirements, resistance to dirt and algae and to fulfil maintenance requirements.
- Specification of PMCR - the quantity of polymer used may vary considerably and the specifier should seek assurance from the manufacturer that the render is suitable for a specific application.
- Racking of renders and differential movement - cementitious-based renders must have movement or expansion joints in accordance with manufacturers' recommendations.
- Movement joints in the existing structure - Overcladding system will need joints at the same location
- Day-work joint - should be specified in the render system.
- Work on site - precautions should be taken to minimise particle spread from rasping of polystyrene insulation.
- Air leakage - must be prevented through the construction by correct detailing to avoid heat loss.

- Sealing of joints - must prevent water ingress into the system.
- Bi-metallic corrosion - must be avoided by correct specification
- DPC detailing - in existing and new buildings must not be compromised by insulation cover.
- Existing and new services - designers and installers need to resolve how to treat, for example, down pipes, gutters, gas mains, phone lines and aerials.

2.4.7. Dry cladding systems

Many dry cladding systems are available. They use a variety of supporting frameworks fixed back to the substrate or building structure. A cladding material is fixed to the framework based on standard cladding technology. Dry cladding systems consist of:
Insulant
Independently fixed to the substrate with a mechanical or adhesive fixing, or partially retained by the framework. Quilt material can reduce the risk of thermal bridging forming a tight fit around the framework.
Support framework or cladding fixing system
Support framework are constructed of treated timber, steel or aluminium. An adjustable framework ensures a true plane can be achieved over an uneven substrate. A stand-off framework or cross battening allows a continuous layer of insulation to the substrate, minimising thermal bridging. Spans can be mounted over substrate areas where fixings cannot be obtained. Frameworks members, their size, frequency and strength of fixing to substrate are designed to withstand wind-loadings in accordance with manufacturers' recommendations. Supports will accommodate the insulation and a ventilated cavity behind rainscreen cladding.
Ventilated cavity
Most dry cladding systems incorporate a ventilation cavity between the cladding and the insulation to ensure that any moisture penetrating the cladding through the joints or migrating from inside the building is carried away
Cladding materials and fixing
Many cladding materials are available, including resin-impregnated laminates, highly compressed mineral wool, fibre-reinforced calcium silicate, aluminium panels and clay tiles. It is possible to have open joints to form a rainscreen cladding, or sealed joints for a fully sealed system. A wide range of colours and textures are available. Cladding fixings include nails, screws, rivets or partial secret fixing using adhesives. Pressed profiles, trims and cover/edge retention strips can add to the decorative effect of a panellised cladding system

2.4.7.1. Use of dry cladding system

Dry cladding system is particularly useful where fixings are restricted to particular areas of the building. Dry cladding is not used frequently on low rise buildings, where the cost can be prohibitive. Moreover the necessity to avoid possible damages of the system at the lower levels of the building suggests the use of different insulation methods for low rise buildings.

2.4.7.2. Critical detailing - dry cladding systems

As for wet systems, methods of application and system detailing should be according to manufacturers' recommendations. Particular care should be taken in the following areas: *Fire spread and fire barriers* - all systems must meet current standards and regulations.

Fixing to substrate - must take into account the nature and condition of the substrate, dead and imposed loads (wind, pressure and dynamic suction), movement of system with or isolated from the building. *Thermal bridging* - prevention by the use of a stand-off framework or cross-battening and ensuring the insulation is fitted tightly around the framework.
Maintenance of ventilation behind rainscreen cladding - by correct configuration of the supporting framework, correct fixings and retention of the insulation material and provision of permanent ventilation openings and non perforated cavity barriers. Bird and insect barrier or mesh should be added. *Air leakage* - must be prevented through the construction by correct detailing to avoid heat loss. *Existing and new services* - designers and installers need to resolve how to treat down pipes, gutters, gas mains, phone lines and aerials.

2.4.8. Bespoke overcladding system design

Designed individually by architects and designers, such a system tends to be simply detailed, allowing a non-specialist building contractor to construct it. The potential for bespoke overcladding system design mainly lies in dry cladding. A typical design may incorporate a rainscreen onto a substrate such as single blockwork, employing simple timber framing technology.

2.4.8.1. Critical detailing and watchpoints for bespoke overcladding systems

As for dry systems, the design should consider: water ingress - maintain a ventilated cavity; dynamic suction and imposed loads; fire protection - incorporate cavity barriers and prevent surface spread of flame; maintenance and durability - suitable specification of cladding material and ease of replacement.

2.4.9. Selecting a system

2.4.9.1. Factors affecting the choice of a system

The main aspect to check in choice of a system is the suitability for the proposed application, for this purpose proprietary systems should be tested and accredited for use in a particular situation. The design and type of fixing and strength of the system have to fit the requirements for wind loading resistance. The condition of substrate can influence the choice of system, according to the type of fixing and framework available. The performance of insulation influences thickness to be achieved. Mouldability and flexibility of the system is required to form or fit around external features on a façade. Incorporation of fire barriers and prevention of fire spread can affect fire performance evaluation. Vapour permeability have to be checked in order to ensure the correct dew point position in the construction. Buildability and ease of construction evaluation may prevent problems on site and increase speed construction for a cost-effective solution. Ease of access itself may affect cost of supply and installation. Maintenance requirement have to be evaluated in order to ensure longevity and low long-term costs. Rough costs of different systems can be indicated as follows: wet traditional, insulated and PMCR renders present the lower cost per square meter, wet polymeric coating and dry bespoke design have medium costs and dry cladding systems present the higher costs per square meter (up to 3 times the cheapest one).
Systems described above present advantages and drawbacks. The following table suggest some of the possible of them in order to facilitate the choice of the system suitable for different situation.

	Advantages	Drawbacks
Dry cladding systems	• Panels can be removed easily for inspection or for replacing • A dry system with a ventilated cavity may be more appropriate where driving rain and high exposure levels are a problem • Vapour permeability is maintained where a ventilated cavity is used • Faster construction than wet systems • Fixing system or framework can provide some degree of stability or span over problem areas • Can be applied in freezing conditions • Manufacturers technical service available	• High performance dry system can be relatively expensive compared with high-performance wet render systems • Supervision is required for correct installation of insulation to ensure reduction in thermal bridging and maintenance of ventilated cavity • Thermal bridging may arise unless carefully designed out • High quality control required on site • High performance dry system can be relatively expensive compared with high-performance wet render systems
Wet render systems	• Different systems are available in a range of technical performances for varying situations • Polymeric coatings do not need movement joints where they are not required in a substrate • Manufacturers' technical service available	• Renders cannot be applied in low temperatures, especially polymeric coatings • It is not possible to inspect behind render after application without remedial works • High quality control required on site • Mess on site may occur when rasping polystyrene
Bespoke systems	• Gives control of the composition and costs of individual materials as they are not part of a manufacturers' package • Gives the opportunity to use sustainability sourced products and materials • Gives the ability to design the system to allow vapour permeability through the wall construction • A wider variety of finishes can be used - eg weather boarding, stone, glass, terracotta and tile hanging • Is of tailor-made design to suit the building and its context	• No guarantee is available • No technical service is available from system manufacturers • Guaranteed performance becomes designer's liability • New designs are untested

2.4.10. Ventilated Roofs

This kind of system may be obtained by the use of an air layer of constant thickness placed between the covering elements and the below layers. This layer has the function to contribute to the control of the igrothermal characteristics of the roof through adequate air changes. This system comes adopted to the aim of:

- in the warm season: reducing the heat gains below the tiles through activation of convective flows, making comfortable the lving of the attic
- in the cold season: avoiding the humidity stagnation under the tiles, with consequent condensations that may deteriorate the insulating materials and the other structures of the cover.

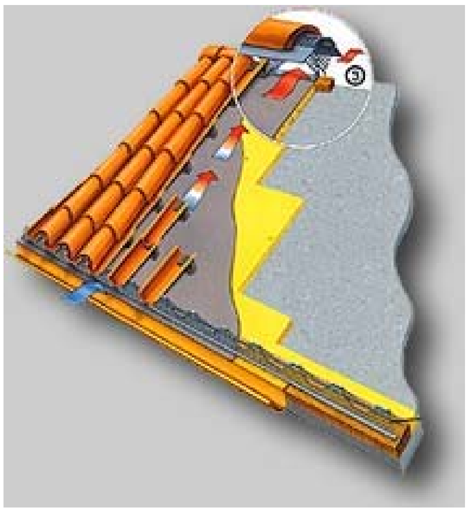
The discontinuous covers, regarding to the methodology of control of the igrothermal behavior of the structure, can be characterized and classified in the four following functional outlines:

- roof without insulating layer neither the ventilation one.
- roof without insulating layer, but equipped of the ventilation one.
- roof equipped with insulating layer, but lacking in the ventilation one (hot roof).
- roof equipped with insulating layer and the ventilation one too (cold roof).

From the igrothermal point of view the last type of cover is perhaps the one which gives the best guarantees of a satisfieing operation. The insulating layer allows to catch up the demanded value of total thermal resistance while the ventilation layer contributes to regulating the igrothermal characteristics of the cover

The ventilated layer (always placed immediately over the insulating one) can be realized by means of the space attic or also obtained by means of an appropriate ventilated air layer of constant thickness, tilted, adjacent to the structural layer. There are several techological systems to obtained ventilated roof.

- Under-tile ventilation system: it consists in a ventilated preassembled panel which makes possible to put down the insulating material, the room of ventilation and the support for the cover mantle in one operation only. The ventilation room has the height of cm.4. The system includes the supply of one antisparrow grill and a ventilated overflow to realize in work.



- Ventilated/Anchorated roof: the system consists in one room of ventilation obtained by means of the application, on every channel between the tiles, of an element with functions of rise-spacer and, at the same time, anchorage of the tiles. The obtained interstice complies with the following technical prescription: ventilation surface not less than cmq./ml.600; absolute absence of horizontal fillets limiting the upward air flow of warm air. The direct contact of the cover with the ventilation interstice takes advantage of the overheating of the air increasing the outflow speed. This system adapted to install new or recovered tiles and it is equipped of an antisparrow grill in a position to let the warm air coming go out

2.5. Doors

2.5.1. External doors

Heat loss through doors can be prevented by draught sealing and also by thermal insulation. The potential heat loss due to air infiltration is however far higher than that due to poor thermal insulation.

Prevention of air infiltration heat losses can be achieved in a number of ways.

1. Provision of draught lobbies
2. Fitting of weatherproof draught seals to external doors
3. Provision of an indoor unheated buffer space between the inside and the outside.
4. Fitting revolving doors fitted with brush seals
5. Fitting draft prevention air curtains
6. Fitting door closers on external doors (although the opening pressure may be too high for primary age or disabled pupils).

Thermal insulation of external doors

Doors should be insulated as far as possible. The UK Building Regulations give minimum standards to be applied to all buildings, see
http://www.safety.odpm.gov.uk/bregs/brpub/ad/ad-l2/pdf/complete.pdf
The maximum elemental U-values for the construction elements are given as:

	Maximum U-values (W/m^{2}K)
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in metal frames	**2.2**
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in wood or PVC frames	**2.0**
Windows, roof windows and personnel doors (area weighted average for the whole building), glazed in metal frames	**0.7**

For doors which are half-glazed the U-value of the door is the average of the appropriate window U-value and that of the non-glazed part of the door (eg 3.0 W/m^{2}K for a wooden door).

Draught prevention on external doors

Main entrances to schools should always be lobbied to prevent large heat losses due to the frequent movement of people into and out of the building. Wherever possible, draft lobbies should also be provided on external doors on circulation routes and on external classroom doors.

Fitting a revolving door fitted with brush seals is an alternative in a large school or university building but a lobby is preferable where there is room to incorporate one.

Revolving doors can be manual or motorised. The manual ones require quite a large force to open them against the brush seals and would not be suitable for primary school children. Generally an additional door must also be provided for wheelchair users and others with mobility problems therefore the space taken up by a revolving door is likely to be larger than a lobby with manually operated doors.

Lobby doors can be motorised and operated by proximity detectors. These are not often necessary in most schools. Because of the use of a lobby the door seals can be simpler and therefore easier to open than doors opening directly to outside.

2.5.2. External classroom doors

External classroom doors are frequently used by the children in early years education where the children spend a lot of time outside, playing with sand and water, using climbing frames, bicycles, wendy houses and the like. A frequent flow of children in and out is encouraged. Sometimes the whole classroom wall can be opened and an inside-outside space is created in summertime. During the colder months however this leads to large heat losses unless some way can be found to prevent the entry of cold air.

Due to space restrictions it is not always possible to lobby a classroom door opening directly to outside. One way of economising on space is to make the lobby serve another function such as a cloakroom or corridor to a toilet area.
A lobby to a primary school classroom can include a changing area and storage for coats. It can also accommodate individual toilet accommodation for each classroom. This is preferable to toilet provision centrally in a primary school as it allows better supervision of the use of toilets.

For less frequently used external classroom doors, eg for older children, or where space is restricted a sliding type door may be appropriate. These may require fitting with heated air curtains which also prevent the ingress of cold air.

2.5.3. Air curtains for draft prevention

Air curtains should be considered wherever there is a single door to outside which is used during cold weather.

<u>Physical curtains</u>
Physical barriers are available as are often seen on industrial loading bays which are used by fork lift trucks and other motorised vehicles. They consist of overlapping heavy plastic or rubber flaps which have to be physically moved aside. They would only be appropriate for industrial type delivery and loading areas for example in heavy engineering laboratories.

<u>Air curtains</u>
Air curtains are widely used in schools both as a retrofit measure to single external doors and where space restrictions or other considerations results in the use of a single external door. They work by blowing a jet of air, usually from above, across the door opening, which prevents cold air from entering. Heated jets are usually used although unheated air curtains are also available. Unheated jets use fans of higher capacity. The fans are usually quite noisy as they need to be of high capacity and are within the room space and therefore can disturb teaching activities.

Both the weather tightness and the sound insulation of door sets require the use of perimeter seals. For example, UK Building Bulletin 93 *The Acoustic Design of Schools* requires a sound insulation of 30 dB R_w for doors from classrooms onto corridors and 35 dB in the case of music rooms. This requires the fitting of threshold and perimeter seals of a similar type to those used on external doors for draught sealing. The guidance for doors in BB93 is based on realistically achievable values of airborne sound insulation from affordable doors suitable for schools.

To maximise airborne sound insulation of door sets[1], doors should be heavy and be sealed around their perimeter. However, safety issues and the need to include disabled pupils in mainstream schools mean that the ease with which doors can be opened and closed and the type of door closers fitted need to be considered when specifying for schools.

The choice of door seals should consider the frequency of use of the door. BS7352:1990 (now withdrawn) gave the estimated number of door operations for buildings. Many smoke seals have been tested for robustness against frequency of operation whereas some acoustic seals have not. Therefore, it may be advisable to choose a seal profile that is rated as both an acoustic and a smoke seal. BS 7352 included the following figures for schools:

	Estimated number of operations	
High frequency heavy duty situations:	Daily	Annually
School entrance	1,250	225,000
Entrance door to school toilets	1,250	225,000
School corridor fire door	600	108,000
Medium frequency medium duty situation:		
School classroom door	80	15,000

Draught seal manufacturers:
www.lorientgroup.com (see information on their *Integrity* range of architectural seals)
www.sealmaster.co.uk

2.5.4. Disabled and pupil access

The specification of door widths needs to take into account the needs of wheelchair users. BS8300: 2001 Design of buildings and their approaches to meet the needs of disabled people, from the British Standards Institution and Approved Document Part M:1999 *Access and facilities for disabled people,* in support of the Building Regulations in England and Wales give requirements relating to door widths, vision panels and maximum door opening pressures.

The maximum acceptable opening pressure is limited by the strength of pupils of different ages and also the requirement for a wheelchair user to be able to open the doors.

Generally the opening force required to open a door is governed by the type of seals applied to a door, the weight/width of the door, the power of the door closer if fitted, the friction in the hinges, the resistance introduced by any seals and the airtightness of the room into which the door is opening.

[1] A door set includes the door, door frame and all furniture.

2.5.5. Door Closers

Overhead or floor mounted door closing devices are often fitted to doors on circulation routes to satisfy the fire regulations. These comprise of a spring and a hydraulic control to regulate the closing speed. They may or may not have power adjustment.
When linked to an automatic fire alarm system these can be replaced with either of two types of automatically released closer devices. “Swingfree” types where the door is free to be operated manually until closed in the event of a fire or “hold open” where the closing device holds the door in the fully open position, again until released in the event of a fire. Where classroom doors are fire rated they have to be self closing and should be fitted with one of the above closing devices.
Door closing devices on external doors can be a problem in that they make doors harder to open, particularly for small or disabled children and there are cases where motorised door opening as opposed to the use of mechanical door closers will be needed on external doors to overcome this problem. An external door closer has to exert sufficient pressure on the door to overcome various amounts of wind pressure and if this pressure is applied mechanically the force needed to open the door against the mechanism can be too high for a young child to operate the door. Therefore, whilst door closers are a low cost energy saving option they need to be used with care.
Sometimes the force required to close a heavy airtight door using a closer is so high that a child would not be able to open the door against the spring pressure of the closer. It is important to provide some trickle ventilators for background ventilation to any classroom as well as larger ventilators which can be closed when the room is unoccupied. This will allow the air in the room to escape without producing undue pressure on the face of the door as it is opened.

2.5.6. Maximum opening forces for different age groups

Guidance on acceptable forces required for the disabled to open doors is given in BS 8300:1991. Section 7.2.6 of this standard states that the closing force on a double swing door across a corridor should not exceed 30N on its leading edge. Note; swing doors are doors that open in both directions, that is doors that have no stop (A dictionary of building, John S Scott, Penguin reference books,1964).
BS 8300:1991, Section 7.3.1 states that the opening force for single swing doors that are not part of a building’s fire protection and are fitted with closing devices for security, privacy or control purposes, should not exceed 20N on their leading edges.
Section 7.3.2 states that single swing fire doors fitted with a door closer should conform to the requirements of BS EN 1154:1996, *Building hardware – controlled door closing devices – requirements and test methods*.
A recent specification for educational inclusion states that “Doors that need to self close for acoustic or security reasons will be fitted with closer devices with closing forces of less than 20 Newtons on the door (30 N if the door can swing in either direction), or will have automatic or push-pad power openers fitted to them.”
Discussions with a research organisation with experience of tests according to BS EN 1154:1996 suggested that 20N is likely to be the minimum force measured in a series of tests according to BS EN 1154:1996 that would give the necessary torque to open a 20kg, 750mm leaf door fitted with a door closer. Such lightweight doors can only be used where there is no requirement for the door to achieve a high sound rating. This is another reason for using lobbies in schools where otherwise the door would prove very difficult for the pupils to open.

Table 1 in BS EN 1154:1996 contains the following information:

Door closer power size	Maximum recommended door leaf width (mm)	Test door mass (kg)	Maximum opening moment between 0^o and 60^o (Nm)
1	<750	20	26
2	850	40	36
3	950	60	47
4	1100	80	62

The values in Table 1, BS EN 1154:1996 are relevant for doors that open one way (doors that have a stop) and swing doors. The table suggests that the maximum opening force on a 40kg door with an 850mm leaf should be ≈ 42N at the leading edge (a clear door opening of 850mm is adequate for wheelchair access according to BS 8300:1991).
BRE information paper IP2/82, Ergonomic requirements for windows and doors, contains a table giving suggested maximum opening forces for females in the age groups 5 – 12 years and 60 – 75 years for hinged doors with knobs and handles.
For the 5 – 12 years age group, the suggested maximum opening forces (push or pull) in IP2/82 are:

- 20N for doors with knobs, (knobs are seldom the correct specification for educational use)
- 45N for doors with handles.

45N force applied at the lever of a door which is 800mm from the hinge side is equivalent to a moment of 36Nm. This is equal to the maximum recommended opening moment for a 40kg door fitted with a closer in Table 1, BS EN 1154:1996.
(Note: maximum operating forces for doors with lever handles of 30N for age group 5-7 years and 70N for age groups 8-11 and 60-75 years are suggested in a document containing test results provided by Janex Ltd).

Compression seals between a door and its stop are often used to improve the sound insulation of door sets and it is unlikely that these will add significantly to the force required to open the door. However seals beneath doors are also necessary to maximise their airborne sound insulation. If these seals add significantly to the force required to open and close doors they could be unsuitable for schools.
Discussions with an organisation with experience of testing to BS EN 1154:1996 suggest that ‘drop down’ threshold seals are the type least likely to add to significant frictional force. An organisation with experience of specifying and supplying doors to schools advised that they specified ‘drop down’ seals because these avoided the need for thresholds. However, it should be noted that no test data comparing the torques necessary to open doors with different types of seals beneath have been made available.

Discussions with manufacturers and examination of available test results indicate that a 30 minute fire door set (FD30) can achieve airborne sound insulation of 30dB – 32dB R_w with a drop-down seal fitted to the underside of the door. It is important to note that these are values for airborne sound insulation measured in a laboratory. For these measurements, it is usual for manufacturers to take special care that doors and seals are installed correctly. Therefore, it is reasonable to assume that the values for airborne sound insulation for doors given by manufacturers are unlikely to be exceeded when they are installed in schools.

Specialist acoustic door sets can be expensive to buy and install correctly. Therefore, it would appear appropriate that readily available fire door sets, or sets with solid core doors of equivalent mass, with appropriate seals should be specified for most situations in schools. If schools decide that specialist 'acoustic' doors are needed for specific applications, then that is a matter for those schools.

2.5.7. Management and maintenance of doors

Keep windows and doors shut when the heating is on

Look to see if draught seals are intact each term as part of energy efficiency walk round

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Gale and Snowden Architects: Good Practice Guide no. 293 - BRESCU Energy Efficiency Best Practce Program

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Types of draught seal

Chapter 3

Heating systems

by

Raphael Haller, Radek Gorzenski

Table of contents

3.1. Introduction

A new approach to evaluate buildings and their HVAC-systems follows the development of requirement from the building with its usage, internal loads and the climate, through the room system (heat, cooling, conditioned air), distribution and the heating- and cooling generation system. Since none of these system areas – room system, distribution- and generation system – can be achieved perfectly, some additional energy input is necessary at each stage. This in connection with the typical reference load requirement for the building and its use gives the total load requirement to be supplied by the generating system.

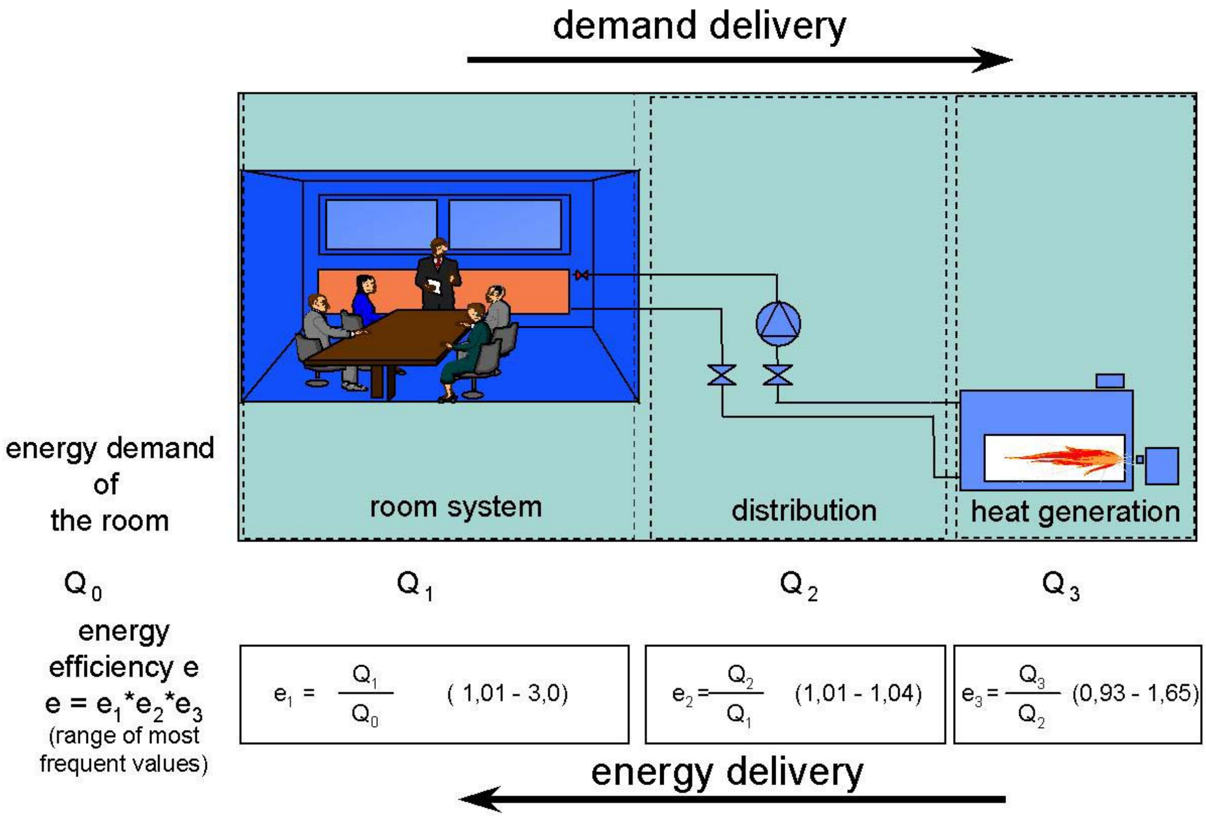

Fig. 3.1.1 Demand and energy delivery

Heating systems are evaluated by comparing benefit and expenditure as it is done in other technical systems. The benefit of a heating system is to maintain comfortable thermal conditions in the rooms for the occupants. The requirements of the occupants for their thermal environment are independent from the heating system. Usually they specify their demands with nominal temperatures for the room air and for the inside surface temperatures of the walls. These temperatures depend on activity and clothing. A further task of a heating system is to warm up the incoming air from outside, which is necessary because of comfort, health, hygiene and building physics. The delivery of the benefit by the heating system is called „room system“. The planning tasks for a good room system consist of suitable selection, dimensioning and arrangement of the room heating systems.

It is possible to determine the heat load which must be transfered to a room in order to supply exactly the existing demand, this is the heating load. The time dependent integral over the heating loads – the ideal minimal energy demand Q_0 – is an energetic value to compare subsequent processes which satisfy the demands (room system, heat distribution, heat generation). DIN EN 832 /1/, DIN 4108-6 /2/ or VDI 2067-11 /3/ contain the description for calculating the building-specific load requirements of heated and air-conditioned buildings.
Figure 1 shows the direction of the demand development in a building. Starting from the building itself, its planned usage and the climatic influences the first level is the room system, second level is heat distribution and the third level is the heat generation system. Since each of these subsections cannot be implemented in an perfect way, an additional energy demand, Q_1 is caused. If this additional energy demand is brought into relation with the ideal minimized energy demand Q_0 , (which is typical for a building and its use), an energy efficiency factor e_i can be defined. This will be used as an energetic evaluation value for the individual subsections. Therefore the minimal energy demand Q_0 multiplied with the energy efficiency factor e_i of each subsection gives the total yearly primary energy demand it is needed by the heat generation system. It is planned to provide the energy efficiency factors for every sub-system of heating systems. DIN 4701-10 /4/ provides primary energy efficiency factors for different heating-, ventilation- and domestic hot water systems. These energy demand values determined by this procedure are calculated values. They are valid for an common legal proof only. It is not applicable to calculate the energy consumption in advance. The essential objective is to show differences between individual systems. This can be determined to a sufficient degree.

This approach is also the basis for the following classification. In some cases (e.g. 2.1.1 – 2.1.3) room system, distribution and heat generation take place in one system. They usually have a combined energy efficiency factor.

3.2 Heating installations

3.2.1. Classification of heating systems

3.2.1.1 Room heating systems

Decentralised stand-alone heating devices

Simple stoves, when there are simple requirements for comfort and ease of use. Single heaters are operated with fuel oil, gas or electrical power. We differentiate between radiative and convective heating.

Single room heating devices

Typically direct gas fired heaters are used for special applications, e.g. in gymnasia or in laboratories. They are also sometimes used in classrooms as room heaters, especially in extensions and temporary buildings.
The devices need a connection to a chimney or a balanced flue. Direct oil fired heaters are rarely installed today but are often found in existing buildings. Direct electrical direct heaters are suitable for buildings with very good thermal insulation only and/or when load requirements are very small ($Q < 20$ kWh/m²a) and/or in buildings, which must be heated only for a short time.
Radiative heaters, e.g. electrically heated plaques made of glass or stone or gas heated radiant tubes (often installed in sports halls) are available. Convector heaters are available either as natural convectors or fan-assisted.

Room air heating device (indirect air heater)

Central ventilating and air conditioning systems are used for the conditioning of the supply air for rooms. These systems can serve several functions: Air can be heated up, cooled, or be de- or humidified after-heating up.

Effective heating surfaces

Effective heating surfaces are classically used in Europe. We differentiate between integrated heating surfaces which are an integral part of the building construction and free standing heating surfaces. High requirements for comfort can be achieved by simple adjustment to the demand. At the same time this is economical.
For these systems very good application and interpretation rules are present in Europe.

Integrated Heating Surfaces

Floor- and wall heating

With floor and wall heating systems the benefits delivery at the surface of the floor and/or the wall takes place. Usually the system with water is operated, the market however offers also electrical systems. In principle, floor and wall heating systems are thermally slow-acting, i.e. they react slowly to the demand in the area. In areas with very high requirements on the comfort e.g. floor heating with radiator heating can be combined. For floor heating a maximum surface temperature of 29°C and/or 9-15K over air temperature is tolerable. The recommended maximum surface temperature may be as low as 25°C where children are sitting on the floor.
Floor heating systems are designed according to DIN 4725 /5/.

Cladding heating

Cladding heating systems are systems where water is flowing through window construction elements. In school buildings they are rarley used. For their design no guidelines are available.

Free heating surfaces

The standard thermal output of heating appliances is - according to DIN EN 442-2 /6 / – an output at temperatures t_1=75°C/t_2=65°C/t_{room}=20°C. The design temperatures t_1, t_2 can be chosen at a lower level in favour of better control.
The heat emission is controlled:
at the heating appliance by the thermostat/ valves installed
with a single room control system, which controls the valve by means of a room temperature sensor, that is installed centrally at a wall.
in heating zones, where a temperature sensor in a typical area of the heating zone controls the heating to the entire zone. This can be combined with thermostatic radiator valves for trim control.

Ceiling heating

Ceiling heating surfaces are room heaters, which are placed horizontally or at an angle under the ceiling. The heat is transfered by radiation and convection depending on the surface temperature of the emitter. They are applied in large areas and heights starting from 3,5 m e.g. in gymnasia, laboratories and workshops. Ceiling heating surfaces are sometimes used in schools as they leave the wall surfaces free for equipment.

Steel-, pipe- and cast iron radiators

In Europe classical steel and cast iron heating elements are still sometimes used due to their appearance and longevity. Due to their weight and their large water content they react slowly to changing demands and have thus relatively high energy efficiency factors. The radiation is less than 40% of the total heat emission. Energy efficiency factors for steel and cast iron heating appliances are given in DIN 4701-10 /4/ and VDI 2067-20 /7/.

Panel Steel Radiators

Panel steel radiators are heating appliances with one or more panel where water-flows between plates. Between the plates additional extended heat transfer surfaces can be attached to increase the output. The radiation of panel heating radiators is approx. 45%. Because of the relatively large radiation portion flat heating radiators are suitable for compensation of cold radiation e.g. from windows or other cold envelope surfaces. Thus comfort deficits are eliminated effectively. Energy efficiency factor for panel heating radiators are given in /4/ or /7/.

3.2.1.2 Distribution systems

Within the system area "distribution" a thermal energy expenditure occurs through a heat losses from the system and its components as well as an electrical energy expenditure for the circulation of the heating medium (air or water usually). The medium used in heating systems is predominantly hot water in the temperature range between ambient temperature and up to 80°C. Water flow is circulated by pumps. In many cases it turns out that circulation pumps are usually over-sized. Therefore potential savings exists by using the correct size of pumps.

In Europe Steam central heating systems have almost disappeared from the market because of their poor controllability and for safety reasons.

3.2.2 Evaluation of Heating Systems Suitable for Educational Buildings

The following heating-systems are suitable mainly for buildings which are predominantly classrooms. The energy demand for hot water is assumed therefore to be small. It is recommended to generate the hot water by decentralised systems, storage or instantaneous type water heaters, electric or gas fired. Furthermore it is assumed that there are no mechanical ventilation systems. The necessary exchange of air being provided by natural ventilation.
The energetic evaluation follows the method described in chapter 3.1. To get the end energy demand after retrofitting with one of the following systems, the energy demand Q_h has to be multiplied with the energy efficiency factor e given in each table.

Description of system 0

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 90/70°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, high-temperature boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy efficiency:

Table 3.2.1: Energy efficiency factors system 0

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	1,4	1,35	1,35
	80	1,28	1,24	1,24
	120	1,24	1,20	1,48
	160	1,22	1,19	1,19
	200	1,21	1,17	1,17
	240	1,20	1,17	1,17

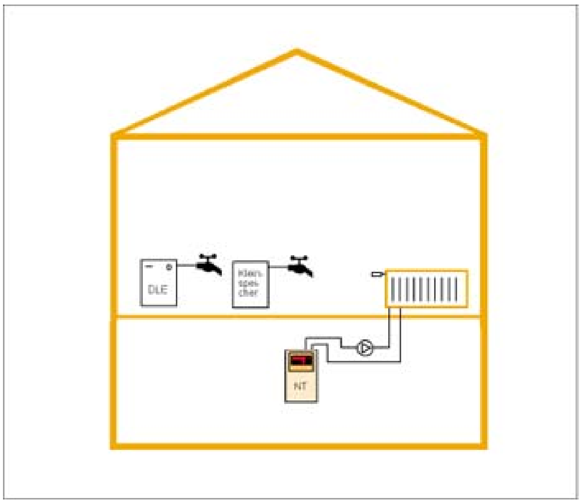

Figure 3.2.1: Illustration of system 0

Description of system 1

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 70/55°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, low-temperature boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy efficiency:

Table 3.2.2: Energy efficiency factors system 1

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	1,28	1,26	1,26
	80	1,19	1,17	1,17
	120	1,15	1,14	1,14
	160	1,14	1,13	1,13
	200	1,13	1,12	1,12
	240	1,12	1,11	1,11

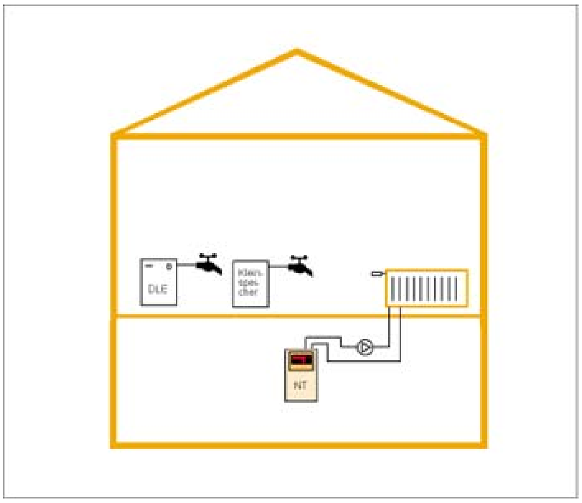

Figure 3.2.2: Illustration of system 1

Description of system 2

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall, P-control (e.g. design proportional range of 2K), 55/45°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, condensing boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy rating:

Table 3.2.3: Energy efficiency factors system 2

e [-]		A [m²]		
		2400	7800	30000
Wh	40	1,18	1,16	1,16
	80	1,1	1,09	1,09
	120	1,07	1,06	1,06
	160	1,06	1,05	1,05
	200	1,05	1,04	1,04
	240	1,05	1,04	1,04

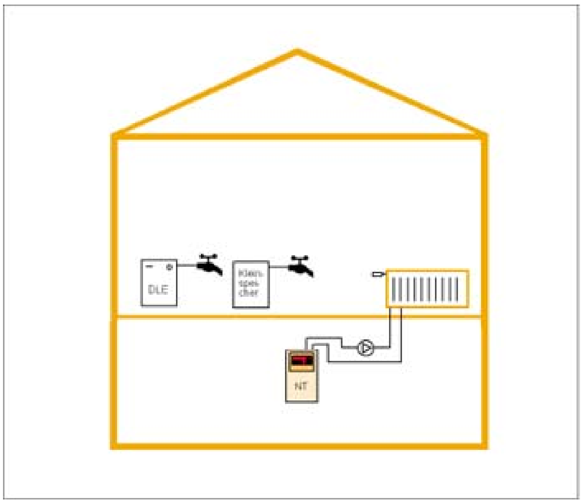

Figure 3.2.3: Illustration of system 2

Description of system 3

Heating:

Room system:
Integrated radiant heating surfaces (floor, or wall heating systems), single room regulation system, 35/28°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, condensing boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy rating:

Table 3.2.4: Energy efficiency factors system 3

e [-]		A [m²]		
		2400	7800	30000
Wh	40	1,11	1,10	1,10
	80	1,04	1,04	1,04
	120	1,02	1,02	1,02
	160	1,01	1,01	1,01
	200	1,01	1,00	1,00
	240	1,00	1,00	1,00

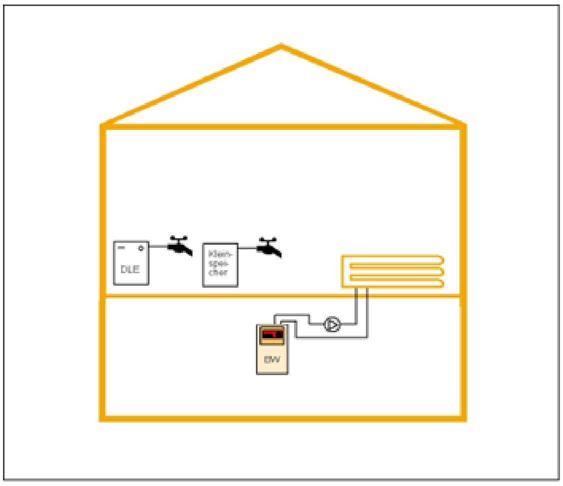

Figure 3.2.4: Illustration of system 3

The following heating- and ventilation-systems are suitable mainly for buildings which are predominantly classrooms. The energy demand for hot water is assumed therefore to be small. It is recommended to generate the hot water by decentralised systems, storage or instantaneous type water heaters, electric or gas fired. Furthermore it is assumed that there are mechanical ventilation systems. The necessary exchange of air is provided by the mechanical ventilation system.

Description of system 4

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 70/55°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, low-temperature boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
central system, outside/discharge air, distribution inside the thermal envelope, air exchange rate 0,5 1/h, heat recovery by cross flow heat exchangers with efficiency 60%

Energy rating:

Table 3.2.5: Energy efficiency factors system 4

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	1,28	1,26	1,25
	80	1,18	1,17	1,17
	120	1,15	1,14	1,14
	160	1,14	1,12	1,12
	200	1,13	1,12	1,11
	240	1,12	1,11	1,11

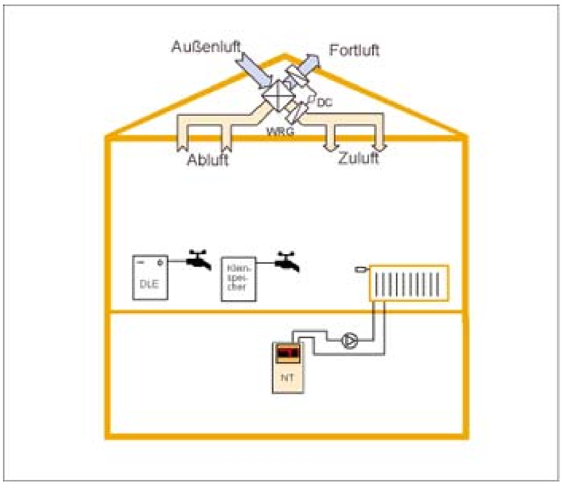

Figure 3.2.5: Illustration of system 4

Description of system 5

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 55/45°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, condensing boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
central system, outside/discharge air, distribution inside the thermal envelope, air exchange rate 0,5 1/h heat recovery by cross flow heat exchangers with efficiency 80%

Energy rating:

Table 3.2.6: Energy efficiency factors system 5

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	0.99	0,97	0,97
	80	1,01	0,99	0,99
	120	1,01	1,00	1,00
	160	1,01	1,00	1,00
	200	1,01	1,00	1,00
	240	1,02	1,00	1,00

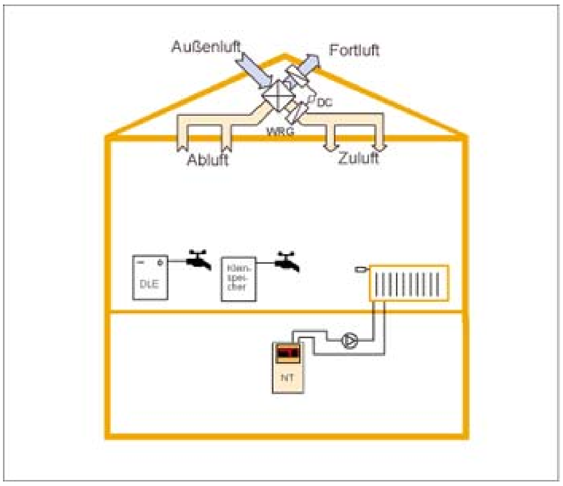

Figure 3.2.6: Illustration of system 5

Description of system 6

Heating:

Room system:
Integrated radiant heating surfaces (floor or wall heating systems), single room regulation system, 35/28°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central system, condensing boiler, installation outside the thermal envelope, using natural gas/light fuel oil/lpg

Ventilation system:
central system, outside/discharge air, distribution inside the thermal envelope, air exchange rate 0,5 1/h, heat recovery by cross flow heat exchangers with efficiency 80%

Energy rating:

Table 3.2.7: Energy efficiency factors system 6

e [-]		A [m²]		
		2400	7800	30000
W h	40	0,93	0,92	0,92
	80	0,95	0,95	0,95
	120	0,96	0,96	0,96
	160	0,97	0,97	0,97
	200	0,97	0,97	0,97
	240	0,97	0,97	0,97

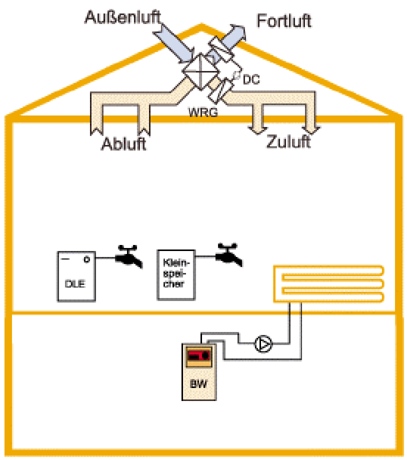

Figure 3.2.7: Illustration of system 6

Description of system 7 (HKW)

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 55/45°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central delivery, installation outside the thermal envelope, heat transfer of district heating supply from heat generation from fossil fuel/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy rating:

Table 3.2.8: Energy efficiency factors system 7

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	1,10	1,09	1,09
	80	1,05	1,05	1,05
	120	1,04	1,04	1,04
	160	1,03	1,03	1,03
	200	1,03	1,03	1,03
	240	1,02	1,02	1,02

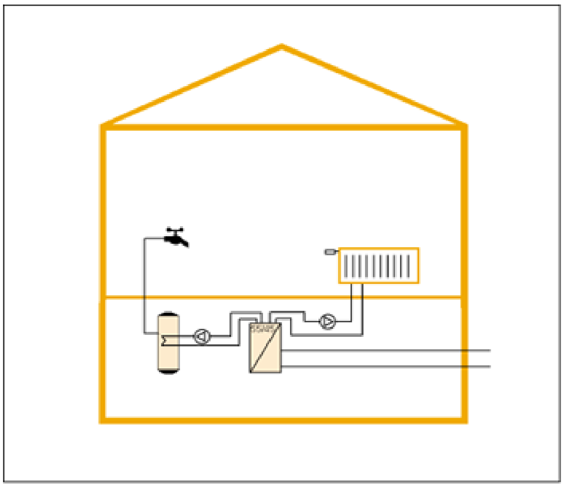

Figure 3.2.8: Illustration of system 7

Description of system 8 (KWK)

Heating:

Room system:
Free heating surfaces (e.g. heating appliances), main installation at the external wall,
P-control (e.g. design proportional range of 2K), 55/45°C-design temperature

Distribution system:
horizontal distribution inside the thermal envelope, pipes indoors, pump controlled by differential pressure or on/off

Generation system:
central delivery, installation outside the thermal envelope, heat transfer of district heating supply from combined heat and power generation from fossil fuel/lpg

Ventilation system:
Natural ventilation, through opening windows

Energy rating:

Table 3.2.9: Energy efficiency factors system 8

e [-]		A [m²]		
		2400	7800	30000
qh [kWh/m²a]	40	1,10	1,09	1,09
	80	1,05	1,05	1,05
	120	1,04	1,04	1,04
	160	1,03	1,03	1,03
	200	1,03	1,03	1,15
	240	1,02	1,02	1,02

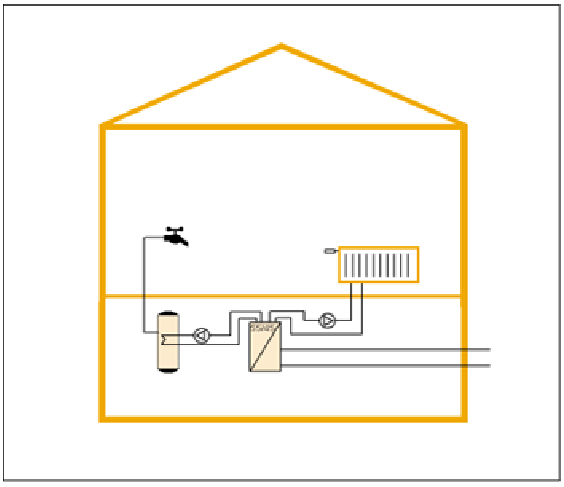

Figure 3.2.9: Illustration of system 8

All of these systems will be available in the ECA. The Table on the following page gives an overview

Table 3.2.10: Examples for heating and ventilation systems suitable for 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

3.2.3. Default Systems in Educational Buildings

Each time period had typical building materials and heating and ventilation systems. The Energy Concept Adviser of Annex 36 (ECA) distinguishes 5 time intervals. In the following tables we try to describe typical systems for these time periods and to estimate values for their efficiency factors as a function of the building type characterised by the heat demand.

Table 3.2.11: Default heating-, ventilation and DHW – systems

Period	Default systems: Description
Before 1960	**Steam heating** **Room system:** cast iron heating elements, 105°C-design temperature, no room regulation **Distribution system:** large dimensioned steel pipes, gravitational force **Generation system:** central system, steam boiler, using coal or coke **Ventilation system:** Natural ventilation **Domestic hot water system:** decentralised system, small storage water heaters, electric resp. coal or coke fired
Period	**Default systems: Description**
1960 - 1977	**Hot water heating** **Room system:** cast iron or steel heating elements, 95°C-design temperature, manually room regulation **Distribution system:** large dimensioned steel pipes, gravitational force **Generation system:** Hot water boiler, using coal/coke or light fuel oil **Ventilation system:** Natural ventilation **Domestic hot water system:** decentralised system, small storage water heaters, electric resp. coal or coke fired

Period	**Default systems: Description**
1977 – 1983	**Pump hot water heating** **Room system:** steel heating elements, 90/70°C-design temperature, manually room regulation **Distribution system:** steel pipes, circulation pump forced **Generation system:** Hot water boiler, using light fuel oil resp. sometimes coal/coke **Ventilation system:** Natural ventilation / mechanical ventilation systems, even air conditioning systems **Domestic hot water system:** Central system, re-circulation, storage water heater, indirect-contact through boiler or direct gas/electric fired
Period	**Default systems: Description**
1984 - 1995	**Pump hot water heating** **Room system:** steel heating elements, 80/60°C-design temperature, thermostatic room regulation **Distribution system:** steel pipes, circulation pump forced **Generation system:** Hot water boiler, using natural gas/light fuel oil **Ventilation system:** Natural ventilation **Domestic hot water system:** Central system, re-circulation, storage water heater, indirect-contact through boiler or direct gas/electric fired
Period	**Default systems: Description**
1995 - 2002	**Pump hot water heating**

	Room system: steel heating elements, 80/60°C-design temperature and lower, thermostatic room regulation **Distribution system:** steel pipes, circulation pump forced **Generation system:** Hot water resp. low temperature boiler, using natural gas/light fuel oil **Ventilation system:** Natural ventilation **Domestic hot water system:** Central system, re-circulation, storage water heater, indirect-contact through boiler or direct gas/electric fired

Table 3.2.12: Energy efficiency of default systems

Period	Heat demand in kWh/m² a	Default systems: Description	Energy efficiency factor e*
Before 1960	360 … 400	Steam boiler, Steam heating, 105 °C, cast iron heating elements, no room regulation, natural ventilation	**2,0 … 1,7**
1960 - 1977	280 … 360	High temperature boiler, hot water heating, 95 °C, gravitational force, mechanical room regulation, natural ventilation	**1,8 … 1,6**
1977 – 1983	180 … 260	High temperature boiler, pump hot water heating, 90/70 °C, thermostatic room regulation, natural ventilation	**1,7 … 1,4**
		District heating, supply from heat generation, pump hot water heating, 90/70 °C, thermostatic room regulation, natural ventilation	**1,5 … 1,3**
		District heating, supply from combined heat and power generation, pump hot water heating, 90/70 °C, thermostatic room regulation, natural ventilation	**1,5 … 1,3**
1984 – 1995 (WSVO 84)	140 … 180	High temperature boiler, pump hot water heating, 80/60 °C, thermostatic room regulation, natural ventilation	**1,6 … 1,4**
1995 – 2002 (WSVO 95)	100 … 140	Low temperature boiler, pump hot water heating, 75/65 °C and lower, thermostatic room regulation, natural ventilation	**1,5 … 1,3**

*) estimated values
All values were estimated with the fact in mind that energy efficiency is strongly coupled to the heat demand of the building. Influences of non optimal operation are not included. Experiences show that due to improper operation increases of the efficiency factors up to a value of 3 occur.
The efficiency factors given relate to end-energy. Therefor they can be applied to both systems with natural and with mechanical ventilation. These systems however differ due to the different amounts of auxiliary energy they need.

3.2.4. Approach for Retrofitting Heating-/ Ventilation Systems in Buildings

Retrofit of systems means to change an existing system to a system as described in subchapter 3.2.2. Principally there are 3 ways to reach this goal: replacement, retrofit or optimisation. To choose the right option we recommend the following strategy

1. Check wether the system or some of the components have to be replaced (see 3.2.4.1)
2. Select data on energy consumption from past years and define average consumption: ($Q_{measured}$)
3. Use the ECA to estimate the heating energy demand ($Q_{calculated}$)
4. Define energy efficiency factor: $e_{total} = Q_{measured} / Q_{calculated}$
5. if **e** > **1,5** (renovation of heating devices **necessary** (see Table 3.2.14 – 3.2.19))
6. if **e** ~ **1,25… 1,5 (think about** renovation of heating devices)
7. if **e** ~ **1,0….1,25**
   - there is **no need** for an renovation of heating devices
   - Optimisation (see 3.1.2.2)
   - special investigations through expert
8. if **e** < **1** check usage-conditions and calculate over again

3.2.4.1 Replacement of Components

Each technical system has an average life time. If this time is reached the replacement of the component is recommended
Typical life times of components of heating systems are given on the following table

Table 3.2.13: Expected useful life of heating installations

Component	expected useful life in years
Room system	
cast iron heating elements	40
steel iron heating elements	35
panel steel radiators	30
floor and wall heating systems	30
thermostatic valves	10
Valves with auxiliary power operation	10
Distribution system	
circulation pumps	10
measuring and regulating device	20
heat insulation of pipes	20
steel pipelines	40
copper pipelines	30
plastic pipelines	30
Heat generation	
cast-iron or steel boiler	20
gas-/oil burner with fan	12
heat pump electric fired	20
heat pump gas/oil fired	15
block-type thermal power stations	15
solar energy plants	18
domestic delivery station for district heating	30

[1)] VDI 2067-1 /8/

3.2.4.2 Energetic Improvement through Optimising Operation

Optimisation of existing systems has the shortest payback. Possible actions are:

a. Optimisation through organisational measures
b. Optimisation of operating method
c. Adaptation of operating time to actual usage

3.2.4.3 Energetic Improvement through Retrofit

The following tables describe retrofit measures applicable to the systems as described in tables 3.2.11 and 3.2.12

Table 3.2.14: Possible Retrofit Measures of Default System build before 1960

STEAM HEATING: Steam boiler, Steam heating, 105 °C, cast iron heating elements, no room regulation		Eff. Factor total system		Costs (starting point natural ventilation)			Costs (starting point mechanical ventilation)*		
		2,0	1,7	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 replace boiler with low-temp. Boiler replace radiators and install thermostatic valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,28	1,11	120	1	8	130	1	8
2	decrease systemtemperature to 55/45 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,18	1,04	140	1	8	150	1	8
3	decrease systemtemperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,11	1,00	160	1	8	170	1	8
4	decrease system temperature to 70/55 replace boiler with low-temp. boiler replace radiators and install thermostatic valves replace and insulate pipework install (replace)* central ventilation system 60% install expansion vessel install circulation pump	1,28	1,11	190	1	12	190	1	12
5	decrease system temperature to 55/45 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install (replace)* central ventilation system 80% install expansion vessel install circulation pump	0,99	1,00	220	1	12	220	1	12
6	decrease systemtemperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install (replace)* central ventilation system 80% install expansion vessel install circulation pump	0,93	0,97	240	1	12	240	1	12

Table 3.2.15: Possible Retrofit Measures of Default System build between 1960 and 1977

	Hot water heating, 95°C: gravitational force, high temperature boiler, mechanical room regulation	**Eff. Factor total system**		**Costs (starting point natural ventilation)**			**Costs (starting point mechanical ventilation)***		
		2,0	**1,7**	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 replace boiler with low-temp. boiler install thermostatic control valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,28	1,11	95	1	8	105	1	8
2	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,18	1,04	120	1	8	130	1	8
3	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install expansion vessel install circulation pump (remove mechanical ventilation)*	1,11	1,00	140	1	8	150	1	8
4	decrease system temperature to 70/55 replace boiler with low-temp. boiler install thermostatic control valves replace and insulate pipework install (replace)* central ventilation system 60% install expansion vessel install circulation pump	1,28	1,11	170	1	12	170	1	12
5	decrease system temperature to 55/45 replace boiler with condensing boiler install install zone control valves replace and insulate pipework install (replace)* central ventilation system 80% install expansion vessel install circulation pump	0,99	1,00	200	1	12	200	1	12
6	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves replace and insulate pipework install (replace)* central ventilation system 80% install expansion vessel install circulation pump	0,93	0,97	220	1	12	220	1	12

Table 3.2.16: Possible Retrofit Measures of Default System build between 1977 and 1983

	Pump hot water heating, 90/70°C: high temperature boiler, thermostatic room regulation	**Eff. Factor total system**		**Costs (starting point natural ventilation)**			**Costs (starting point mechanical ventilation)***		
		1,7	**1,4**	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 replace boiler with low-temp. Boiler install thermostatic control valves Insulate pipework replace expansion vessel replace circulation pump (remove mechanical ventilation)*	1,28	1,11	95	1	8	115	1	8
2	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework replace expansion vessel replace circulation pump (remove mechanical ventilation)*	1,18	1,04	115	1	8	125	1	8
3	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework replace expansion vessel replace circulation pump (remove mechanical ventilation)*	1,11	1,00	135	1	8	145	1	8
4	decrease system temperature to 70/55 replace boiler with low-temp. boiler install thermostatic control valves Insulate pipework install (replace)* central ventilation system 60% replace expansion vessel replace circulation pump	1,28	1,11	165	1	12	165	1	12
5	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework install (replace)* central ventilation system 80% replace expansion vessel replace circulation pump	0,99	1,00	195	1	12	195	1	12
6	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework install (replace)* central ventilation system 80% replace expansion vessel replace circulation pump	0,93	0,97	215	1	12	215	1	12

Table 3.2.17: Possible Retrofit Measures of Default System build between 1977 and 1983 (district heating)

	Heat plant (fossil fuels) district heating: Pump hot water heating, 90/70°C, thermostatic room regulation	**Eff. Factor total system**		**Costs (starting point natural ventilation)**			**Costs (starting point mechanical ventilation)***		
		1,5	**1,3**	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 remove supplier's service installation install low-temp. boiler install thermostatic control valves Insulate pipework replace expansion vessel replace circulation pump remove mechanical ventilation system (remove mechanical ventilation)*	1,28	1,11	95	1	8	105	1	8
2	decrease systemtemperature to 55/45 replace supplier's service installation install zone control valves Insulate pipework replace expansion vessel replace circulation pump remove mechanical ventilation system (remove mechanical ventilation)*	1,10	1,02	85	1	6	95	1	6
3	decrease system temperature to 55/45 remove supplier's service installation install condensing boiler install thermostatic control valves Insulate pipework replace expansion vessel replace circulation pump remove mechanical ventilation system (remove mechanical ventilation)*	1,18	1,04	115	1	8	125	1	8
4	decrease systemtemperature to 32/28 remove supplier's service installation install condensing boiler replace radiators and install zone control valves Insulate pipework replace expansion vessel replace circulation pump remove mechanical ventilation system (remove mechanical ventilation)*	1,10	1,00	135	1	8	145	1	8
5	decrease system temperature to 70/55 remove supplier's service installation install low temp. boiler install thermostatic control valves Insulate pipework replace central ventilation system install (replace)* heat recovery 60% replace expansion vessel replace circulation pump	1,28	1,11	165	1	12	165	1	12
6	decrease system temperature to 55/45 remove supplier's service installation install condensing boiler install zone control valves Insulate pipework replace central ventilation system install (replace)* heat recovery 80% replace expansion vessel replace circulation pump	0,99	1,00	195	1	12	195	1	12
7	decrease systemtemperature to 32/28 remove supplier's service installation install condensing boiler replace radiators and install zone control valves Insulate pipework install (replace)* central ventilation system 80% replace expansion vessel replace circulation pump	0,93	0,97	215	1	12	215	1	12

Table 3.2.18: Possible Retrofit Measures of Default System build between 1984 and 1995

	Pump hot water heating, 80/60°C, thermostatic room regulation	eff. factor total system		Costs (starting point natural ventilation)			Costs (starting point mechanical ventilation)*		
		1,6	1,4	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 replace boiler with low-temp. Boiler replace thermostatic control valves Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,28	1,11	90	1	8	100	1	8
2	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,18	1,04	110	1	8	120	1	8
3	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,11	1,00	130	1	8	140	1	8
4	decrease system temperature to 70/55 replace boiler with low-temp. boiler replace thermostatic control valves Insulate pipework replace circulation pump install (replace)* central ventilation system 60%	1,28	1,11	160	1	12	160	1	12
5	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework replace circulation pump install (replace)* central ventilation system 80%	0,99	1,00	190	1	12	190	1	12
6	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework replace circulation pump install central (replace)* ventilation system 80%	0,93	0,97	210	1	12	210	1	12

Table 3.2.19: Possible Retrofit Measures of Default System build between 1984 and 1995

Pump hot water heating, 75/65°C, thermostatic room regulation		eff. factor total system		Costs (starting point natural ventilation)			Costs (starting point mechanical ventilation)*		
		1,5	1,3	area-dependent in €/m²	demand-dependent in €/(kWh m²a)	Mainte-nance costs in €/m²a	area-dependent in €/m²	demand-dependent in €/(kWh/m²a)	Mainte-nance costs in €/m²a
1	decrease system temperature to 70/55 replace boiler with low-temp. Boiler Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,28	1,11	80	1	8	90	1	8
2	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,18	1,04	100	1	8	110	1	8
3	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework replace circulation pump (remove mechanical ventilation)*	1,11	1,00	130	1	8	140	1	8
4	decrease system temperature to 70/55 replace boiler with low-temp. boiler replace thermostatic control valves Insulate pipework replace circulation pump install (replace)* central ventilation system 60%	1,28	1,11	150	1	12	150	1	12
5	decrease system temperature to 55/45 replace boiler with condensing boiler install zone control valves Insulate pipework replace circulation pump install (replace)* central ventilation system 80%	0,99	1,00	180	1	12	180	1	12
6	decrease system temperature to 32/28 replace boiler with condensing boiler replace radiators and install zone control valves Insulate pipework replace circulation pump install central (replace)* ventilation system 80%	0,93	0,97	210	1	12	210	1	12

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3.3. Domestic Hot Water installations

3.3.1. Introduction

Domestic hot water (DHW) system is required in buildings for showering, bathing, hand washing, clothes and dish washing, etc. It makes use of two resources, water and energy, and therefore retrofitting efforts should respect proper DHW system installation.

Average hot water demand in educational building operated 250 days a year runs at 5-15 litres a day and person in schools without showers and 30-50 litres in schools with showers at 45°C. Average lifetime of DHW equipment is 10-15 years. Most of DHW systems in European Union make use of gas and oil as an energy source, 30% are powered by electricity. Proper systems should meet the following requirements:

- continuous and instantly water flow at desired volume and given temperature
- low capital and operation costs
- easy regulation of temperature
- proper water quality
- easy to maintenance and reliable in use
- legionella disaster proof

3.3.2. Individual systems

Electric:

storage:

- instantly hot water flow allowed without high power demand; low tank capacity power demand; low tank capacity limits the hot water volume

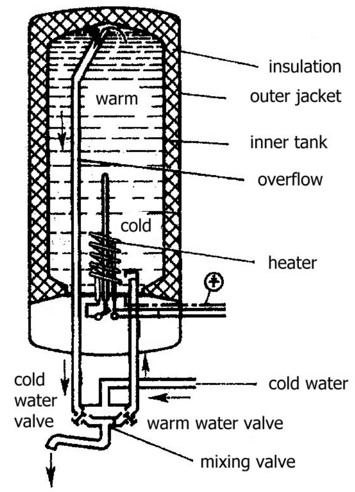


Fig 3.3.1. Low pressure electric storage water heater

low pressure (Fig 3.3.1):

- heater installed near the tap point
- only one tap point allowed
- capacity 5-100l; power 2-6kW
- no pressure effect; fewer fittings, less complicated
- lever mixing valve required
- tank made of copper, steel, plastic
- immersion and bar heaters
- maximum 20l/min @ 40°C

high pressure (Fig 3.3.2):

- water-pipe network pressure (6-10 bars) effect
- more tap points allowed
- constant temperature
- fittings and safety valves required
- capacity 5-1000l
- more reliable tank required

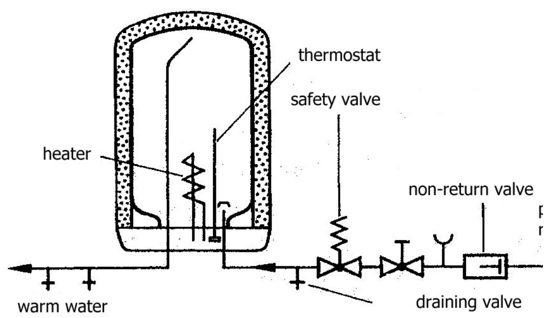


Fig 3.3.2. High pressure electric storage water heater with safety fittings

- tank made of copper, steel
- bar heaters

flow (instantaneous) (Fig 3.3.3):

- instantaneous and continuous heating
- more tap points allowed
- low capital and high energy cost
- high power consumption (1l/min Δt=40-10=30°C P=2.1kW)
- bar heaters, heater wires
- power 12, 16, 18, 21, 24kW
- hydraulic water contact (Venturi tube) P=f(V)
- continuous temperature control
- maximum flow 10l/min

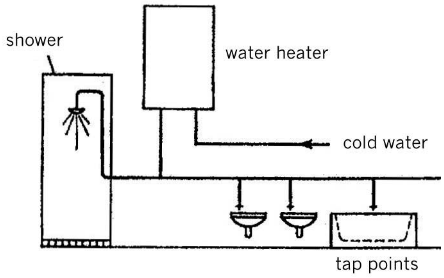


Fig 3.3.3. Single flat central hot water delivery with flow water heater

mixed storage/flow:

central heating cooperated with electric domestic water heaters:

heat pumps (Fig 3.3.4):

- high capital cost and low energy consumption
- air finned evaporator
- coil or tube condenser
- single family flat 300l; 0.35kW t=50-55°C
- profitable with use of waste, technology heat source (or use of evaporator as a cooler/refrigerator)
- reserve electric heater 2kW

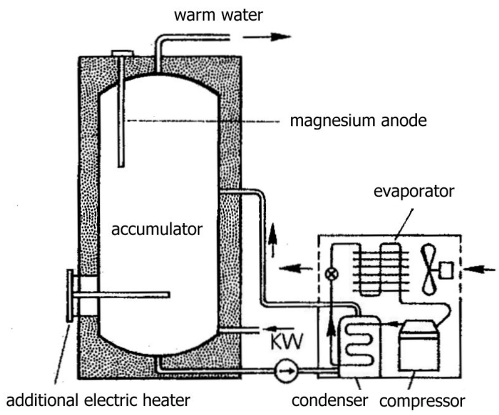


Fig 3.3.4. Heat pump as a separate domestic hot water system component

- in European Union common only in new houses with the use of mechanical ventilation (used for heat recovery from exhaust air)

Gas-fired:

flow (instantaneous) (Fig 3.3.5):

- instantly high volume of hot water allowed
- water heated with combustion gases
- 5-16l/min, 10-35^{o}C, 9-28kW
- pilot flame or piezo electric igniters; gas savings with piezo although electric installation required
- open combustion chamber disadvantages: chimney, low emission of combustion gases, leakiness, boiler room cubature, heat loss
- close combustion chamber - no cubature requirements, disadvantages: fittings and price,
- gas flow controller (Venturi tube) with gas valve needed
- fluent power modulation allowed

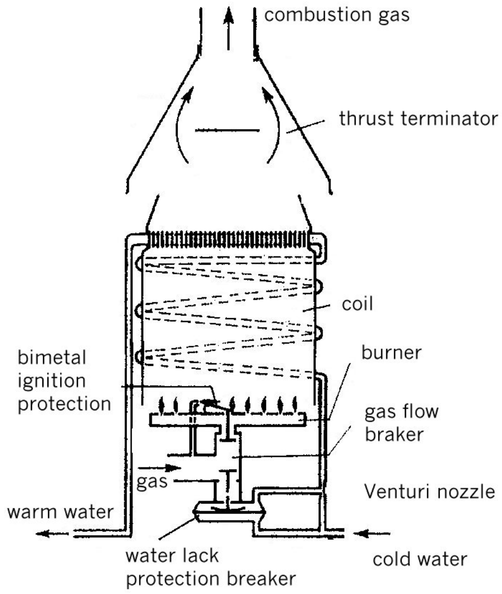


Fig 3.3.5. Gas-fired water flow heater with open combustion chamber

storage (Fig 3.3.6):

- low and high pressure
- higher capital costs
- 5-300l
- circulation pump needed
- single family flat 100-150l

central heating cooperated with gas-fired DHW heaters (Fig 3.3.7, 8):

- in most cases central heating inertia allows for short-time switching off for domestic water heating; one boiler for both systems without major discomforts
- types: flow heaters (direct and indirect), storage heaters

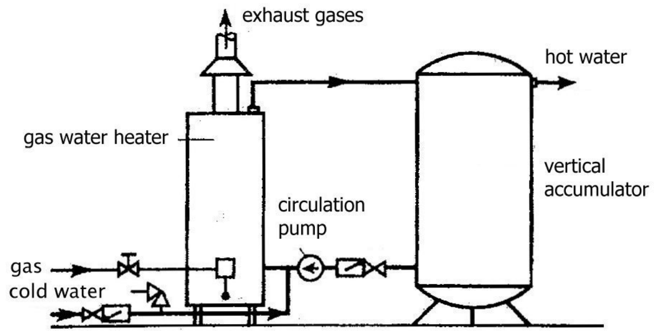


Fig 3.3.6. Gas-fired water storage heater with vertical storage tank and circulation pump

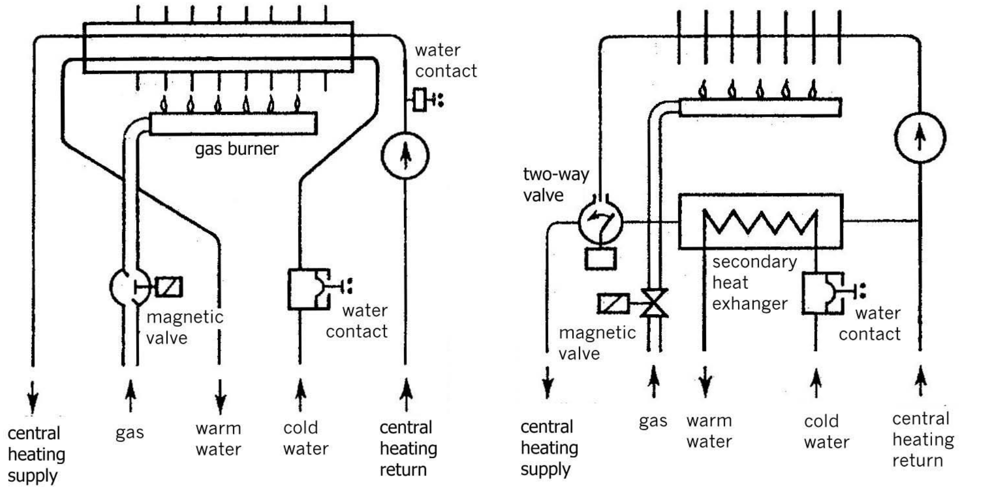


Fig 3.3.7. Combined gas-fired domestic hot water and central heating flow heater: direct DHW heating (left), indirect DHW heating (right)

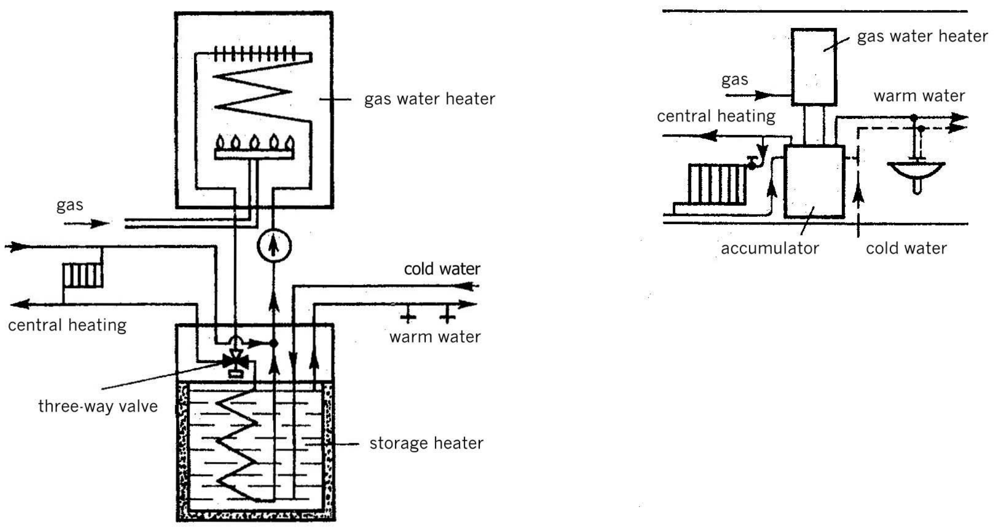


Fig 3.3.8. Gas-fired water heater in combined DHW/central heating system with high pressure water storage tank

Solar collectors (Fig 3.3.9):

- climate and weather dependent
- ~2kWh/m^2, average 2m^2 and 100-150l/person; savings 300kWh/m^{2}a
- efficiency up to 80% in summer and 20% in winter of energy demand
- circulation pump and addition back-up electric heater needed
- high capital cost, difficult to amortization with high electricity costs and without government help

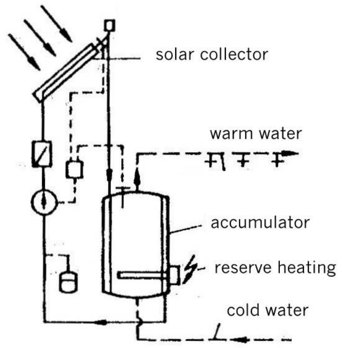


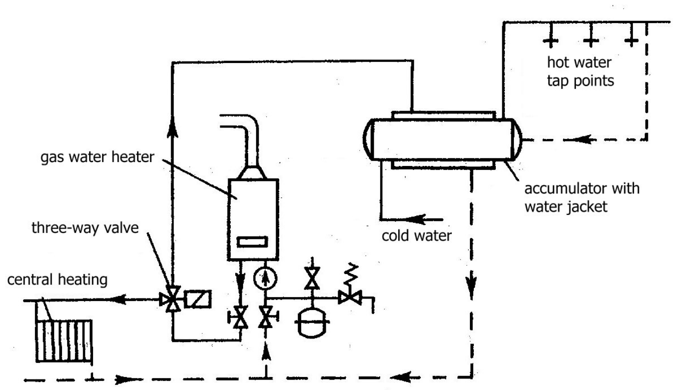
Fig. 3.3.9. Solar energy water heating with additional reheating in boiler

3.3.3. Central systems

- circulation system needed
- high pressure up to 10 bars

<u>*storage (Fig 3.3.10):*</u>

- heat transfer through the water heat jacket or coil heater
- advantages: peak load equalization with storage tank, high water volume in short time, easy water temperature regulation, high water capacity with small boiler
- disadvantages: scale and corrosion in accumulator, higher capital cost compared with flow heater, heat loss, low heat-transfer coefficient



<u>Fig 3.3.10. DHW system with circulation water gas heater and accumulator with double jacket</u>

<u>*flow (instantaneous) (Fig 3.3.11, 12):*</u>

- types: heat exchanger built in storage tank (coil or plate exchanger), heat exchanger built in a boiler (high water boiler volume, less profitable with large water draft inconsistent)
- advantages: always fresh hot water, higher heat transfer coefficient
- disadvantages: boiler scale, difficulties with water temperature regulations
- without prospects

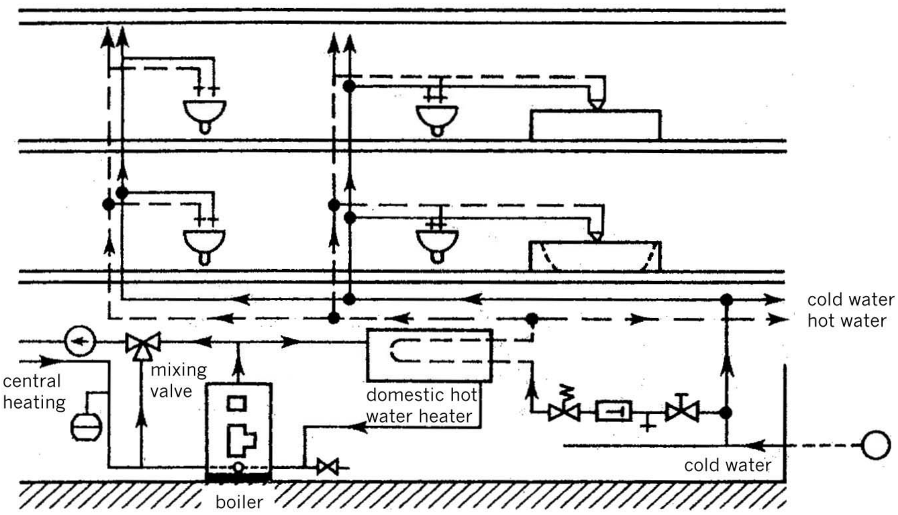


Fig 3.3.11. DHW system with flow heater

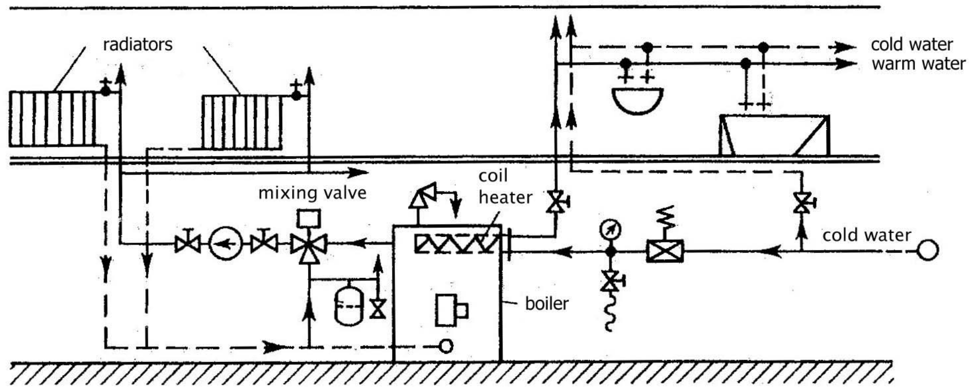


Fig 3.3.12. DHW system with flow heater built in the boiler

3.3.4. Distribution network of domestic hot water

Temperature

Due to energy savings, boiler scale and corrosion protection DHW temperature is limited to maximum 60^{o}C in pipe network. On the other hand, the real danger is the *Legionella pneumophila,* bacteriums causing pneumonia and Pontiac fiver. The following conditions improve the legionella reproduction: hot water @ 32-42^{o}C, vertical thermal gradient in storage water heater, water stops, boiler mud. Water @ 60-65^{o}C effectively kills legionella; short time overheating is apply.

CIRCULATION (FIG 3.3.13)

- necessary in large installations, useless in small installations (high heat losses)
- types: natural (with duct drops), forced (circulation pump, continuous or break work; switch on/off depending on water temperature 35-40°C in return pipe correlated with time switches)

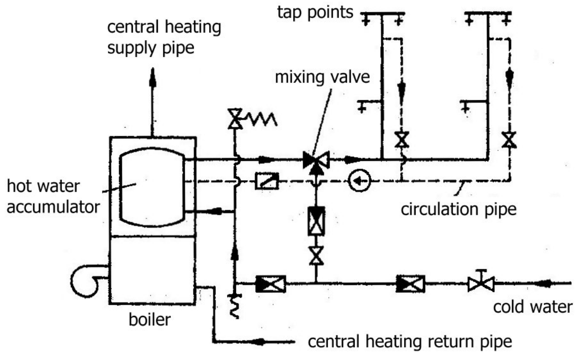


Fig 3.3.13. DHW distribution network with boiler blocked with accumulator and circulation piping

- pipe insulation needed
- disadvantages: additional fittings (non-return valves), additional pipes with insulation, electric pump (energy consumption), heat losses in additional pipe network, improper thermal gradient in storage tank

ASSISTING HEATING

- substitute for circulation system
- supply pipe network heated with electric strip (belt) heaters
- energy savings about 50-60%, though due to high electricity costs 10-30% higher energy cost compared with circulation systems
- legionella bacterium killing possibility thanks to opportunity of temporary overheating

PIPE NETWORK

- overhead, bottom or floor distribution
- pipe made of steel, copper, plastic with proper heat insulation

3.3.5. DHW systems development according to EU Directorate

- inefficient instantaneous electric heaters replacement with systems that will aid peak power management (e.g. energy efficient storage-type DHW systems, instantaneous gas heaters, solar-assisted systems)
- equipment improvement, e.g. highly efficient instantaneous gas heaters, gas, oil and electric storage heaters, and efficient distribution systems and components
- developing of appliances that minimise hot water use, e.g. low flow rate, high pressure showerheads, faucet and showerhead aerators, hot/cold water mixers, optimised volume bathtubs, improved washing machines and dishwashers
- developing kits to facilitate the retrofitting of solar systems onto existing storage-type DHW systems

- developing integrated heat recovery/water heating systems that use warm "grey water" for pre-heating feed water in centralised DHW systems in the residential and non-domestic sectors
- researching and demonstrating units that combine compressive refrigeration with storage-type DHW systems.

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2. Domestic Hot Water Overview
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3.4. Energy sources and Generation system

It is necessary to differentiate between conventional energy (= traditional energy) and renewable energy sources. The heat generation can take place in both cases by means of heat exchange, i.e. transfer of energy due to temperature differences or by conversion from energy to heat, e.g. by means of combustion.

3.4.1. Traditional energy

By traditional energy sources we mean those forms of energy, which are generated from fossil fuels, i.e. with oil, gas or coal.

Heat generation through heat transfer

Heat generation by heat transfer takes place decentral, i.e. the actual heat generation takes place in power plants. Coal, oil or gas are burned as fuels. So-called cogeneration generate power and hot water for local heat supply systems.

- **district heat**
- **local heat**
- **electric power**

Heat generation through conversion

By heat generation through conversion we understand a heat generation, which is generated in boilers (with hot water storage), block type thermal power plants or other e.g. thermal-chemical processes of transformation in fuel cells.

- **fossil fuel (oil, gas, coal, solid fuel)**
- **block-type thermal power plants**
- **fuel cell**

3.4.2. Renewable energy

Renewable kinds of energy are all forms of energy, which are available in nature sustainably. Also in the case of renewable energy heat can be produced through heat transfer or through energy conversion:

Heat generation through heat transfer

Heat energy is produced with the use of solar power by heat transfer. The solar radiation is absorbed in the solar heat collector, converted into heat and used to heat up a heat distribution medium, usually water.

For the generation of heat, hydronic solar panels, with a temperature range up to 70°C are used. Vacuum tube collectors (heat pipes) are suitable for the production of process heat with temperatures beyond 70°C.
The solar heat is usually not available at the time of demand when heat is needed. Therefore solar systems are always combined with storage systems.
Differences are short time storage, i.e. storage of the demand of approx. 1-3 days and long-term storage or even inter-seasonal heat storage, which stores the heat from summer months for the demand of winter months.
In schools solar technology is usually used only for the generation of domestic hot water.

- **solar heat**
- **hydronic solar panel**
- **vacuum hydronic solar panel**
- **glas pipe collector**
- **heat pipe**

Apart from solar energy there are further renewable energy sources, which can be used for heat transfer. However economic use depends strongly on local conditions. Geothermal energy belongs to this group. Probes reach a depth of 300m. The water warmed up in this way can be heated additionally by means of a heat pump. Water from boreholes or watercourses can also be used with a heat pump for heating or as a free source of cooling.

- **geothermal heat**
- **heat form bore holes or watercourses**

Renewable sources of electrical power are photovoltaic panels, water turbines and wind generators. These all depend on local weather conditions.

- **solar generated electric power (PV)**
- **water and wind power**

Heat generation through conversion

As in the case of fossil fuels heat can be generated also by combustion of renewable materials. These are either in form of fermentation gas or liquid renewable fuel. Vegetable oil can also be used for combustion. Wood, in the form of wood chips or in form of pellets can be burnt CO_2 neutrally.

- **Renewable oil or gas fuels**
- **wood chips**
- **wood pellets**

3.5. Control Strategies

3.5.1. General information

Control especially as part of more comprehensive energy management can be understood and defined as an energy saving technology itself. An efficient control system of building and HVAC plant is necessary for achieving energy efficient building. However the “optimal” control strategy for a specific building depends not only by technical parameters as building type and design, ventilation and climatization plants etc, but also on human behaviour i.e. parameters like dress code, user attitude and user expectations. In general in each building there is a strong interaction between the energy plant and the control system. In buildings with active components, this aspect is enlarged to the envelope also; it is therefore important that all these parts are designed together in one process and a strong co-operation between architects, HVAC engineers and control engineers is necessary.

One of the most challenging item in control systems is to allow user interaction without compromising the overall well working of building energy devices. The impossibility of influencing the local climate conditions is often one of the main reason of complaint by the occupants. Recent research indicates that users are more tolerant of deviations in indoor climate if it is controlled by themselves, this fact is of great importance even for energy related evaluations. Even if users should have a high possibility of controlling their own environment, automatic control is needed to support users in achieving a comfortable indoor climate and to take over during non occupied hours to reduce energy consumption and to precondition rooms for occupation. Simplicity and transparency of the user/system interface is of great importance, and one of the main request is that the control system responds to their needs and allows them to change indoor conditions with rapid feedback.

The control system should obviously follow external climate conditions, in order to allow a correct regulation of heating/cooling plants according to the real needs of the occupants. Building with active envelope or with natural or hybrid ventilation devices are in closer contact with external climate conditions, so special care have to be taken in studying this aspect. Control system should be in these cases self learning, in order to be ready to exploit the favourable conditions and to mitigate the unfavourable ones**.**

The main control tasks in an energy efficient and healthy building should be:

- Room temperature
- Room heating and cooling
- IAQ during occupied hours
- IAQ during non occupied hours
- Solar shading
- Night ventilation during summer
- Preheating of ventilation air during winter

Thermostats and TRVs were the first control equipment to disseminate in the building sector owing to the first energy crisis. Building management systems developed in the ‘80s in the residential and services sectors, as simplified applications of systems and technologies already developed in the industrial sector in the ‘70s to automate production processes and to optimize plant performances.

3.5.2. Control methods

There are numerous methods by which heating and other building services within buildings can be controlled. Most systems seek to control either by:

- Time i.e. when a service like heating or lighting for instance is provided and when it should not be provided or
- A parameter representative of the service like temperature for space heating. This can also vary with time.

As an example some typical control methods are described hereafter:

Time Control Methods (for heating):
- Time switches turn on and off the heating (or water heating) system at pre-selected periods (of the day, of the week)
- Optimisers: these controls start the heating system in a building at a variable time to ensure that, whatever the conditions, the building reaches the desired temperature when occupancy starts.

Temperature control methods:
- Frost protection generally involves running heating system pumps and boilers when external temperature reaches a set level (0°C) or less in order to protect against freezing
- Compensated systems: which control flow temperature in the heating circuit relative to external temperature thus allowing a rise in the circuit flow temperature when outside temperature drops.
- Thermostatic radiator valves: these units sense space temperature in a room and throttle the flow accordingly through the emitter (radiator and convector) to which they are fitted
- Modulating control: can be applied to most types of heat emitters and is used to restrict the flow depending on the load demand and thus controlling the temperature.
- Proportioning control: involves switching equipment on and off automatically to regulate output

Other methods:
- Occupancy sensing: In areas which are occupied intermittently, occupancy sensors can be used to indicate whether or not anybody is present and switch the heating/cooling and ventilation on accordingly. Detection systems are based on ultrasonic movement or infrared sensing.
- Other methods can be thermostats and user interactive control

The basic control technologies have been in existence for some time. Systems available range in complexity, from the extreme case of the timer-controlled water heater or thermostatic radiator valves, to the so-called "intelligent houses" which manage everything from the security and safety systems to the air conditioning, lighting and ventilation system, to telematic services and to most appliances of a house according to efficiency criteria. The use of these technologies allows the optimisation of various services often with large energy savings. A well funcioning BEMS can be expected to save 20%, and occasionally more, of the energy consumption of the plant being controlled. Savings can be expected to recur year after year which makes installation of modern cintrol or BEMS even much more profitable.

3.5.3. Building Energy Management Systems

The term Building Energy Management Systems (BEMS) encompasses a wide variety of technologies which includes also energy management systems and building controls. Their function is to control, monitor and optimise various functions and services provided in a building, including heating and cooling, ventilation, lighting and often the management of electric appliances. Building Energy Management Systems are also referred to by various other names ilike Energy Management System (EMS), Building Management System (BMS) or Building Automation System (BAS).

A Building Energy Management System (BEMS) consists normally of one or more self-contained computer based 'outstations' which use software to control energy consuming plant and equipment, and which can monitor and report on the plant's performance. These outstations have the ability to be linked together in a modular fashion by a network, and can communicate with each other and with an optional central operator's terminal, which is often a conventional Personal Computer (PC). BEMS provide control by using software logic and are re-programmable, whereas older controllers of the electrical or electro-mechanical type relied on purpose built hardware which required hardware changes to change their characteristics or abilities.

Typically BEMS consist of both hardware and software and systems are divided to subsystems of three different levels: field level, automation/control level, and management level. In addition, remote monitoring and servicing is a feature utilized in some special application areas when supervised systems are geographically scattered.

The hardware is usually represented by one (or more) control and processing units and by a number of other peripheral devices (which control the operation of say, heating or cooling systems, artificial light-sources or other appliances and which can also be represented by sensors, thermostats, etc.) connected to the control units. The control unit, based on the information supplied by some of the peripherals or based on pre-set instructions, runs the system. The control unit can be as simple as a relay or a timer switching on or off an electric water heater or as sophisticated as a microprocessor operating on «fuzzy logic». Commands can be sent from the central unit to the peripheral units through Ethernet cable, power-lines or telephone lines, or fibre-optic cables. The material "medium" through which commands and messages between the various parts of the system are exchanged, is often called (Field)BUS.

The software is simply the program and the instructions that allow the control unit to manage the operations of the peripheral devices and of the appliances..

Integration of all controls into one Building Energy Management System has some advantages: it makes it easy for operators, it co-ordinates the control of different systems, it reduces the number of sensors. New standards for data interface at field level like LON (Local Operating Network) for instance, can result in easier integration of components from different suppliers into one system without the need for protocols to translate between suppliers. A local operating network consists of intelligent devices, or nodes programmed to send messages to one another in response to changes in various conditions and to take action in response to messages they receive. The nodes on a LON may be thought of objects that respond to various inputs and produce desired outputs. Linking the inputs and outputs of network objects enables the network to perform applications. While the function of any particular node may be quite simple, the interaction among nodes enables a local operating network to perform complex tasks. A benefit of local operating networks is that a small number of common node types may be configured to perform a broad spectrum of different functions depending how they are linked in a network.

The ongoing fast development of information and communication technologies is rapidly changing the technology basis of BEMS too. The development is going to towards more open systems and standards from the proprietary and therefore expensive systems of today. In the future the BEMS technology will evolve from vertical into horizontal where big companies perhasp no longer control the whole chain. Open interfaces at every level of system enable open competition throughout the life cycle of systems. In the future internet, mobiles and wireless technologies will be widely popular also in the controlling of buildings

3.5.4. Advanced control strategies

Nevertheless an energy efficient and coherent management of controls can hardly fulfilled by means of traditionally rule-based control strategies, because the different systems can get to different (sometimes contradictory) requirements: optimisation in these cases, at the end, can result in an overwhelming task. On the other hand advanced control techniques can find natural application in this technological context of sensors network, allowing to control several parameters through an optimised strategy.

Advanced control strategies require, besides a number of sensors, a number of actuators and require to be tuned to get optimum results. Advanced control strategies can be distinguished in:

- Optimum and predictive
- Simulation assisted
- Neural networks
- Fuzzy logic
- Adaptive artificial life based techniques

The most advanced techniques, like those based on artificial life, can be self learning, providing a great improvement in control systems potentials. In spite of all these advantages, and though they have been known for many years and have been commonly applied in industrial processes, advanced control strategies are not widely used in the building industry. The reason for this is mainly implementation difficulties, especially with regard to the need for a very complex and time consuming tuning process for the systems. The application of building and plant dynamic simulation techniques, more and more reliable, can now be helpful in a wider use of these techniques of building control management. The adoption of advanced control strategies needs an amount of sensors to measure:

- Temperature
- Relative Humidity
- Indoor Air Quality
- Occupancy

Some of these sensors, like temperature ones, are reliable and not expensive, and further improvement are not necessary, some other, like those for IAQ, still present some problems. One of the purpose of the control system is to establish the desired air flow rate and airflow pattern at the lowest energy consumption possible.
During past years It has been proven that an energy efficient healthy building needs a Demand Controlled Ventilation (DCV) system. A DCV system needs to be managed by a reliable control system and for this purpose the adoption of IAQ sensors is necessary. CO2 is at now the most suitable parameter for measuring the indoor air quality in places where humans are the most dominating pollutant. Unfortunately IAQ sensors (either CO2 or VOC sensors) are still quite expensive, of uncertain reliability (VOC sensors) and needs periodical recalibration. For these reasons some alternative way for reaching the same information about IAQ level, have been tested. The main alternative methods is to try to correlate occupancy and IAQ levels with the adoption of Passive Infra Red sensors and/or with the adoption of people counting systems even by means of image recognition techniques.

PIR techniques were adopted successfully in some building with cellular offices studied in Annex 35 HybVent project of International Energy Agency. IR sensors can detect movements in the room; the major advantage of this system is its relative low cost (compared to CO2 sensors) and its autonomy (the inlet with the IR sensor works on a long-life battery, no wiring is required). The major disadvantage is that the airflow is only indirectly correlated to the demand. Sometimes, the airflow can be too low, or too high. Anyway, presence detection has proved to be a good way to control the ventilation demand in rooms with low variation of occupancy. It could be successfully applied, in some cases, in school classrooms. For conference rooms, simple people meter techniques (usually adopted in commercial building even for security reasons) or more sophisticated image recognition and processing techniques could be more suitable because it should better estimate the real needs.
One of the most interesting and promising task of control system is the possibility of intervention in cooling peak loads reduction. For this purpose, different strategies can be studied, according to different climate conditions, here a list of possibilities, some of them are well known, some other are new and promising. Both of types need a good control strategy.

<u>Night time ventilation</u>: this strategy can help in pre cooling occupied space in building with a sufficiently heavy thermal structure. The effect of this strategy is the

possibility of reducing the use of mechanical cooling during first daily building working hours, in this way the peak of energy demand (always observed at starting of cooling machines) can be delayed. A differentiation of plant starting time between different zones of the building, can result in a substantial peaks reduction.

Solar shading: an optimal solar shading is often the most logical solution for reducing summer cooling loads. The task of control system is in these case the optimisation between the reducing of solar gain and the necessity of a good luminance level without the use of artificial light that vanished the benefit of solar shading.

Local removal of heat and contaminant loads: an optimisation of the local removal of heat and contaminant loads near to the zones of heat and contaminant production, before their diffusion in the indoor environment, can help substantially in reducing thermal and ventilation loads. In this way, actually, it is possible to reduce the amount of overall renewal airflow rate.

Desiccant devices and personalised local thermal comfort island.
The use of sorption air dehumidification - whether with the help of sorption regenerators or liquid systems – offers new possibilities on air conditioning technology. This can mean the general of classic compression refrigeration equipment by means of the incorporation of evaporation cooling, or the increase of evaporation temperatures in refrigerating plants by means of the of air dehumidification by cooling below the dew-point. The desiccant technology thereby represents a new quality in air conditioning technology. The terms desiccant cooling or DEC are synonyms for the procedural combination of "air drying, evaporation cooling and heat recovery“ In contradiction to production of chilled water the desiccant system is a system to directly produce conditioned fresh air. The main purpose of it therefore ventilation of air and thereby to condition this air in order to achieve comfortable indoor conditions. Economic advantages arise for DEC equipment when coupled with district heat or with waste heat from a cogeneration plant. Of particular interest is coupling with thermal solar energy. According to the design conditions, regeneration temperatures of the air of up to 80°C may be necessary; however under part load conditions the system provides air conditioning also with lower driving temperatures down to 50°C.

The use of DEC technology is specially convenient in coupling with local thermal comfort island, achieved by mean of radiant panels system. In this case the possibility of ventilation with pre treated and de-humidified air prevents the risk of undesired condensation over the surface of radiant panels, especially in warm and humid climate.

This strategy can allow a strong reduction of cooling loads in partially occupied open plan buildings. In this way only the actually occupied zone can be cooled, at the desired level, obtaining a double positive effect of energy saving and users satisfaction. Of course in this case also it is important, once again, the role of control system.

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Chapter 4

Ventilation systems

by

Timo Kauppinen
Tomasz Mróz

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4.1. Introduction

Ventilation is a decisive element in energy economy of educational buildings - and also a decisive element from point of view of indoor air quality. This fact sets requirements and also limitations in improving energy efficiency or equipments. The primary demand should be a good indoor climate, when we tend to improve environmental engineering or energy economy. In terms of good indoor climate "good" is in connection with health, comfort and safety, just indirectly in engineering. The insufficient indoor air quality is bouncing back as declined results and increased disturbance. In designing new schools or in renovation of the old ones, we must place the good indoor air quality in the first position, also not to forget the optimal use of energy.

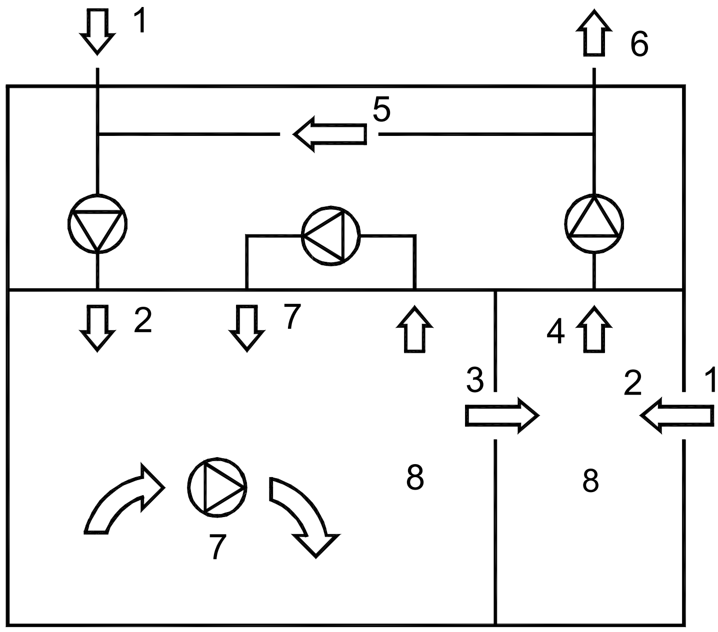


Fig 4.1. Air flow terms (Finnish Building Code Book, Part D2): 1. Fresh air, 2. Intake air, 3. Transfer air, 4. Exhaust air, 5. Recirculated air, 6. Waste air, 7. Return air, 8. Indoor air

Air change and ventilating units

Air change and health

The indoor air, what we respire, contains about 3000 different element and compounds. Carbon dioxide (CO_2) is the most important factor describing the indoor air quality. The concentration of CO_2 can go up to 800 ppm (parts per million) without we can sense it. When the concentration is 1500 ppm, it causes tiredness and often headache; when the concentration exceeds 2500 ppm, we can begin feel to be sick. The concentration of CO_2 over 10 000 ppm can cause collapse.

We feel immediately the possible uncomfortable odours in our nostrils, when entering a room. The nose is a good sensor. There are elements which we can't recognize, like CO (carbon monoxide) and radon.

The requirements and building codes in each country determine the conditions for air exchange rate, for positioning of air supply units and exhaust and indoor air quality.
For instance, the following values are valid in Finland from 1.10.2003 on:

The concentration of CO_2 in normal weather conditions and during the use of the area of a space must be in general not more than 2160 mg/m^3 (1200 ppm). Table 4.1 shows some other requirements for air exchange rates of schools and educational buildings in Finland:

Table 4.1. Educational buildings, schools

Space / use	Fresh air make up (dm^3/s)/ person	Fresh air make up (dm^3/s)/ m^2	Exhaust air (dm^3/s)/ m^2	Sound level $L_{A,eq,T}$ / $L_{A,max}$ dB	Air speed winter / summer m/s
Classrooms	6	3		33 / 38	0,20/ 0,30
Corridors / Hallways		4		38 / 43	
Gym:					
–sports use		2		38 / 43	0,30
– assembly hall use		6		33 / 38	0,25
Lecture hall	8	6		33 / 38	0,20/ 0,30
Group work area	8	4		33 / 38	0,20/ 0,30
Dining room	6	5		33 / 38	0,25
Storages			0,35		

Amenities (bathrooms etc) have own requirements.

According to various studies carried out in different countries, the indoor air quality can be at very unsatisfactory level in the end of the lesson. The concentration of CO_2 can be 2500 - 4000 ppm or even higher. If the indoor air quality is not at sufficient level, the teaching and learning environment is getting worse and in longer run we can see that in learning results or in student's comfort.

<u>Progress of air change</u>

Before the World War II the natural ventilation was dominating. The driving force of natural ventilation is based on gravity circulation of the warm exhaust air and generally colder fresh air and the ejector effect of the wind. The warm exhaust air flows out through room-specific exhaust ducts.
There was eg. an open able clap or leaf valve in the exterior wall and an adjustable grille valve for exhaust air. Room heights and windows were high. One or more windows were opened when necessary, during the breaks or during the lessons, to boost ventilation. Various window-types were created for better intake of fresh air.
The dark side of the natural ventilation system was the space needed for the ducts and design problems. The system is depending on the weather conditions, temperature drop and wind, and the system is very difficult to control.
Mechanical exhaust ventilation was first taken into the use for school kitchens and then more generally for classrooms. Various types of air supply units were installed in exterior walls. Mechanical exhaust ventilation released the use of the room space.

Mechanical intake air and exhaust ventilation has been used first in gyms and assembly halls. From late 60`s on mechanical ventilation system has been installed in almost all new schools. In 80`s heat recovery units came more general. The thermal comfort is better controlled, because the intake air is warming up in the heat recovery unit, and can be heated in heating unit if needed.
The control systems has been improved from late 50`s - first came time clock operations and then in the course of time various centralized control and -monitoring systems.
In 90`s and in the turn of the decade natural ventilation applications has been tried out, also combined with mechanical ventilation. When the control methods and techniques have been improved, hybrid ventilation systems have also been installed. Natural ventilation, boosted with mechanical exhaust can be acceptable in old educational buildings, if the users feel it sufficient and working.

Requirements for air change

<u>Air requirement and air flow rate</u>
When people are staying in a room, air flow rate must be at least 4 liter/second per person. This is about 15 m^3/hour. If we want a good and odourless air change, the previous value must be doubled (8 liter/second/person). The unemployed room must ventilate because of material emission, and the basic continuous air flow rate should be 0,2 l/s/m^2.
The air exchange can be divided into three different stages:

1. The basic ventilation (unemployed building)
2. Normal ventilation (conventional use)
3. Boosted ventilation (special use)

The need of air change is determined by that impurity, which removal needs highest amount of air. The various use of different room spaces and load strain variously indoor air and because of that the design standards determine different exhaust air flows for room spaces. The effecting factors are

- oxygen content of room air
- carbon dioxide content of room air
- human odours (metabolism, skin bacteria)
- fouling, impurities (eg. smoking, emissions from building materials)

The information available about the impurities and the impacts of impurities is partially even defective. The requirements can be found from National Building Codes and recommendations from other sources.
Some features of good ventilation (valid also for the schools):

- the air flows from clean spaces to the unclean areas
- the air does not flow directly from air supply unit to exhaust valve
- the room air has a negative pressure drop compared with the outdoor air (to prevent the moisture penetration into the structures)
- the ventilation is in continuous use and can be intensified if needed
- the ventilation system is noiseless, draft less and odourless
- the ventilation system is energy efficient
- easily controlled and adjusted
- easy to use and maintain
- the machinery and equipments are clean and easy to keep clean

Removal of contaminants

Impurities can be solid or gaseous contaminants. Intake air contains dust and pollen, which must be filtered. Filters can be mechanical filters with a filter cloth or electrical filters.
The gaseous contaminants include carbon dioxide, tobacco smoke, radon, ozone, nitrogen oxide, carbon monoxide and formaldehyde.

Noise levels

Ventilation ducts are "holes in the wall", and one must pay attention enough to sound problems in designing and in installations. There are requirements for noise level (including noise of ventilation) in national building codes.

Cleaning

The comfort, healthy, fire safety, energy efficiency and the performance and the condition of the system will be secured by cleaning. The inspection of the ducts must be done regularly, at least in 5 year periods. The need for cleaning can be determined by video cameras and cleaning can be carried out using various equipments, such as compressed air brushing. Cleansable must be taken into account in design and installation of ducting.

Air conditioning

Goals and requirements

The goal of air conditioning is to create an acceptable and demanded indoor climate by temperature, indoor air quality and moisture. This is effected by leading sufficient amount of heated, dried or moistened air to the rooms, according to the prevailing conditions. The air flow of ventilation has parallel and simultaneous tasks.
The ventilation should be managed as advantageously as possible. Advantageousness means optimized total costs. In determining these costs, we must take into account the costs caused by poor indoor air quality and investment and operating costs. The facility management costs are minor compared with the total costs of the building. Poor IAQ causes dissatisfaction and illnesses, which increase costs. The air conditioning equipments form the main part of investment costs, and the biggest cost item is the costs of ducts. Heating and the use of electric power cover the biggest part of operating costs.
The investments should be compared using life-cycle costs (LCC) methods. Ventilation is the biggest energy consumer in the building, the share of ventilation can be more than 50 % from the energy balance. The greatest savings and shortest pay-back times can be found from ventilation. In spite of this, calculations done by LCC-methods show, that if we choose the system and the components producing good indoor air quality, the annual energy cost is not necessary significantly higher than in the case in which IAQ-level is lower.

Heat load and cooling load

One of the most important tasks of ventilation is to remove the additional heat which is flowing into the room, cooling. Because of this additional heat the ambient room temperature can easily increase too high. The increased insulation level and simultaneously increased use of electricity have caused need of cooling also in the winter conditions.

The additional heat load is derived by solar radiation, use of electricity and by human load. The most significant load is caused by the solar radiation. The use of electric power is formed of lighting, office machines (computers, copiers etc) and other electrical devices, depending on the use of the space. In educational buildings the computers increase the heat load significantly, especially if the displays are not flat-type displays and the main module is not energy-saving type.

Heat loads and need for cooling can be decreased by various methods:
- Positioning and covering of windows
- Heavy and massive structures (in some cases)
- Locating of electric devices

The control of radiation load

The solar radiation load can be reduced significantly by various window structures and screens. By using absorbing and reflecting glass, light venetian blinds and mobile screens the reduction of solar radiation can be 50 - 70 % compared with the usual bright glass.
The colored glass reduces also light transmission and will increase the need of artificial lighting.

Air handling units

The parts of the air handling unit

The ventilation system is formed always from similar parts, in principle. The central part is ventilating unit, from which the air is transferred through the ducts and distributed by means of air distribution units to the rooms. The task of ventilating unit is to treat air to the demanded temperature and moisture level. The basic components are equal regardless of the system.

Space requirements and placement

The space for air handling units and especially a space for the plant room is one crucial task in building design. From energy efficient point of view, the proper space for maintenance in the plant room is very important. For example, the routine maintenance operation should be carried out without problems, such as the change of filters. The access to the plant room should be safe, thinking of personal and goods traffic. The plant room is not either any storage.

The ventilation of the building is commonly distributed to many units. The units can be located in separate plant rooms.

Air filtering

The harmful impurities and particles are cleaned from air by suitable way. The demands for filtering are required according to health, safety, cleanliness, performance of the equipments, wearing or spoiling of products. The usual place for filter is in the intake air flow, as a first part of ventilation unit.

The particle size is an important quantity in characterizing the particles. The behaviour of the particles is depending on the size of particles eg. in respiratory organs and in air cleaners. The most unhealthy particle size is < 2µm. Particles > 10 µm sink relatively fast and they are visible in suitable conditions.
The filters are divided according to the separating capacity into prefilters, fine filters and microfilters.
Electric filter can separate also the small particles. Because the malfunctions caused by moisture, it is difficult to use in the temperature level < 0°C. It is not normally used in ventilation machines, partially for cost reasons.

Ducts

Nowadays ducts are sheet metal ducts. The dimensions of the ducts are standardized, the relation of sequential flow areas is about 1,6. Ducts must be air tight, and they need space enough for installation. Intake air ducts are often insulated, so the need of space is bigger.
Untight ducts cause many problems, eg. noise and higher fan capacity
In duct design and installation one must pay a special attention to cleaning and how to clean the ducts. There must be necessary number of cleaning doors.

Air distribution

Air distribution consist the air inlets and exhaust air equipments, and the flow in the room caused by them. In practice, air distribution rules the quality of the ventilation.
By poor air distribution we can deteriorate a good ventilation system.
That`s why the air distribution has so crucial role in ventilation.

A good air distribution provides required thermal conditions in the occupied zone. Air distribution can be divided into four basic cases:

- mixing air distribution, partial short-cut flow(avoided), laminar piston flow (requires large air volumes)and displacement (volume) flow (causes temperature differences and cleanliness' differences)

The principles are shown in the figures 4.2 – 4.5.

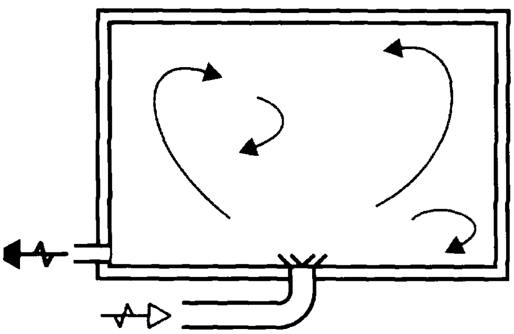


Fig. 4.2. Mixing air distribution (All the pictures are taken from Seppänen, O, Seppänen, M: Rakennusten sisäilmasto ja LVI-tekniikka, ISBN 951-97186-5-6).

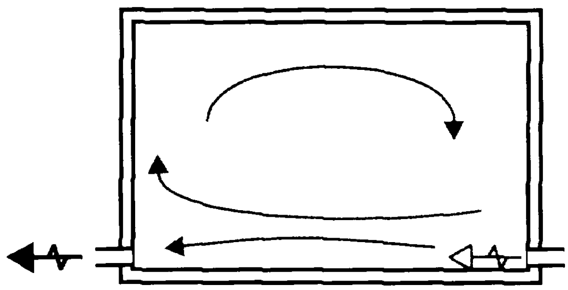


Fig. 4.3. Partial shortcut flow

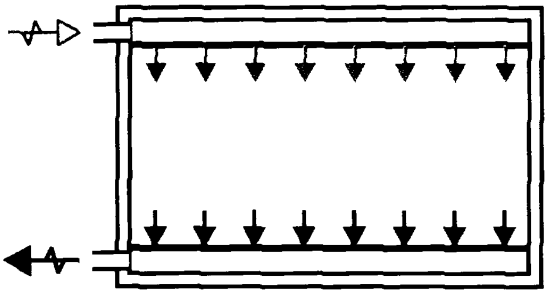


Fig. 4.4. Laminar piston flow

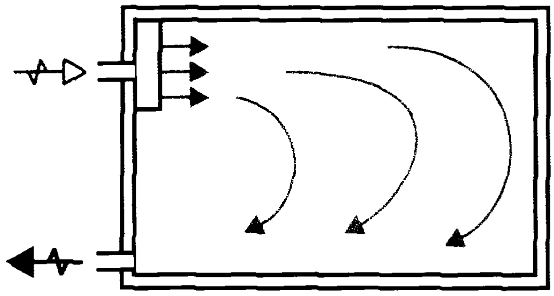


Fig. 4.5. Displacement flow

The air distribution and the placement of air inlets and supply units is very important. There are several possibilities and ways to locate the air inlets, depending on the case and the use of the space in question.
Also in this connection we must emphasize how important the good indoor air quality is for learning environment.

Cooling capacity

The dimensioning factor in many building is the required maximum cooling capacity. By various air distribution units provide different cooling capacities.

The selection of air handling system

The selection process is a complex process and from it`s essential parts integrated in building design. The baseline is the demanded level for indoor climate. In renovation of educational buildings or in designing new buildings, this selection process plays very important role. We can affect to energy efficiency and energy consumption in many stages of the process - design, installation and use - and in the most important decisions will be made already in the design phase. The possible faulty solutions are difficult to correct afterwards, and, anyhow, they cause extra costs. Air flow controlled system

4.2. Natural ventilation

4.2.1. Operational preconditions and driving forces

The principle of natural ventilation is introduced in the figure 4.6.
Natural ventilation is the most common ventilation system in old building stock. It is commonly used even nowadays in one-family houses.
The air change in natural ventilation is based on density differences caused by temperature drop between outdoor and indoor air both the effect of wind. The air flows are changing according to weather conditions. Natural ventilation system has exhaust duct from each exhaust valve to the roof. The ducts cannot be connected, because it is possible that the air is transferring from the room/space to another. This is not acceptable because of hygienic and fire safety reasons.

The driving forces (pressure drop) causing the air flow is usually very small. The ducts must be straight without curves and without long horizontal shifts. The length of the horizontal shift must be limited.

The exhaust ducts has been usually centralized into the same point inside the building, to prevent too many breakthroughs. This provides that the rooms which needs exhaust (kitchen, WC, bathrooms) could be connected to the ducts without long horizontal shifts.
These rooms must be relatively close from each other.
The performance problem of natural ventilation is, that there is no air flow in the ducts when there is no temperature difference or wind. In some cases the ducts can work backwards. If one can't boost contemporaneously the ventilation, occurs a obvious danger of insufficient air change and, by the same, increase of moisture. It can cause damages for building and furnishing materials. The backward flow (general if the drags vary in the ducts) can cause hygienic inconveniences.
The intake air is transferred through cracks or/and air supply units in natural ventilation system. The colder and windy it is outside, the more air is flowing through the building.

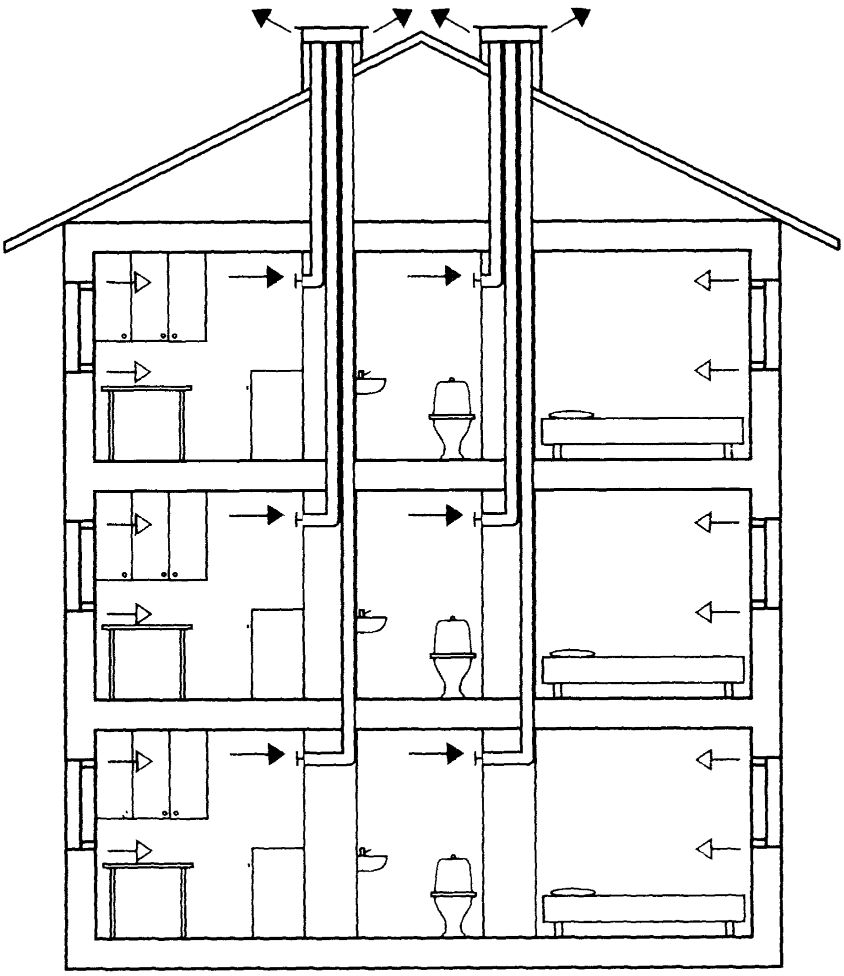


Fig. 4.6. The principle of natural ventilation (Seppänen, O, Seppänen, M: Rakennusten sisäilmasto ja LVI-tekniikka, ISBN 951-97186-5-6).

The air flows may vary depending on the room. The tighter is the envelope, the more air flows through the air supply units.
The tightening of the building envelopes sets big challenges for natural ventilation and for its design. In general, the design and dimensioning of natural ventilation is very difficult compared with the design of mechanical ventilation.

One way to intensify natural ventilation (and other systems, too) is venting. The air flows increase momentarily and indoor air will clean quickly. Long-lasting venting is not recommendable because of energy losses.

4.2.2. Natural ventilation, boosted

Natural ventilation can be boosted using ceiling ventilators or equal fans for specific targets. Natural ventilation combined with passive cooling consumes less energy, but in some conditions the learning and teaching environment can be unsatisfactory, and the performance of the system should be periodically intensified. In many cases, when there is a question about renovation, the choices must be done between mechanical and natural ventilation. It is possible to combine the best features of each system to create a new type of ventilation system, called hybrid ventilation. Hybrid ventilation systems are introduced in the chapter 4.4

4.3. Mechanical ventilation systems

4.3.1. Mechanical exhaust ventilation

The principle of mechanical exhaust ventilation is introduced in the figure 4.7.

The mechanical exhaust ventilation system is generally used, eg. in multi-storey and apartment houses. The air flow is boosted by fan or ceiling ventilator, the exhaust ducts can be led separately to the attic, where they can be combined by means of collecting chamber with the fan. The most general practice was to connect the overlapping spaces to the same duct. This is not in use anymore because of noise problems.

By means of fans we can get the demanded air flow for valves. The air flow is not significantly depending on weather conditions. The exhaust ducts will be dimensioned for higher air speed than in the case of natural ventilation, therefore the need of space is smaller.

Because the intake air is not heated, the mechanical exhaust system has the same disadvantage than natural ventilation. The incoming air flow may cause draft. The energy efficiency is weak.

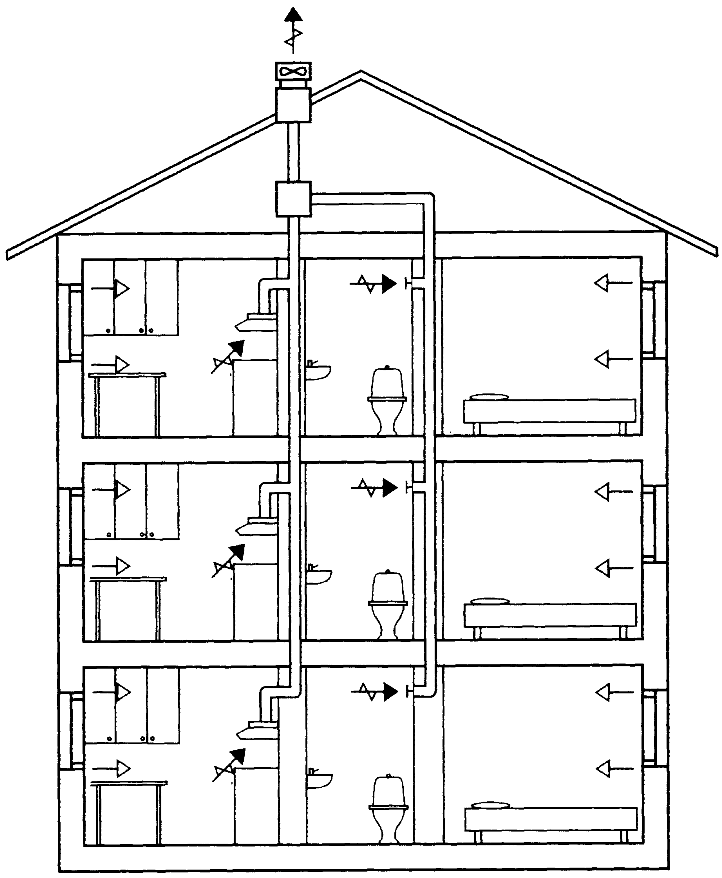


Fig. 4.7. Mechanical exhaust ventilation (common-based ducts) (Seppänen, O, Seppänen, M: Rakennusten sisäilmasto ja LVI-tekniikka, ISBN 951-97186-5-6).

4.3.2. Mechanical ventilation

Mechanical ventilation can be divided into two applications:

- Mechanical air supply and exhaust
- Mechanical ventilation with heat recovery

The principle of mechanical ventilation is shown in the figure 4.8 and 4.9.

The building envelope can be made tight and energy saving, when the intake air is led mechanically. This way we can have demanded air change and air flow for each room. The fresh air can't be led in without heating; using good heat recovery units we can warm up the intake air enough without any separate heating unit. Reheater units can be used if needed.
Mechanical ventilation system equipped with heat recovery unit serves the best possibilities for good indoor air quality and energy efficiency, if the system is properly designed, operated, controlled and maintained.

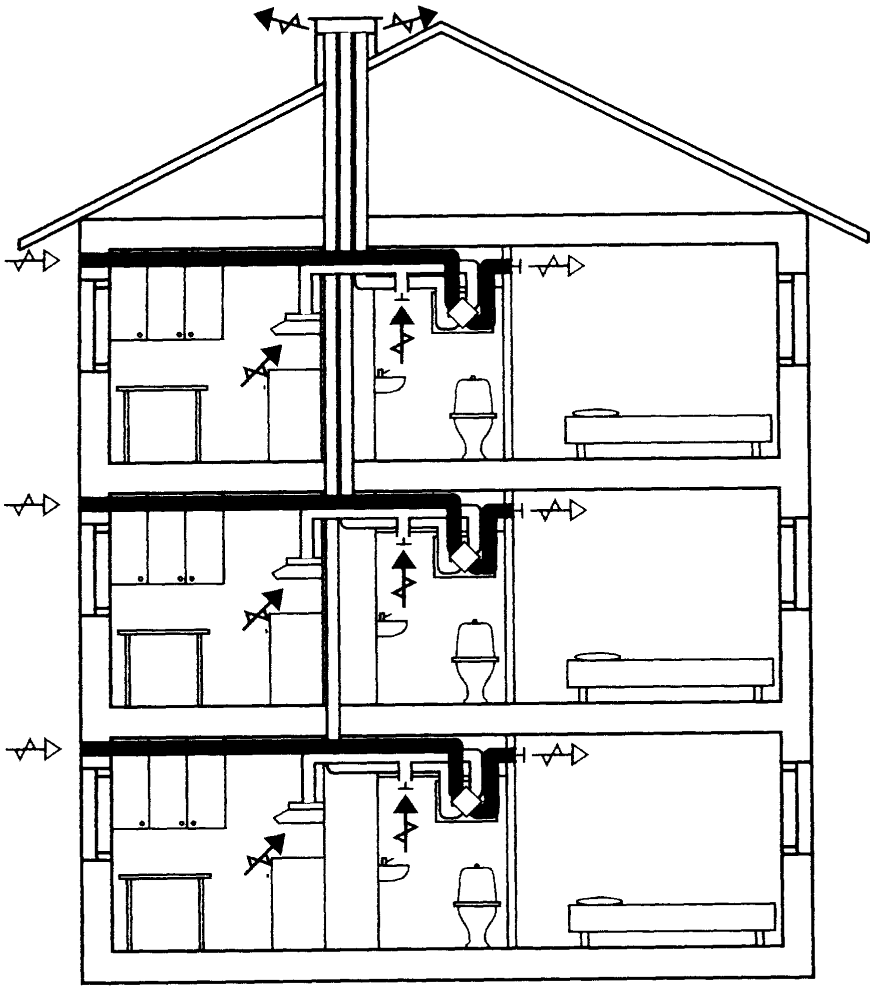


Fig. 4.8. Mechanical ventilation (room-specific system). (Seppänen, O, Seppänen, M: Rakennusten sisäilmasto ja LVI-tekniikka, ISBN 951-97186-5-6).

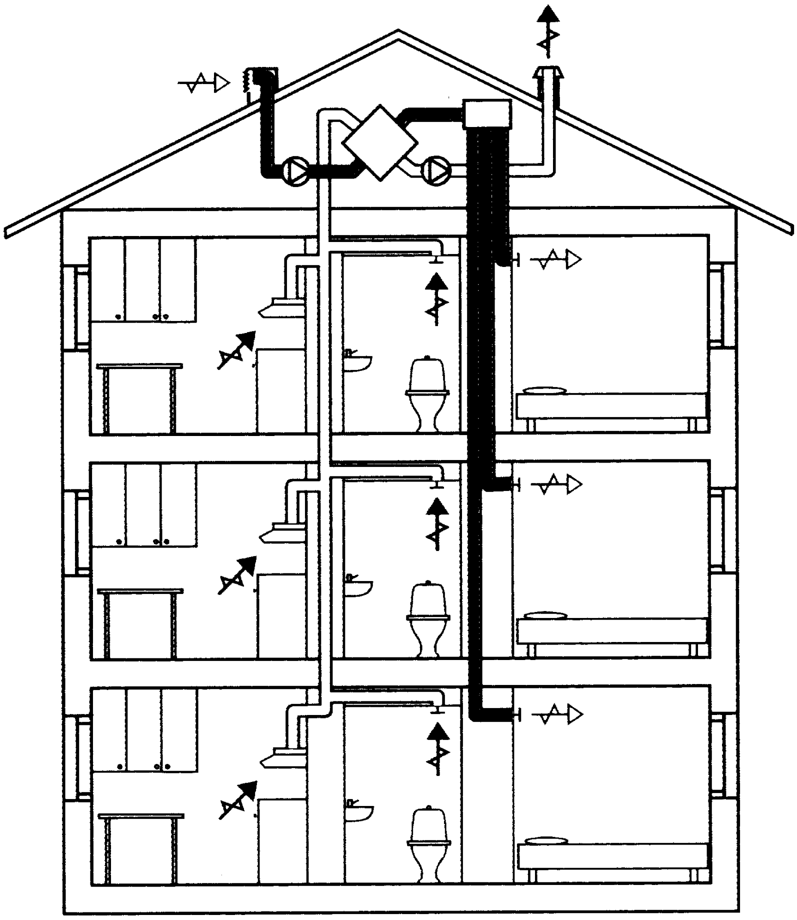


Fig. 4.9. Mechanical ventilation (centralized system). (Seppänen, O, Seppänen, M: Rakennusten sisäilmasto ja LVI-tekniikka, ISBN 951-97186-5-6).

Air heating
In air heating system the air change is combined with heating. The heat is transferred to the rooms by means of air. The main part of it is circulated back to the air heating unit and only a part of it as exhaust air out. Air heating system as the main system is only used in one-family houses.

4.3.3. Heat recovery systems

Very significant part from the heat content could be recovered in ventilating unit by means of heat exchangers. The efficiency of heat exchange is depending on the temperature difference between the transferring and receiving air flows.

The profitable application of exhaust air is heating of intake air. Heat can transfer from the exhaust air to fresh air directly through the plate which differs the air flows. We are talking about direct recuperative heat exchanger in this case; if the heating fluid absorbs heat alternately warming and cooling in the airflow, it is a regenerative, heat storing heat exchanger.

The direct recovery from the exhaust air provides the supply air and exhaust air into the same heat exchanger unit, which means more space reservation for the plant room.
Plate heat exchangers and tube heat exchangers represent usual heat exchanger structures, and heat exchange can be intensified by fins.
In general heat recovery devices that are installed in air handling units can be systemized as follows:

- Heat recuperation devices:
    - Plate heat exchangers with counter-flow,
    - Heat exchangers with water-glycol circuit,
    - Heat pipes based heat exchangers,
    - Heat pump based heat exchangers,
- Heat regeneration devices:
    - Regenerative heat exchangers with rotating wheel.

The different configurations of air handling units varying with heat recovery device are shown in the figures 4.10 to 4.14. Figure 4.10 shows the air handling unit equipped with plate heat exchangers with counter-flow, which is one of the most commonly used solutions.

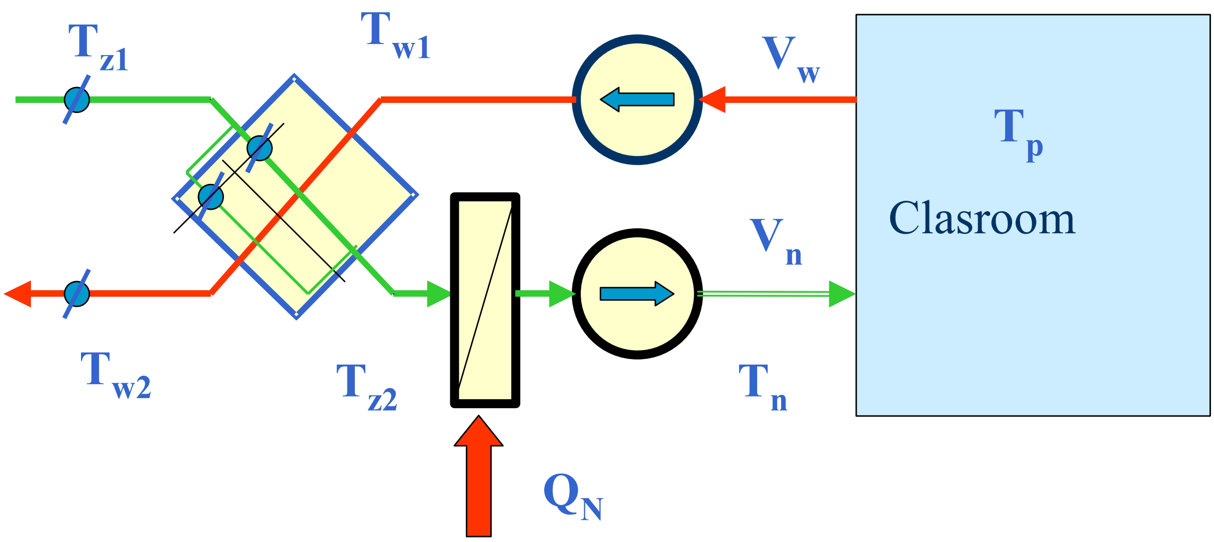
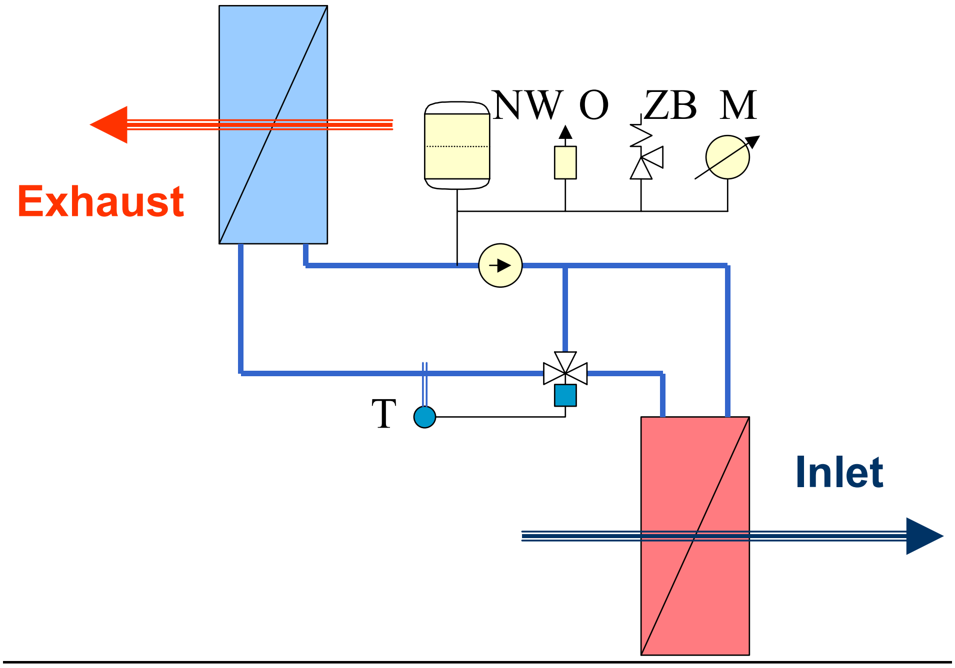


Fig.4.10. Air handling unit with plate heat exchanger

Figure 4.11 shows the air handling unit equipped with heat exchanger with water-glycol circuit. The advantage of that system is that the exhaust ducts and intake air ducts don´t need to be in the same place. This can be beneficial considering the retrofitting process. The circulation liquid is in general 30-40 % water-ethylenglycol-mixture and heat exchanger unit is baffle plate-type one.



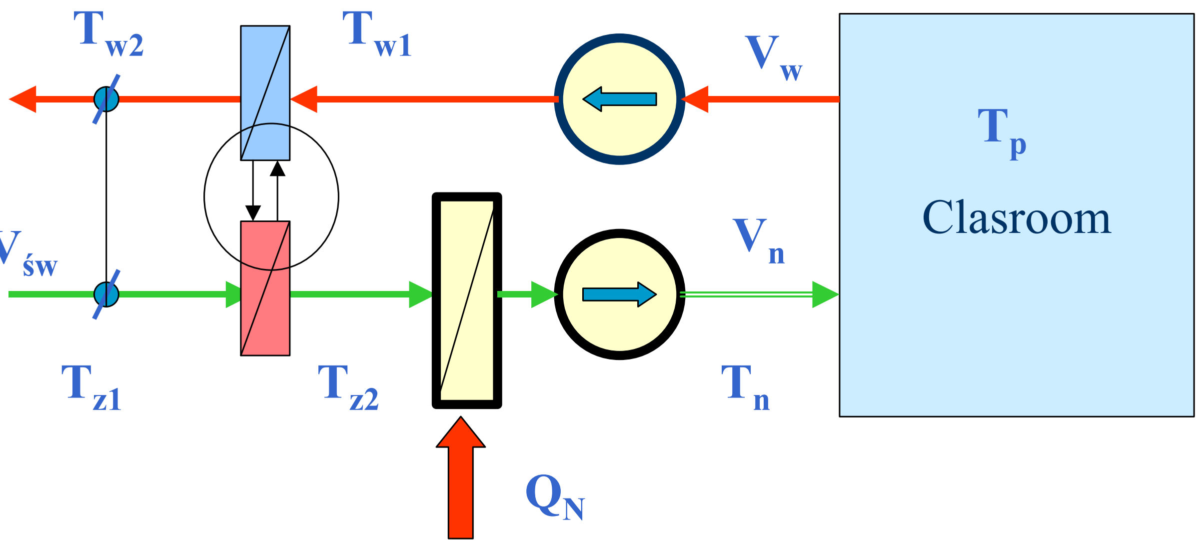


Fig.4.11. Air handling unit with water-glycol circuit

Figure 4.12 shows the flow diagram of air handling unit operating with the heat pump as the heat recovery device. The refrigerant is the operating fluid in the system. The heat extracted from exhaust air stream is utilized for the evaporation of the refrigerant in the evaporator. The refrigerant vapour is compressed by the electricity driven compressor to the pressure of condensation – condenser operating pressure. The heat of condensation which is released from the condensing refrigerant is transferred to the fresh air flowing in the air handling unit. The refrigeration cycle is completed by the transfer of liquid refrigerant to evaporator. The flow is directed via the expansion valve in order to equalize the pressure in the system. The overall efficiency of heat recovery is reported to be in the range of 45-55%.

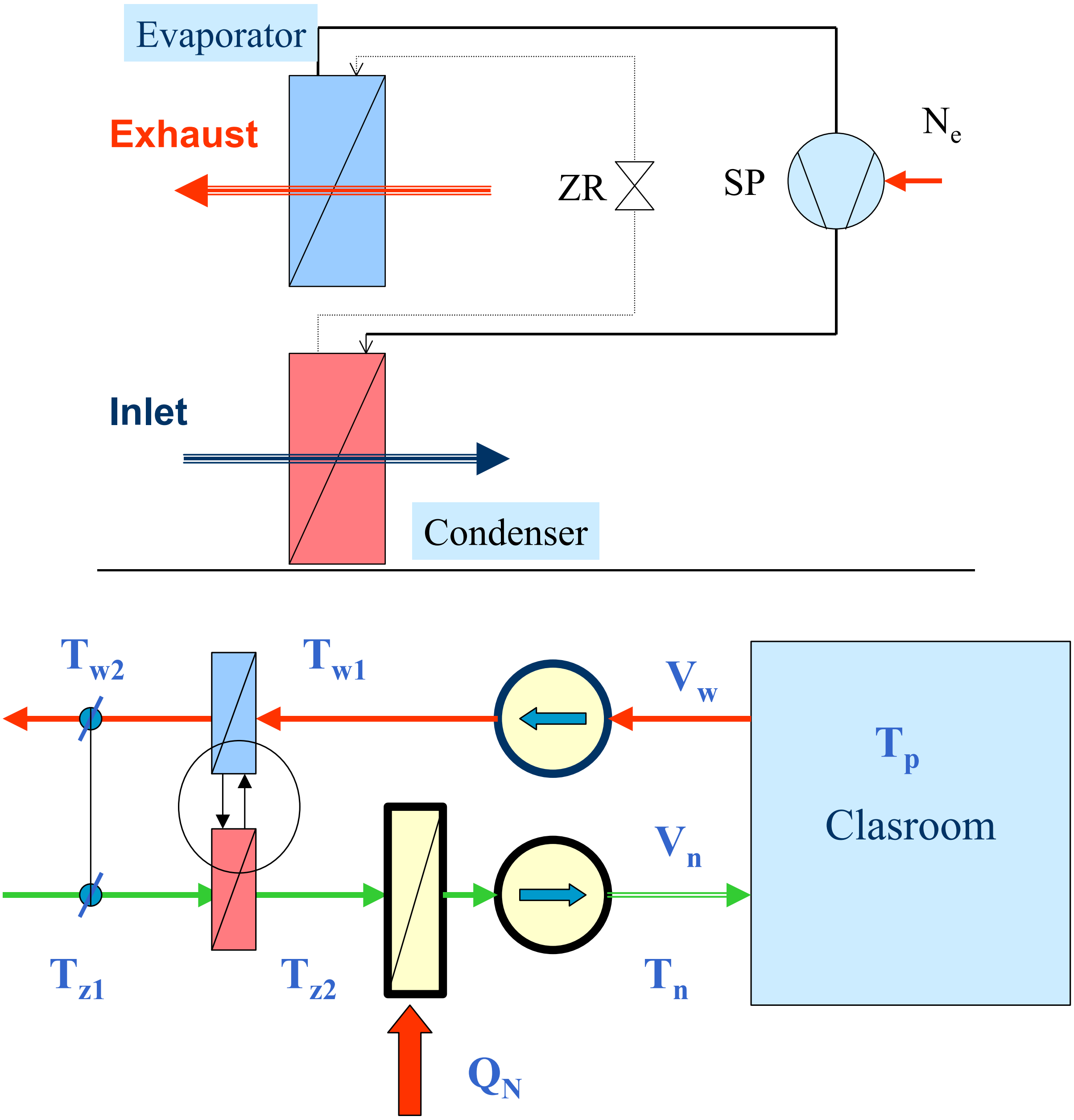
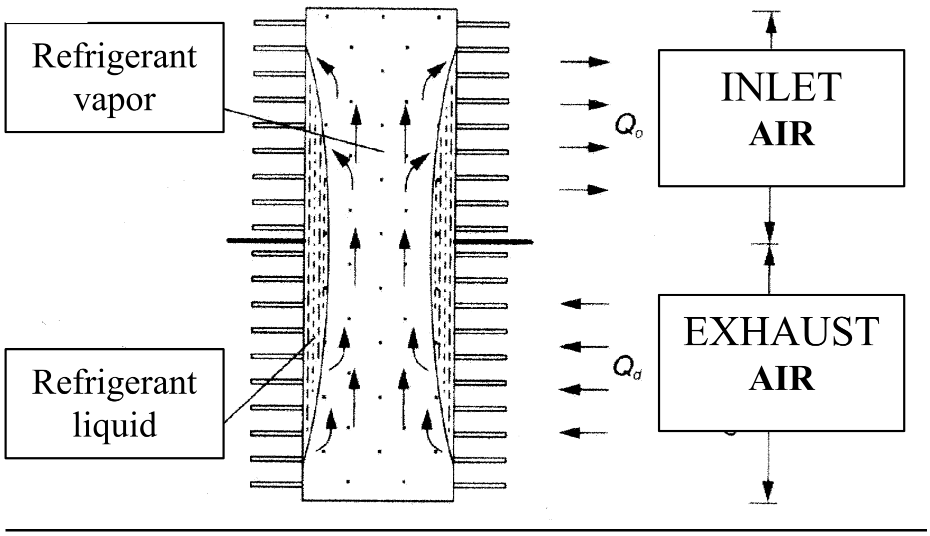


Fig.4.12. Air handling unit with heat pump based heat recovery device

The principle of heat recuperation which is the basis for the operation of the above described heat recovery devices is also utilized in the system operating with heat pipes – figure 4.13. The operating fluid in that case is also the refrigerant which is evaporating in the lower part of the exchanger due to the heat transfer from the stream of exhaust air. In the upper part of the exchanger, which is located in the fresh air duct the condensation of the refrigerant occurs. The liquid refrigerant flows due to the gravity forces to the lower part of the exchanger. The overall efficiency of the system is 40 to 50%.

Figure 4.14 shows the principle of rotating wheel regenerative heat exchanger. Heat transfer mass is cooling in supply air flow and it is warming in exhaust air flow. It is also possibilities for leaks (moisture, gaseous impurities). Heat recovery efficiency is relatively good and can reach a range of 75-85%



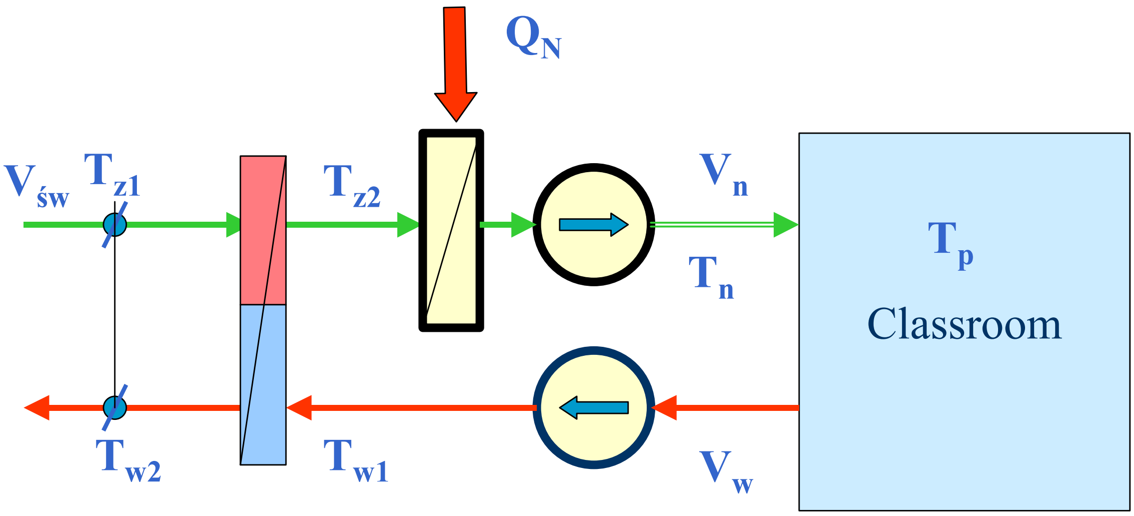


Fig.4.13. Air handling unit with heat pipes based heat recovery device

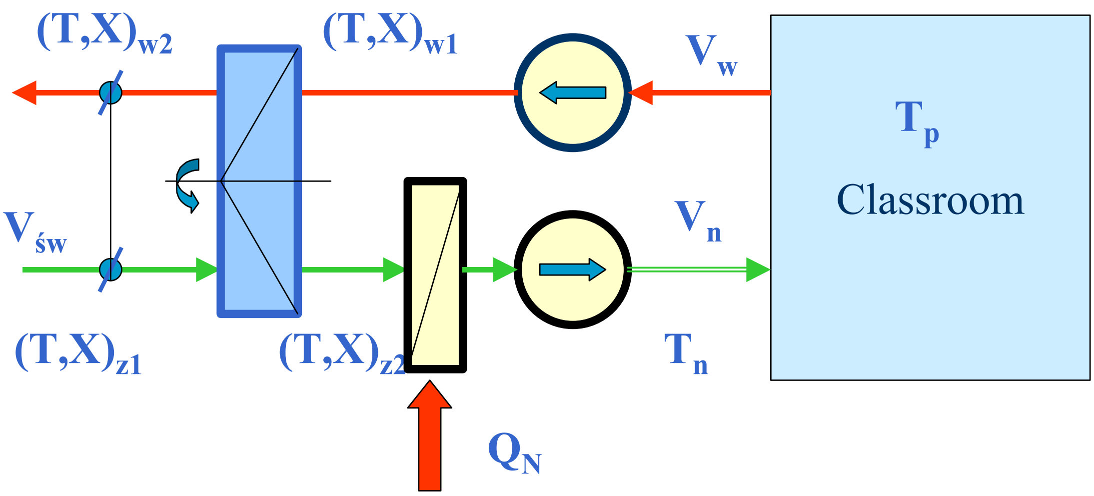


Fig.4.14. Air handling unit with rotating wheel regenerative heat exchanger

4.4. Hybrid ventilation systems

Hybrid ventilation systems can be applied by various concepts and strategies, depending on the case and the building. A good presentation of the principles of the hybrid ventilation is presented in the reference 7.
The main principles for hybrid ventilation are:

- Natural and mechanical ventilation
  Based on two fully autonomous systems, where the control strategy either switches between the two systems or uses one system for performing certain tasks and the other systems for performing other tasks
- Fan-assisted natural ventilation
  Natural ventilation system combined with extract or supply fan(s)
- Stack- and wind assisted mechanical ventilation
  Based on mechanical ventilation system that makes optimal uses of natural driving forces (wind and stack effect)

The control strategies can based on IAQ (Indoor Air Quality) control or temperature control (natural cooling).
Hybrid ventilation is a relatively new technology, and could be used in many renovation cases. It can be also problematic in some cases. Hybrid ventilation needs a proper and careful design in each design stages. According to results achieved, it can be quite effective in achieving good IAQ and thermal comfort but not so effective in achieving outstanding energy performance. In the future the system development will create new solutions for control systems and devices.

4.5. Control and information systems

Control strategy is one of the key elements when evaluating the performance of a ventilation system.
In natural ventilation system, the performance of the system is depending on the wind speed and direction and the temperature differences between indoor and outdoor. It can be boosted by opening windows, but the adjustability in general is limited, even the new devices and technology will give better tools for it. In many schools there is still a natural ventilation system, and the CO_2 -concentration can be very high in the end of the lesson - over 2000 ppm, even 5000 ppm in the worst possible cases, according to many studies in various countries.
In mechanical exhaust ventilation, the flow of the exhaust air is normally controlled by single- or two-staged fan with time control. The need of the air exchange varies in different rooms, and there can be a too effective ventilation in some part of the building and defective ventilation in the other part of the building. Energy economy is low. According to energy audits in many countries, the adjustment of the running time of ventilation gives the biggest and fastest savings.
In the case of mechanical ventilation, more complicated control systems has been used. Earlier there was a constant air flow with single- or two-staged time controlled fans and boosted ventilation in the special targets (kitchen, gym). In modern systems the fans are equipped with frequency converters, and the rotating speed of a fan can be varied. One type of an "idealistic" ventilation control system in schools could be as follows:

– constant pressure system with adjustable fan motors with frequency converters

- a damper motor and a valve in each class, controlled by CO_2 - and temperature sensors (if either carbon dioxide concentration or indoor temperature will approach the limit value
- CO_2 - control and timer in gyms
- constant speed system in the kitchen area, availability for boosting by the personnel if needed
- heat recovery unit can have a reverse function if cooling is used

Control system can be based on can manual unit controllers. If we have DDC- (direct digital control)system, it include sensors and devices which are controlled by one computer in the operating room. The system can also be distributed to the sub-stations, which control their area, and the sub-stations are connected to the operating room and main unit. Now there are smart unit controllers available, which can be monitored by remote control, by GSM phone or by Internet, for instance. In such case the service personnel is not fixed physically to the same building and the operating room can locate in some other place.

The main goal of the control system in educational buildings is to create as good learning and teaching environment as possible - energy economy and energy performance demands could be in contradiction with indoor air quality requirements. The result should be an optimized condition for energy performance and IAQ. In cold climate weather conditions, ventilation is the biggest consumer of heating energy, and its share presents >50 % of the energy balance in some cases. There is many cost-effective tools to decrease the energy consumption of ventilation, from which the running time optimization needs no investments.

One very important tool for controlling and management of the energy efficiency and ventilation is a continuous monitoring of the systems. The new building automation systems make it possible. This means a proper measurements and instrumentation of the process.

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Chapter 5

Solar control and cooling systems

by

R. Cantin, G. Guarracino, C. Laurentin,
V. Richalet, Lorenz v. Schoff

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5.1. Introduction

→ Richard C and Larry (Copenhagen Minutes)
In school buildings, there is a need for sufficient daylighting in teaching areas for both comfort and energy savings purpose. As a result, large glazed surfaces are often proposed as part of the facade retrofit. It is of particular importance that the problems of glare and summer overheating can be analysed at the same time. Indeed, if the luminance of the sky seen through a window is very high compared to that of visual task, disability glare can result in a reduced performance (even a risk of accident). Discomfort due to high luminance contrast is most likely to happen and should be treated with special devices attached to the window design. These devices must be chosen in order to reduce at the same time inconveniences due to sunlight, likely to lead to excessive direct heat and glare.
As a result, ideal shading devices should reduce solar radiation whilst admitting diffuse radiation as daylight and allowing 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 from skylight can be classified into the following means [1]:

- Selection of appropriate orientation, tilt and size of the openings
- Obstruction of sun beam by use of envelope appendices or shading devices
- Selection of internal or external shading devices according to their solar optical properties

This paper will not deal with bioclimatic buildings eg. solar collection or stocking, but only with solar control and especially shading devices. Also, the design of the openings will not be discussed any more as a solar control technique although it is certainly the first step to avoid summer discomfort and visual glare in the designing process.
As part of the solar control techniques we will then consider specific devices of last two kinds of the previous list.

5.2. Shading systems and glare protections

To choose a solar control device we need to consider:

- The site latitude
- The orientation of the facade
- The orientation of the openings (vertical or horizontal)
- The aesthetic of the facade
- The glazing type of the window
- The need for daylight
- The need to get a completely opaque solution or not
- The need to have air passing through it
- The performance of the solar control device itself
- The control of the solar shading if movable

The overall thermal and optical performance of a solar control device in respect to solar radiation impinging on it is based on the phenomena:

- Primary transmission: beam solar radiation passes directly through the shading assembly
- Reflected transmission: beam solar transmission passes through the shading assembly by multiple reflection on the slats and/or the set-back (belonging to the building)

- Diffuse transmission: diffuse solar radiation passes through the shading assembly directly and by multiple reflection
- Solar absorption: solar radiation is absorbed by the shading assembly and may in turn be transmitted via:
  - Conduction within the shading assembly
  - Convection to the surrounding air
  - Longwave radiation towards the glazing, set-back; outdoor or indoor environment (depending on the location of the device) or another part of the shading assembly at a different temperature.

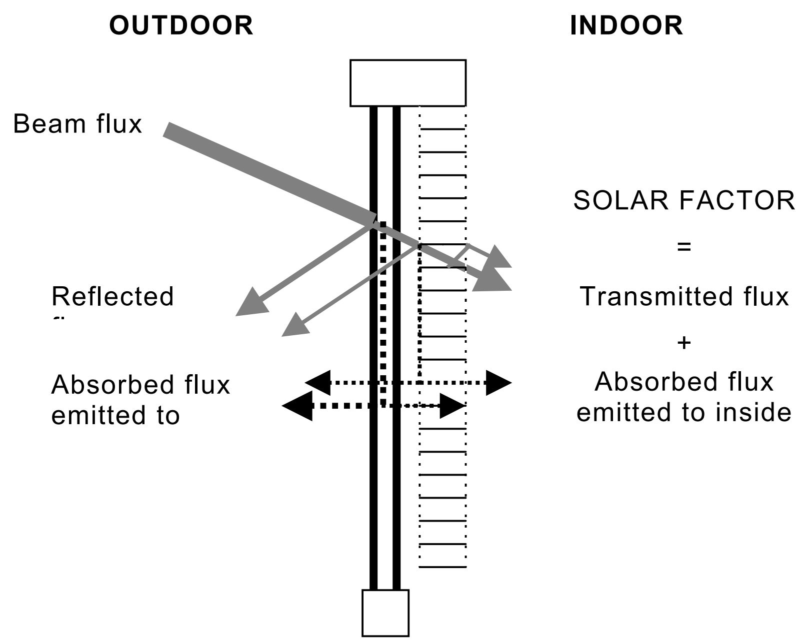


Fig. 5.1. Illustration of the thermal and optical performance of a solar control device in respect to solar radiation

The global shading efficiency of a device is the result of all these direct and indirect transmission processes. Two parameters are commonly used to characterise the device performance:

- Solar gain factor or solar factor (SF) defined as the fraction of the incident solar energy which passes through the device
- Shading coefficient (SC) defined as the ratio between the solar factor of the assembly and the solar factor of the reference opening made of a single pane clear glass (table 5.1).

Shading devices are also essential to avoid glare situations. If their luminous transmittance is too high (above 10% in general), the risk of glare is significant, with luminance reaching more than 1 000 cd/m^2 for an illuminance on the awning of 40 000 lux [2]. So, screens with transmission factors lower than 10% are sufficient to avoid glare from the sky.
The principle of an 'ideal' screen is to reflect the maximum amount of solar rays from its external surface and to reduce transmission to ensure optimum control of glare phenomena. From the table above, we can observe the performance for example of the grey screen, in outside position (ref: Hexcel Lyverscreen Satin 525). With this screen, we obtain a shading coefficient of 0.14, this signifies that the reduction of the thermal contribution of the window is significant since the screen eliminates around 80% of the thermal contribution of the

window (the same screen placed inside eliminates around 50% of the thermal contribution of the window). The daylight transmittance equal to 5% is sufficient to avoid glare from the sky.

Table 5.1. Example of shading coefficient given by manufacturers for some shading devices

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

We have seen before that the choice of shading device is influenced by the site latitude and façade orientation. The choice of the screen fabric best adapted for each façade is defined by the trajectory of the sun or its absence on the façade concerned. In fact, in Northern European countries the sun is low over the horizon for most of the day, lighting south oriented façades. Therefore a screen with a very low transmission rate must be installed (3% for example). On the contrary, north facing facades need to optimise the sky's luminance, as there is no direct exposure to the sun. In this case, there is no point in using a screen with a low transmission rate, as this would considerably reduce the contribution of natural light inside the office. A screen with 10% daylight transmittance will manage this level of external luminance.

These parameters are based on the boundary conditions assumed in the ISO/DIS 9050 for glass tests. Designers and decision makers must be conscious that the performance of the shading assembly might be different in the actual application conditions. Main reasons are:

- Only the direct solar radiation and a fixed solar incidence angle are considered in the standard tests, although some experiments have shown that the shading device performance is strongly dependent on the ratio direct/diffuse.
- The distance between the shading device and the glazing is ignored. As far as the size of slats is small this distance can be disregarded but the fraction of sunlit device for medium/large slats can be influenced by this distance.

Moreover, the terminology itself is misleading as Shading Factor should consider the reduction of heat gain achieved by the shading device.

5.3. Cooling Systems

The control of the environmental conditions for educational facilities directly impacts the performance of the students and staff that occupy the space. One of the elements which control environmental conditions is the cooling (air conditioning) system selected. There are five categories of cooling systems with several variations within each. This section will highlight these five categories looking at appropriate climate zones to use, cost effectiveness, benefits, and operation and maintenance.

The five categories cooling to be described are:

a. Natural
b. Evaporative
c. Direct expansion
d. Chilled Water Plant
e. Geo-Exchange

Natural Cooling – There are two methods of providing natural cooling (ventilation): Cross and Stacked.

a. **Cross ventilation/cooling –** This method depends on the movement of air through the space to equalize the pressure. Wind which blows against a wall or barrier is deflected around and above the barrier creating a higher pressure on the windward side of the building. The pressure on the leeward side of the building then has a lower pressure creating a suction and thus a pressure differential. When windows or other means of ventilation are opened, the outdoor air enters on the windward side moving to the lower pressure area. The movement across the teaching space, results in exhausting the internal air and cooling the space.

This method is very effective in mild climates and coastal climates. In coastal climates the need for a cooling system will almost be eliminated. This method does require an initial greater up front cost for operable windows which can range from 42 Euros to 62 Euros per classroom.

The benefits from using cross ventilation/cooling are:

1. In moderate climates meet most of the cooling load needs
2. Simple pay back for inclusion of this method from 8 to 10 years
3. Better indoor air quality
4. Simple to install and little maintenance
5. Give occupants a sense of individual control

b. Stack ventilation/cooling – This method depend on the difference in air densities to

Provide air movement in the teaching space. Two vents are needed for this method to work: One Close to the floor and the other high in the space. Warmed by internal loads (student/faculty, lights, and equipment) the indoor air rises. The warmer the air the less dense and it rises. This rising of the warmer air creates a vertical pressure gradient. The vent close to the system will allow the rising warmer air to escape and as it escapes it will draw in cooler air from the lower vent to replace it. Thus causing air movement and cooling of the space.

This method like the cross ventilation/cooling is very effective in mild and coastal climates. This method is especially effective in the winter when inside-outside temperature differential is at its maximum. And during mild weather conditions it can meet most of the cooling requirements. The benefits are the same as above as are the cost effectiveness.

Evaporative Cooling

Evaporative cooling is an alternative to air-conditioning with low energy costs because no compressor is needed, only a fan and a pump. This method is good for educational areas with high outside air ventilation requirements. Evaporative cooling can be either direct or indirect. Direct cooling involves the water being exposed to an air stream. This happens when water flows over a medium designed to maximize the surface area of water in contact with the air and air is cooled through evaporation. Effectiveness can be as high as 80 – 90%. Example: 26.7C air dry-blub with a 10C wetbulb, then the leaving air is cooled to 11.7C to 24.4C drybulb.
Indirect evaporative cooling is not as effective as direct, but adds no moisture to the air. Air passes over and through a cooling coil supplied with water from a remote cooling tower. This method is only 60% effective in reducing the dry blub temperature of the entering air to its wetblub temperature. When the direct method provides 22.2C to 23.3C air in the above example then indirect would only provide 25.6C air.
Initial installation costs are more than a typical AC unit the operating costs are significantly less. It is cost effective in war and dry climates when higher indoor temperatures are acceptable during hot periods.

Direct Expansion Cooling

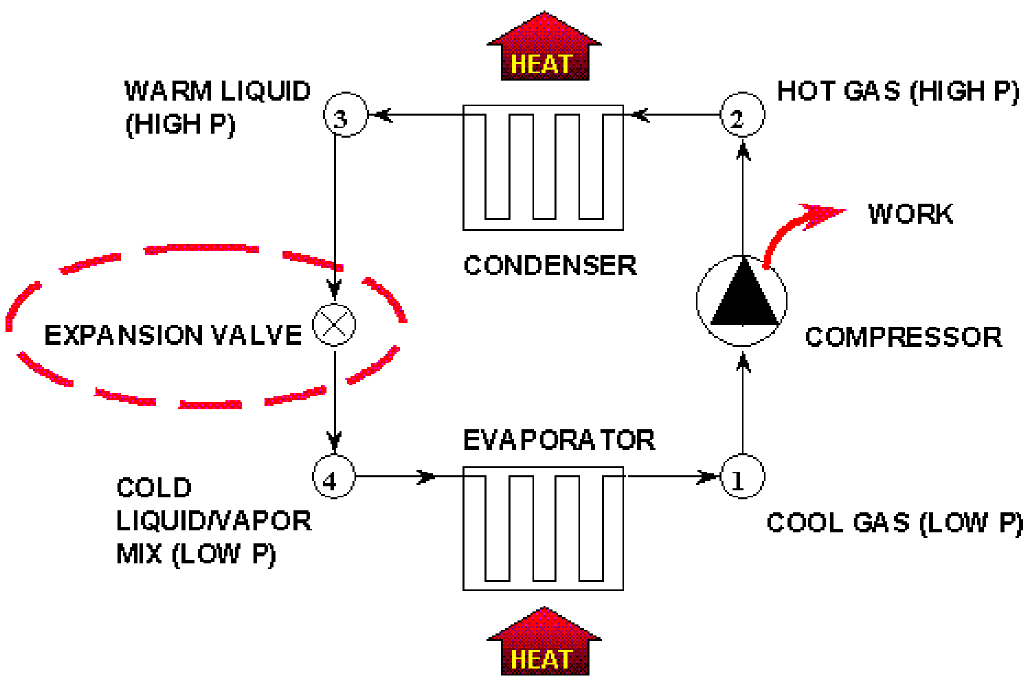


Fig. 5.2. The flow diagram of Direct Expansion Cooling cycle

Direct Expansion, or "DX", cooling uses the vapour compression refrigeration cycle in which a fluid called a refrigerant moves heat from one part of the cycle to another. The "cool" refrigerant is produced between states 3 and 4, after a large pressure drop (expansion) takes place. Typical devices used to produce the pressure drop include expansion valves, capillary tubes, and orifice plates. The cool refrigerant can then be used as a heat transfer medium in the evaporator to absorb heat where needed. In a normal DX unit this medium in air. DX systems are connected to Air Handling units for distribution of cooled air to specific zones of the educational facility these are know as split-systems.

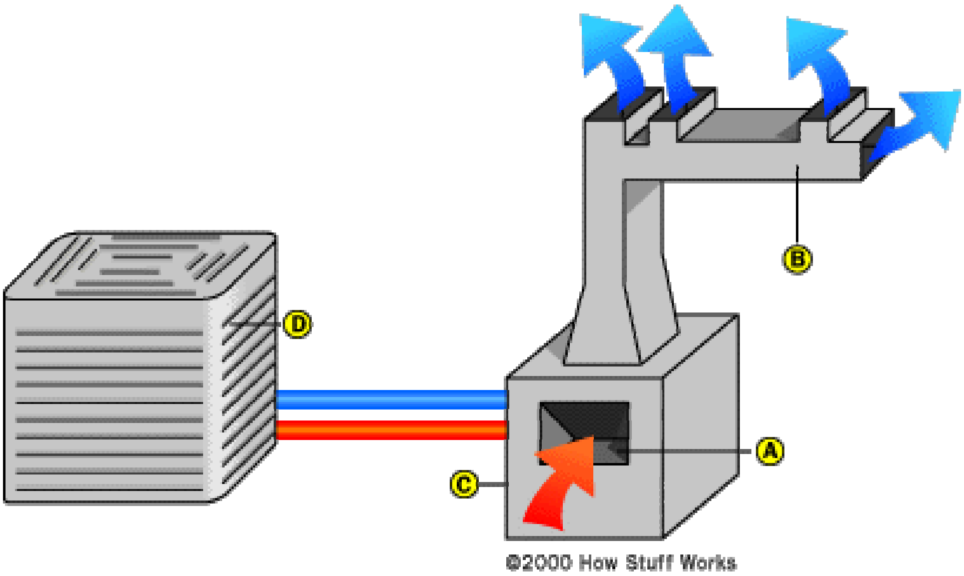


Fig. 5.3. A **split-system air conditioner** splits the hot side from the cold side of the system

The **cold side**, consisting of the expansion valve and the cold coil, is generally placed into a **air handler**. The air handler blows air through the coil and routes the air throughout the building using a series of ducts. The **hot side**, known as the **condensing unit**, lives outside the educational facility and in most cases on the roof. In other systems the medium will be a liquid which is normally a treated water.

Chilled-water System

In larger educational buildings and particularly in multi-story educational buildings, the split-system approach begins to run into problems. Either running the pipe between the condenser and the air handler exceeds distance limitations (runs that are too long start to cause lubrication difficulties in the compressor), or the amount of duct work and the length of ducts becomes unmanageable. At this point, it is time to think about a **chilled-water system**.

In a chilled-water system, the entire system lives in a mechanical room or behind the building. It cools water to between 40 and 45 F (4.4 and 7.2 C). This chilled water is then piped throughout the building and connected to air handlers as needed. There is no practical limit to the length of a chilled-water pipe if it is well-insulated.

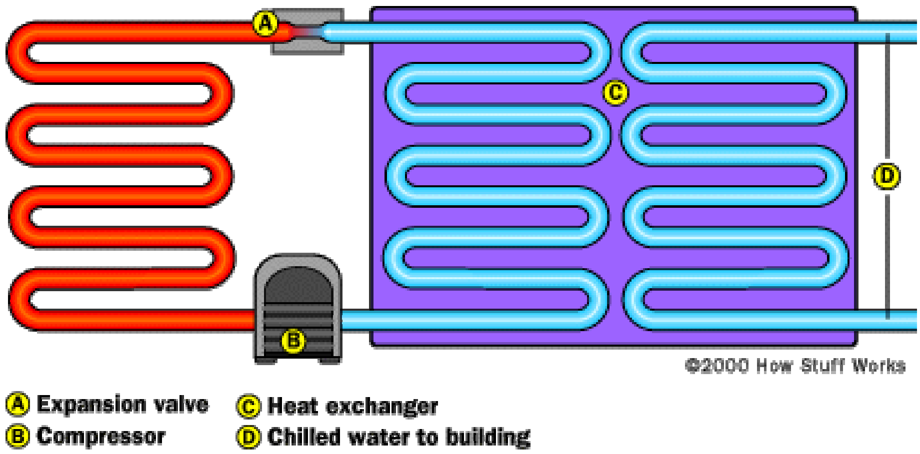


Fig. 5.4. Cooling Tower

You can see in this diagram that the air conditioner (on the left) is completely standard. The heat exchanger lets the cold Freon chill the water that runs throughout the building. To obtain maximum cooling capability of the Water in ©, a cooling tower is added in the flow of water in (D) to remove the heat gained while in the building and before it returns to © to be chilled again. Cooling towers fall into two configurations: Direct and Indirect. The direct one is when the fluid in D comes in direct contact with air in the cooling tower and is cooled. The other is indirect and the fluid is cooled by cascading water over the outside of the tubes. Air flow through the towers can be by either force draft (blown air through the tower) or induced draft (air pulled through the tower).

Geo-Exchange

The earth around an educational facility can serve as a heat and cooling source when energy unit cost is high and climbing. These system are known by many names include geothermal, earth-coupled, ground-coupled, close-loop and water-coupled. They all use a fluid transported by a hydronic system through a Ground Source Heat Pump (GSHP) to either remove heat from the ground to the air in a space when heat is needed or to transfer the heat from a space to the ground when cooling is required using a refrigeration cycle.

Fig. 5.5. Typical Ground Source Heat Pumps for Varied Requirements

There are two types of geo exchange systems: Open-loop and Closed-loop. An open-loop system takes water directly from a well, lake, stream or other source and passes it directly through condenser loop GSHP. When cooling, the water is warmed as it passes through the condenser loop and the water is returned to the lake or stream or to another well. These systems have limit use. The system that is used the most is the closed loop system. This system circulates a fluid (usually containing a substance that prevents freezing in cold weather) through a subsurface loop of pipe to a heat pump. See illustration below.

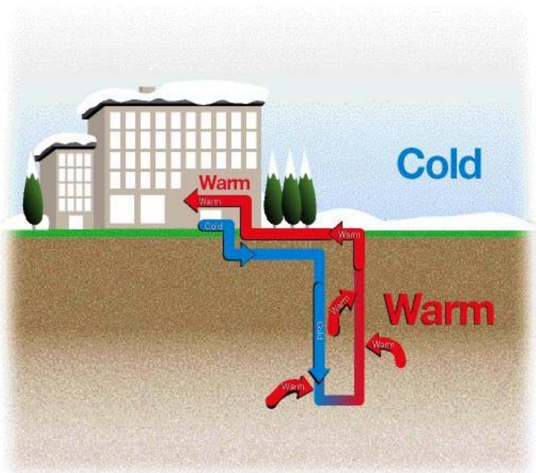


Fig. 5.6. Typical Geo Exchange Closed Loop Diagram

The subsurface loop typically consists of polyethylene pipe, which can be placed horizontally in a trench or vertically in a well. This pipe can also be placed in a pond or lake in coils to serve the same purpose. This thin-walled pipe is a heat exchanger, transferring heat to and from the earth. The earth temperature normally ranges from 10 to 15 (50 – 60 F) degrees C. The fluid inside the pipe circulates to the heat exchanger of an indoor heat pump where the exchange takes place with the refrigerant. The use of GSHP, allow for individual controls in the classrooms and allows for heating and cooling to occur at the same time in a educational building.

Cost of these system are normally more costly than a typical system from 10-15% but this first cost is offset by a 20-50% reduction in energy costs and a 30% reduction in maintenance costs. Payback for a typical Geo-exchange system ranges from 5 to 10 years. These systems can reduce peak energy demand and reduce the heat island effect, since waste heat is returned to the ground and not to the air.

All of the cooling systems described above are used in different configuration for installation in schools. The next section will described air conditioning installations.

5.4. Air conditioning Installations

Air conditioning installation in the retrofit of educational facilities is dependent on many elements including use of space, size of facility and climate. In this section several Air Conditioning installation options will be discussed each has it specific use and advantages and disadvantages. These are: Split DX Installation, Packaged Rooftop Installation, Displacement Ventilation, Ductless Split, Hydronic Distribution, and VAV Reheat System.

Split DX Installation

A split DX installation normally is for a single room. These units known as a split unit can be two separate units – Air Handler and evaporator coil inside and the compressor and condenser outside. Some units can operate a split unit but all wall though units with the Air Handling unit on the inside of the wall and the compressor and condenser on the outside of the wall. Some units have natural gas as a means for heating if that is required and they are known as a split Gas/Electric units. Individual temperature control is a benefit.

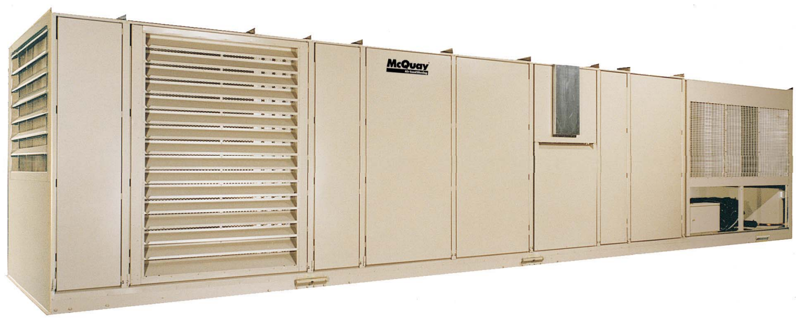
Efficiency of these units can range as high as 14 seasonal energy efficiency rating (SEER). These units can range in cost for a classroom from 93 euros/square meter to 112 euros/square meter. Economizer units can be added to these units for between 260 to 435 euros. Moderate initial cost and operating costs. Energy use will average about 190 kWh/square meter/year

Package Rooftop Installation

A package rooftop unit is fully self-contained and most consist of a constant volume supply fan, DX cooling coil, heating strips if required, filters, compressors, condenser coils and fans. The entire unit is mounted on the roof. Package units are normally installed for a single zone and are a retro-fit package for educational facilities where older units might exist. Units should include an integrated economizer and design of the duct work should allow for proper flow for both low and medium fan speed. Since this unit supply's cooling to a zone and not a room then the control of temperature is central and not allow for individual room control.

High efficiency cooling units have a (SEER) of 12 to 13. Units can be purchased as heat pumps to allow for both heating and cooling. These units come in sizes from 24000 btu/hour to over 1.2 million btu's / hour. Cost of the unit including duct work, controls and installation will range from 140 Euros/square meter to 187 euros/square meter. Unit cost alone range from 1304 euros for 2 tons to 1739 for 5 tons. This relates to an energy use of 140kWh/square meter/year.

These units have a low initial cost and low cost to maintain with energy costs are higher than average and the life expectancy of the unit is less than 30 years.

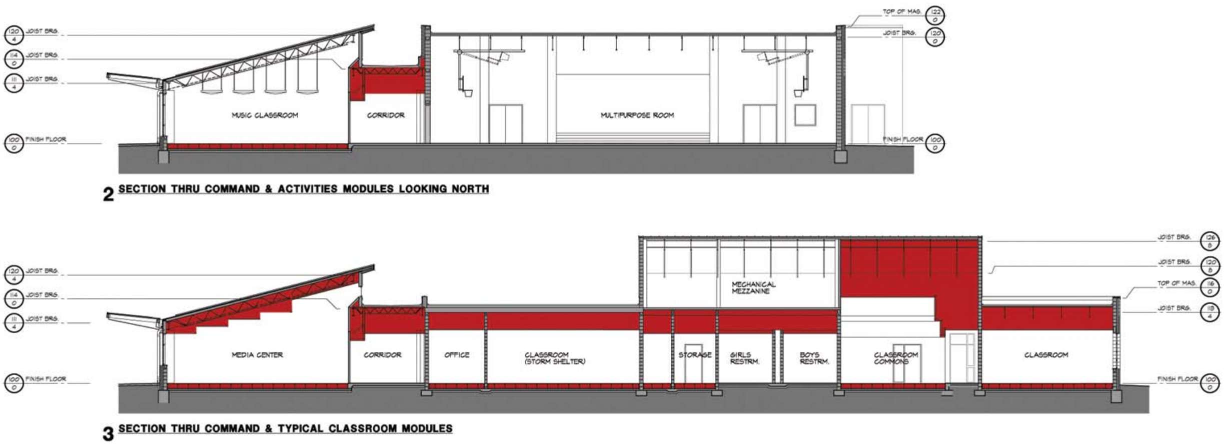


Typical Package Roof Top Unit

Displacement Ventilation

Displacement ventilation is one that is different from most used in educational facilities. Displacement systems deliver air near the floor at low velocity and at a temperature between 17.2 to 18.3 C (63-65 F as compared to 55 F with other systems) The goal of displacement ventilation or cooling is to not cool the space but to cool the occupants. When cool air flows along the floor until if finds warm bodies. As the air is warmed by the occupants the air rises and cools the occupants and then is exhausted out of the space. Cooling loads decrease significantly because most of the load is generated by occupants, lights and computer equipment. Air quality is improved since the contaminants are raised out of the breathing zone.

The supply of air has three options: Access floor (raised flooring); Low wall outlets and infloor outlets. See photo below for examples;



Areas is red on floor level are raised floor with vents

Low wall outlets

The best cooling source for displacement cooling is a chilled water system. For this system to operate properly ceiling height should be at least 3.05 m. The cost of this system is initially it about the same as conventional systems, because of the down sizing of the chiller system and motors and fans because of the features of the displacement system.

Hydronic Distribution

Hydronic distribution system describes the transfer of heat by circulating a fluid (as water or vapour) in a closed system of pipes to cool a space. The fluid can be either heated by a boiler or cooled by a chiller or fluid from a Geo-Exhange system. When cooling is required, this distribution system circulates chilled water to either individual unit ventilators, large fan coil units to extract heat from the space and transport is back to the chiller for heat extraction and re-cooling of the fluid. Energy savings can be obtained in the design by using Variable Drive Pumps (VDP). Hydronic systems can be designed for either 2–pipe or 4-pipe operations.
Two pipe systems are less expensive and complicated to design and build but only allow for either cooling or heating at one time. Four pipe systems allow for cooling and heating at the same time. Four pipe systems are more complex in design and control and more costly to operate but allow for extreme flexibility.
These systems are common in school construction because of its simplicity and use of common equipment, materials and controls for maintenance personnel. The cost effectiveness of this system is dependent on it initial design and depends quantity, size and type of piping, valves and pumps. The system properly sized and installed will provide a quiet, efficient and virtually maintenance-free operation at minimal cost. Oversized piping will not only reduce the need for pumping power required but will also for increase in load requirements when additions or renovations are needed without a complete system overall. Energy used for these systems range from about 130 kWh/square meter/year for a two pipe system to 180 kWh/square meter/year for a two pipe system.

Typical Unit Ventilator Used in Retro-fits

Variable Air Volume (VAV) System

VAV is a general term for a type of HVAC system supplying on the amount of air needed to satisfy the load requirements of a building zone or room, and can supply different volumes to different zones at the same time. The result is the total supply of cool air changes over the course of the day, depending on the heat gains in different building areas at different times.
In a VAV system, a central supply fan sends air through medium-pressure ductwork to terminal units (VAV boxes) throughout the building. The airflow to each zone or classroom is controlled by the VAV box (a smart damper), which varies the airflow in response to the space temperature. As cooling loads in the zone drop, the damper continues to close until it reaches a minimum position. The minimum position provides the occupants of the zone with adequate ventilation air. Some VAV boxes, especially those in perimeter zones, contain a reheat coil for times when the minimum airflow provides too much cooling. The reheat coil provides heat in the winter. A duct mounted pressure sensor that decreases the fan output as the VAV box dampers close controls the main system fan.

The overall efficiency of VAV systems depends on the diversity of zone heating and cooling loads. This system is best used in a large school building that is multi-story and a large number of classrooms and varied uses. The typical VAV reheat system costs between 145 to 164 euros per square meter to install.

Advantages of the VAV system include:

1. Better comfort control results from steady air temperature
2. Moderate initial cost for buildings that require multiple zones
3. Better de-humidification control
4. Energy efficient
5. Centralized maintenance
6. Relatively simple to add or rearrange zones

Disadvantages of the VAV system include:

1. Requires more sophisticated controls than a single zone
2. VAV box can generate noise the radiates out of the sheet metal walls and travel down the supply ducts

The above described air conditioning installation system use varying sources or systems to supply the cooling medium. Some of these sources are reviewed and addressed in the Section 5.3 Cooling Systems.

5.5. Solar control systems

5.5.1. Glazing with solar optical control

Today, a large variety of glazing or selective coatings is proposed by the manufacturers, some of them devoted to protect internal spaces from excessive light, reducing the brightness glare of the glazing and heat with respect of luminous performance. Three innovative trends are particularly attractive [3]:

- An active control of transmittance, eg. thanks to a varying dc voltage/current which may be controlled manually or automatically (electrochromic glazing) or thanks to a temperature dependent properties layer or deposit (thermotropic or thermochromic glazing) in order to switch from a transparent state to a lower transmitting state when indoor temperature is likely to exceed overheating limit.
- An angular selective coating, obtained thanks to anisotropic coatings. Previous work in this field has considered metallic or cermet films obliquely deposited by thermal or filtered cathodic arc evaporation.
- A light scattering or deviation surface eg. prismatic surfaces which displace the incident light sideways, arrays of microlens which act as controlled diffusers, etc

Among these innovative trends, switchable glazing technology can be used to control the amount of solar energy passing through windows. The use of switchable glazings should reduce the peak electricity demand and the cooling, lighting, and total electricity consumption associated with windows, compared with all other window technologies currently available. The maximum benefits can be obtained when the glazings are used in conjunction with dimmable electric lighting controls. These technologies are still in the field of research at this date and consequently they may be difficult to find, to implement and to justify economically.

Other less advanced technologies proposed in most manufacturers catalogues are:

- the coloured panes, that lower the daylight and solar transmittance

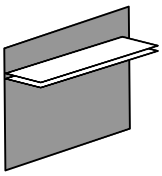
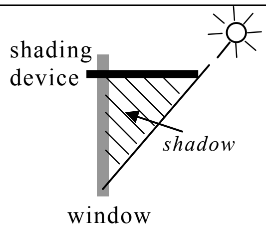
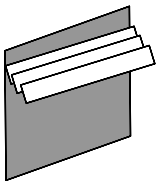
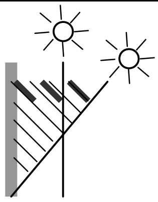
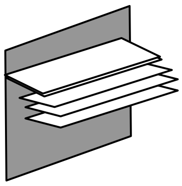
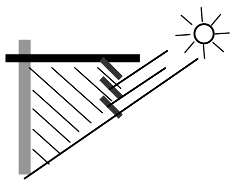
- the reflective coatings, that increase the reflected part of sun radiation
- the sealed blinds between panes, whose blades tilt is calculated depending on the orientation and the shading requirement of the window, in order to reflect incoming sun light
- the transparent insulation

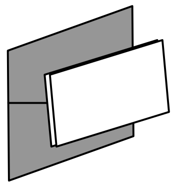
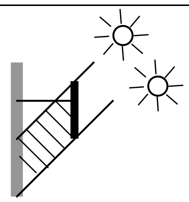
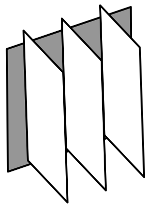
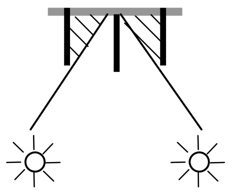
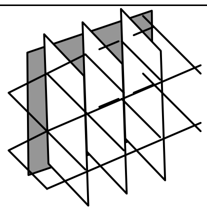
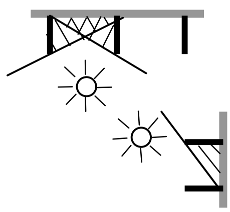
First two types of glazings should be used with caution: the associated reduction in daylighting is quite important for a solar gains reduction that varies a lot depending on the type of device. Furthermore, they are not adapted to variability of the solar gains depending on the season. Documentation must be found directly at the manufacturers' to use such king of glazing or coatings.

5.5.2. Fixed shading control systems

An important advantage of fixed shading devices is that they are passive or self operating. However they have an impact on the aesthetic of the facades and must be robust enough to resist snow loading. Large horizontal overhang can also reduce in a significant way the availability of daylighting in deep plan school resulting in a need for permanent artificial lighting.
Design of fixed shading device depend on the seasonal angle of incidence of the direct solar radiation to permit some selective control to be achieved. Orientation, inclination and geometry of fixed overhangs and fins must be carefully analysed [4].

Table 5.2: Examples of fixed shading devices and their protection against direct sunlight [5]

		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.

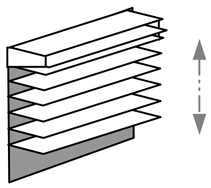
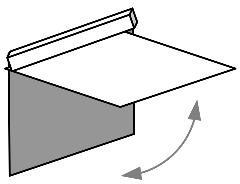
		A solid or perforated screen parallel to the wall can block lower rays of the sun.
		Vertical fins serve well towards east and west and near these orientations. They may be oblique for more efficiency and detached from the wall to avoid heat conduction.
		“Eggcrates” or any combinations of horizontal and vertical fins are also possible to benefit of previous advantages.

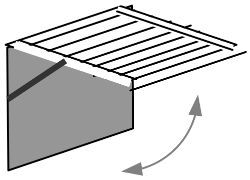
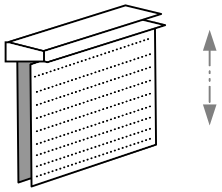
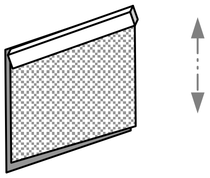
Landscaping is also a natural means to protect facades against direct sunlight. Vegetation needs no specific device and is naturally adapted to the season climate (the choice of a vegetal specie with deciduous leaves is of main importance). It is however uncontrollable upon time and can reduce daylighting more than expected.

5.5.3. Movable shading control systems

They are more responsive than the fixed shading devices, but their movement mechanisms can present installation and maintenance problems. For external ones, weather implies some robustness constraints and sometimes some control implications (eg. awnings might be withdrawn if the wind is too strong).
Combination of a movable outdoor shading device and an indoor light blind offers best opportunities to control solar gains all year long.
A wide range of blinds is available at the manufacturers’ documentation. Robustness is an important factor to take into account in addition to the daylighting and energy performance.

Table 5.3. Examples of outdoor movable shading devices

	Movable horizontal louvers can change their mask characteristics according to their position. Ventilation through the blades avoids overheating. Low security protection, bad night insulation (same idea with movable vertical louvers).
	Canvas canopies have the same characteristics as solid slanted overhangs but may be retractable and not completely opaque to light.

	Bahamas shutters offer a sun obstruction whatever is their position. With disjointed slats, they can be not completely opaque to light. Manual control only.
	Roller blinds offer good protection against night heat losses and sometimes allow infiltration through it in a specific position. However possibilities to control simultaneously solar gains and daylight are very limited.
	Screens can be used indoor and outdoor, but will be more efficient outdoor. Usually made of PVC covered material with a wide range of solar factors. Not completely opaque to light. Air infiltration somehow allowed to pass through it.

Indoor shading devices includes: screens, horizontal or vertical venetian blinds, and curtains. Usually they are not as efficient as outdoor shading devices unless they have a high reflective property.

Most of the shading devices presented in this paper could be motorized and automatically controlled. Combined with a control system for electric light, the energy consumption could significantly be reduced.
The shading devices can be classified on the basis of their adaptation to the seasonal requirements and to the climate conditions as fixed/movable, or on the basis of their position as internal / external / interpanes. External shading devices provide more effective shading because the solar energy is rejected before it can enter the building. However, they tend to be expensive due to the need for weather resistance and maintenance. Shading devices can also be classified on the basis of their construction features: horizontal axis slat/fin, vertical axis slat/fin, blind, awning, screen, curtain, shutter, coatings, tints, film, opaque pattern, integrated louvers.
Venetian blinds, vertical fins, screens and slatting shutters permit simultaneous shading and ventilation on the contrary of roller blinds and curtains that can be an obstacle if maintained in operation.
Finally, they can be classified on the basis of the material, as metallic/plastic/wooden/glazed.

The shading devices options can be classified following a more architectural point of view:
- Special solar optical properties of the glazing : reflective, selective, thermochromic, etc Architects often appreciate the potential of aesthetics offered by the large choice of glazing and films manufacturers. Spectrally-selective tints and spectrally-selective low-E coatings have entered the market more recently. Solar control retrofit film is widely available.
- Fixed external solar obstruction: overhang, vertical fin, eggcrate, etc They can also be integrated to the facade as part of its aesthetic by the architect.

- Movable external or internal shading devices: screen, blind, louver, awning, etc They are only considered as necessary appendices by most architects. Integrated louvres and silk-screened glazing are available from specialised window manufacturers.

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Chapter 6

Lighting and electrical appliances

by

R. Cantin, G. Guarracino, C. Laurentin,
R. Jakobiak V. Richalet

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6.1. Introduction

Learning and teaching both rely upon good lighting of indoor spaces. The lighting design for a school needs to provide a lit environment which is appropriate for the particular interior and indeed exterior, achieving lighting which enables students and staff to carry out their particular activities easily and comfortably in attractive and stimulating surroundings. It is important to identify the particular activities for the different spaces in schools (classrooms, circulation areas, science work and laboratories, libraries, art rooms, sports halls and gymnasia, general purpose halls, design and technology rooms and workshops, etc) in order to achieve appropriate lighting.

In that concern, daylighting should be particularly looked at as a means to provide satisfaction to the users through

- Psychological comfort contributing to outside view, and amenity though time variation of lighting level and penetration
- Physiological comfort in both quantity and quality of lighting provided.

In existing educational buildings that are in need of retrofitting, it is not sufficient to replace simply old lighting equipment. Innovative lighting designs are also required to meet new needs and to reduce energy consumption [6].

The aim of this overview is to describe the various lighting options and lighting controls available and the implications resulting from them.

6.2. Lighting systems

6.2.1.Natural lighting options

Natural lighting or daylighting uses natural sunlight to supplement or replace artificial light. It is incorporated into new school designs at little or no cost, providing a considerable benefit in environmental terms. Although it is difficult to achieve when retrofitting buildings, it should be considered when a school undergoes significant remodelling or when new structures are added. There are numerous aspects of daylight that make its use in educational facilities desirable as a light source and valuable from a psychological, aesthetic and economic viewpoint.

Daylighting is connected to architectural design through integration of glazed area into the building envelope.

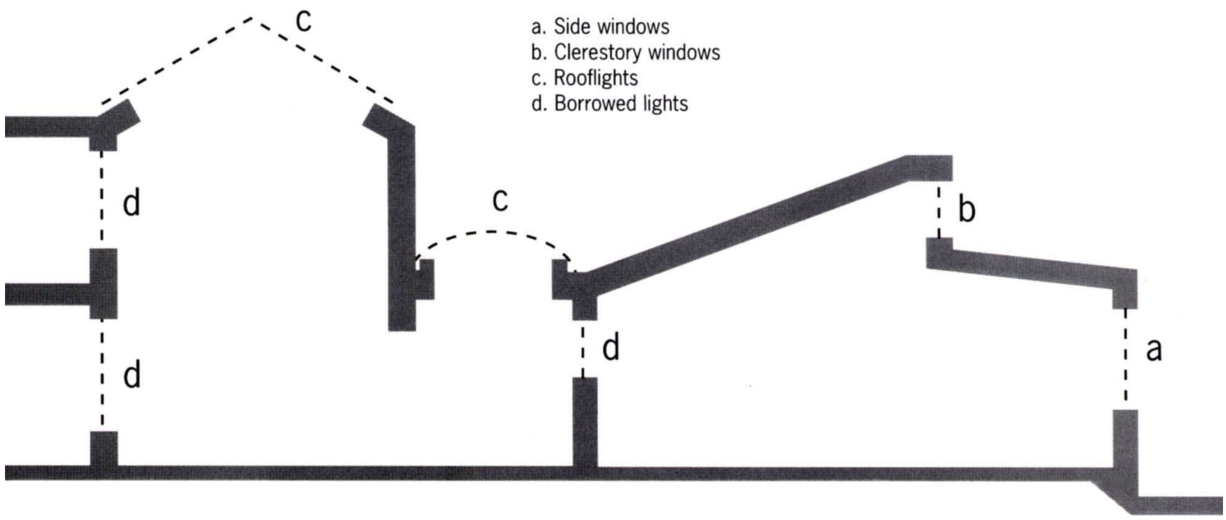


Fig. 6.1 : Windows types [1]

Windows provide a considerable benefit to school buildings: consider skylight, sunlight, views out and other related environmental matters. The means for admitting daylight can be broadly classified as follows [1]:

Side windows (fig. 1-a)

- Definition: common vertical aperture at the external facade
- Advantages: permit a view to outside in addition to daylight penetration
- Drawbacks: possibility of obstruction (in/out)
  daylight for ring rooms only
  possibility of glare and thermal discomfort
- Usage: general teaching rooms, gymnasium, offices, bedrooms

Clerestory windows or lightshelves (fig. 1-b)

- Definition: vertical transparent aperture located at the ceiling level
- Advantages: unlikely to be obstructed
  provide light from brighter part of the sky
  can provide daylight deep into space
- Drawbacks: possibility of glare and thermal discomfort if other than north
  security glass necessary
  no direct view to outside except the weather conditions
- Usage: deep plan rooms (eg. workshops) in single story building or building with a complex section

Rooflights (fig. 1-c)

- Definition: horizontal transparent aperture located into the roof of a building
- Advantages: unlikely to be obstructed
  Provide light from brighter part of the sky
  can provide daylight deep into space

- Drawbacks: possibility of thermal discomfort
  Security glass necessary
  no direct view to outside except weather conditions
  only one storey can be lit (unless light-wells are used)
- Usage: corridors and stairs

Light-wells

- Definition: Specific rooflights when light is introduced to indoor space
  through narrow reflective ducts
- Advantages: visual amenity of blind spaces
  can provide light to deep blind spaces at lower floors
- Drawbacks: very small light provision
  no direct view to outside
- Usage: corridors, stairs, entrance halls, back of classrooms

Borrowed light (fig. 1-d)

- Definition: when rooms open off a zone which is top lit or an atrium
- Advantages: can provide light to blind space (visual amenity)
- Drawbacks: very small light provision no direct view to outside
  balance of luminance if lit from 2 sides
- Usage: corridors and stairs, back of classrooms

Atria

- Definition: largely glazed internal spaces
- Advantages: can provide light and attractive views for attached spaces
  create space with high luminance free of rain
- Drawbacks: reduction of light in comparison with no atrium
  no direct view to outside
  possibility of glare and thermal discomfort
  energy consumption if heated or cooled
- Usage: corridors, entrance halls, resource areas, non-task areas

6.2.2. Daylight design

As direct sunlight is very variable, it is excluded for design purposes and window sizing and an overcast sky with a specified luminance distribution is chosen (usually CIE standard sky). The design parameters of daylighting concern:

- the existing availability of daylight on the site due to surroundings,
- the outdoor reflectance,
- the relative geometry of the windows and room, eg. wide shallow windows give a broad distribution and tall narrow windows provide deep but narrow distribution,
- the glazing type (see glazings),
- the choice of movable and/or fixed shutter (see solar control),
- the choice of fixed solar obstruction and its calculation (see solar control),
- the choice of the indoor surface colours and reflectances (table 6.1).

Table 6.1: Example of reflectance values for various surface finishes [1]

Paint colours	**Reflectance**
White	0.85
Pale cream	0.8
Light grey	0.7
Mid-grey	0.45
Dark grey	0.15
Dark brown	0.1
Black	0.05
Internal materials	
White paper	0.8
Carpet	0.45 – 0.1
Brickwork	0.3 – 0.2
Quarry tiles	0.1
Window glass	0.1

The design parameter of the indoor daylight level is the daylight factor (DLF). The daylight factor is defined as the daylight illuminance (lux) at a location indoors expressed as a percentage of the prevailing unobstructed illuminance outside, both values being measured simultaneously on a heavily overcast day. Table 6.2 provides with visual sensitivity to daylight factor. Usually a 2% DLF is considered as a minimum to prevent a frequent use of artificial lighting.

Table 6.2: Daylight factors and visual impression

DLF in %	Less 1%	1…2%	2…4%	4…7%	7…12%	More 12%
Lighting level	Very low	Low	Moderate	Average	High	Very high
Location	Far from windows, 3 or 4 times the windows height			Close to window or under sheds		
Brightness	Dark	low lighting	Low lighting to bright		Bright to very bright	

Uniformity ratio should be considered also as a design criteria to ensure that a room does not have areas which will appear too dark. It is defined as Minimum Daylight Factor divided by the Average Daylight Factor. Ratio of 0.3 to 0.4 is recommended for side lit rooms. Higher values can be expected for top-lit rooms.

The optimum window area, from the standpoint of energy, amenity and cost, will be a compromise between thermal and visual imperatives. It is usually wise to start by calculating the area needed for good daylighting using a daylighting tool or CIBSE Application Manual: Window design, then trimming if it is necessary to control heat losses in winter and solar gains in summer. T

Having determined a target area of glass, a designer has to choose the shape and position of windows to accommodate it, also with maintenance considerations. The final outcome is likely to be a compromise between conflicting requirements for view, avoidance of glare, and an even spread of daylight indoors [4].

6.3. Electric lighting

In school buildings, most of the spaces will have daylight but not always over the whole area. It will be necessary to design the complementary electric lighting distribution to ensure they enhance one another. For example, to improve the sensation of brightness in the areas remote from the window, it can be preferable to highlight surfaces and particularly the walls rather than to use general lighting.
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 saving in the lighting demand can be obtained through task lighting instead of general lighting and smart control of lighting and careful design of the overall room.

6.3.1. Electric lighting options

Ambient lighting can provide an even pattern of light, at the illuminance level specified within lighting standards or guidances (100-400 lux). A large variety of lamps and luminaires can be used from very low cost to very efficient equipment. However, the most energy efficient solution is not always the best for visual amenity. Task lighting or accent lighting should be considered sometimes as a valuable alternative as described below.

General lighting with ceiling mounted luminaires (recessed, surface mounted or suspended)

- Advantages: provide lighting level as designed for tasks (100-400 lux)
  economic solution for general lighting
  high utilisation factor
- Drawbacks: unattractive impression of light wash, possibility of glare
- Usage: classroom, library, office
  computer room with special louver type luminaire

General lighting with indirect or upward lighting

- Advantages: lights the ceiling
  shadowless lighting
  reduced glare
- Drawbacks: low utilisation factor
  requires efficient light source
  possibility of glare for high luminance of ceiling
- Usage: classroom, computer room, reading room, gymnasium

Local task lighting

- Advantages: more accurate optical control
  low power density
- Drawbacks: possibility of glare for adjacent seats
  additional energy use
  need electrical supply
- Usage: to complete a general lighting (direct/indirect) in computer room, science room, design room, reading room, amphitheatre

Accent lighting and wall washers

- Advantages: more accurate optical control on the surface to illuminate
  high illuminance
  high luminance
  high utilisation factor
  visual amenity for cluttered surfaces
- Drawbacks: glare for people nearby
- Usage: to complete a general lighting (direct/indirect) on blackboard of a classroom or a lecture room, on book shelves in library, on special displays or for visual amenity of circulation.

We give in table 6.3 the 'standard maintained illuminance' which is the form of recommendation used by the national and the international lighting institutions. This is the minimum illuminance which should be provided at all times through the life of the installation. The CISBE Code for interior lighting, 1994, 'Public and education buildings' provides figures for a wider range of specific interiors and activities.

Table 6.3: Standard maintained illuminance [1]

Spaces	Standard maintained illuminance (lux)
General teaching spaces	300
Teaching spaces with close and detailed work (eg, art and craft rooms)	500
Circulation spaces: corridors, stairs entrance halls, lobbies & waiting areas reception areas	 80-120 175-250 250-350
Atria	400

6.3.2. Lamps

The efficacy of a lamp is measured in lumens of light per Watt of electricity, usually excluding losses in lamp control gear where this is used. A comparison of efficacy values in table 6.4 highlights some obvious routes of upgrading the energy performance of an obsolescent lighting system. The payback periods for each lamp type vary depending on the hours of use and daylight availability of a school.

Table 6.4: Electric lamp characteristics [4] (Note: Rapid development of lamps; need to update these data quite frequently. See the manufacturers literature).

Lamp family	Type of lamp	Efficacy Lumens/Watt	Advantages / Disadvantages
Tungsten lamp Low and mains voltage tungsten halogen (TH) lamp	Common General Lighting Service (GLS), reflector (R) (PAR) Linear and capsule TH Reflector TH	8 - 12 16 – 25	Point source, excellent colour rendering, warm colour, dimmable, cheap, instant start. Short life, low efficacy, sensitive to voltage variations and to vibrations. Point source, excellent colour rendering, warm colour, dimmable, instant start, longer life and higher efficacy than GLS. Still low efficacy, transformer required for low voltage, expensive, sensitive to voltage variations and to vibrations.
Compact fluorescent lamps (CFL)	Various configurations with or without integrated control gear	50 - 80	High efficacy, long life, relatively cheap, good colour rendering, prompt start and restart, some types can replace GLS and TH lamps. Diffuse source, requires control gear, full light after 2 minutes, tube very bright can cause glare.
Fluorescent tubes	Halophosphate 38 mm (T12) Triphosphor 26 mm (T8) Triphosphor 16 mm (T5) Circular	60-80 60-95 95-110 30-50	Very high efficacy, cheap, long life (old New technology T8 (T5) more efficient than T12, less mercury content and better colour rendering, dimmable circuits available. Diffuse source, standard lengths, control gear required, T5 only works on high frequency gear.
Discharge lamps	High pressure sodium (SON) Low pressure sodium (SOX) High pressure Mercury Vapor (MBF) High pressure Metal Halide (MBI)	65-140 100-190 40-60 60-80	Very high efficacy, long life except “white” SON, various wattages. low colour rendering (except MBI), control gear required, long run-up time and delayed restart.
Induction lamp	Standard Reflector	70 47	Very long life (60000 hours, 10000 for Reflector), good colour rendering, no flicker, virtually maintenance free. Limited range, requiring careful use, diffuse source, expensive.

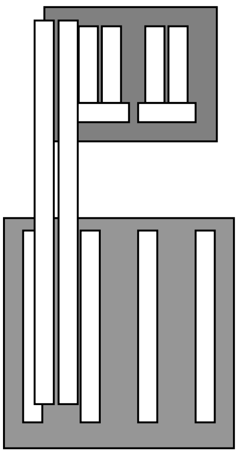
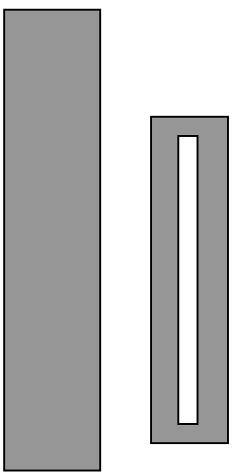
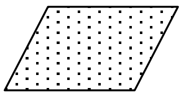
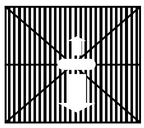
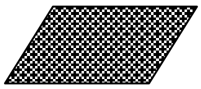
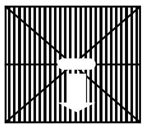
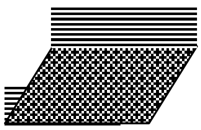
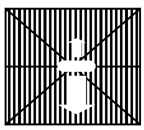
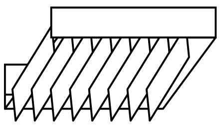
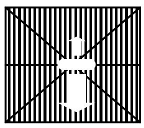
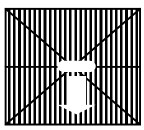
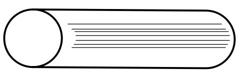
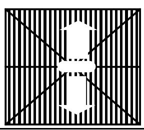
All discharge lamps including fluorescents require a control gear (ballast) to create the right condition to start the discharge and to regulate the voltage and current. The type of ballast will greatly influence the connected load. Unlike most electrical products, luminaires for discharge lamps, including fluorescent are not labelled with their connected load but by the nominal wattage of the lamp which should be installed. The additional ballast load should, therefore, always be taken into account when calculating the connected load.

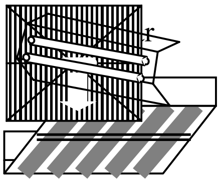
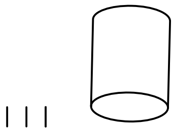
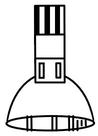
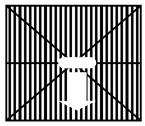
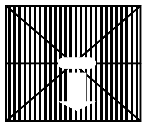
Ballasts have significantly improved their performance since the first use of fluorescent lamps. For energy efficiency, the minimum standard should be the low loss ballast, hardly more expensive than the standard ballast supplied with most luminaires. High frequency ballast is an electronic gear with 30 % lower electrical losses than any electromagnetic types. It is light and can be supplied in dimming form. Other advantages of HF ballast are that it is silent, there is no flicker and stroboscopic effect, and lamps last longer.

6.3.3. Luminaires

Next table provides an overview of qualitative performance of a range of luminaire types [1].

Table 6.5.: Range of luminaire types [1]

Luminaire type		Distribution/mounting	Performance
 Modular 	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.
	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.

	White trough reflector Perforated screen reflector	Direct Direct	High utilisation factor for LHR rooms. High risk of glare for LLR rooms. Middle utilisation factor for LHR rooms. No risk of glare for LLR rooms.
Downlight  High bay reflector 		Direct  Direct 	

6.4. Daylighting technologies

A good daylighting strategy provides adequate lighting levels and a visually attractive environment. Daylighting is impacted by the ever changing luminance distribution of the sky, obstructions, Window design, the proportion of spaces, reflectance's, furnishings, the usage of spaces etc. When retrofitting for daylighting, many key design features such as the dimension and location of glazed areas and the proportion of spaces can not be changed while new daylighting systems can be applied easily. The use of daylighting systems hence is an option for retrofitting.

Daylighting systems adapt the window to changing exterior conditions and to different interior requirements. Daylighting Systems have the following main functions:

- shading
- protection from glare
- redirection of daylight

While traditional daylighting systems such as manually operated conventional louver blinds primarily protect from too much daylight they often do not transmit enough daylight. As a consequence electric lighting will be switched on although abundant daylight is available. Advanced daylighting systems allow to combine the protection from heat and glare and the distribution of adequate daylight levels to the space. Therefore advanced systems have a high energy saving potential compared to conventional systems.

There are several principles of advanced daylighting systems:
- **Shading systems**
- **using diffuse daylight**
- Direct sunrays are reflected or absorbed while diffuse daylight is transmitted.
- *Examples: Prisms, Holographic elements, sun protecting mirror elements*
- **using direct sunlight**
- Direct sunlight is partially distributed to the space while partially reflected or absorbed.
- *Examples: Louvers and blinds, reflected louvers, Light shelf, Light guiding shade*
- **Daylight redirecting systems without shading**
- **redirection of diffuse daylight**
- Daylight from a broad incident angle, mostly from the zenith is redirected to the depth of the space while attenuating the daylight level in the window area.
- *Examples: Anidolic ceiling, fish-system, zenith light guiding elements with holographic elements*
- **redirection of sunlight**
- Direct sunlight is redirected to the depth of the space. In most cases only the altitude angle is redirected, some systems do redirect the azimuth angle as well.
- *Examples: reflected Blinds, light guiding glass, Laser Cut Panels, prisms, holographic panels*
- **scattering systems**
- Incident daylight is evenly distributed to the space.
- *Example: Scattering glass*
- **daylight transport systems**
- Daylight is transported from the facade to the core of the building using optical technology.
- *Examples: Heliostat, Light pipes, Solar tube, optical fibres.*

In most cases advanced daylighting systems are designed for specialised functions. The provision of a view, the redirection of daylight and the protection from heat and glare may require different systems for different parts of the window. A good selection of systems therefore often is a good combination of systems.
The use of daylighting systems is an integration issue dealing with many design aspects. Each daylighting system has different design considerations. Good window design and the use of architectural daylighting features are key elements in daylighting design. The use of advanced daylighting systems and control systems cannot compensate for omissions at the design stage, but enables to fully explore the daylight potential of a space.

6.5. Control systems

Lighting controls of an installation eg the switches or the dimmers are an important part of a lighting design and need careful attention if the installation is to be convenient to operate and energy efficient.
Well-planned lighting controls can save energy in two ways:
- they can make good use of available daylight by reducing electric lighting levels where possible,
- they can ensure 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 the typical school situation.

Table 6.6. Lighting controls [2]

Name	Description	Advantages	Disadvantages
Automatic systems			
Time switching	Lights are switched off at the same times each day Clock or BEMS	Low cost Not annoying for users	May be annoying for occupants with eccentric schedule
Occupancy sensor	Respond to movement or infrared sources such as human body in motion or reflected ultrasonic waves	Energy savings : 20-30% Freedom for users	Switching off because of wrong detection Bad manners for users Frequent switching of light sources
Daylight responsive lighting control system	Artificial lighting is regulated as a function of daylight thanks to a photocell or On/Off response	Energy savings : 20-60% More pleasant lighting?	Deficiency in current practice if bad commissioning and calibration Possibility of dissatisfaction due to variation of artificial lighting
Maintenance of lumens	Reduction of lamp lumen output when the lamps are new	Energy savings : 20% per year for 5 years	Difficulty of calibration with photocell
Peak demand limiting	Function of peak demand	Energy savings	Users' acceptance?
Task tuning	Function of tasks	Comfort	Users' acceptance?
Dimmers	Adjustment of the light levels between full light output and off	Comfort for tasks or illuminance equilibrium	Users' acceptance? Limited choice of lamps
Manual systems			
Fixed emitters	Switch, push button, potentiometer, computer		
Remote control or radio			
Localised or centralised systems			
Integrated systems to luminaires	A sensor is integrated to each luminaire	Individualised control	
External systems to luminaires	The sensor is located outside the luminaire	Control by group of luminaires	No possibility to vary depending on special illuminance gradient
System with 'bus de terrain'	Local control	Simplicity of programming	Non central control
System without 'bus de terrain'	Communication between luminaries	Easy to control	Complexity of programming

Occupancy sensors are generally accepted as an effective energy saving technology despite earlier difficulties caused by improper settings, placement or selection. Intermittently occupied spaces – such as offices, restrooms and conference rooms- are good candidates. In any case, it is important that the user may over-ride the automatic switches at any time that they require.
Daylighting dimming can be used in schools. It can enhance lighting quality by maintaining a constant, uniform light level and providing greater light-level flexibility to the occupants.
Daylight switching – an alternative to daylight dimming- can cut lighting operating hours and reduce electricity use. This technology is typically used outdoors but may be used indoors in common areas. Both systems may be used with occupancy sensors or timing controls [3].

6.6. Conclusions

An effective use of energy in lighting is an essential part of lighting design. It depends on:
- the availability of natural lighting indoors,
- the efficiency of the electrical components: lamps, ballasts and luminaires,
- the lighting controls, and especially how they take advantage of available daylight,
- the maintenance regime [4].

When planning energy efficiency in lighting it is necessary to consider daylighting and electric lighting both individually and in conjunction with one another. An extensive use of natural lighting can provide considerable energy savings but the other environmental aspects of large glazed areas must be taken into account, especially thermal comfort during sunny weather. Several important points to remember when working to improve lighting energy efficiency are:
- do not over-illuminate, using light where and when necessary,
- use efficient fittings, lamps and ballasts,
- control lighting efficiently and keep fittings and lamps clean [5].

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Chapter 7

Management

by

Richard Daniels, Fiona Fanning, Euphrozine Triantis,
Lorenz v. Schoff

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7.1. Introduction

With energy use and costs increasing and resources available to improve educational facilities decreasing, energy inefficiency and mis-management or use contributes to its high costs and usage. Improving the energy efficiency of equipment and systems requires significant resources to either upgrade (retrofit) or replace, while improvement in the management of energy systems and their use, requires little or no resources. Most low cost / no cost items when implemented can reduce energy usage from 10-15 %.
Chapter 7 addresses those issues, when properly implemented can reduce energy use and costs with minimal to expenditure of the limited educational resources. The issues addressed include:

- Auditing
  Inventory of energy systems and equipment in an educational facilities and benchmarking of energy use

- Commissioning
  Addresses system performance as designed and constructed. Re-Commissioning should be accomplished periodically to insure
  Performance of equipment and systems is maintained at design levels

- Education
  Education and training of the users, occupants and maintainers is essential to insure proper use and level of maintenance of the energy systems in the facility

- Non- investment Measures
  Scheduled maintenance and care of systems ie., changing of filters and calibration and maintenance of controls – Preventive maintenance reduces energy costs and usage.

Management of energy systems including all mentioned in this chapter can assist educators redirect limited educational resources from energy needs to student needs. With the added benefit of using low / no cost energy efficient measures being that there is no need for new equipment to be installed which can be time consuming and disruptive to a school.

7.2. Energy auditing techniques

7.2.1. Introduction

An audit is defined as a “systematic examination”. For a school (or indeed any type of building) there are three levels of auditing that could be carried out:

- Level 1. Compare energy (or resources) use with other similar schools. This is often known as benchmarking.
- Level 2. Carry out a visual inspection of the rooms and facilities in a school for deterioration of fixtures and fittings, to check whether equipment is operating correctly and where energy (or resources) is being wasted.
- Level 3. To estimate, calculate or measure where and when the energy is being used (or wasted) to achieve the optimum in energy conservation.

7.2.2. Different types of audit

There are a number of different types of auditing schemes available in the UK, which can be carried out at a number of different levels.

Level 1: Comparison with other schools

There are a number of schemes set up in the UK to compare the energy (and other resources) used with other schools. They involve using the utility bill to find out how much energy (or the cost of the energy) that has been used over a certain time period (normally a year) and normalising it per pupil or area. Disadvantages of such schemes are that there are a number of factors that may mean a school uses more or less energy than another and make the comparison unfair, for example:
a school could be used far greater outside of curricula hours than another,
the type of equipment installed at the school eg number of PCs, age of the equipment,

- the school’s location, and
- the utilities that a school uses.

Also, if a school sees itself as ‘good’ there may be little or no encouragement to try to do better. This type of process may be carried out by the Local Education Authority (LEA) who have overall control over a number of schools in a specified area, also they may have greater knowledge why a school is different from another. As can been seen from the examples below, there are a number of schemes that have been set up.
The Building energy efficiency in schools – a guide to a whole school approach [I] publication was developed as part of the DETR Energy Efficiency Best Practice Programme, and provides a simple method of calculating energy performance and CO_2 emissions together with guidelines for energy consumption and CO_2 emissions for primary or middle schools and secondary schools (with and without swimming pool). It includes simple corrections eg for normal and extended occupancy, lightweight/heavyweight building, and urban/rural location. The guidelines do not take into account the different facilities provided in schools, other than swimming pools, which may affect the energy performance.
The Schools Financial Comparisons website (the Audit Commission) [II] provides a means for schools to enter their own data and prepare charts to compare their expenditure with similar schools, including the ability to compare the cost of energy. The scheme uses a pool of information describing approximately 4,000 schools provided by the LEAs and DfES. Of course because there are different costs for energy depending on the supplier and the amount of energy purchased (some LEAs buy energy for all the schools in the area, which results in a lower per unit price) the comparison between schools can be affected.
School Asset Management Plans [III] have been set up to improve the quality of thinking and decision making that goes into managing the school estate at LEA and school level. Data has been collected centrally by DfES. This information includes information on the energy and water usage, floor areas, and the number of staff and pupils. Currently the data is being analysed and it is hoped that data could be collected for another three years. This data has been used to populate the Schools OnLine Energy Benchmarking Tool. The National analysis will be published in October 2002 providing reliable benchmarking information for English Schools.
ActionEnergy (formally BRECSU) was contracted by DETR to develop a Schools OnLine Energy Benchmarking Tool [IV]. The website aims to obtain data on schools’ overall energy

consumption and compare it to floor size, and number of pupils and staff to obtain benchmarks. It does take into account the location of the school but as of yet the additional information that is requested (eg hours that the school is used, age and type of building) is not used. Graphs of electricity, fuel, gas and carbon dioxide using kilowatt-hours per square metre and comparisons are made with using typical (median), good (first quartile), poor (third quartile), best (top 15%) and worst (bottom 15%) practice.
The above schemes are very useful to give quick, overall guidance on how well a school is performing but for schools whose energy usage is higher than normal a more detailed audit will need to be carried out to investigate where the energy is being used, and whether improvements could be made to its usage.

Level 2: Visual Inspections

Visual inspections are useful to check where energy is being used needlessly or where fixtures and fitting could be replaced with more energy efficient ones, or repaired to ensure that they are operating at their optimum. Below are two examples of visual inspections.
The Energy Efficiency Best Practice Programme has produced a guide on how to conduct an energy walk round [V] for schools. There are two checklists that are available for no investment measures:

- Where energy is being wasted (ie where good housekeeping practices are not followed), and
- Where repair or maintenance work is required to reduce energy costs.
- Also the guide recommends that a note be made where capital investment may be required to improve energy efficiency.

The DfES has published a guide on energy and water management in schools [VI]. The guide includes the types of checks that have to be made about fixtures and fittings to ensure that energy is saved. It is recommended that a systematic visual inspection is carried out on all rooms, and apart from the plant room where a specialist consultant or LEA advisory may be required, this can be carried out by school business managers, bursars, head teachers and/or caretakers.
Visual inspections can be used as part of the maintenance programme and investigate whether on going work is required, but if a school uses far more energy than another school then it may be necessary to carry out a third level analysis.

Level 3. Where energy is used

These third level schemes can be used to show where energy is being used and justify additional funding for improvements in the fabric, fittings or fixtures. Below are three schemes in the UK, which try to calculate where, and in some cases when energy (and other resources), are used in a school
Advanced Student Scheme for Energy Savings in Schools (ASSESS) [VII] is a package designed to give university students the opportunity to carry out energy audits in local schools and to make recommendations for improving their energy usage. The students carry out an audit and examine:

- fuel use,
- plant rooms and domestic hot water production,
- space heating,
- building fabric,

- lighting,
- small power appliances, and
- hot and cold water use.

The information provided in the students' reports would enable the schools to apply for school energy programme grants and hence receive capital support to carry out the students' recommendations.

The BREEAM school toolkit [VIII] has been issued to all schools and can be used to analyse and improve environmental performance. It requires the facilities manager to estimate the energy and water used for various activities, using information about the appliances or estimates from utility bills. It includes a basic audit of a wide range of environmental and cost factors in schools that includes the use of harmful substances, paper and printing, transport (including travel to and from school, and excursions), waste, and impact on the local environment (grounds and visual).
BRE has been developing a bottom up assessment of how and where energy and water is being used in schools and looking at benchmarking compared to per pupil and per area. It has set up a detailed means of describing the facilities that a school has, the times of day that the school is being used (whether activities are part of the function of a school or not). In the future it is hoped by removing the energy and water that has been used outside normal school hours that comparisons can be made between a number of schools to give realistic benchmarking figures. Also, comparisons can be made between the end uses between the different facilities for energy and water use. For energy it will also be possible to calculate the carbon produced.
The auditing process involves looking at all energy and water using equipment in a school and estimating how much energy/water it uses and when the energy and water is being used. The work is based upon the Energy Assessment and Reporting Methodology (EARM) for offices and the subsequent CIBSE Technical Memorandum TM22 [IX] and the ongoing series of PROBE studies. It also forms an essential part of the background to the Carbon Performance Index method included in Part L of the Building Regulations [X] as a means of assessing new office design.

AM5 Energy Audits and Surveys [XI] give information from initial data analysis (level 1) to final monitoring (level 3) on the preparation of specifications, commissioning and undertaking of surveys both for staff in house and for external specialists. Also it contains technical information on plant and building services. This manual is not only for schools but all buildings in the public and private sector, regardless of size but would assist a school, specifically if a second or third level audit were required.

7.2.3. Summary

There are a number of different techniques that can be used to carry out an audit of energy used in schools. The flow chart below gives a summary when different techniques can be used.

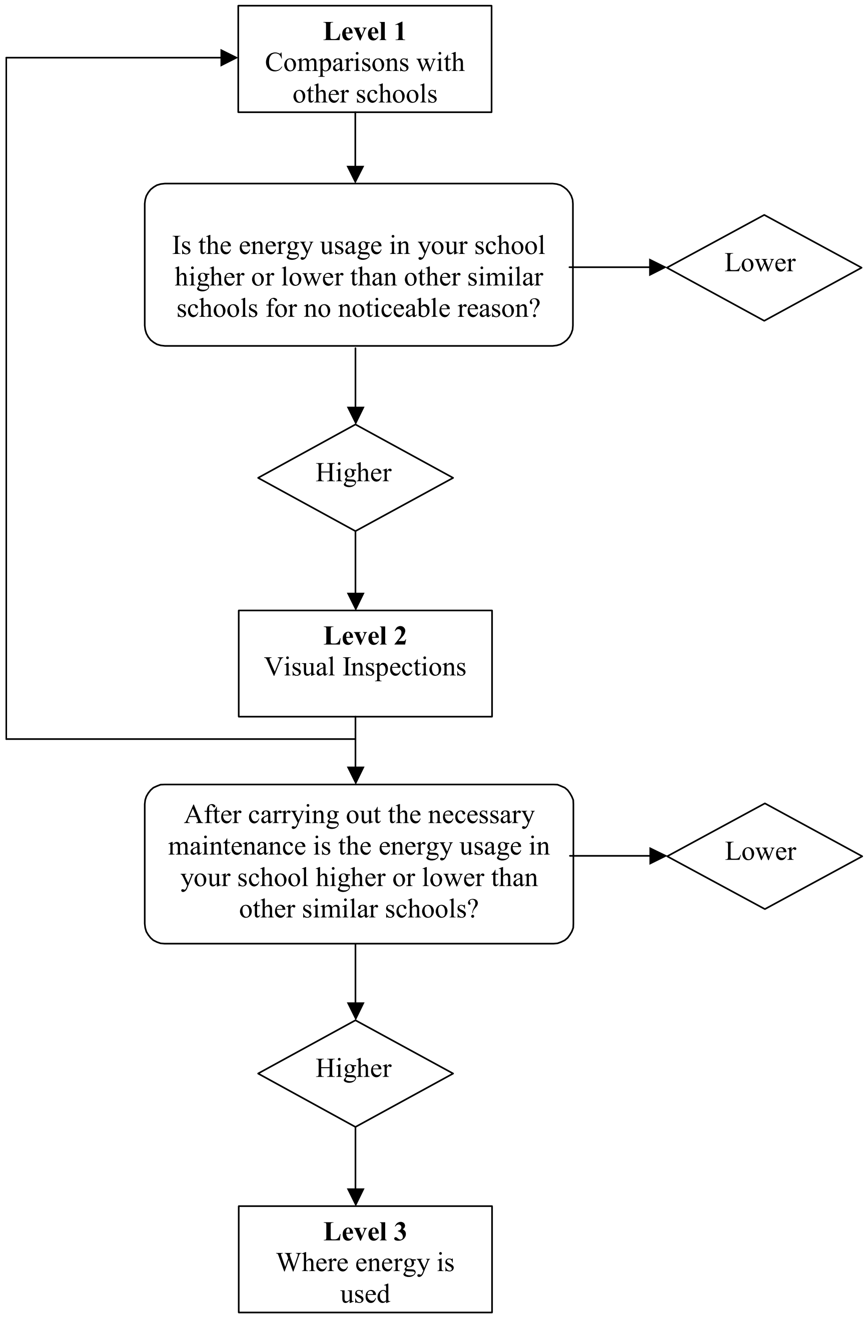

Fig. 7.1. The flow chart of the use of different techniques

7.3. Commissioning

Commissioning is a quality-assurance process that increases the likelihood a newly renovated building meets the owner's expectations. Commissioning can optimize the energy efficient design features and improve overall facility performance. Educational facility personnel can use this proven, systematic approach to reduce change orders and liability exposure, and to ensure they received their renovated building that functions to their original project design parameters. The commissioning provider best serves the owner if the provider is not connected with the construction contractor but is a third party hired by the owner.

a. **What is commissioning**?

1. Process ensuring building systems perform according to contract documents, Design intent, and operational needs
2. Begins in the Pre-design phase of a project – most cost-effective
3. Continues through design, construction and warranty period
4. Verification is through review, testing and performance documentation
5. Determines how well mechanical and electrical systems meet operational goals

b. **Commissioning Approach** –

1. Encourages parties to communicate and solve problems earlier in the construction phase.
2. Beginning proper commissioning during the design phase can help identify and solve problems that later may turn into performance problems, occupant comfort complaints, indoor air quality issues, and decrease equipment life.

c. Benefits of Commissioning

1. Proper and effective equipment operation
2. Improved coordination between design, construction, and occupancy
3. Improved indoor air quality, occupant comfort, and performance
4. Reduced operation and maintenance costs

d. Cost of Commissioning – Building commissioning can cost between 0.5% to 3.0% of the renovation cost.

e. Commissioning Phases

1. Pre-design Phase – Time to select the commissioning provider
   a. Provides an advisory role with design team and owner
   b. Could assist in determination of contractual performance or energy targets
2. Design Phase – Goal to ensure the efficiency and operational concepts developed in the pre-design phase are included
   a. Main tasks -- compiling and reviewing design intent documents
   b. Incorporating commissioning into bid specifications
   c. Reviewing bid documents
3. Construction Phase – Used construction checklists to ensure equipment and Systems are properly installed and ready for testing
   a. Oversees Tests systems and reports on tests
   b. Ensures corrective actions, if needed are performed properly
   c. Ensures training session for operational personnel are given and in accordance with specifications
4. Warranty Phase – Continuation of testing evaluation of systems in accordance with the specifications during the warranty period.

f. When Does Commissioning End? -- Commissioning never ends if one intends that the educational facility will continue to have a high level of performance. Re-commissioning should take place every 3-5 years during the life of the facility.

7.4. Education and training

A major element in the operational success of an energy retrofit to or renovation of an educational facility rests with the education and training of personnel who occupy and those who operate and maintain facility. It is essential these personnel using the new retro-fit or renovated energy systems and assigned to operate and maintain these systems be educated on their proper use and operations. In addition, energy education to the students at the appropriate level should be included in subject matter of instructional programs to sustain energy efficiency will into the 21st century.

The following is the level of education and elements which should be included for each segment of educational personnel involved with a newly retro-fit or renovated educational facility:

- Superintendents, School Boards, Headmasters, Principals and other supervisory personnel
    1. Energy Awareness of energy used and cost
    2. Overview of energy systems in use and benefits to students and staff
    3. Potential budget impacts of systems in use
    4. Overview of how systems are to function
    5. Operation of electronic/IT equipment
- Instructional Personnel – Teachers, Instructors, Teachers Aides
    1. Detailed instruction on how to use systems installed in their rooms
        a. Lighting and day-lighting
        b. Heating and cooling systems with controls
    2. Include how, why and benefits to the students and them
    3. General energy awareness and how they can contribute
    4. Include energy savings potential
    5. Operation of electronic/IT equipment in their classrooms
- Support Staff – Food Service personnel, Clerical
    1. Proper energy efficient operation of equipment in kitchen and office and other systems in their areas – lights and heat and solar
    2. General energy awareness and how they can contribute
    3. Sources of energy waste in their areas
- Custodial/housekeeping Personnel
    1. Training on basic maintenance of key energy systems in the building including energy management system -- include filter changing
    2. Energy Awareness of how energy is used in the building and sources of energy waste (energy inefficiencies) and how to report
    3. How cleaning procedures can impact energy use and energy efficiency of systems installed
- Maintenance Technicians
    1. Complete systems training and retraining as necessary to understand all energy efficiency aspects of systems
    2. General energy awareness and how they can contribute
    3. Energy Management training and understanding
    4. Sources of energy waste in the facility other than their system and how to report
    5. Need for and maintenance of a preventative maintenance program

- Building Systems Operators
    1. Same education and training as the maintenance technicians
    2. Detailed training on operation and maintenance of large equipment like boilers, compressors, pumps and air handling units

Sustaining the energy efficiency into the 21st century will require that energy efficiency be included in the subject matter being taught in the classrooms. Including knowledge of sources of energy, how energy is being used, how energy can be used and how students can contribute to the energy efficiency in the classrooms is essential. Classroom teachers and instruction must be provided the educational material necessary to insure this data is included in each of the subject matter taught.

Energy awareness subjects can be included in many courses already in the primary and secondary school curriculum and, depending on the age of the students can involve them in various activities resulting in energy conservation, such as recording energy use, acting as energy monitors, performing energy audits, investigating ventilation patterns or even analyzing energy use and calculating payback for proposed retrofit measures.
Such courses can develop the students' awareness and enthusiasm on "green" subjects by bringing energy conservation issues to life through the combination of teaching and practical experiences, which can result in specific benefits in cost or comfort. What is more, students can participate in energy conservation and ecology networks (such as ecoschools) through which they can exchange information and compare their own experience to this of other students.
Universities and Technical Institutions are mostly responsible for **education and training of future professionals** in the energy fields. Besides specialized courses on energy conservation, renewable energy and energy management already forming part of the curriculum in many disciplines, the opportunity of involving university students in practical energy conservation experiments or campaigns in their own environment can increase their awareness of energy and ecology issues and develop an active energy conservation conscience both for students and staff. Broader initiatives can thus be initiated, such as user motivation campaigns, information exchange and networks of universities involved in energy conservation and environment activities such as the European Network of "Energy Efficient Universities" which can have a multiple influence on other social groups, both in the public and private sectors.
Apart from university courses, training courses and seminars are important for informing professionals on **new developments in the energy conservation field** including e-learning courses, which can be conducted by Universities or specialized education institutions. Such courses include the training of energy auditors for building and industry who will be shortly in demand in many European countries for the application of the new European Directive concerning the energy performance of buildings.

7.5. Non-investment measures

7.5.1. Introduction

It is not always necessary to invest in new equipment to achieve energy savings. It is possible to save energy by the implementation of good house keeping techniques, for

example switching off equipment when not in use and carrying out basic maintenance. The following sections give suggestions on how energy could be saved.
It is important to involve everyone in the school with the measures, from pupils to school governors so that they all do their bit in saving energy. Reminders on the good house keeping measures could be given during assemblies, whilst reminders by lights and other equipment will assist as aid memoirs to pupils and staff.
To be able to see where non investment energy savings can be made, it may be necessary to carry out a simple audit of the school and noting where equipment is needlessly left on, that controls are suitably set and where maintenance is required.

7.5.2. Lighting

- Switch off lights if daylight is sufficient.
- Switch on lights needed only for tasks in hand.
- Make sure blinds and furniture do not prevent maximum use of daylight.
- Use only local task lighting if possible.
- Switch off lights when leaving room for more than ten minutes and at the end of the day.
- Use reduced lighting levels for cleaning, night-time and security staff.
- Switch off exterior security lighting during daylight hours.

7.5.3. Hot water

- Turn off taps.
- Check for and report leaking or dripping taps.
- Report if water temperature in taps is excessive.
- Turn off electric water heaters when they are not required.

7.5.4. Cold water

- Turn off taps.
- Check for and report leaking or dripping taps.
- Check frequency of urinal flushing.
- Check for leaks by checking the water meter when water is not being used (eg weekends).

7.5.5. Office equipment

- Switch off electrical appliances, including computers, printers and photocopiers, when not in use.
- Do not use high energy consuming equipment during daily maximum demand period for electricity, unless it is essential to meet operational needs (check tariff arrangements).

7.5.6. Space heating

- Check that room thermostats are set to temperatures consistent with comfort.
- Check heating controls (eg thermostatic radiator valves) are at the correct setting.
- Do not use portable electric heaters (except as a last resort).
- Do not place obstructions in front of radiators or heaters.
- Switch off non-automatic extract fans when the room is unoccupied.
- Close blinds or curtains at the end of daylight.
- Turn off non-automatic heating when the room is unoccupied.
- Report faulty door closers and window catches and draughtstripping.
- Report if the room suffers from under- or over-heating.

7.5.7. Boiler room plant

- Check that controls are labelled to indicate function, and are set correctly.
- Check that optimum start/stop controls and weather compensation controls are set and work correctly.
- Check that boiler sequencing controls are set correctly.
- Ensure timer switches are set to minimum periods consistent with requirements.
- Make sure fans and pumps run only when required.

7.5.8. Swimming pools

- Cover swimming pool when pool is not in use – eg lunch times, and after hours - to save both water and energy (pool covers on external pools can save 80% of energy costs).
- Check the water temperature is correct (not above 27^{o}C).

7.5.9. Temporary classrooms

- Temporary classrooms can often be high users of energy due to their poor insulation, large areas of glazing and use of electric heating. Has the use of temporary classrooms been minimised where possible and proper replacements planned?
- Has heating been switched off when not in use?
- Investigate the cost of installing occupancy sensors to the electric heaters, with night setback temperatures.

7.5.10. Other

- Recommission optimiser and heating controls.
- Check that boiler air/fuel ratio is correct (as part of regular maintenance).
- Fit boiler sequence controls.
- Repair leaks on distribution mains.
- Reduce use of supplementary electric heaters.
- Install, repair or replace thermostats.

- Insulate domestic hot water cylinders.
- Provide additional heating controls for individual heaters.
- Reset domestic hot water thermostats and time switches and make them tamperproof.
- Fit reflective foil behind radiators.
- Replace tungsten lighting with compact fluorescent lamps.

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- ECG73, Saving energy in schools: A guide for headteachers, governors, premises managers and school energy managers
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*Further information is available from ActionEnergy at www.actionenergy.org.uk.