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

SUBTASK A
Overview of Retrofitting Measures

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Chapter 3

Heating systems

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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.

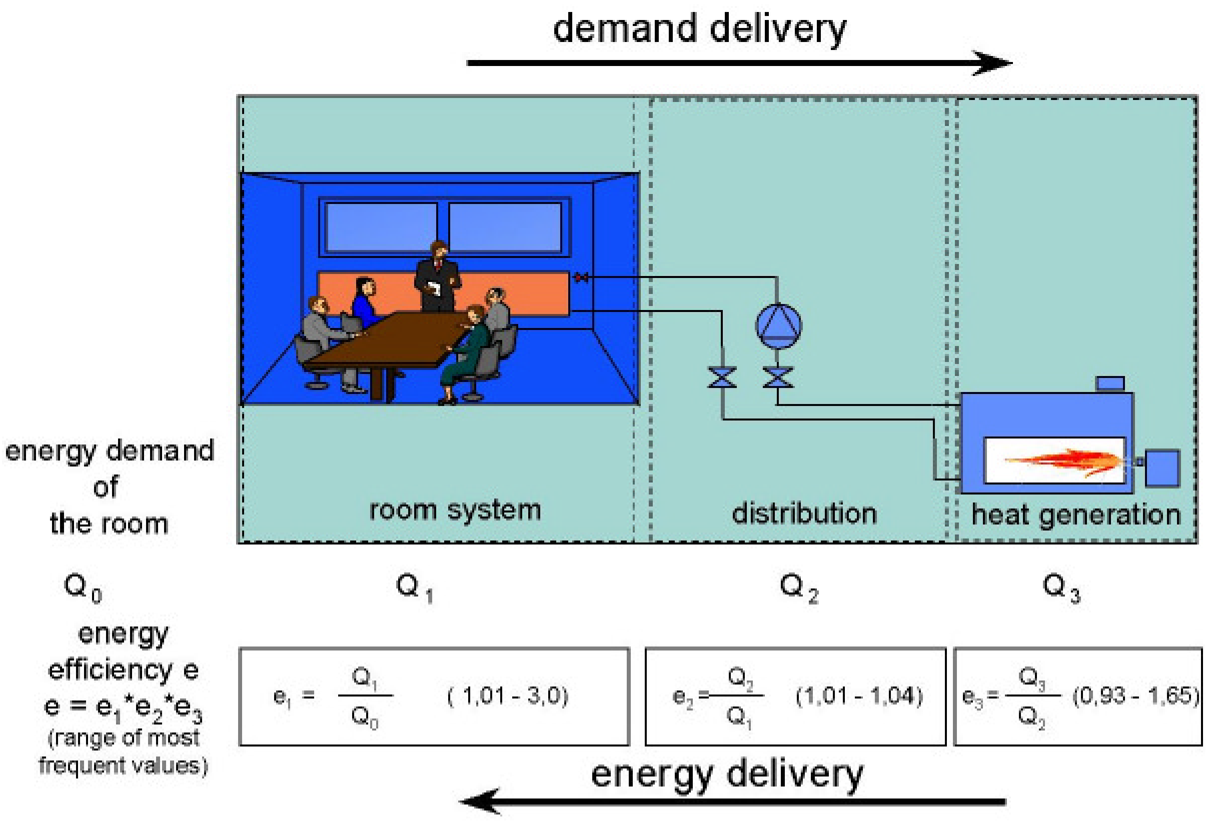


Fig. 3.1.1. Demand and energy delivery

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_l 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

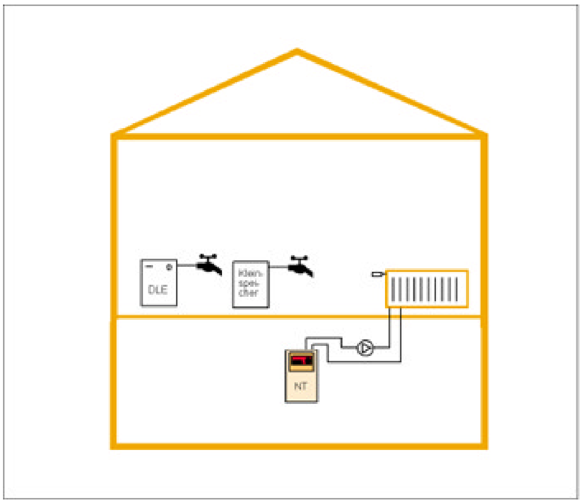


Figure 3.2.1: Illustration of system 0

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
Wh	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

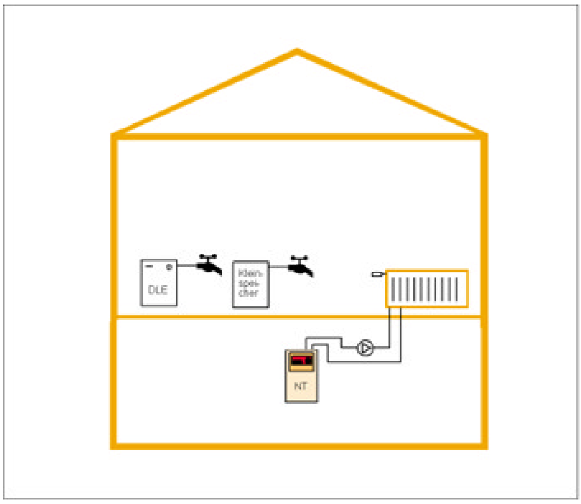


Figure 3.2.2: Illustration of system 1

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

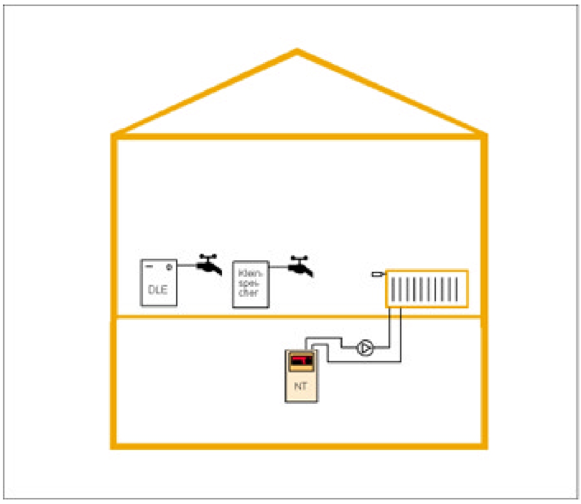


Figure 3.2.3: Illustration of system 2

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
W h	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

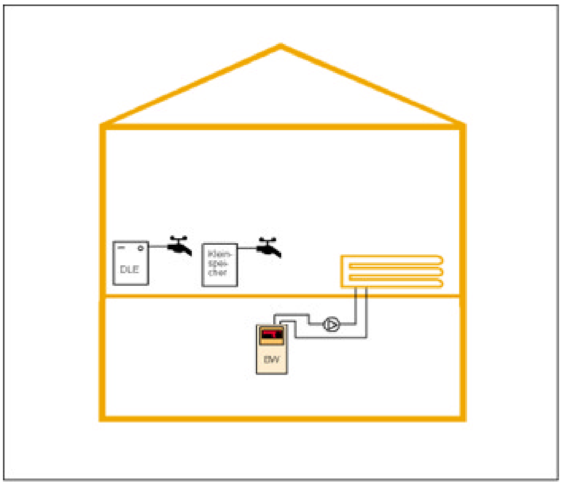


Figure 3.2.4: Illustration of system 3

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

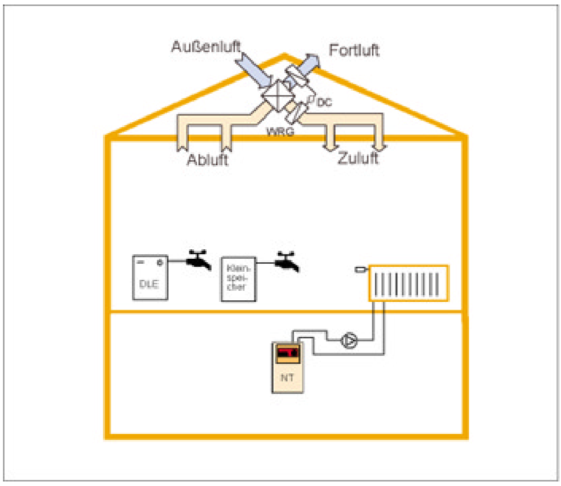


Figure 3.2.5: Illustration of system 4

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

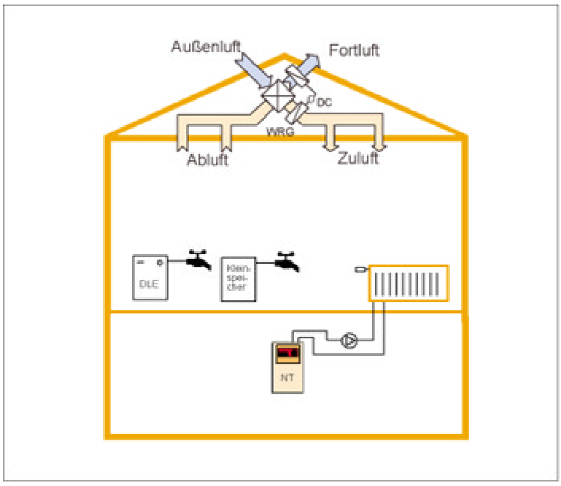


Figure 3.2.6: Illustration of system 5

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
Wh	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

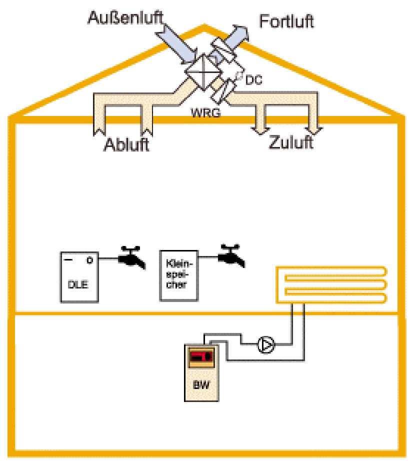


Figure 3.2.7: Illustration of system 6

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

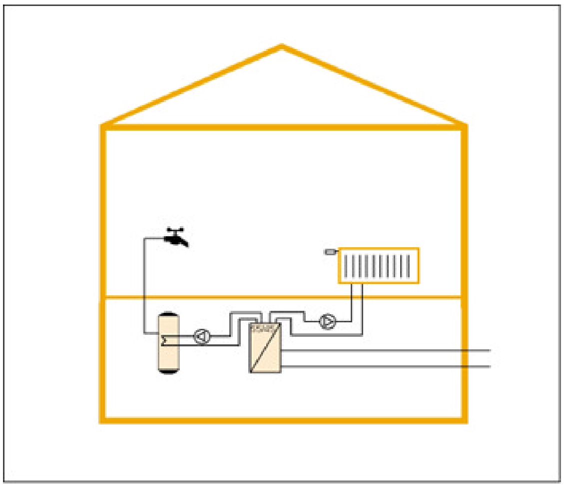


Figure 3.2.8: Illustration of system 7

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

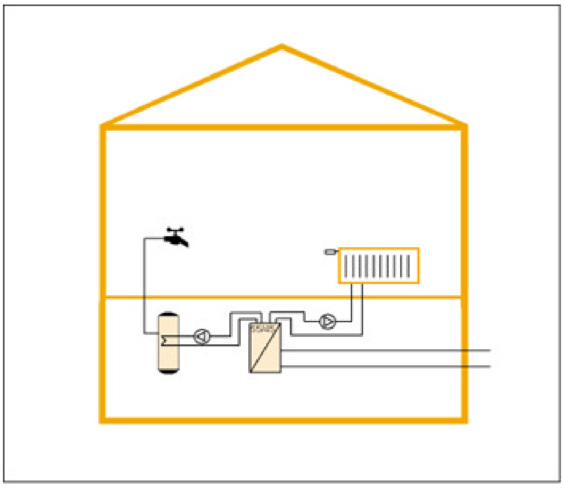
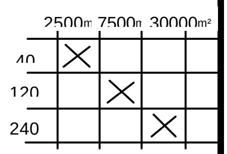
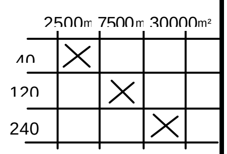


Figure 3.2.9: Illustration of system 8

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			
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
0	**O**				**O**	**O**			
1		**O**			**O**		**O**		
2			**O**		**O**			**O**	
3				**O**	**O**			**O**	
4		**O**			**O**		**O**		
5			**O**		**O**			**O**	
6				**O**	**O**			**O**	
7			**O**		**O**				**HKW f**
8			**O**		**O**				**KWK f**

Central ventilation system		Domestic hot water system			primary efficiency factors	end efficiency factors
Natural ventilation	Outside/ discharge air WRG: 80%	non system	Central system	Central system, bivalent with solar energy		
O		**O**			1,56/1,33/1,29	1,40/1,20/1,17
O		**O**			1,43/1,26/1,22	1,28/1,14/1,11
O		**O**			1,32/1,17/1,14	1,18/1,06/1,04
O		**O**			1,25/1,13/1,10	1,11/1,02/1,00
	O	**O**			1,59/1,31/1,25	1,28/1,14/1,11
	O	**O**			1,27/1,16/1,13	0,99/1,00/1,00
	O	**O**			1,22/1,12/1,10	0,93/0,96/0,97
O		**O**			1,44/1,35/1,33	1,10/1,04/1,02
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

1977 – 1983	**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

<u>3.2.4.1 Replacement of Components</u>

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

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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

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

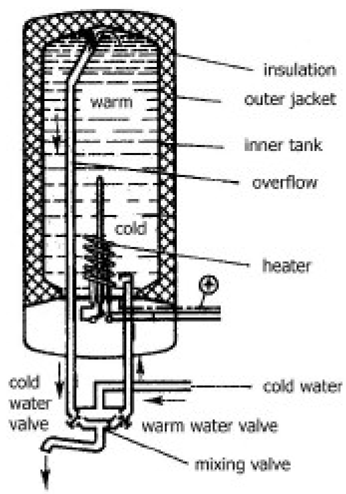

Fig 3.3.1. Low pressure electric storage water heater

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

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
- tank made of copper, steel
- bar heaters

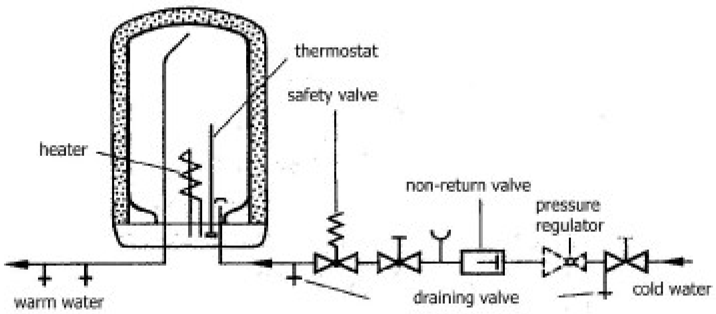

Fig 3.3.2. High pressure electric storage water heater with safety fittings

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 ? t=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

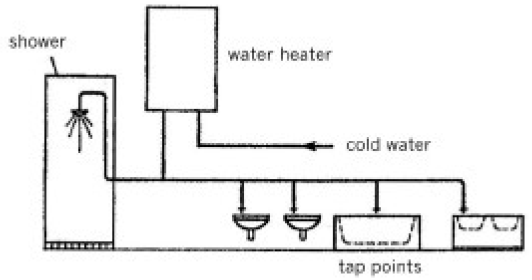

Fig 3.3.3. Single flat central hot water delivery with flow water heater

mixed storage/flow:

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

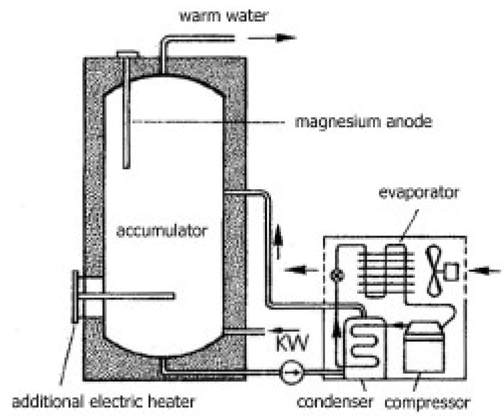

Fig 3.3.4. Heat pump as a separate domestic hot water system component

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°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

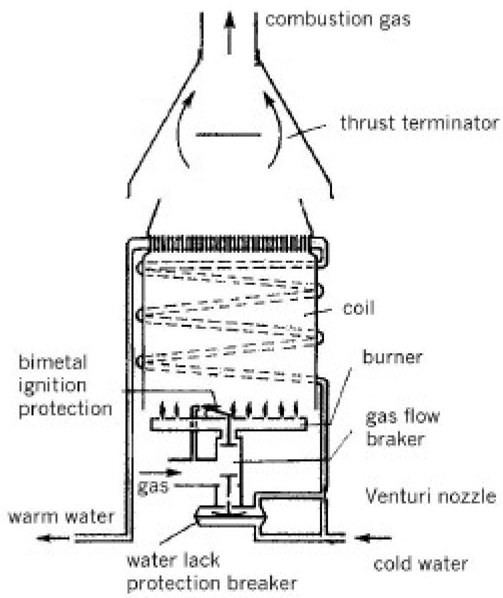

Fig 3.3.5. Gas-fired water flow heater with open combustion chamber

<u>*storage (Fig 3.3.6):*</u>

- 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

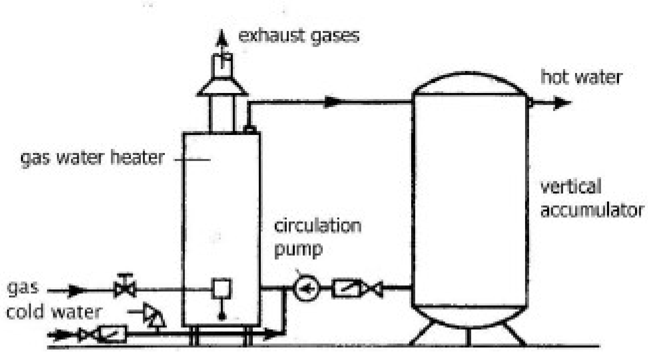

Fig 3.3.6. Gas-fired water storage heater with vertical storage tank and circulation pump

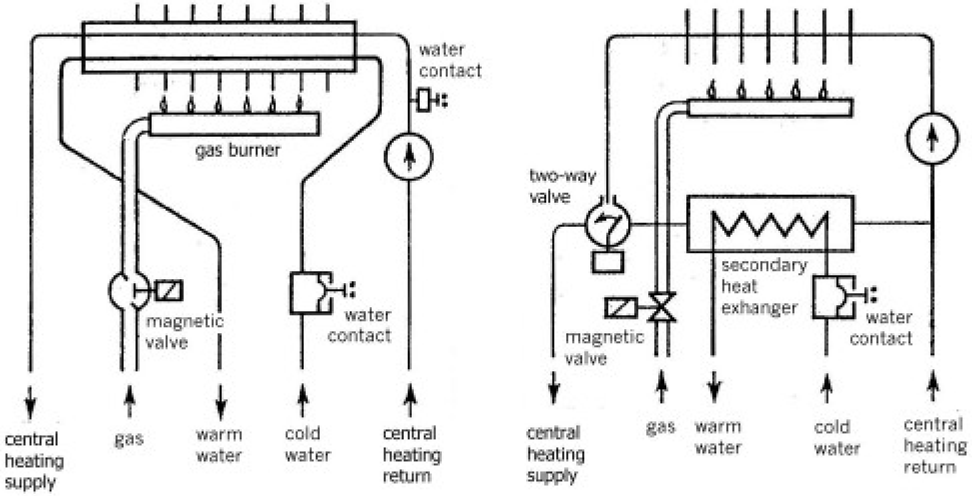

Fig 3.3.7. Combined gas-fired domestic hot water and central heating flow heater: direct DHW heating (left), indirect DHW heating (right)

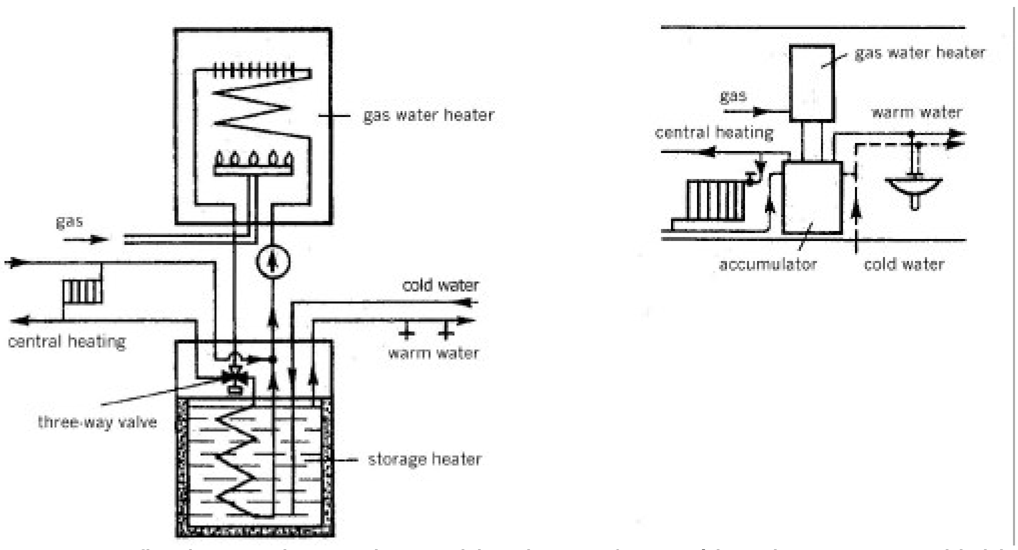

Fig 3.3.8. Gas-fired water heater in combined DHW/central heating system with high pressure water storage tank

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

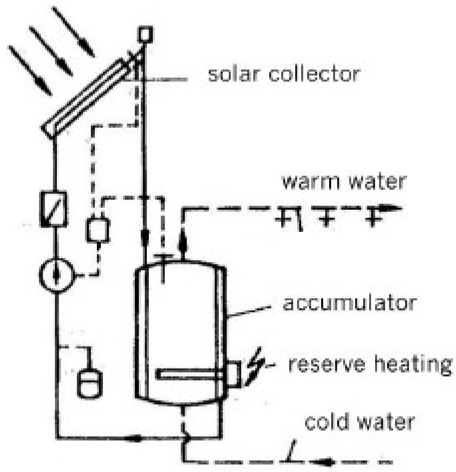

Fig. 3.3.9. Solar energy water heating with additional reheating in boiler

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

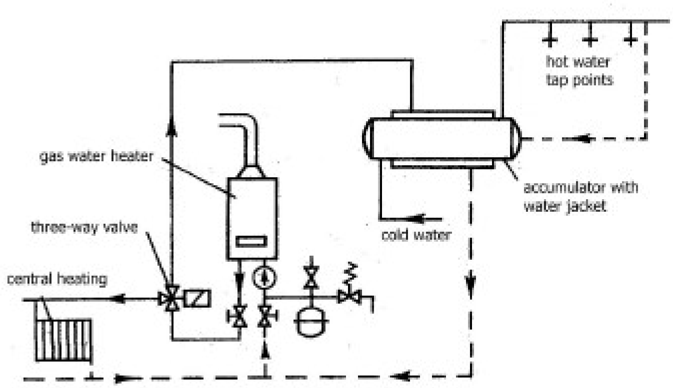

Fig 3.3.10. DHW system with circulation water gas heater and accumulator with double jacket

<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

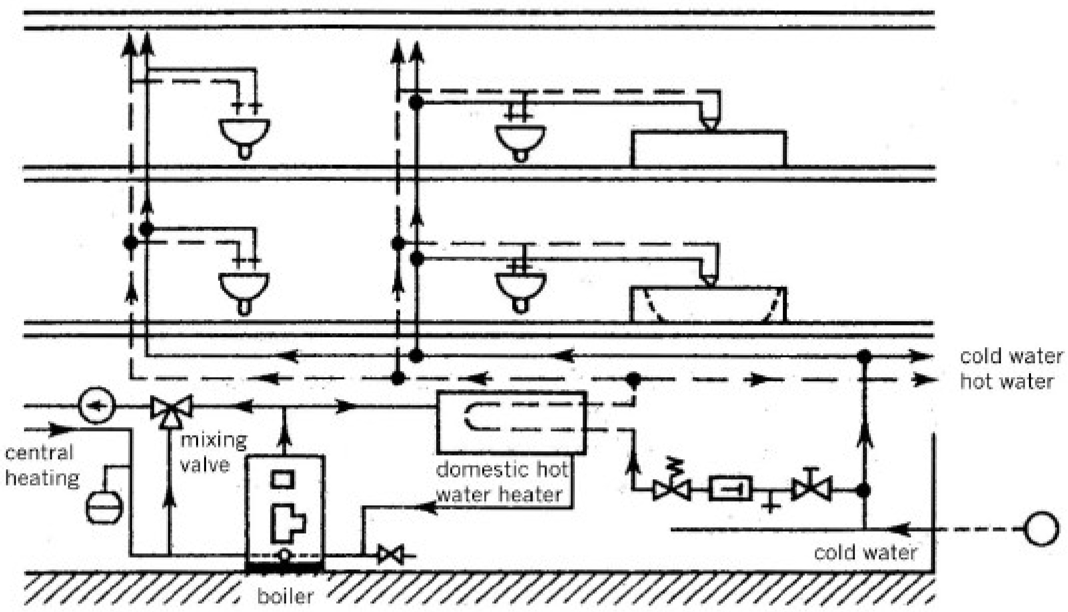

Fig 3.3.11. DHW system with flow heater

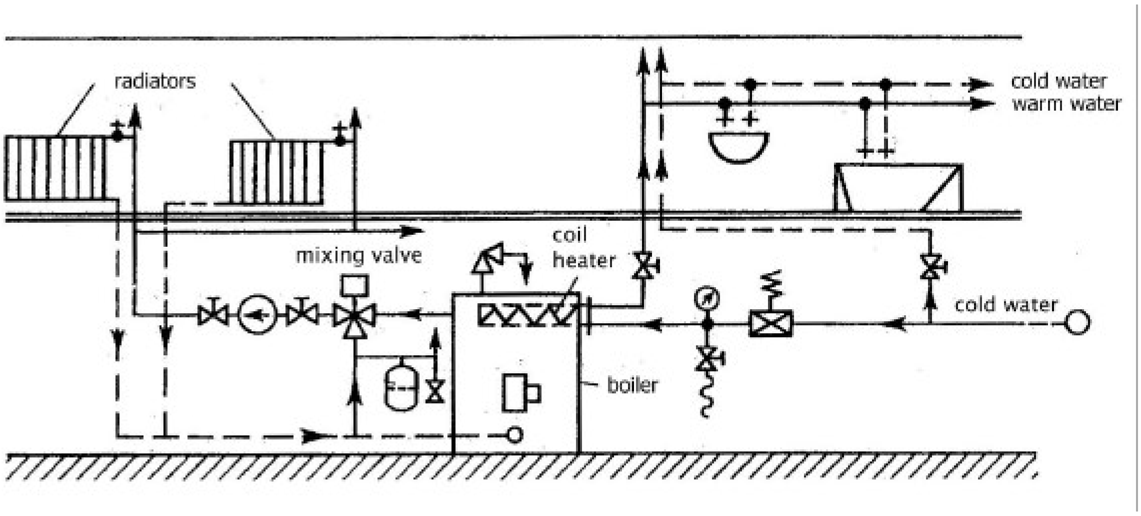

Fig 3.3.12. DHW system with flow heater built in the boiler

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°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°C, vertical thermal gradient in storage water heater, water stops, boiler mud. Water @ 60-65°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)
- 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

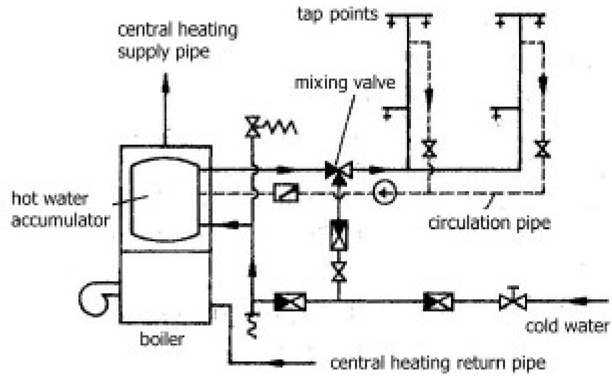

Fig 3.3.13. DHW distribution network with boiler blocked with accumulator and circulation piping

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 (eg. energy efficient storage-type DHW systems, instantaneous gas heaters, solar-assisted systems)
- equipment improvement, eg. 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, eg. 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.

3.4. Energy sources and Generation system

It is necessary to differentiate between conventional energy based on fossil fuels 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. Conventional energy

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 eternally. 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 (Thermostatic Regulation Valves) 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 somebody 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 functioning 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 control 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 alike 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. CO_2 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 CO_2 or VOC – Volatile Organic Compounds 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 (PIR) 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 CO_2 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.

Night time ventilation: 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 pretreated 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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