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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3.2. 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 [m^2]		
		2400	7800	30000
qh [kWh/m^2a]	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

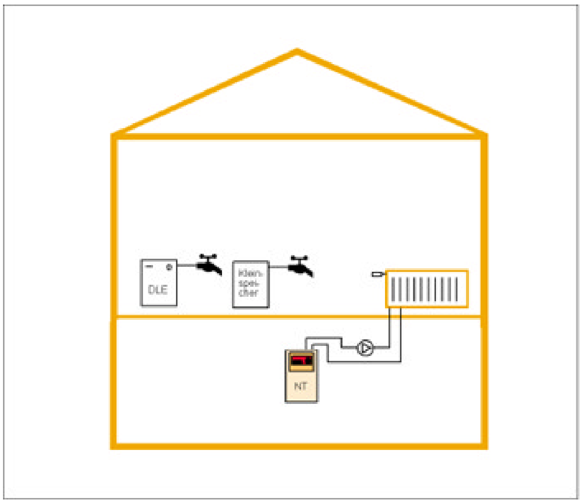

Figure 3.2.1: Illustration of system 0

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

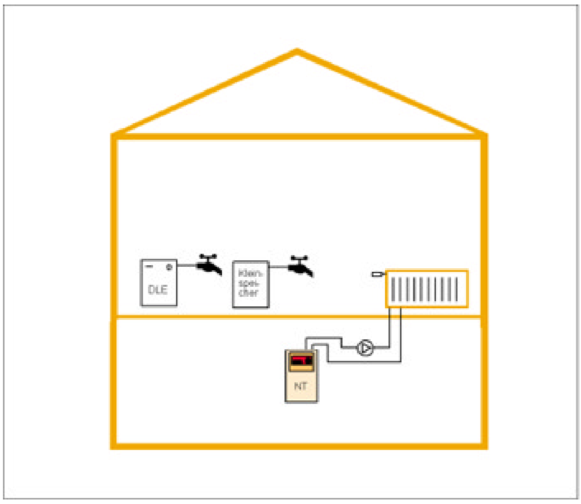

Figure 3.2.2: Illustration of system 1

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
W h	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

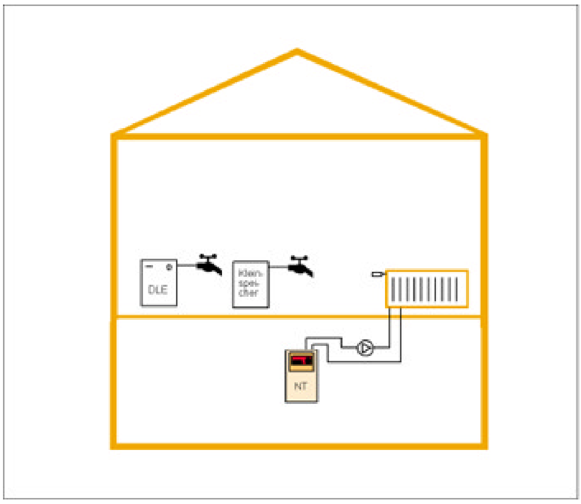

Figure 3.2.3: Illustration of system 2

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

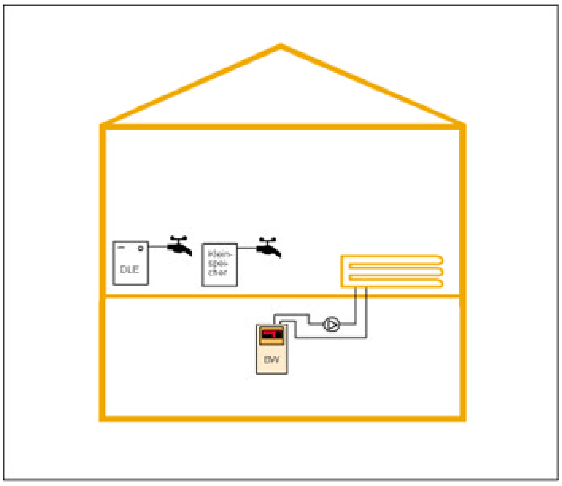

Figure 3.2.4: Illustration of system 3

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

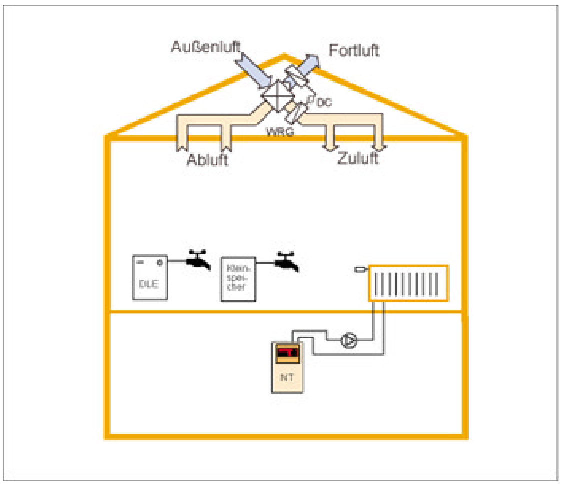

Figure 3.2.5: Illustration of system 4

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

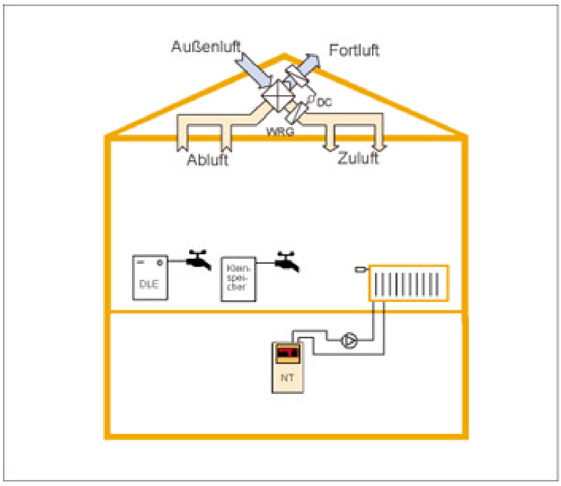

Figure 3.2.6: Illustration of system 5

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 [m^2]		
		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

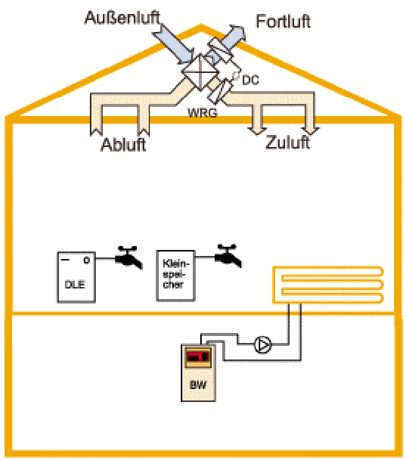

Figure 3.2.7: Illustration of system 6

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

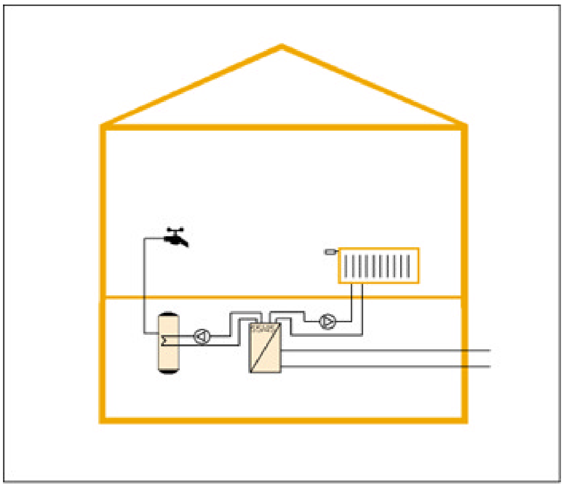

Figure 3.2.8: Illustration of system 7

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

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

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

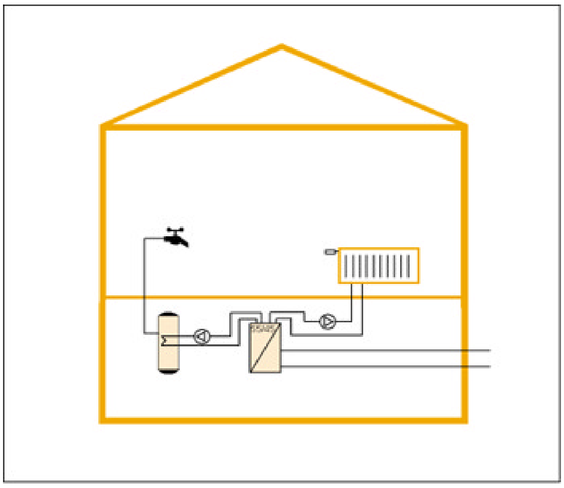

Figure 3.2.9: Illustration of system 8

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	2500m² 7500m² 30000m² / 40 120 240	2500m² 7500m² 30000m² / 40 120 240
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

[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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