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Current state of the debate about wall heating systems

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1 Basic principles

1.1 Wall heating systems

Wall heating systems come in a number of different versions. Classic wall heating systems operate according to the principle of underfloor heating and are mounted on the wall (see Figure 1.1). They can be roughly divided into water-based and electric systems. Some of the properties of the systems differ and are therefore not equally suited to the same application fields.

Wall heating can fundamentally be installed using either wet plastering or drywall installation. In the case of wet installation, prefabricated heating elements consisting of plastic, copper or composite tubes or of electric heating cables are directly attached to the substructure and then plastered over (see Figure 1.2a). The foundation may either be the wall itself or internal insulation. The plaster used may be permeable plaster made from lime, lime/cement or clay. In addition to prefabricated heating elements in various heights and widths, it is also possible to install the heating pipes individually on site, which provides greater design scope and enables the position of heating pipes to be adapted to local circumstances.

In the case of drywall installation there are various ways of integrating wall heating in building elements. Heating pipes can be installed in a substructure (Figure 1.2b) or alternatively there are prefabricated drywall boards in which the heating pipes have already been integrated (Figure 1.2c). After installation these merely have to be connected to the flow and return flow or to the power supply. The advantage of the drywall version is that no moisture is introduced to the building structure, which protects the fabric of the building and avoids the need for drying time. Furthermore installation can be completed very quickly. Since drywall boards usually need to be fitted in any case, the only additional work is the time taken to connect the wall heating.

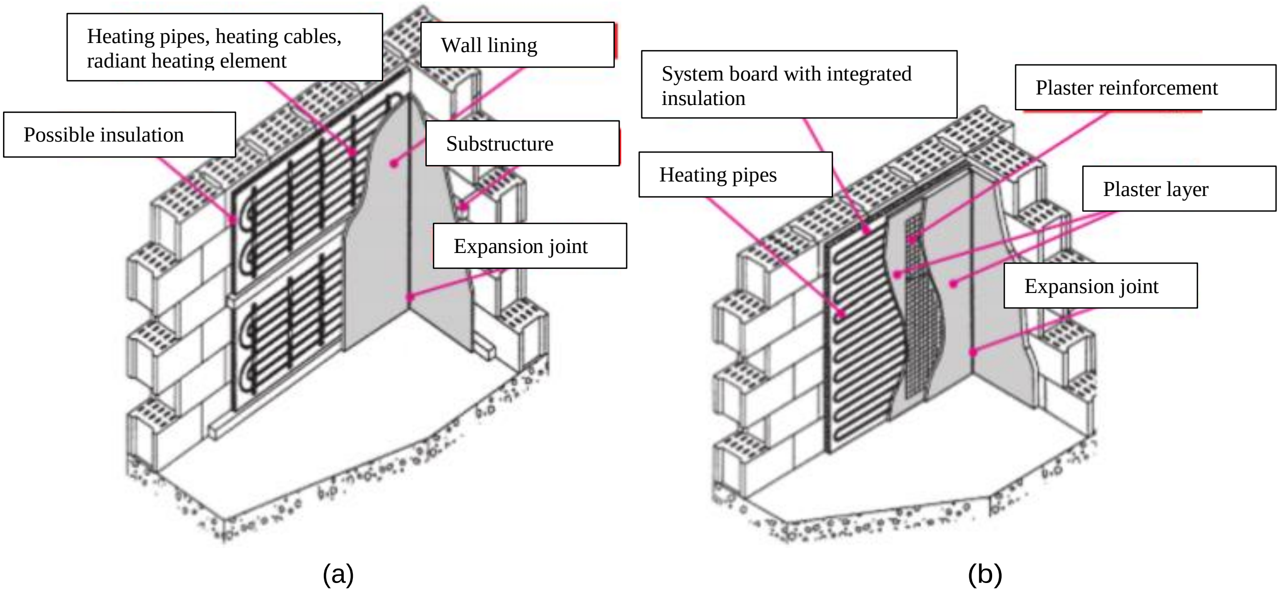

Figure 1.1: (a) Wall heating with installation of heating pipes directly on the wall; (b) Wall heating with installation of the heating pipes in or on a system board (from: [3])

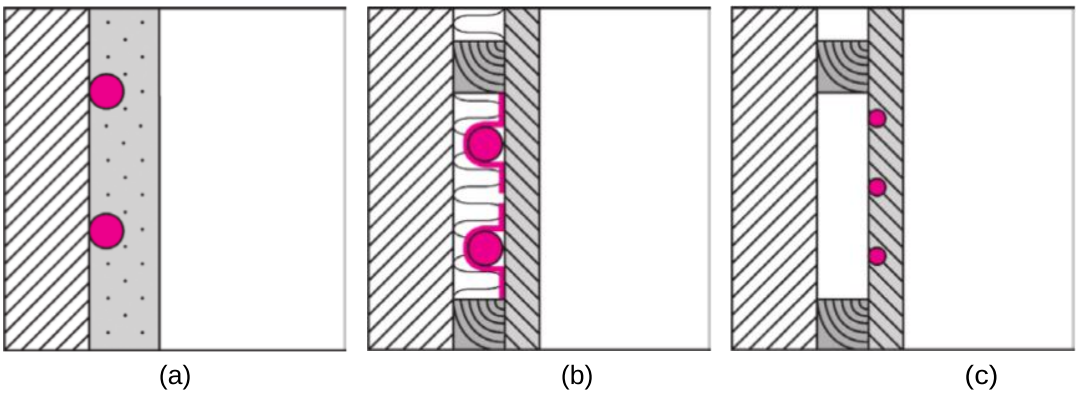

Figure 1.2: Vertical sections: (a) Pipe system in wall plaster; (b) pipe system in substructure with drywall board; (c) pipe system in drywall board wall (from: [3])

1.1.1 Water-based wall heating

With the appropriate connection technology water-based wall heating systems can be connected to existing heating systems. In addition to use in new buildings, they are therefore also suitable for renovation work. The heating pipes are usually made from pure copper as this is both diffusion-resistant and non-ageing. The high heat conductivity of copper ensures high heat transmission even at low flow temperature, which has a positive influence on efficiency. These low flow temperatures also facilitate the use of heat pumps and solar collectors. If reversible heat pumps are used, cooling is also possible through operation with cold water, which presents an alternative to conventional air conditioning systems on hot summer days.

A water-based wall heating system reacts more quickly than comparable underfloor heating because it is closer to the surface of the building component. However it responds much more slowly than electric versions.

The water-based heating pipes are also often used in renovation work to control the temperature of building elements (see Chapter 2.4). Here the pipes in areas with damp problems (plinth area of external walls or other building elements in contact with the ground) are mounted to the wall without internal insulation. Controlling the temperature in these areas prevents rising damp in the building component. The building element temperature control therefore serves both to protect the building structure and to heat rooms. Of course use purely to heat rooms in building elements without damp problems is also possible. This option is frequently used in museums.

Building element temperature control will not be taken into consideration below unless explicit reference is made to it.

1.1.2 Electric wall heating

Electric wall heating (which is often also referred to as infrared radiant heaters[1]) may either be integrated in the wall structure as drywall system or can be installed in objects applied to the wall surface. For example, the bathroom mirror can be used as heat surface, which has the added advantage that it no longer steams up.

The minimum depth of heating surfaces is just 0.8 – 3.0 cm, because the sole task of the heating surface is to evenly distribute the heat on the electric heating cables which are on the back or are integrated, thereby generating an evenly radiating surface. This kind of electric wall heating is also referred to as “low temperature radiation heating” or “tube heater” because the

[1] Heat radiation is within the infrared range (see 1.2)

connection output is relatively low and the surface temperatures at 106°C[2] are correspondingly low[3].

A great benefit of electric wall heaters is that they respond immediately. They are therefore excellent as supplementary heating for temporarily or rarely used areas. Especially devices which are not integrated in the wall structure can be consciously positioned and their position can be changed relatively easily.

1.2 Radiant heating (vs. convection heating)

A wall heating systems involves "radiant heating". In order to understand the different modes of action of diverse heating systems, it is helpful to clarify the physics underpinning them. Heat is a form of energy that can overcome system limitations. There is a continuous attempt to achieve temperature equalisation, something that is realised by various heat transport mechanisms. A distinction is made between 3 types of heat transport, which are shown in Figure 1.3:

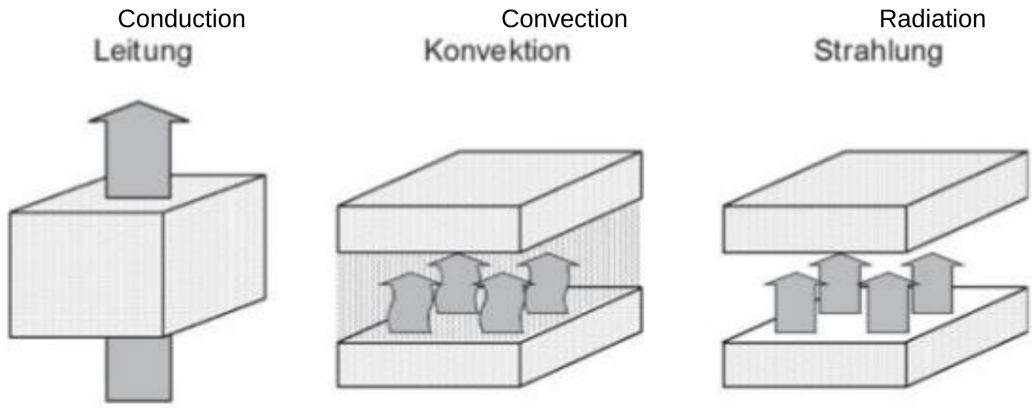

Figure 1.3: Diagram of conduction, convection and radiation heat transport mechanisms (from: [9])

The various heat transport mechanisms occur simultaneously but, depending on the system, in different ratios. From its name it is not difficult to recognise that heat radiation prevails in radiant heating. How high the radiation share actually is depends on a number of factors such as type of installation, installation location, air movement in the room etc. In order to make best use of radiant heating, the radiation proportion should be as high as possible.

[2] Permissible surface temperature in residential spaces at easily accessible height up to 1.80 m in accordance with DIN EN 60335-2

[3] Compared to high temperature radiators with surface temperatures up to 950 °C (not further considered in the following)

In the case of heat radiation, the temperature difference between the surfaces of two bodies is equalised by heat transport via electromagnetic waves. In contrast to the other two transport mechanisms, no material is required as carrier medium in the case of radiation heat transport. Heat radiation can therefore in principle also take place in a vacuum.

A distinction is made between shortwave and longwave radiation according to the source of the heat radiation. The radiation wavelength of a body here depends on its surface temperature. The warmer the surface, the shorter wavelength and more energy-rich the heat radiation it emits. Particularly shortwave radiation is also defined as “solar radiation” because its origin is the sun. This is compiled as follows:

Proportion [%]	Type of radiation	Wavelength [µm]
7	UV radiation	< 0.38
47	Visible radiation	0.38 – 0.78
46	Longwave solar radiation	0.78 - approx. 3.00

Table 1.1: Composition of solar radiation

The wavelength range of the heat radiation emitted by a radiant heater lies in the infrared range at approximately 3 - 800 µm. The limit value of 3 µm is cited in literature, but cannot actually be precisely determined because there is actually a smooth transition from solar radiation to heat radiation.

When the radiation meets a body, this does not absorb the complete radiation. Depending on its material, the radiation

- is partially absorbed (absorption);
- is partially transmitted (transmission),
- and partially reflected (reflection).

The total of the three figures always adds up to 100% or 1. The rule is therefore:

$R + A + T = 1$ or $\rho + \alpha + \tau = 1$

where

ρ or R	=	degree of reflection
α or A	=	degree of
τ or T	=	degree of transmission

The part of radiation absorbed by the body therefore ensures that this body is heated. This is the great advantage of radiant heating compared to convection heating. The latter primarily gives off its heat energy to the air flowing past, which then in turns passes the heat energy on to people or to objects. The heat energy is therefore not transmitted directly, but via air used as additional transport medium. This means that the heat output of convection heaters is also directly dependant on the flow velocity of the passing air flow. Warm and thus dryer air result in an unpleasant indoor climate; the increased air movement causes dust to be stirred up and suspended, which then increases dust exposure in the ambient air. In damp air this dust can be consolidated by the dampness and fall to the ground because of its increased weight. However a dryer atmosphere enables particles to last longer in the ambient air.
A further advantage of radiant heating compared to conventional convection heating is the option of installing heating surfaces out of sight in building elements (ceilings, walls, floors) or in flat objects (pictures, mirrors). This is not possible in the case of common convection heaters, because they need to be surrounded by ambient air in order to distribute the heat in the room via the medium of air. An exception is presented by so-called floor duct heating systems. These are flush-mounted in the floor directly in front of larger glass surfaces. The rising heat forms a warm air curtain in front of the cold window areas. The only visible part of the convection heaters in this version are the openings through which the hot air rises.

1.3 Effects in the room (for the user)

As can be seen from Figure 1.4, there is a certain link between thermal comfort, room temperature and the temperature of surfaces enclosing the room. It can be seen that the room temperature can be reduced without loss of thermal comfort if the surface temperature of the areas enclosing the room is simultaneously increased. This is precisely what happens in the case of radiant heaters.

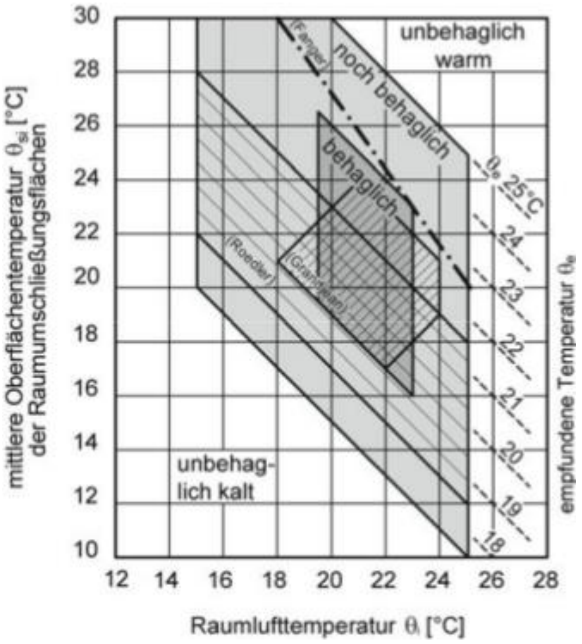

Figure 1.4: Comfort range for the pair of values of room temperature/mean temperature of surfaces enclosing the room (according to [5], [15], [6] and [7])

Of course the wall surface in which the wall heater is mounted is warm and radiates heat into the room. As soon as the radiation then meets a body, an object or another wall, this object absorbs part of the radiation and is likewise heated by it.

As explained in 1.2, part of the heat is reflected, encounters another object and then heats this. The result is that all walls are heated evenly, which likewise contributes to well-being. The draughts and discomfort occurring near poorly insulated or uninsulated external walls are effectively reduced as a consequence.

The radiation heat itself does not heat the air in the room. However the air absorbs the heat from wall surfaces heated by the radiation, so that the entire area is heated by the slight convection triggered by this. However the convection effect with wall heating is less than with a convection heater.

The specified effects ensure that wall heaters generate heat which is physiologically favourable for the human body. The high radiation and low convection ratio mean that the air in the room is less heated and stirred up than is the case with convection heaters. Wall heaters are therefore particularly suitable for museums or rooms with high hygiene requirements such as hospitals.

2 Current scientific research projects

Extracts from selected, current studies on the subject of “wall heating” are compiled below, and are intended to communicate an impression of the current status.

2.1 Research into the energy parameters of the radiant heaters from the company SunVital GmbH

Project processed by:

IET GmbH
Institut für angewandte Energietechnologie (Institute for applied energy technology)
Jena, 2011-08-11
Keßlerstraße 27
07745 Jena

Description:

SunVital GmbH manufactures electric natural stone radiant heaters, of which three examples have been assessed in terms of energy. The assessment involves two radiators with an area of 0.9 m x 0.6 m and a nominal output of 500 W, and one radiator with an area of 1.1 m x 0.6 m and a nominal output of 600 W. Their manageability and use in the home were also studied.

Results:

The energy properties of the radiant heaters examined were judged to be good. A radiation ratio of 45% was measured, which could also be achieved in partial load operation. When mounted on the ceiling, radiation ratios of up to approx. 70% were even reached.

The reason is that hot area rises, so the heat is not carried away by the restricted convection below the ceiling. The test results certify a substantial energy-saving potential. The suitability as supplementary heating for cooler areas such as a study or dining room is specifically emphasised.
Additionally a precise location-based heating load determination for the radiant heaters is advisable, according to which the requisite number of radiators can be determined.

2.2 Measurement comparing infrared radiant heaters and gas heating in old buildings

Project processed by:

Dr.-Ing. Peter Kosack
Graduate School CVT
Arbeitskreis Ökologisches Bauen
(Environmentally sound construction
working group)
Technical University of Kaiserslautern
Gottlieb-Daimler-Straße 42
67663 Kaiserslautern

Description:

The energy consumption of an infrared radiator from the company Knebel and a conventional gas heater was compared during the 2008/2009 heating period, in order to examine the fundamental benefits and suitability of infrared panel heating in the home. The infrared panel heating used throughout was an electric tube heater (see Chapter 1.1.2) with surface temperatures of between 70°C and 100°C.

Results:

The examinations demonstrated that the infrared heating represents a very practical alternative to conventional heating systems. It is pointed out that standards and regulations either fail to take them into consideration at all or do so only insufficiently. Savings of up to 50% were specified with use of an infrared heater compared to underfloor heating or night storage heating.

The arguments in favour of infrared heating are as follows:

- Low investment costs
- No ancillary costs (e.g. for a chimney sweep)
- No maintenance
- Can be operated with 100% renewables

Without having conducted comparative examinations with other brands, the following general properties are set out for infrared radiant heating in the home:

- 60°C - 120°C surface temperature[1]
- No storage masses
- Constructions as simple and flat as possible

2.3 Thermographic measurement of a solid brick wall comparing different heating methods

Project processed by:

TSK - Andreas Kinz
Klingerweg 35
D-64853 Otzberg

Description:

Two adjacent rooms in a building with solid brick masonry were fitted with different heating systems. One room was heated by conventional radiators and the other by water-based wall heating. Thermographic records of the walls were used to examine the influence of both heating systems on the masonry. No reference is made in this report to the energy carrier used by the heating systems.

40 cm	Solid brick masonry with lime plaster

Table 2.1: Wall structure in the area of conventional radiators

40.0 cm	Solid brick masonry with lime plaster
1.0 cm	klimalehm® clay plaster for heating
2.0 cm	Reed insulation board
2.7 cm	Multilayer metal composite pipe 16 mm, plastered in klimalehm® plaster for heating
0.3 cm	Clay finishing plaster

Table 2.2: Wall structure in the wall heating area

40 cm	Solid brick masonry with lime
0.3 cm	Clay finishing plaster

Table 2.3: Wall structure in the area of the unheated external wall

Results:

With an identical indoor climate (22°C, 33% rel. humidity), the temperature of the external wall heated by the wall heater (facing NNW) on the outside was 0.4 K below the temperature of the wall of the room heated by radiators (facing NNW). This was despite the fact that the external wall in the area of the wall heater was heated inside to 38.5°C. The surface temperature inside the other room was 21.5°C.

A further measurement examined the outer surface temperatures of the external wall heated by the wall heating and an unheated external wall (facing ONO) in the same room. The temperature difference here was 1.5 K.

According to the report's author, the temperature difference can be attributed to lower humidity in the external wall in the area of the wall heater with associated improved insulating effect. This theory should be regarded critically, because the wall structure (see Tables 2.1 to 2.3) has a great influence on the heat distribution via the cross-section, so that it is essential that it is taken into account. The reed insulating layer to which the wall heating is mounted obstructs energy entering the wall. It is therefore unlikely that this causes humidity in the wall to be displaced, improving the insulating effect of the external wall.

[1] Such high surface temperatures can only be applied in special cases in which direct contact with the user can be ruled out (e.g. ceiling installation)

The more probable explanation for the slightly raised external surface temperature is the absolute energy entering the wall. As mentioned above, this is prevented in the area of the wall heating by the layer of insulation, and can therefore not be used to increase the outer surface temperature of the external wall. Where less heat energy is introduced into the overall structure, less can also radiate to the outside.

Research work by the Technical University of Braunschweig [18] analysed the energy input of wall heating in a brick wall. Among other things a wall structure was examined which is comparable to that discussed here (wall heating with 12 mm pipe diameter in 19 mm XPS heat insulation[2] on 11.5 cm brick masonry). The study confirms that the energy input in the brick wall is very low, so that it can scarcely be responsible for any humidity reduction inside the external wall. A Co_2olBricks research project also takes a closer look at this subject. More information on Co_2olBricks projects can be found at http://co2olbricks.eu.

In addition to the objective measurement results, the report states that the subjective perception of heat in the room heated by the wall heating improved, which is attributed to the low convection heat and high ratio of radiation heat.

2.4 Asamstraße 3 research project – the renovation of two buildings from the “Wilhelminian period”

Project processed by:

Wolfgang Robl
MGS Münchner Gesellschaft für Stadterneuerung
mbH Haager Straße 11
81671 Munich

Description:

Two buildings from the Wilhelminian period with almost identical layout were examined. Wall heaters for controlling the temperature of building elements (see Chapter 1.1.1) were installed in 2 apartments in one building and in 2 cellar rooms. To do this slits were made in the existing walls to make room for the heating cables.

[2] Extruded polystyrene hard foam

The walls were then plastered in conventional fashion and the dimensions selected to permit subsequent connection of radiators where applicable.
Firstly the energy consumption and the drying effect were examined, excluding possible user influences. To do this, an experimental set-up was installed before the premises were moved into, and was designed to record the following data:

- Energy consumption
- Temperature course
- Thermal comfort
- Air temperature
- Mean surrounding surface temperature
- Heat volume
- Flow and return flow temperature of the heating circuits

In addition core holes were drilled into the cellar masonry at various depths so as to examine the drying effect on the basis of the core samples.

Results:

Fundamentally there is nothing to be said against wall temperature control, also with respect to the construction of rental housing. The user behaviour (ventilation, room temperature control) has a great influence on energy saving, however. Optimisation potential exists in the use of solar energy, especially in warmer weather. Under these circumstances it would certainly be possible to save energy compared to conventional heating systems. The wall heating was particularly effective with respect to moisture content in the cellar masonry.

2.5 Energy-related assessment of electric wall heating

Project processed by:

Baltzer, Sidney; Streblow, Rita; Müller, Dirk
E.ON Energy Research Center (E.ON ERC), RWTH Aachen University c/o
Mathieustraße 10
52074 Aachen

Description:

An innovative electric wall heating system was studied during the project (see Figure 2.1). This wall heating system is attached directly to the wall of modern residential and office buildings and is designed to offer thermal comfort in just a few minutes due to its fast response qualities. The objective here is to save energy, because energy only needs to be supplied as required. The examinations looked at the wall heating system in two residential buildings with low energy and passive house standard and in one office building.
The dynamic behaviour of the wall heating system was tested both by means of dynamic building simulation and in experiments by members of Munich Technical University. The experimental data were used to validate the simulation model.

Results:

According to Baltzer, Streblow and Müller, a dynamic electric wall heating system adapted to suit requirements can save up to 25% of primary energy compared to conventional systems using a condensing boiler (see Figure 2.2).
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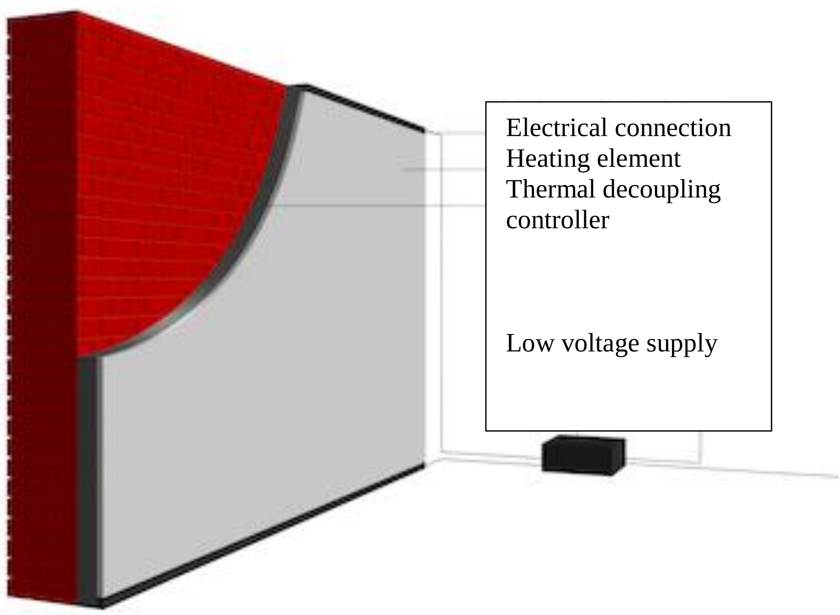

Figure 2.1: Diagram of the electric wall heating system (from: [1])

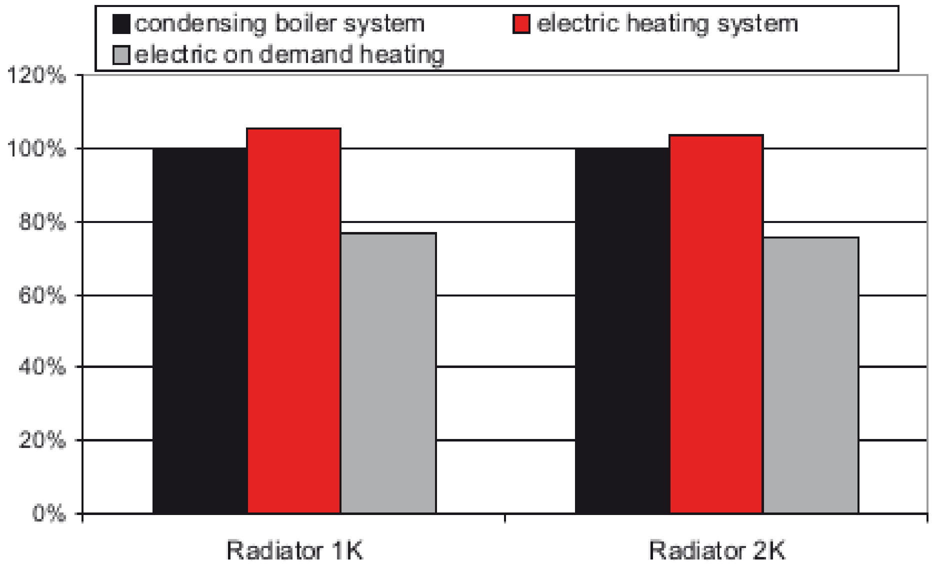

Figure 2.2: Comparison of the primary energy requirement of a wall heating system and a conventional heating system (from: [1])

3 Current state of the debate

3.1 Publications from research and practical experience

This chapter reproduces content from selected publications in professional journals in order to communicate an overview of current fields of application for wall heating systems.

3.1.1 Protecting the fabric of the building and enhancing user comfort

SBZ issue 15/16-2009 (SBZ.Sanitär.Heizung.Klima – professional journal for sanitation, heating and air conditioning) [12]:

The selection of a suitable heating system plays an important part in the renovation of churches. The widely used convection heating systems combined with the wrong heating behaviour have resulted in substantial damage to buildings. In terms of comfort and hygiene too, such systems no longer correspond to current requirements. For these reasons the St. Elisabeth Church in Hanau was fitted with a wall heating system during the eight-month renovation project which took place from August 2008 to April 2009.

One of the main objectives was to eliminate thermal bridges and by doing so prevent future damage to the basic fabric of the building caused by condensation contaminated with soot produced by candle smoke. In the course of the renovation measures, the old oil-fired convection heating system was to be replaced to simultaneously reduce the convective distribution of soot and smoke. The renovation measures were coordinated by Jürgen Krieg from architects Krieg + Warth. He decided in favour of the Hypoplan wall heating system from the company KME. With this system, the heat is given off via mineral heat surfaces on the wall which are embedded in the copper pipe heating elements (see Figure 3.1).
An important criterion when selecting the heating system was to enable the church to be heated without obstructive large radiators or air outlets, in order for the heating system not to impair the interior design. In addition to the characteristic properties of wall heaters such as high radiation ratio which prevents air and dust swirling, the system also offers energy benefits.

Figure 3.1: Installation of a Hypoplan wall heating system (from: [12])

The reduction in room temperature while retaining the subjective perception of warmth (see Figure 1.4) saves approx. 5 – 6% heating energy per K temperature reduction compared to a convection system. This aspect is very noticeable here because the church is only heated temporarily rather than permanently.
The comfort of visitors is positively influenced by a higher relative humidity and the prevention of downward draughts. The wall heating system was planned by Eckert-Planungsgesellschaft für Heiztechnik in Ostheim/Urspringen. The wall heating system has the following properties:

- Heat output: 78 kW
- 174 heating elements (height: 2.30 m, width: 1.00 m, pipe diameter: 10 mm)
- Heated wall surface: 391 m^2
- 4 distributors with a total of 30 heat circuits
- Every heating group distributor supplies a maximum of 8 heating groups
- Flow temperature: 40°C
- Mean return flow temperature: 27°C
- Maximum pressure loss: 16156 Pa

In this case the wall heating is connected to the district heating grid. As a result of the low flow temperatures, the system is also suitable for operation with low temperature and condensation boilers, however, and of course with renewable energy.
The connecting pipes on the heating elements were flush-mounted near to the floor which enabled the frequently occurring problems of dampness to be rectified (temperature control of the building element). This meant that the improved indoor temperature was accompanied by protection of the building structure from rising damp.

3.1.2 Perfect indoor temperature

BundesBauBlatt (Federal Construction News) Edition 3/2013 – ENERGY [2]:

The market share of surface heating and cooling systems in the sector dealing with the renovation of older buildings is increasing. In addition to the advantages relating to interior design and air hygiene, the focus here is above all on the lower temperature level[1] (see Chapter 1). The energy-related advantages in particular have a positive influence on the current market trend for these systems. The wide range of system solutions furthermore means that surface heating and cooling systems can be used in almost all situations. In the case of energy-related renovation it is common to initially improve the external insulation to meet the thresholds set out in energy legislation. The next step should involve heat distribution and transfer as well as the replacement of oversized heaters. Surface heaters are suitable for water-based heating systems; their temperatures are 35/28°C (flow/return flow).

The possible uses of surface heaters in renovation will depend on the structural situation. The appropriate surfaces must be present when using wall heaters. There should not be any installations behind the free wall surfaces.
Surface heaters constitute an efficient heating system in combination with renewable sources of energy and the corresponding low system temperatures. Attention should be paid to the coordination of the various trades during planning and installation.

[1] Surface heating systems are generally operated at lower temperatures than conventional heating systems.

3.1.3 Combination of wall and underfloor heating

SBZ 21/11 [16]:

Due to the popularity of renewable heat generators such as heat pumps or combinations of condensing boilers with solar energy, surface heating forms part of the standard equipment used in new buildings. However surface heating can also contribute to saving primary energy in the renovation area. The reason is that as soon as an old building indicates lower energy requirements as a result of insulation measures, surface heaters are suitable for heat distribution because of their low flow temperatures. Heating energy can then additionally be saved by a lower indoor temperature which is compensated by the radiant heat. Previously these properties were reserved for classic underfloor heating. The following points argue in favour of the combined use of underfloor and wall heating:

- Small bathrooms do not have sufficient floor space to cover the required heat load; users nevertheless want an energy-saving surface heating system
- Energy-saving heat generators with low flow temperatures are frequently installed in new builds; as a result, other forms of heat distribution would be counterproductive
- The high radiation ratio creates a high level of thermal comfort
- In children's bedrooms, for example, the underfloor heating can cover basic requirements whilst fast responding and separately switched wall heating caters for temporary demand peaks; this enables the principle of "play warm – sleep cool" to be achieved.

Water-based wall heating can be implemented both with wet and drywall installation. However the trend is distinctly towards the drywall version[2]. There are two main reasons for this:

- Since the trend for new buildings is generally moving towards fast dry construction, many clients decide to provide wall heating elements on the cladding panels which are required in any case, saving building costs.
- The drywall installation requires no drying times and no additional dampness is introduced to the room.

[2] Does not apply to listed buildings.

Wall heating generally represents a cost favourable alternative to underfloor heating systems, because these require comparably complicated integration in the floor structure. By contrast wall heating is installed near the surface and can be operated at higher surface temperatures.
It can be seen from the article that as a rule it is possible to achieve the same heat output on a wall with a heating surface that is half the size of that required on the floor. It therefore follows that given the same area, it is possible to distinctly reduce the flow temperature compared to that in underfloor heating without reducing the heat output.

3.1.4 Restoration and energy-related optimisation of a listed building (built in 1679)

Bausubstanz (Building fabric) Issue 4|2011 [13]:

Wall heating has in particular been tried and tested with respect to the renovation of old and listed buildings. The even heating of walls has a drying effect. Especially in the case of high ceilings, wall heating ensures even temperature distribution which in turn prevents the problem of rising heat below the ceiling. The surface temperatures also remain constant on heat bridges and do not fall abruptly as is the case in convection heating systems. This effectively prevents the formation of mould caused by condensation in these areas (see Figure 3.2).
This heating of potentially cold external walls therefore permits a high degree of thermal comfort to be achieved at relatively low indoor temperature. The size of the heat surfaces required will depend on the type of building, the heat insulation, on the system and on the corresponding flow temperature.
Systems where water-based pipework is integrated under the interior plaster are used most frequently. Prefabricated heating elements are usually deployed here. Suitable types of plaster are lime, lime/cement or clay plaster. The advantage of clay plasters is that they have excellent structural-physical and indoor temperature conditioning properties. They regulate air humidity by absorbing and discharging moisture, and are able to absorb pollutants and smells from the air. Added to this is their outstanding workability and excellent heat conduction compared to plaster with coarse pores. The latter ensures ideal heat distribution.
An alternative to wet installation is offered by wall heating in drywall installation. Clay is used here too, albeit in the form of finished plasterboards in which the heating pipes have already been integrated.

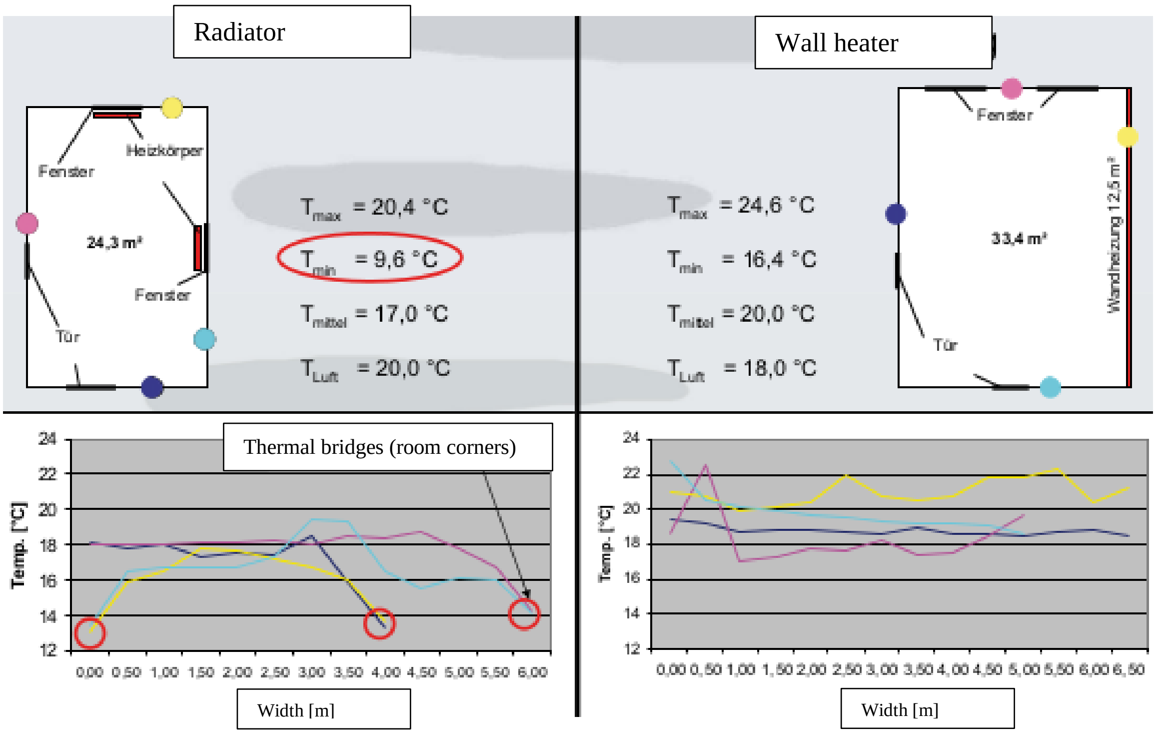

Figure 3.2: Comparison of surface temperatures of rooms with different heating systems (from: [13])

These boards can be used wherever the input of additional dampness is damaging the building structure and drying times need to be shortened. Examples are attic conversions and wooden houses.

The timbered house to be renovated that was the subject of the report consists of a quarry stone plinth, has a total area of approx. 400 m² and consists of a main house and an extension to the side. The building has internal insulation made from reed boards on the ground floor and softboards on the upper floor, and is completely heated using wall heating. Drywall clay elements are used in the well-insulated attic, while in other parts of the building pipework has been plastered into the mortar. The heat is generated by a gas-fired low temperature condensing boiler.

The report concludes that the selected building materials and technologies used during the ten-year renovation period have proven to be very effective. The building offers an excellent indoor temperature combined with historical atmosphere. Accordingly in 2012 the renovation project was awarded first place in the national prize for handicraft in the care of monuments from the Deutsche Stiftung Denkmalschutz (German foundation for the protection of monuments) and the Zentralverband des Deutschen Handwerks (Central association of German crafts and trades).

3.1.5 Building element integrated surface heating and surface cooling systems – structure and mode of operation

Surface heating + cooling information service. Guideline No. 11 [4]:

Irrespective of their positioning, surface heating and cooling systems should always be regarded as a complete concept. It is particularly important here to systematically coordinate all trades involved in planning and implementation. The efficacy of surface heating and cooling systems substantially depends on their positioning. It is therefore significant whether the system is installed in the floor or ceiling or in walls. In order to make best use of the advantages of the systems, it may be necessary to combine various positions. The wall coverings and flooring should also not be ignored. Their specific energy transmitting properties may have a great influence on the efficacy of the systems.

In the case of wall heating it must be considered that the convective heat transfer is less than with underfloor heating. However with wall heating there is no limitation to the maximum surface temperature, because unlike underfloor heating, permanent contact can be excluded. This means that greater heat output can be achieved through higher surface temperatures. The mean hot water temperature must be increased, however, to reach these surface temperatures. Since not all walls of a room are usually available for the installation of wall heating, it may be practical to combine wall and underfloor heating so as to minimise the mean hot water temperature.

The low temperature level permits surface heating and cooling to be operated ideally using heat pumps. In an ideal case, the heat pumps can be directly connected to the heating circuit. Since heat pumps require a minimum flow rate to function properly, they should always be combined with a storage tank

3.2 Energy efficiency of wall heaters

Water-based wall heating is operated with low flow temperatures of max. 50°C. These are sufficient for the optimal heating of the wall surface, minimising the temperature gradients between the indoor temperature and that on the surfaces enclosing the room. Convection heating, by contrast, is usually operated with higher flow temperatures depending on the insulation standard and outdoor temperature.

It is not quite correct to derive an energy-related benefit for the wall heating compared to convection heating from this, because the higher temperature level of the convection heating cannot be immediately equated with higher energy consumption. Namely the added heating energy generally only arises at the start of the heating period in order to reach the corresponding temperature level. How much energy ultimately needs to be supplied to maintain thermal comfort depends much more on user conduct and on heat losses caused by a poorly insulated building shell. The latter is also the reason why high energy losses sometimes occur when using wall heating to regulate the temperature of building elements.

Electrically operated radiant heating has a genuine energy-related advantage, however. It reacts very quickly and can therefore be switched on as required. The room is then only heated when it is also being used (see Chapter 2.5). Furthermore the technical losses during generation, storage and distribution with electric systems is extremely low. By contrast water-based standard heating systems have additional energy losses through undesired heat currents or auxiliary energy requirements.

3.3 Uses for the fabric of the building

It has been confirmed in a number of practical examples (see Chapter 2 for example) that the installation of wall heating can have a positive effect on the fabric of the building. The heating of structural elements displaces any dampness and prevents rising damp in the plinth area. Especially in the case of building renovation, where the installation of horizontal barriers or other sealing measures is not possible due to the protection of existing structures etc., the installation of wall heating systems represents a good alternative. In this case an internal insulation between the wall heating and the existing wall must be dispensed with, however, in order that the energy input into the wall is sufficient to displace the dampness. Care must be taken in an application of this kind that energy is not lost when heat is transported outside. It is therefore absolutely essential to have such systems planned by expert planners in order to receive realistic energy balances in advance.

Internal insulation is used for many energy-related renovation measures on existing buildings. Its use is necessitated by historic frontages worth preserving in conjunction with current energy legislation. The problem with using internal insulation is that condensate can form in the layer between the internal insulation and the external wall. If the dampness created as a result is no longer able to dry out, this can attack the fabric of the building and then cause damage to the building. The internal insulation system must be suitable for exposure to dampness of this kind. In practice various systems (permeable, non-permeable, with or without capillary action) have proven to be effective. In the case of such so-called condensate-tolerating internal insulation, a steam flow is consciously permitted into the insulation layer (see Figure 3.3), because the dampness that occurs has the opportunity to escape from it again.

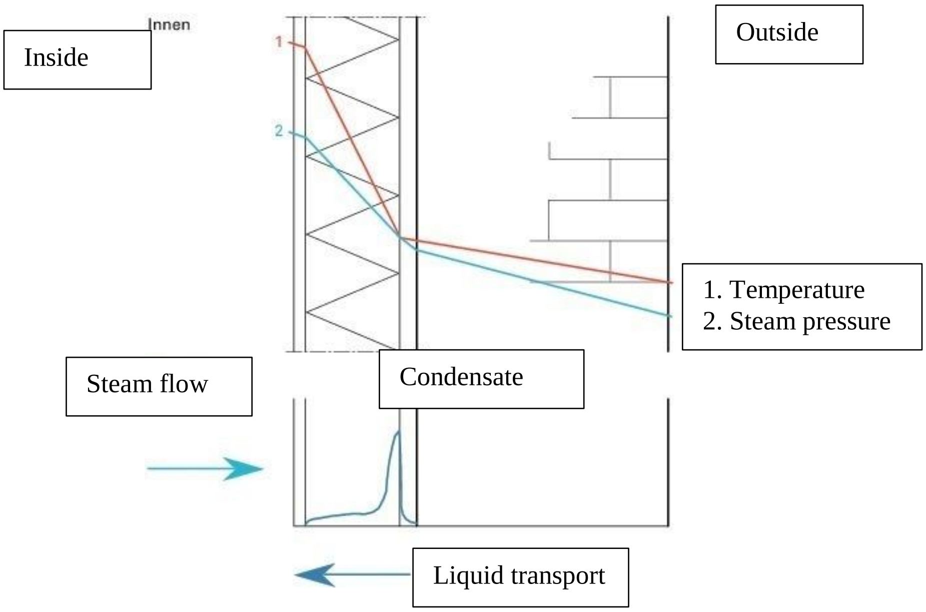

Figure 3.3: Schematic diagram of a permeable, capillary action internal insulation (from: DBZonline Issue 02/2011 – Bautechnik (construction engineering)

Wall heating should assist the drying out of condensation. The dampness which has occurred between the internal insulation and the external wall which does not dry out by itself should dry out with the help of the heat from the wall heating and diffuse through the internal insulation and into the building. Initially it would appear unlikely that this principle actually works. After all, the purpose of the internal insulation is to let as little heat as possible through towards the external wall. In this case there would also be no heat to dry out any accumulated dampness. The influence of wall heating on dampness in external walls with and without internal insulation is being examined more closely, also as part of Co2 olBricks research.

An important property of wall heating is that, due to the radiant heat, it heats all walls almost uniformly, even in large rooms (e.g. museums).

The temperature remains evenly distributed, also in critical areas such as thermal bridges, and does not fall suddenly as is the case with convection heating. As a result the surface temperature in these areas can be increased and thereby counteract mould formation.

3.4 Uses for the user/resident

The integrated wall heating requires neither dusting nor regular painting, and is therefore the lower maintenance alternative to radiators. The interior design may be restricted by the fact that the heating surfaces should where possible be left free for the heating to function well. If, for example, a large cupboard is standing in front of the heating surface, then the heat radiation is no longer able to radiate onto the user and other walls to heat these, but only on the cupboard. By contrast pictures hardly impair the function of wall heating due to their small mass, but they cannot be hung just anywhere. Utmost caution is needed if holes are to be drilled in a heated wall. Depending on where exactly the heating cables or pipes have been installed in the wall, it may not be possible to drill any holes in it. In most cases, however, they have been installed at sufficient distances to enable drilling between them in principle. There are various ways of determining the position of heating cables or pipes. There are special thermofoils which can be held against the wall heating, initially when it the heating is off (cold) and then when it is operating; the colouring of the thermofoil then indicates the precise position of heating cables or pipes.

The principal use of a wall heating system is, however, the abovementioned high radiation ratio, with its associated thermal comfort and good indoor climate. Fewer air and dust swirls are created, and the air does not get as dry. Relatively low extra costs can therefore produce a healthy sense of well-being.

3.5 Combination opportunities with other technologies; interaction with renewable energies

Wall heating operates predominantly with low flow temperatures and is therefore suitable for use with various heat generators. These include the following:

- District heating;
- Low temperature and condensing boiler;
- Solar heating; and
- Heat pumps.

This is particularly appealing because support is available when using technology of this kind. The combination of surface heating + heat pump is furthermore ideal for providing comfortable and efficient air conditioning in the summer. A combination with ventilation systems makes sense. This facilitates a minimum outdoor air rate and controlled indoor air exchange, preventing too much cold outdoor air entering the room – air which in turn first requires energy to heat it to the respective temperature level. Simultaneously, however, the necessary indoor air exchange is guaranteed in order to supply the room with sufficient fresh air. These two factors, along with the thermal comfort, are very important when creating a pleasant indoor climate. It also permits the humidity in the room to be regulated.

Electrical wall heating as set out in Chapter 1.1.2 is ideal for rooms which are only used rarely or temporarily, because it reacts quickly when needed. In rooms used long and often, a combination of underfloor heating and water-based wall heating is appropriate. Since the underfloor heating is embedded in the floor more deeply than the wall heating in the wall, it reacts much more slowly. This makes it suitable for covering basic heat requirements. The faster response of the wall heating means it can additionally be switched on as required.

4 Application/ use in practice

4.1 Cost examples

The low system temperatures of wall heating systems permit heat pumps to be used. According to the manufacturer Uponor, substantial heating savings are possible each year compared to a conventional heating system, so that the investment costs have been amortised within just a few years. According to an article in SBZ (Issue 21-11), wall heating appears to be around 25% less expensive to produce compared to underfloor heating if one refers to the installed output and not the area.

There is support for energy-efficient construction, e.g. from the German reconstruction loan corporation (Kreditanstalt für Wiederaufbau - KfW) or the German Energy Agency (Deutsche Energie-Agentur - dena). In the renovation sector, energy-efficient modernisations are supported by low-interest loans and subsidies.

Once wall heating systems have been installed, the resultant low ancillary costs and pleasant indoor climate represent a persuasive argument in the case of rental property. It is important for landlords to ensure, however, that tenants know how to use wall heating systems. This prevents them being used uneconomically and possibly damaging them, for example by drilling holes in the wrong places.

Concrete building data and costs are also specified in 2.4:

Construction (cost groups 300 and 400)	Euro 0.8 million
Wall temperature control per apartment	Approx. Euro 2,800
Heating installation per apartment (conventional)	Approx. Euro 1,800

Table 4.1: Cost distribution

4.2 Compatibility with current energy legislation

Current laws and regulations in the area of energy are firstly aimed at reducing general energy consumption and secondly at procuring essential energy from renewable energy sources where possible.

The German Energy Saving Ordinance (Energieeinsparverordnung - EnEV) is the most prominent representative of energy legislation. The EnEV 2014 will probably be introduced in May 2014, replacing the current EnEV 2009. Up-to-date information can be found on the website of the Federal Ministry of Transport, Building and Urban Development (www.bmvbs.de) or at www.enev-online.de. No new requirements are predicted in relation to existing buildings.

According to EnEV, the primary energy requirement of a building is calculated on the basis of primary energy factors (see Figure 4.1). The higher the factor, the higher the primary energy requirement. In the heating systems area it is the energy gain and not the heat distribution that is assessed here, however. EnEV therefore basically makes no distinction between water-based wall heating and a normal heating system. The problem that arises in the case of electric wall heating, however, is that electricity as the energy source has a very high primary energy factor. This could be balanced out by very good building insulation or by a main heating system that is not electrically operated. Excellent building insulation which compensates for the high primary energy factor of the electricity is usually no longer possible or is uneconomical. This only leaves the option of installing electric wall heating merely as auxiliary heating, and covering basic heating requirements with a heating system that uses a source of energy with a low primary energy factor. This can be regarded critically from a long-term point of view, especially against the background of the increasing share of electricity generated from renewable sources and the already high insulation standards. Baden Wurttemberg already has the so-called Renewable Energy Heat Act (Erneuerbare-Wärme-Gesetz BW - EWärmeG) for old buildings. This requires the proportion of renewable energy used in heating in Baden Wurttemberg to be increased from the current 8% to 16% by 2020. A similar law is conceivable in other German states, and generally speaks in favour of using electric wall heating systems. In order to gain an overview of energy laws and ordinances, some of them are listed in Table 4.2.

Energy carrier[a]		Primary energy factors *fp*	
		Total	Non-renewable share
		A	B
Fuels	Heating oil EL	1.1	1.1
	Natural gas H	1.1	1.1
	Liquid gas	1.1	1.1
	Coal	1.1	1.1
	Lignite	1.2	1.2
	Wood	1.2	0.2
Local/district heating from CHP[b]	Fossil fuel	0.7	0.7
	Renewable fuel	0.7	0.0
Local heat/district heating from heating plants	Fossil fuel	1.3	1.3
	Renewable fuel	1.3	0.1
Electricity	Electricity mix	3.0	2.7
Environmental energy	Solar energy, ambient heat	1.0	0.0
[a] Reference value final energy: heat value H_2			
[b] Details are typical for average local/district heating with a CHP ratio of 70%			

Figure 4.1: Table A.1 – Primary energy factors[a] from DIN V 18599-1 (02-2007)

ARegV	Incentive Regulation Ordinance
EBPG	Energy-Using Products Act
EnEG	Energy Saving Act
EnEV	Energy Saving Ordinance
EnVHV	Energy Maximum Consumption Ordinance
EnVKV	Energy Consumption Labelling Ordinance
EnWG	Energy Industry Act
EEG	Renewable Energy Act
KWKG	Act on Combined Heat and Power
KraftNav	Power Plant Grid Connection Ordinance
NAV	Low Voltage Connection Ordinanance
StromGVV	Ordinance regulating the provision of basic electricity supplies
HeizAnlV	Heating Systems Ordinance
WärmeschutzV	Thermal Insulation Ordinance

Table 4.2: Examples of energy laws and ordinances

5 Outlook/possible applications

The objective of the German government is to have established a climate-neutral building standard by the year 2050. To achieve this objective it is necessary to use new technologies intelligently and to promote their development. This should take into account the entire life cycle of a building (manufacture, operation, demolition). In the renovation area the aim is to best integrate new technologies in order to find the best possible compromise between the requirements of the user and the preservation of the existing structure. In some cases it is necessary to handle the existing structure with care so as to preserve historically valuable buildings for as long as possible.

Their flexibility in terms of use means that wall heating systems can make a valuable contribution to reducing the energy consumption in building operation, thereby conserving the environment. Above all their suitability for use with renewable energy makes them a future-proof system. They can also be deployed in historic buildings without disturbing the fabric of the building. Quite the contrary: when used correctly, wall heating systems may contribute to protecting the structure of the building.

Professional planning and execution is essential, however, to make use of all the benefits offered by wall heating systems.

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