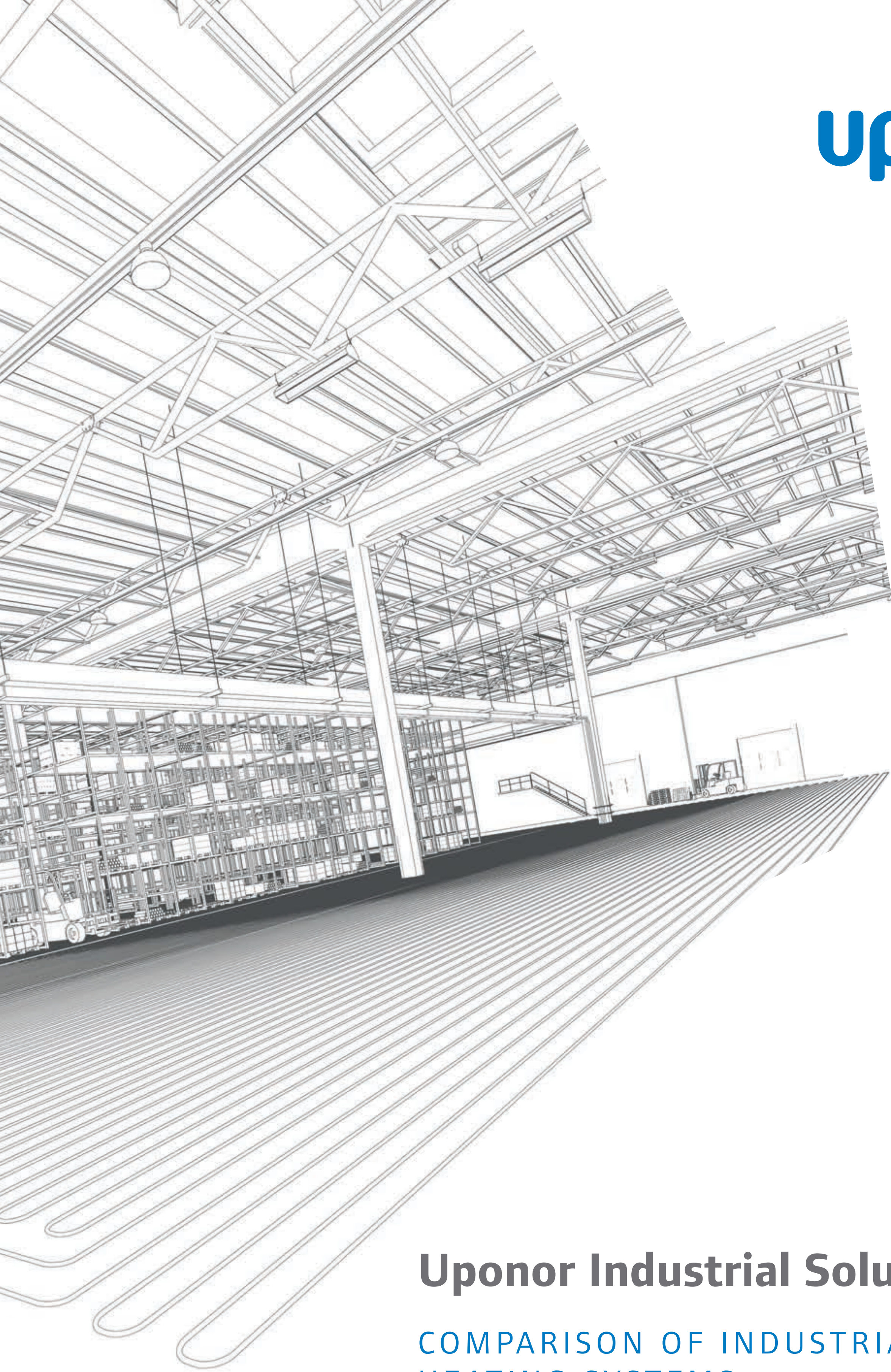

Uponor Industrial Solutions

COMPARISON OF INDUSTRIAL HEATING SYSTEMS


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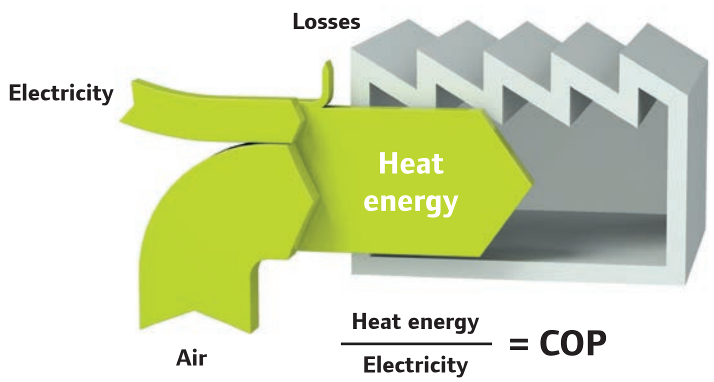
This report is based on the results presented in the diploma thesis 'economic evaluation of heating concepts based on reference buildings and industrial heating systems' by Vivien Dissel for Fachhochschule Münster, University of Applied Sciences.

The Study

Modern industrial buildings used for production, storage, and logistics must meet high demands today in their functionality, reliability, flexibility and economic efficiency. The facilities to serve industrial businesses need to be optimally adapted to daily work flows including material flow, distribution and co-ordination, while at the same time being flexible enough to accommodate modifications and extensions.

This report focuses on the following topics related to industrial heating systems:

- Energy costs
- Return on investment
- Energy-efficiency
- How the systems affect the Energy rating value



Energy sources

The energy sources selected were natural gas and electricity. Natural gas was chosen because this fuel can be used for five of the six systems and it is usable in systems that employ direct firing, such as gas-fed tube heaters.

The coefficent of performance (COP) of the electrically driven air-to-water heat pump was assumed to be 2.6.

All systems rely on electricity as their auxiliary energy source.

Calculation background

The usage scenarios for the reference halls are assumed to be identical.

Based on the reference halls structural data, an energy performance certificate was issued in accordance with the German Energy Conservation Ordinance 2009 (EnEV 2009). The energy consumption was calculated according to the DIN V 18599 balancing standard.

The energy balances were used to calculate the heating load of the reference halls on the basis of said.

An installation design was drawn up for each industrial heating system and current installation costs were determined.

Constant energy prices were used in the calculations since it was not possible to forecast energy price fluctuations.

The individual cost types were added and projected for a usage period of 30 years.

Systems

The investment costs for each industrial heating system depend on the required output and expected service life.

The investment costs comprise the following items:
- Piping and accessories
- Heat insulation
- Heating units
- Other items
- Conveying equipment

Systems with a service life of less than 30 years will accrue additional investment costs due to partial system replacement.

Additional investment costs accrue in three areas:
- Central appliances
- Heating units
- Other items

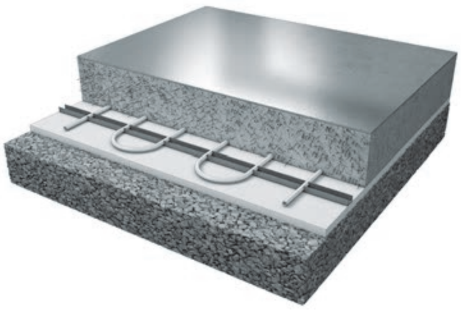
In calculation of additional investment costs, the items that do not need to be replaced are deducted.

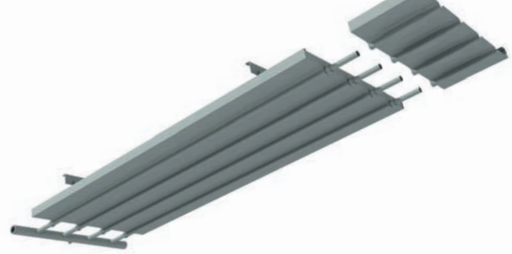
The system's service life is directly linked to its mode of operation. Systems with direct firing (infrared or luminous heaters / tube heaters) have a much higher system load, in their 'short' service life of 10 years.

The systems based on indirect firing are subjected to much lower temperatures, which positively affects boiler and pumps, resulting in a longer service life and thus making partial system replacement unnecessary.

System	Service life	Primary energy source
Ceiling radiator panels	20 years	Natural gas
Industrial UFH with boiler	30 years	Natural gas
Industrial UFH with heat pump	30 years	Electricity to run the heat pump
Ceiling-mounted air heater	15 years	Natural gas
Infrared or luminous heater	10 years	Natural gas
Tube heater	10 years	Natural gas

All systems are considered over a total operation period of 30 years. Since not every system has an actual 30-year service life, parts of the systems may need to be replaced. Service life of the heating system is presented according to VDI 2067.





Industrial UFH design with boiler

The system is designed to have a supply water temperature of 50 °C and a return water temperature of 35 °C.

The facility is heated with an underfloor heating system for industrial buildings. PE-Xa heating pipes are directly installed in the concrete floor slab and the entire floor surface acts as a radiant heating surface. It is divided into separate heating loops, whose details depend on the installation design. The heating loops are supplied with hot water from the boiler through the manifolds.

The indoor temperature is controlled by a central outdoor weather dependent room thermostat.

Industrial UFH design with heat pump

The heat-pump-based Industrial underfloor heating system is designed to have a supply water temperature of 40 °C and a return water temperature of 30 °C.

The facility is heated by means of an underfloor heating system for industrial buildings. PE-Xa heating pipes are installed directly in the concrete floor slab and the entire floor surface acts as a radiant heating surface. It is divided into separate heating loops that depend on the installation design. The heating loops are supplied with hot water from the boiler through the manifolds.

The indoor temperature is controlled by a central outdoor weather-dependent room thermostat.

Ceiling radiator panel

The system is designed to have a supply water temperature of 85 °C and a return water temperature of 65 °C.

Ceiling radiator panels are mounted below the hall ceiling to heat the facility. Ceiling radiator panels are static heating systems composed of sheet steel profile ribbons with welded pipes and heat insulation located on the top (against the ceiling). The system is connected to the hot water heating system. The radiant heat passes unobstructed through the ambient air and is transformed into heat energy after hitting the floor, hall perimeter or equipment. Surface temperatures rise to 1 to 3 K above the ambient air temperature.

The indoor temperature is controlled via a programmable room thermostat that addresses the regulating valves of the individual heating ribbons. The set-point indoor temperature is monitored via a combined radiation and temperature sensor that detects both the air temperature and the radiation component. This corresponds with the temperature as felt by users.

Ceiling-mounted air heater with condensing boiler

The system is designed to have a supply water temperature of 85 °C and a return water temperature of 65 °C.

Ceiling-mounted air heaters are mounted below the hall ceiling to heat the facility. The ceiling air heaters transmit the heat distributed from the boiler to the ambient air by using copper/ aluminium heat exchangers. Fans then blow the heated air into the lower hall space. The ceiling-mounted air heaters are fully based on recirculated air operation. Air distribution is controlled via specially mounted air vents equipped with movable fins. Depending on the height of the hall ceiling, the air is guided along either a slightly circular or a vertical path. the hall air is induced into the primary air flow from all sides, to ensure that the hall air is mixed to a high degree.

The indoor temperature is controlled via a programmable room thermostat that addresses the individual air heating units via intermediate terminals and soft-start devices.

Infrared/luminous heater and tube heater

There is no need for a central heat source, since the heat is directly generated by the infrared or luminous heaters. The gas is fed to the individual combustion units via a steel pipe network.

Gas infrared or luminous heaters are mounted on the hall ceiling to warm the space below. Infrared or luminous heaters generate heat by burning an oxygen-natural-gas mixture near perforated ceramic tiles. The surface of the ceramic tiles is heated up, and the resulting heat radiation is transmitted into the hall space by means of reflector plates. The gas is burned in the open, making the process visible, in order to enhance the degree of efficiency, the reflector plate is equipped with heat insulation based on a mineral fibre. Reflector inserts of different shapes can be used to realise various emission patterns.

The resulting, nearly pollutant-free exhaust fumes pass directly into the hall space and are cleared out as part of the required minimum air circulation. The necessary supply of combustion air must be provided.

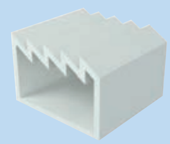
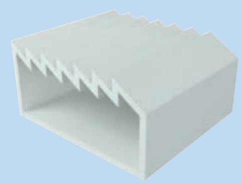
The radiant heat passes unobstructed through the ambient air. Surface temperatures rise to 1 to 3 K above the ambient air temperature.

The indoor temperature is controlled via a programmable microprocessor. The heater has two operation settings. In this solution, the setpoint room temperature is monitored via a combined radiation and temperature sensor that detects both the air temperature and the radiation component, for sensing of the temperature as felt by users. the temperature difference is measured by a characteristic curve, for control of the air outlet via the freely adjustable fins.

Reference buildings

As a basis for this calculation three existing reference buildings in northern Germany were chosen, to ensure that the same climatic conditions exist in all structures. Heating simulations were carried out with EnergyPlus energy simulation software. The buildings are one-storey industrial halls of differing heights and volumes; the 'small' hall, however, is 17.10 metres high, which is more than twice the height of the other two halls.

The application scenarios for the reference buildings are not relevant in terms of comparison of the different industrial hall heating systems, as the same conditions were assumed for all three halls to facilitate the comparison. The metrics are listed in the following table:

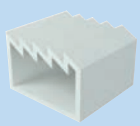
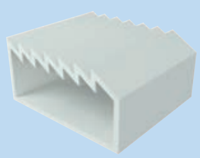
	 **Small hall**	 **Medium hall**	 **Large hall**
Outdoor temperature	-12 °C		
Mean outdoor temp.	8.5 °C		
Interior temperature	18 °C		
Building length	65.40 m	89.00 m	121.00 m
Building width	48.20 m	87.15 m	119.00 m
Building height	17.10 m	7.96 m	7.90 m
Building area	3,152 m²	7,756 m²	14,400 m²
Building volume	53,899 m³	61,738 m³	113,760 m³
Number of storeys	1		
Minimum air exchange rate	0.30 1/h		
Specific transmission heat loss	0.45 W/m²K	0.34 W/m²K	0.27 W/m²K
Building heating load	289 kW	402 kW	625 kW
Net heating load/m²	90 W/m²	56 W/m²	43 W/m²

- All reference buildings are constructed as non-residential buildings of lightweight design.
- The reference objects are located in a moderately shielded environment. 'Moderate shielding' is a shielding category referring to buildings that stand alone but are shielded by trees or other buildings such as those found in suburbs or industrial/business parks.
- All three industrial halls conform to the air-tightness category 'tight'. This means that there are no openings through which heat can escape unintendedly.

Energy performance of buildings

The energy-efficiency ratings and energy costs have been calculated for two specific markets (France and Germany) according to the energy consumption data from the study.

Overall yearly energy use and definition of energy ratings

				France	Germany
Warehouse	System	Auxiliary energy kWh/m²a	Primary energy kWh/m²a	E-value under EN 15603 kWh/m²a *	E-value under EN 15603 kWh/m²a *
	Industrial UFH with heat pump **	15	37	134	156
	Infrared or luminous heater	14	192	228	253
	Tube heater	15	196	235	261
	Ceiling radiator panels	14	201	237	263
	Industrial UFH with boiler	14	206	242	269
Small hall	Ceiling-mounted air heater	14	276	312	346
	Industrial UFH with heat pump **	14	25	101	117
	Infrared or luminous heater	15	92	131	146
	Tube heater	14	94	130	145
	Ceiling radiator panels	14	94	130	145
	Industrial UFH with boiler	14	96	132	148
Medium hall	Ceiling-mounted air heater	14	135	171	191
	Industrial UFH with heat pump **	3	26	75	87
	Infrared or luminous heater	3	100	108	119
	Tube heater	3	102	110	121
	Ceiling radiator panels	3	104	112	123
	Industrial UFH with boiler	3	107	115	127
Large hall	Ceiling-mounted air heater	3	151	159	175

* energy-efficiency rating according to EN 15603, based on total energy consumption and represented as one energy value of kWh/m2 a.
** Uses electricity as a primary energy source.

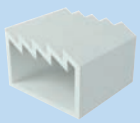
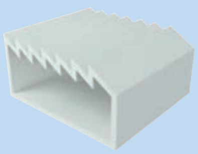
The yearly energy consumption is the sum of the consumption of the primary energy source for heat generation and the consumption of electricity as an auxiliary power for tasks such as monitoring, controlling heat distribution, etc. In the case of the heat pump, electricity is the only energy source.

For the calculation of the energy rating, the actual energy consumption will be adjusted by primary energy factors, which are specific to each EU member state.

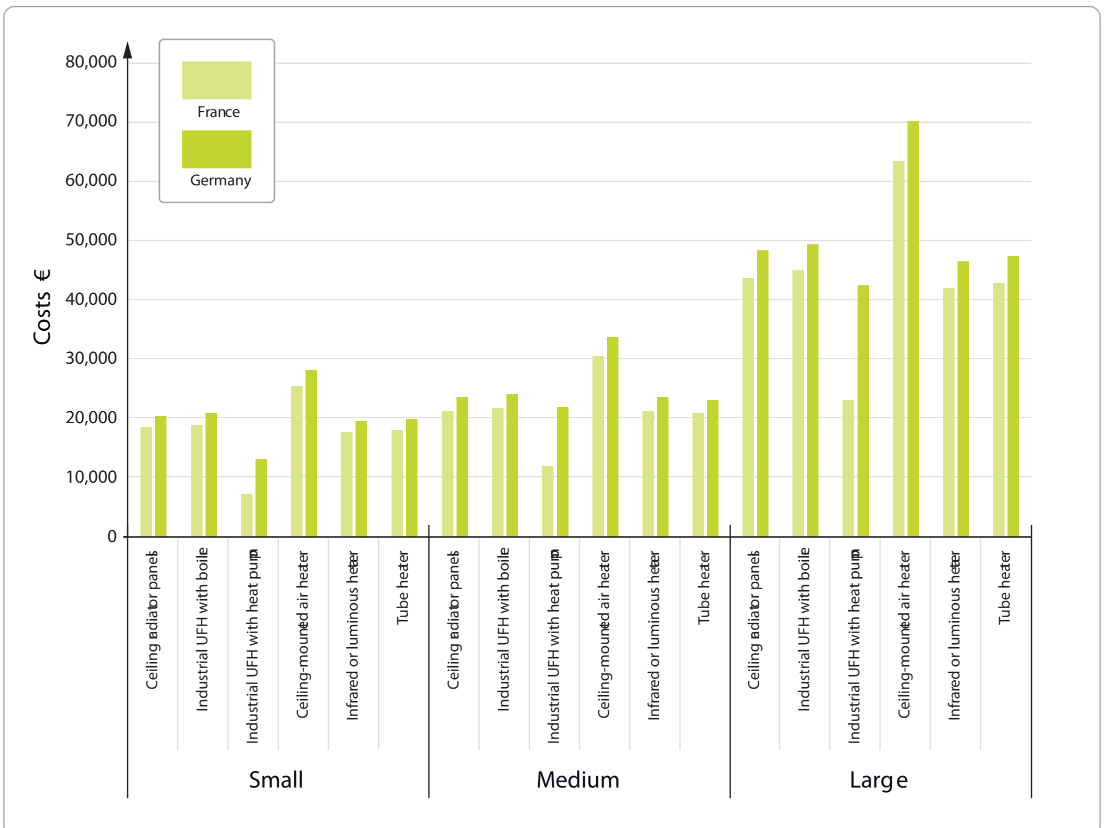
Primary energy factors in EU countries for natural gas and mixed electricity under EN 15603:2008

Energy source	France	Germany	UK	Spain	Italy	Poland	Romania	Hungary	Denmark	Sweden
Natural gas	1.00	1.10	1.15	1.011	1.10	1.10	1.10	1.00	1.00	none
Mixed electricity	2.58	3.00	2.50	2.60	2.80	3.00	2.80	2.50	2.50	1.50

Annual energy cost

Warehouse	System	Example markets	
		France	Germany
 Small hall	Ceiling radiator panels	€18,500	€20,500
	Industrial UFH with boiler	€19,000	€21,000
	Industrial UFH with heat pump	€7,200	€13,200
	Ceiling-mounted air heater	€25,400	€28,100
	Infrared or luminous heater	€17,700	€19,500
	Tube heater	€18,000	€20,000
 Medium hall	Ceiling radiator panels	€21,300	€23,500
	Industrial UFH with boiler	€21,700	€24,000
	Industrial UFH with heat pump	€12,000	€22,000
	Ceiling-mounted air heater	€30,600	€33,800
	Infrared or luminous heater	€21,300	€23,500
	Tube heater	€20,800	€23,000
 Large hall	Ceiling radiator panels	€43,700	€48,400
	Industrial UFH with boiler	€45,000	€49,800
	Industrial UFH with heat pump	€23,200	€42,500
	Ceiling-mounted air heater	€63,500	€70,200
	Infrared or luminous heater	€42,000	€46,500
	Tube heater	€42,900	€47,400

The yearly energy consumption costs depend on the energy consumption of the individual systems and are calculated in line with the end-user prices for EU industrial consumers by europe's energy portal for germany and france. Pricing is based on an average electricity consumption of 2,000 MWh/year and gas consumption of 115 MWh/year.



End-user energy prices for industrial consumers in EU member states

Energy prices offered for industrial consumers depend on consumption. The table below shows the pricing structure in the EU member states for two different consumption profiles (small and large industrial consumers).

	INDUSTRIAL ELECTRICITY RATES		INDUSTRIAL GAS PRICES	
	Consumption: **2,000 MWh/year** See note 1. Effective: September '10	Consumption: **24,000 MWh/year** See note 2. Effective: September '10	Consumption: **115 MWh/year** (10,550 m^3 of gas) Effective: September '10	Consumption: **11.5 GWh/year** (1.05 million m^3 of gas) Effective: September '10
Austria	€0.1031	€0.0754	€0.0344	€0.0356
Belgium	€0.1070	€0.0779	€0.0291	€0.0275
Bulgaria	€0.0635	€0.0496	€0.0215	€0.0211
Cyprus	€0.1592	€0.1113	NO DATA	NO DATA
Czech Republic	€0.1138	€0.0942	€0.0209	€0.0211
Denmark	€0.0948	€0.0890	€0.0419	€0.0518
Estonia	€0.0645	€0.0449	€0.0188	€0.0182
Finland	€0.0681	€0.0559	€0.0265	€0.0273
France	€0.0619	€0.0519	€0.0292	€0.0234
Germany	€0.1134	€0.0848	€0.0323	€0.0260
Greece	€0.0946	€0.0790	NO DATA	NO DATA
Hungary	€0.1314	€0.0961	€0.0254	€0.0224
Ireland	€0.1152	€0.0799	€0.0242	€0.0247
Italy	€0.1224	€0.1009	€0.0247	€0.0218
Latvia	€0.0885	€0.0695	€0.0254	€0.0211
Lithuania	€0.0747	€0.0730	€0.0218	€0.0228
Luxembourg	€0.1145	€0.0687	€0.0307	€0.0323
Malta	€0.1231	€0.0741	NO DATA	NO DATA
Netherlands	€0.1103	€0.0925	€0.0369	€0.0235
Poland	€0.0957	€0.0849	€0.0316	€0.0234
Portugal	€0.0935	€0.0697	€0.0232	€0.0213
Romania	€0.0847	€0.0595	€0.0201	€0.0198
Slovakia	€0.1380	€0.1081	€0.0295	€0.0233
Slovenia	€0.0958	€0.0913	€0.0268	€0.0261
Spain	€0.1082	€0.0808	€0.0259	€0.0205
Sweden	€0.0715	€0.0602	€0.0531	€0.0512
United Kingdom	€0.0969	€0.0837	€0.0205	€0.0188

1) Maximum demand: 500 kW, annual load: 4000 hours. Luxembourg: 50% power reduction during hours of heavy loading.
2) Maximum demand: 4000 kW, annual load: 6000 hours. Luxembourg: 50% power reduction during hours of heavy loading.

source – Europe´s Energy Portal - http://www.energy.eu/#Industrial
10.3.2011

Total cost breakdown over 30 years

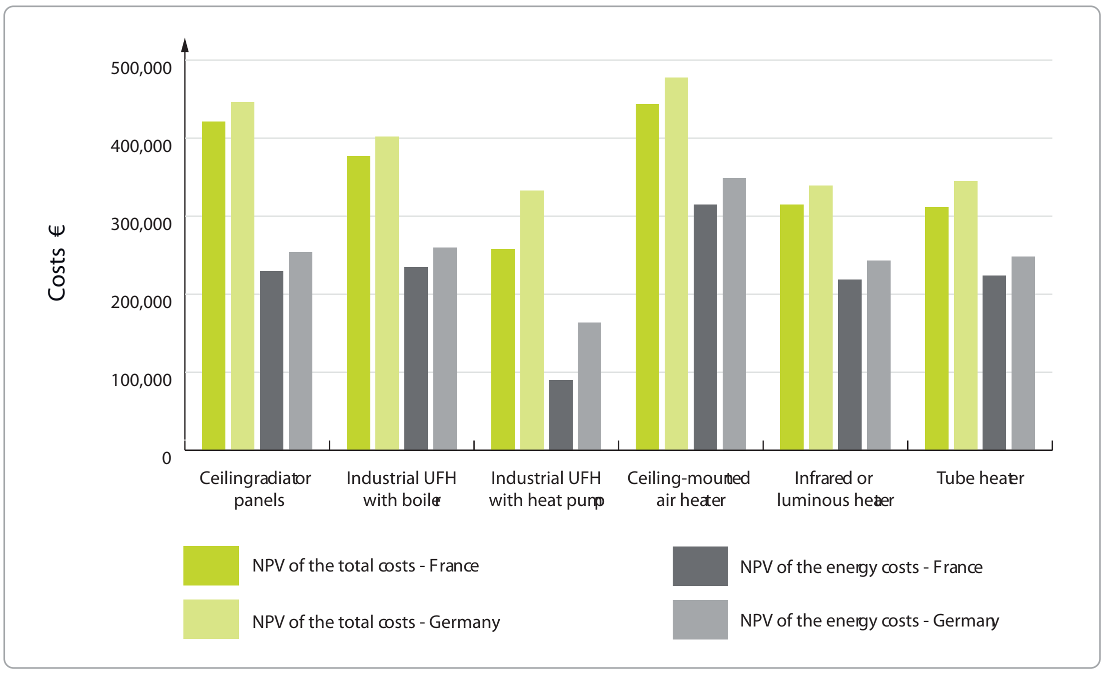
The following tables present the total cost (initial investment, maintenance investments and annual energy cost) for each of the systems over a 30-year period. Initial investment is assumed to take place at year 0 and the energy costs start in year 1 (the first year of operation). The net present value (NPV) of the costs have been calculated with 7% used as the cost of capital.

Net present value of investment and energy costs - 'small' hall

 Small		Ceiling radiator panels	Industrial UFH with boiler	Industrial UFH with heat pump	Ceiling-mounted air heater	Infrared or luminous heater	Tube heater
Initial investment		€155,000	€135,000	€168,000	€103,000	€56,000	€55,000
Gas connection		€7,000	€7,000	€0	€7,000	€7,000	€7,000
Maintenance cost at 10 years		€0	€0	€0	€0	€44,000	€46,000
Maintenance cost at 15 years		€0	€0	€0	€53,000	€0	€0
Maintenance cost at 20 years		€118,000	€0	€0	€0	€44,000	€46,000
Total		€280,000	€142,000	€168,000	€163,000	€151,000	€154,000
Net present value (NPV) of total costs over 30 years *	France	€421,000	€377,000	€258,000	€444,000	€315,000	€321,000
	Germany	€446,000	€402,000	€333,000	€478,000	€339,000	€345,000
Net present value (NPV) of annual energy cost over 30 years *	France	€230,000	€235,000	€90,000	€315,000	€219,000	€224,000
	Germany	€254,000	€260,000	€164,000	€349,000	€243,000	€248,000

* energy costs are calculated with europe's energy portal energy prices for germany and france. Pricing is based on 2,000 MWh/year average consumption of electricity and 115 MWh/year average gas consumption.

Cost breakdown – 'small' hall



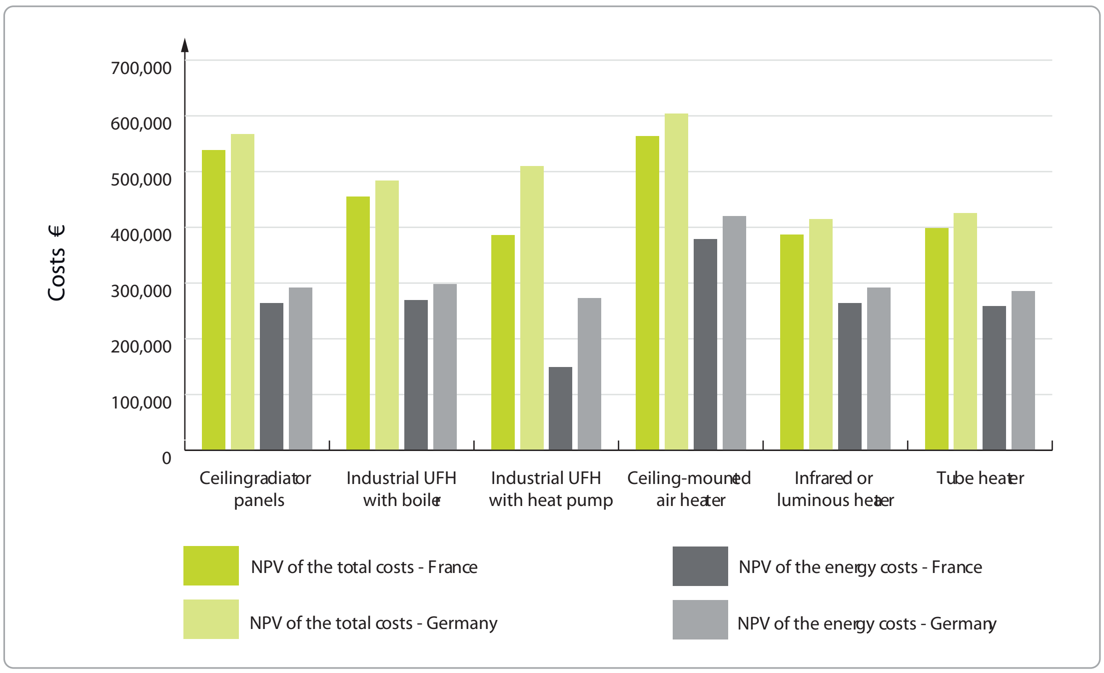
Cost distribution in the industrial halls according to system
This section provides a breakdown of the total costs. The images highlight the various cost types using different colours so that the ratio of the individual items can be grasped at a glance.

Net present value of investment and energy costs - 'medium' hall

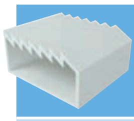
Medium		Ceiling radiator panels	Industrial UFH with boiler	Industrial UFH with heat pump	Ceiling-mounted air heater	Infrared or luminous heater	Tube heater
Initial investment		€223,000	€179,000	€237,000	€146,000	€73,000	€83,000
Gas connection		€7,000	€7,000	€0	€7,000	€7,000	€7,000
Maintenance cost at 10 years		€0	€0	€0	€0	€57,000	€66,000
Maintenance cost at 15 years		€0	€0	€0	€89,000	€0	€0
Maintenance cost at 20 years		€175,000	€0	€0	€0	€57,000	€66,000
Total		€405,000	€186,000	€237,000	€242,000	€194,000	€222,000
Net present value (NPV) of total costs over 30 years *	France	€539,000	€455,000	€386,000	€564,000	€387,000	€399,000
	Germany	€567,000	€484,000	€510,000	€604,000	€415,000	€426,000
Net present value (NPV) of annual energy cost over 30 years *	France	€264,000	€270,000	€149,000	€379,000	€264,000	€259,000
	Germany	€292,000	€298,000	€273,000	€420,000	€292,000	€286,000

* energy costs are calculated with europe's energy portal energy prices for germany and france. Pricing is based on 2,000 MWh/year average consumption of electricity and 115 MWh/year average gas consumption.

Cost breakdown – 'medium' hall

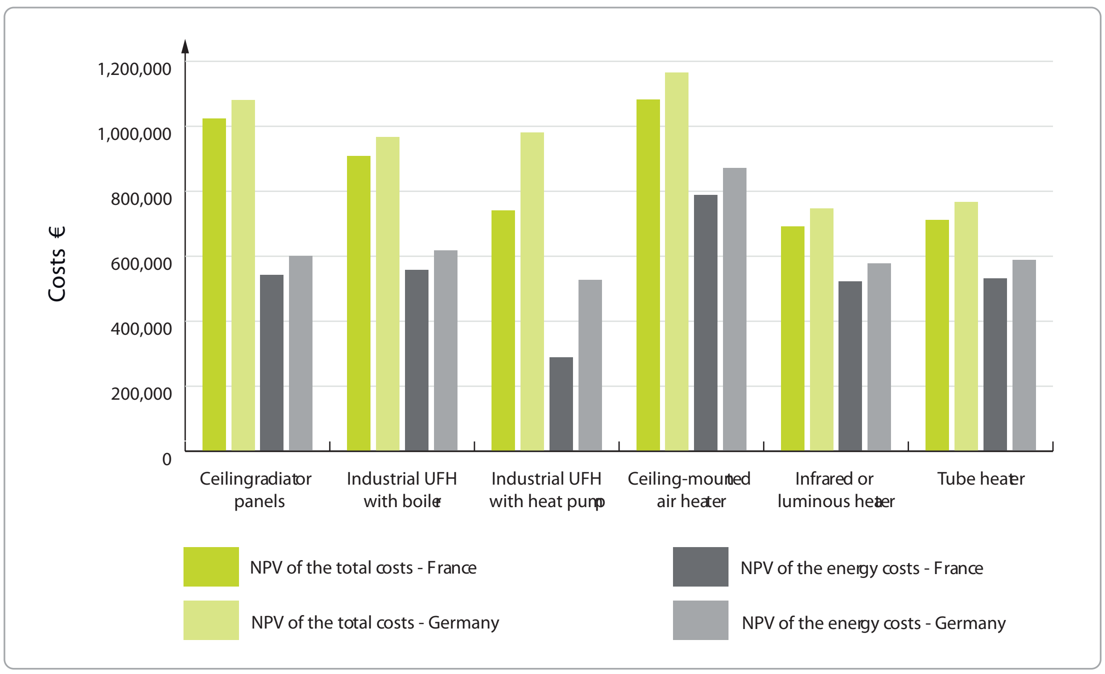


Net present value of investment and energy costs - 'large' hall

 Large		Ceiling radiator panels	Industrial UFH with boiler	Industrial UFH with heat pump	Ceiling-mounted air heater	Infrared or luminous heater	Tube heater
Initial investment		€405,000	€343,000	€453,000	€241,000	€104,000	€109,000
Gas connection		€7,000	€7,000	€0	€7,000	€7,000	€7,000
Maintenance cost at 10 years		€0	€0	€0	€0	€77,000	€82,000
Maintenance cost at 15 years		€0	€0	€0	€129,000	€0	€0
Maintenance cost at 20 years		€267,000	€0	€0	€0	€77,000	€82,000
Total		€678,108	€349,802	€453,306	€376,083	€263,933	€279,185
Net present value (NPV) of total costs over 30 years *	France	€1,023,000	€908,000	€741,000	€1,082,000	€691,000	€711,000
	Germany	€1,080,000	€967,000	€980,000	€1,165,000	€747,000	€767,000
Net present value (NPV) of annual energy cost over 30 years *	France	€543,000	€558,000	€288,000	€788,000	€522,000	€532,000
	Germany	€600,000	€618,000	€527,000	€872,000	€577,000	€589,000

* energy costs are calculated with europe's energy portal energy prices for germany and france. Pricing is based on 2,000 MWh/year average consumption of electricity and 115 MWh/year average gas consumption.

Cost breakdown – 'large' hall



Conclusions

All systems discussed meet all requirements and legal provisions regarding occupational health and safety, etc. Whether any of the systems meet the demands of the user depends on the usage scenario and the corresponding specific requirements of the building (which, for ease of comparison, were not taken into account here).

Each system has advantages and disadvantages that make it either viable or unsuitable for installation and operation in a given scenario. Because of this wealth of arguments for or against each of the systems, the comparison focused solely on their economic performance.

From an energy-efficiency point of view, industrial underfloor heating powered by a heat pump has the best (i.e., lowest) energy rating in all three reference buildings, whereas the ceiling-mounted air heating system is clearly the worst system. All other systems have energy ratings relatively close to each other between these two extremes.

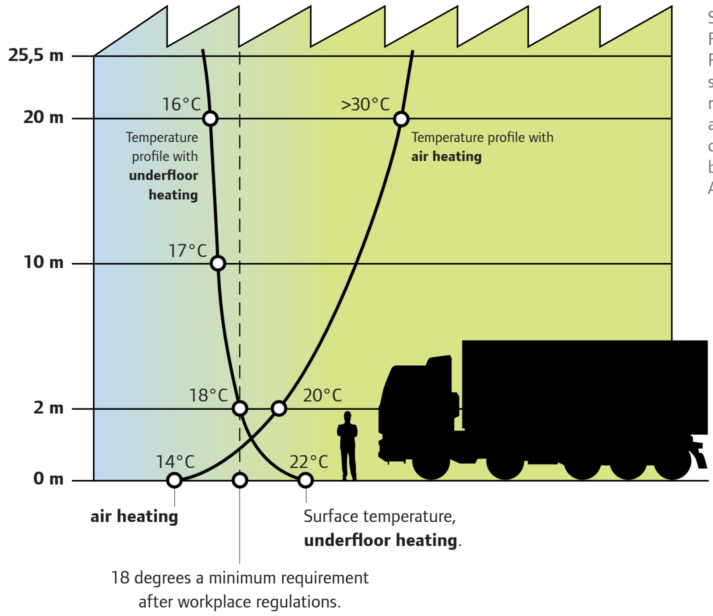
As for energy costs, industrial underfloor heating with a heat pump has clearly the lowest cost in the ‘small' (and high) hall, and the ceiling-mounted air heater system the highest. again, the other systems have fairly similar costs between these two extremes. In the ‘medium' and `large' halls, a ceiling-mounted air heater system has the highest cost, while all other systems show only small differences. It should be noted that the above conclusions are contingent on local relative pricing of the primary energy used.

From the total cost point of view, over 30 years, the relative ranking of the systems depends on the size and geometry of the building, but also the relative pricing of primary energy has strong influence. In all three reference cases infrared luminous heaters and tube heater systems have competitive total cost, because of low investment cost and the attractive pricing of natural gas. In the case of the ‘small’ reference building, the industrial underfloor heating with a heat pump has a similar total cost. In all reference buildings the ceiling mounted air heating has the highest total cost.

As a general conclusion, it can be stated that from the energy-efficiency and environmental point of view industrial underfloor heating with a heat pump clearly outperforms the other types of systems in all three building types. Also from energy cost standpoint it is the most attractive system, although the differences from other systems depend on the relative pricing of electricity and gas.

Temperature curve of an industrial underfloor heating and ceiling-mounted air heating system:

Industrial underfloor heating primarily conditions the occupied space close to the floor, whereas air heating systems cause high temperatures in areas close to the ceiling. This explains the huge difference in energy consumption, since industrial underfloor heating applies the energy where it is needed, while air heating energy is wasted in heating unoccupied space.



Source: BVF (German Federal Association for Radiant Heating) News service, Installation of radiant floor heating and cooling systems for commercial and industrial buildings. Guideline nr.:8 April 2010.

An efficient work environment is

- **Cost-effective**
  Minimised running costs, due to ability to use free and low-cost energy.

- **Human friendly**
  An optimal working environment, with neither dust nor indoor draughts. A pleasant temperature motivates staff to perform at their best.

- **Reliable**
  A safe working environment with products that are proven in use. Being a partner with Uponor will bring benefits – reliably.

Comparison of industrial heating systems 06/2011

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