REDWELL HEATING COMPARISON SURVEY 2010

Redwell Infrared Heaters compared with conventional heating systems

REDWELL MANUFAKTUR GmbH is pleased to be permitted to announce the results of the comparative heating study carried out at their request by the Aristotelian University of Thessaloniki and would like simultaneously to officially confirm all of the results of this study.

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Hartberg, December 2010

In cooperation with

ARISTOTLE UNIVERSITY THESSALONIKI

Laboratory of Heat Transfer and Environmental Engineering

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redwell® INFRARED HEATING

HELLENIC REPUBLIC

ARISTOTLE UNIVERSITY THESSALONIKI

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SCHOOL OF ENGINEERING

MECHANICAL ENGINEERING DEPARTMENT

ENERGY SECTION

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A preface to the study

The construction branch accounts the most for the energy and resources consumption amongst all other branches in Europe, whilst it produces significant amounts of demolition waste, without being very efficient in its reuse and recycling.

A huge potential lies, however, precisely in this situation, as the branch presents the single most important potential for a sustainable approach of the anthropogenic environment.

It is of interest to notice, that almost forty years after the first oil crisis, space heating demand of residential buildings remains the most interesting field to save energy. In addition one cannot neglect to consider the issues of thermal comfort and indoor air quality, which are far more important today than they used to be thirty years ago, as they are tightly linked to the energy performance of buildings and, reasonably enough, to their operational expenses.

The evaluation of space heating systems, and therefore also of infrared radiative systems is, in this line of approach, a necessity.

It is not an easy task, as the evaluation of heating power and efficiency of radiative systems is depending to a much larger extent on parameters like the quality of the building shell's thermal insulation and its thermal storage capacity, as well as on the control and regulation of the systems, compared to the one of conventional, convective systems. The lack of respective EN standards does not make this task easier.

The research project „Evaluation of Redwell Infrared Heating Systems", was carried out in the Laboratory of Heat Transfer and Environmental Engineering, at the Mechanical Engineering Department of the Aristotle University of Thessaloniki, funded by Redwell Manufaktur GmbH and in the period between May 2009 and July 2010. The evaluation was based on a life cycle approach and on the comparative consideration of the most popular space heating systems.

Considering their energy efficiency, Redwell Infrared heating systems are efficient and effective, as one can deduce from the comparison between those and conventional systems. Redwell systems rank amongst the leading ones, considering their primary energy demand and their eco-efficiency over the systems' life cycle. The same applies with respect to the operational expenses and the feasibility of the systems considered, with Redwell systems being highly competitive.

When it comes to thermal comfort, one cannot fail to notice the clear advantage of Redwell systems, compared to conventional heating systems with convective baseboard heaters, provided that the building shell is well thermally insulated.

Finally, one can only stress the necessity for a European EN standard on infrared radiative heating systems, within the umbrella of the space heating systems standard, in order to be able to evaluate these efficient systems correctly and fairly and in a way conforming to the demands set by contemporary regulations like the German EnEV 2009.

For the effective co-operation within this project we would like to thank the managing director of the Redwell Manufaktur GmbH company, Mr. Michael Buschhoff, as well as the head of distribution DI Mr. Werner Erhart.

For the elaboration of this study I would like to thank the staff members of our Laboratory and in particular:

- Dipl.-Ing. Alex Adam (Mr.)
- Dr.-Ing. Dimitrios Anastaselos (Mr.)
- Dr.-Ing. Simos Oxizidis (Mr.)
- Dipl-Ing. Ifigeneia Theodoridou (Ms.)

Thessaloniki, November 2010

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Contents

Application

In this research project, our laboratory was commissioned by REDWELL Manufaktur GmbH, to examine comprehensively and to compare the REDWELL produced "REDWELL Infrared-Heating Systems" with the conventionally known heating systems (direct electric, oil, gas, and heat pumps). This study shall inter alia be seen as a recommendation to the policy makers (Environment Ministers) and/or European energy offices to contemplate that REDWELL Infrared Heaters' due to their excellent overall properties, should be classified as distinct category of heating system, worthy of its own classification.

Objectives

1. Objectively comparable parameters

The assessment of the REDWELL Infrared Heaters must be carried out using objectively comparable parameters:

- Efficiency (primary energy demand, performance, global warming potential)
- Economic efficiency (acquisition, installation and operating costs)
- Quality (processing, materials, warranty)
- Thermal Comfort (comparable figures)
- Environmental relevance

2. Comparison with conventional heating systems

All parameters examined are compared with reference to heating systems listed below:

- Direct Electric Heating
- Oil Heater
- Gas Heating
- Air/Water or Water/Water Heat Pump (combined with Floor Heating)
- Extension with Solar Water Heating
- Inclusion of Photovoltaic power generation

3. Defining a new category for Redwell Infrared Heaters

On the basis of the results determined at the laboratory level and in practical field tests, we see a special position for the Redwell Infrared Heaters and the need to define a completely new heating system category can be shown.

The basis of calculation

1. Standards and regulations

Underlying set of standards and regulations with its main limits, which have been used are:

- **EnEV 2009**

The calculations were made according to the requirements of EnEV, Section 4 (units of heating, cooling and air conditioning and hot water supply), carried out, namely taking into account the default values in appendix 1 (to § § 3 and 9) requirements of residential buildings and 2 (on § § 4 and 9) requirements for non-residential building and in accordance with DIN 4701.
The most important standards and regulations of the EnEV 2009, that were used, are:

- DIN 18599, Parts 1 to 10, energy assessment of buildings
- DIN V 4108-6:2003, calculation of the annual heating and annual heating energy demand
- DIN V 4108-2:2003, minimum requirements for thermal protection
- DIN V 4701-10:2003, Energy efficiency of heating and ventilation systems
- DIN V 4701-12:2004, Energy efficiency of heating and ventilation systems in existing buildings
- DIN EN 832:2003, calculation of heating energy demand, residential buildings
- DIN EN ISO 6946:2003, component thermal resistance and heat transfer coefficient
- DIN EN ISO 13789:1999, specific transmission heat loss coefficient
- DIN EN ISO 13370:1998, heat transfer via the ground
- DIN EN ISO 10077-1:2000, Thermal performance of windows, doors and shutters
- EN 13790
- Thermal comfort was evaluated according to EN-ISO 7730 and ASHRAE 55
- Measurements for climatic conditions of Thessaloniki, Greece.
- Simulation of climatic conditions in various European climatic regions.

Redwell Infrared Heater

- Wall System, 900W power, 90% from radiation, 10% from convection, temperature differential from 0.5 to 2 ^{0}C.

Convective Systems

- Fuel oil system with feed temperature of 70 ^{0}C and 20 ^{0}C temperature drop. Annual middle coefficient of performance 85%.

2. Methodology of EnEV-evidence

The methodology is presented below the EnEV-evidence and therewith also the importance of the consumption figure e_p and significant characteristics shall be highlighted.

Methodology of EnEV-evidence

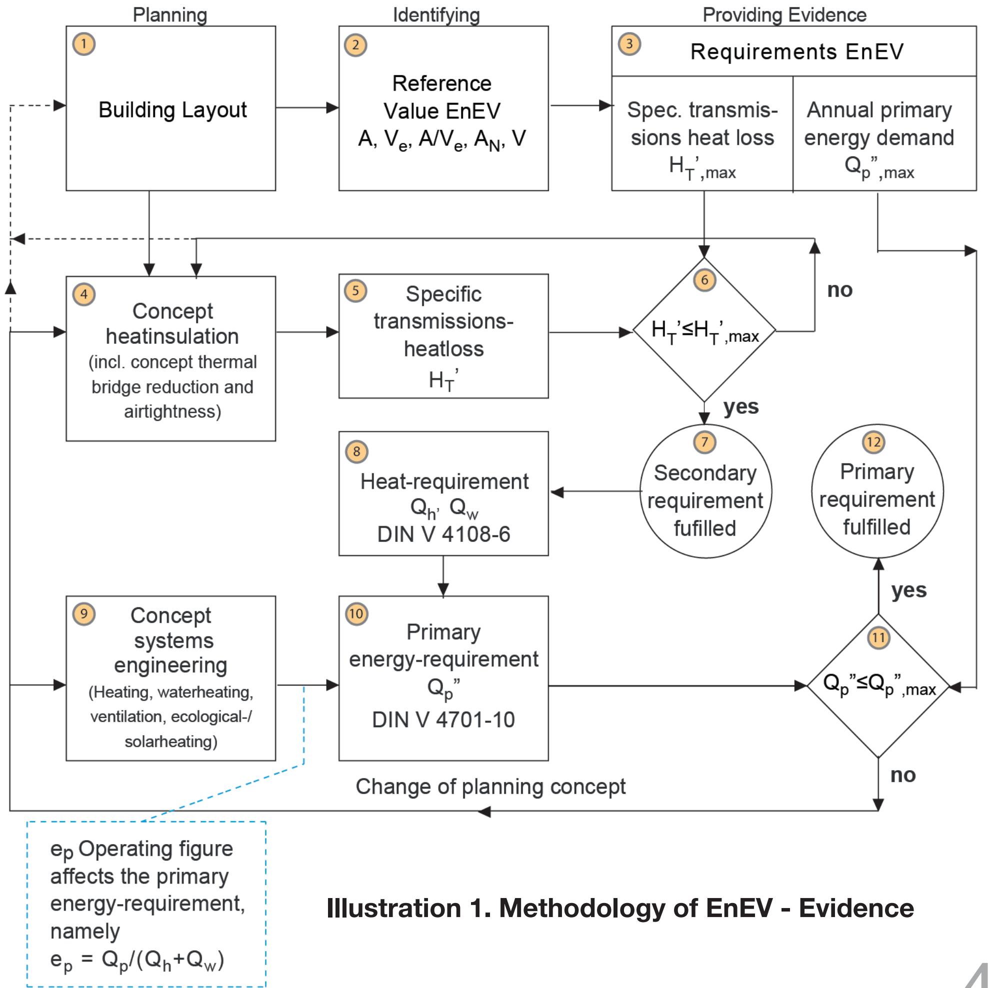

Illustration 1. Methodology of EnEV - Evidence

3. Consumption figures for Redwell Infrared Heaters

The consumption figure e_p is determined according to DIN V 4701-10 and is generally definable of the basis of standard values. The methods described here allow the consideration of device-specific parameters, which can be taken from the manufacturer records.

A goal of the research project was to document that a Redwell Infrared Heater does accomplish more than theoretically possible because of the installed electrical capacity and this according to DIN. Compared to conventional convective heating this can only be done based on two analyses:

a) The evaluation of the heating of the building shell and the interacting radiation of the walls.

b) The evaluation of the improved thermal comfort, which results in a reduction of the air temperature and thus leads to a lower energy consumption.

These procedures allow the inclusion of device-specific parameters, but it should be noted that both factors are dependant on the type of building:

1. They depend on the thermal insulation (U_m and respectively k_m)
2. They depend on the surface materials (radiation emission and absorption factors α and ε)
3. They depend on the thermal inertia of the building
4. They depend on the ratio of ventilation to the transmission losses

These four relations can in principle be determined computationally and experimentally. This has the effect of achieving maximum precision, as well as more generally applicable results, which are therefore not just limited to specific applications. In this sense a combination of measurements and calculations was carried out, which had the objective of maintaining the full comparison of a conventional convective heating systems with a Redwell Infrared Heater regarding the thermal comfort and energy demand.

i. A room equipped with Redwell Infrared Heaters heated the surface of the room as well as the items in the room and not directly into the air. In comparison, a convective heating system heats the entire room air, resulting in a much higher installed capacity of up to +32%.

ii. Because a room heated with Redwell Infrared Heaters, heats the surrounding surfaces the heat storage capacity of the components can therefore be used, and the heat losses due to ventilation are significantly lower. This allows the installed capacity compared with conventional heating systems to be designed lower saving up to 35% capacity.

iii. Since the wall surfaces in total have a higher surface temperature when compared with convective heating systems, this produces good thermal comfort conditions at up to 3.5 °C lower air temperatures. When you perform an effective control of the radiator based on the room temperature, it results in a difference in the installed capacity and the real operating time of up to -7%.

iv. Since all these results strongly depend on the building-related factors (1) - (4), one arrives at the conclusion that the input power for room heating (“factor input power” or “factor energy requirement figures” in the EnEV calculation) can be expressed solely as a formula. From the arithmetical results, one comes to the conclusion that for a typical building, isolated according to EnEV 2009, with a per radiator heated volume of up to 100m³ (approx 40m²), the input power factor, or energy requirement figure e_p can be evaluated with 0.65. In very well insulated buildings (k <0.2W /m²K) e_p -values can be reached of 0.55 and smaller.

The simulations which were carried out produced the curves in the following illustration 2, in which the dependence of the energy requirement figure e_p on the power input (-correlates with a heat transfer coefficient as a relation of the influence of the thermal insulation) and the room size (with a very sensitive thermostat) was calculated.

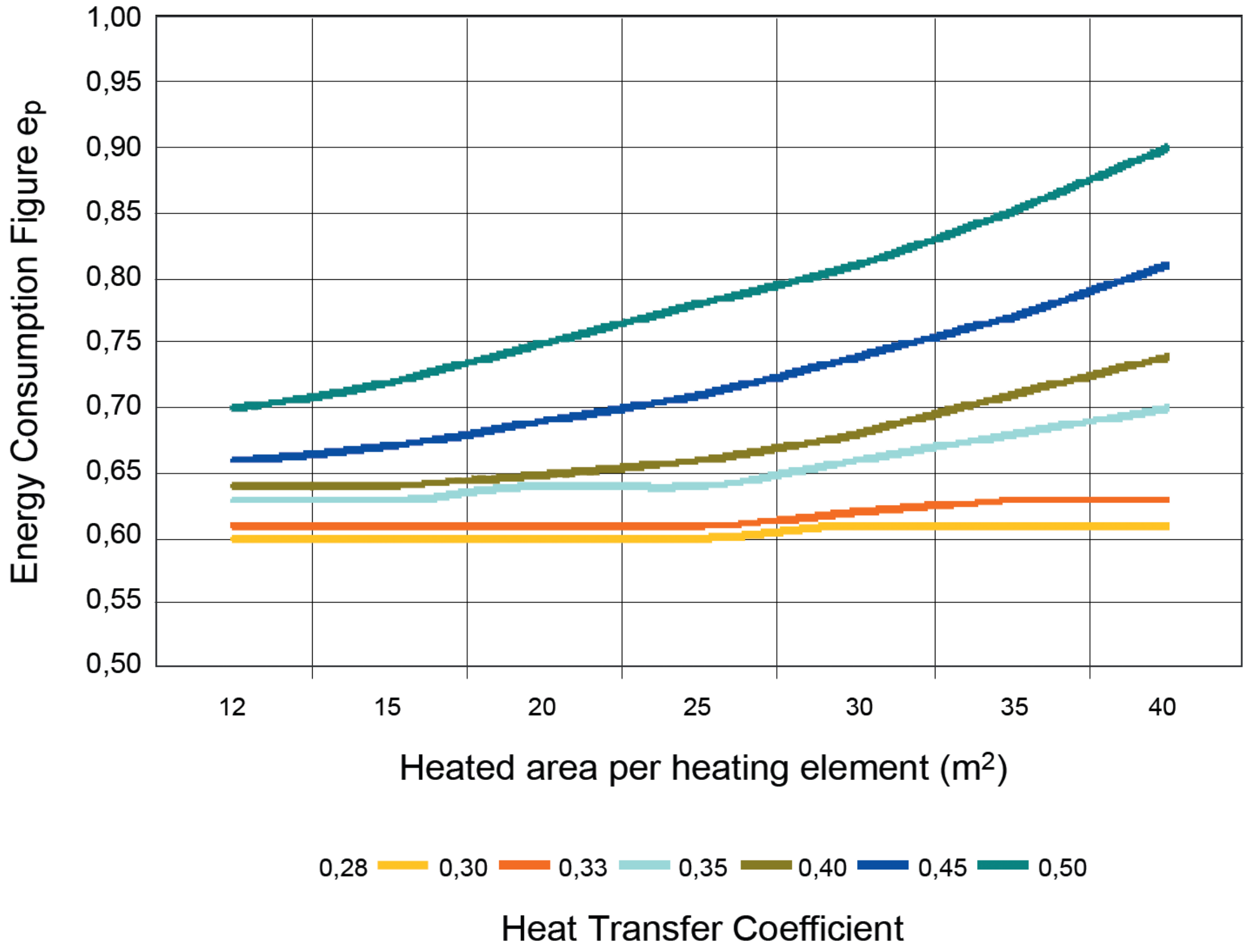

Illustration 2. Energy consumption figure e_p in dependency of the heated area and the heat transfer coefficient

Therefore, the following calculations of the primary energy requirement and the energy requirement figure for the room heating with Redwell Infrared Heating with the represented input power values corresponding to the requirements of EnEV are correct and applicable.

4. Investigated Heating Systems

The scenarios to be examined for the building (built 1970), are shown in the following table (Table 1).

Table 1 Parametric analysis - scenario analysis - Year 1970

	Scenario	Insulation	Windows	Fuel Economy Burner	Redwell Infrared Heaters	Solar Collectors	PV System
0	Basis (old Oil Boiler)	Yes	Old	Old	No	No	No
1	Redwell Infrared Heaters	EnEvog	EnEvog	No	Yes	No	No
2	Redwell Infrared Heaters + Solar Collectors	EnEvog	EnEvog	No	Yes	Yes	No
3	Redwell IH + Solar Collectors + PV-System	EnEvog	EnEvog	No	Yes	Yes	Yes
4	Air/Water Heat Pump with Floor Heating	EnEvog	EnEvog	No	No	No	No
5	Water/Water Heat Pump with Floor Heating	EnEvog	EnEvog	No	No	No	No
6	Direct Electric Heating	EnEvog	EnEvog	No	No	No	No
7	New Oil Boiler	EnEvog	EnEvog	New	No	No	No
8	New Oil Boiler + Solar Collectors	EnEvog	EnEvog	New	No	Yes	No
9	New Gas Boiler	EnEvog	EnEvog	New	No	No	No
10	New Gas Boiler + Solar Collectors	EnEvog	EnEvog	New	No	Yes	No

5. Test object

For the life-cycle analysis of the building the CML 2001 method was used (CML 2 baseline method, 2001). The calculations were made with the software AKZ SimaPro (Pré Consultants, 2009) version 7.1 in which version 2.1 software Ecoinvent served as a database. This twin house is located in an urban area in central Germany at Frankfurt am Main (Figure 3). Accordingly, the climatic data for Frankfurt am Main were used (Table 2).

Location, “Frankfurt am Main”, [N 50 ° 2 ‘] [E 8 ° 36’] target inside temperature = 19.0 °C

Table 2. Data for the dimensioning of heating systems (Source: “Climate Design Data 2009 ASHRAE Handbook”)

	Maximum Temperature [^{0}C]	Day Temperature [^{0}C]	Wind speed [m/sec]	Wind direction
Heating period	-10.5	0.0	3.2	30
Cooling period	30.8	10.6	3.7	210

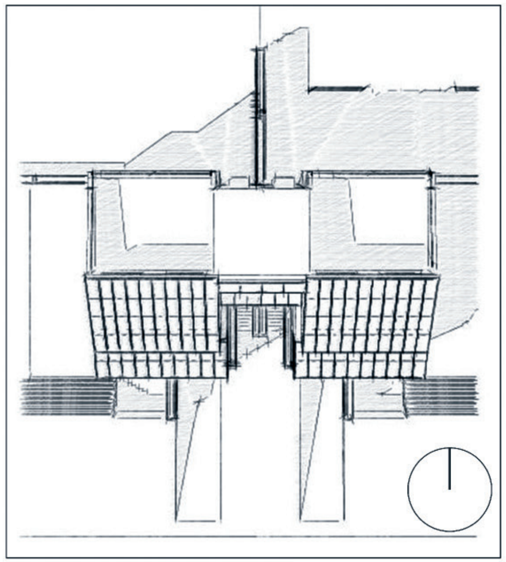

Illustration 3. Views of the semi-detached house to be evaluated

Table 3. Typical construction elements and their U-values for a 70´s building

Component	Construction (from outside to inside)	U-Factor [W/m^{2}K]
Outer Wall	• Chalk based plaster. • Reinforced concrete • Cement / chalk rendering	3,69
Basement Ceiling	• Min. footfall sound attenuation • Concrete, steel ceiling beam	1,59
Flat Roof	• Plaster of lime based mortar • Steel ceiling. stone TV 600/190 • Cement-rendering	2,12
Steep Roof	• Plaster of lime based mortar • Wood fibreboard • Ventilated air layer • Battens • Counter battens • Roofing	1,51
Window	• 2-pane double glazing wood frame without thermal break	4,30

Results

1. Evaluation of the tested Redwell Infrared Heaters

• Energy efficiency

To optimise the Redwell Infrared Heaters and for the investigation of the intervention scenarios, the building was dynamically simulated with Energy Plus software. In practical test runs, an average surface temperature of the Redwell Infrared Heaters of about 95 °C, A constant proportion of infrared radiation of 90% was measured. This was done by measuring the electrical input power and the resulting difference to the calculated radiation power on the basis of the measurements of surface temperatures. This difference represents the convective component of the systems.

• Integrated assessment of the various heating systems

For the life-cycle analysis of the building the CML 2001 method was used (CML 2 baseline method, 2001). The calculations were made with the software AKZ SimaPro (PRé Consultants, 2009) Version 7.1, and the Ecoinvent software version 2.1 was used as a database.

• Key Intervention Points

Building envelope

The building envelope has been recalculated with the help of EIFS and the EnEV reference values for the heat transfer coefficients to be achieved. On this basis, the external components were insulated, so that the EnEV requirements were fulfilled.

Heating systems

In each of the different scenarios, the old oil boiler is replaced with a new boiler (oil or gas) with better efficiency, or with a direct electrical heating system, a heat pump system or by a Redwell Infrared Heater.

Renewable energies

In order to achieve the energy and environmentally optimal result, the heating systems were combined with renewable energy systems. These are PV-systems to support the production of electricity for operating the Redwell Infrared Heaters and solar collectors for water heating.

2. Adjusted efficiencies of various heating systems

The results for the 1970's building concerning the impact and efficiencies are presented in Table 4.

	Scenario	Efficiency	Performance Ratio	Energy Requirement Ratio e_p
0	Basis (old Oil Boiler)	0.85	0.85	1.18
1	Redwell Infrared Heaters	1.00	1.54	0.65
2	Redwell Infrared Heaters + Solar Collectors	1.00	1.54	0.65
3	Redwell IH + Solar Collectors + PV-System	1.00	1.54	0.65
4	Air/Water Heat Pump with Floor Heating	2.50 (COP)	2.00	0.40
5	Water/Water Heat Pump with Floor Heating	3.50 (COP)	3.00	0.29
6	Direct Electric Heating	1.00	1.00	1.00
7	New Oil Boiler	0.94	0.94	1.06
8	New Oil Boiler + Solar Collectors	0.94	0.94	1.06
9	New Gas Boiler	0.95	0.95	1.05
10	New Gas Boiler + Solar Collectors	0.95	0.95	1.05

Table 4. Effects and efficiencies of the systems and the resulting expenditure figures

3. Primary energy needs of the various heating systems

Figures in Table 5. show that only a new gas and oil boiler system achieve a better overall primary energy demand than Redwell Infrared Heaters. In combination with renewable energy systems (solar collectors and photovoltaic) lowest primary energy needs are achieved with Redwell Infrared Heaters. Direct electric heaters or air/water heat pumps achieve consistently between +20 to +40% higher primary energy requirements compared to Redwell Infrared Heaters.

A major influence in the calculation of heating and hot water needs is the dependent primary energy-demand factor. The interplay between the primary energy factor and the energy consumption figure and the efficiency of the system directly leads via the heat demand to the comparable primary energy demand of the different systems.

$Q_p = (Q_h + Q_w) * e_p$ is.

Table 5. Primary energy demand base West Germany - 1970 building

	Scenario	Heating demand Q_H	Primary energy factor Germany	Hot water demand Q_W	Primary energy factor Germany	Primary energy requirement Q_P
0	Basis (old Oil Boiler)	327.59	1.15	12.58	2.70	401.40
1	Redwell Infrared Heaters	152.64	2.70	12.28	2.70	107.20
2	Redwell Infrared Heaters + Solar Collectors	113.85	2.70	0.00	2.70	74.00
3	Redwell IH + Solar Collectors + PV-System	41.54	2.70	0.00	2.70	27.00
4	Air/Water Heat Pump with Floor Heating	341.72	2.70	12.28	2.70	141.60
5	Water/Water Heat Pump with Floor Heating	369.10	2.70	12.28	2.70	110.60
6	Direct Electric Heating	133.92	2.70	12.28	2.70	146.20
7	New Oil Boiler	69.51	1.15	12.28	2.70	86.70
8	New Oil Boiler + Solar Collectors	50.57	1.15	0.00	2.70	53.60
9	New Gas Boiler	67.62	1.15	12.28	2.70	83.90
10	New Gas Boiler + Solar Collectors	43.38	1.15	0.00	2.70	50.80

4. Lifetime Usage and eco-efficiency

To get a directly comparable result between the different scenarios, the evaluation factors (cost, primary energy consumption and eco-efficiency) must be normalized. Only the appropriate correction factors provide strictly comparable conclusions as shown in Table 6. These are represented as a dimensionless number - performance (life cycle), where the smallest value represents the most effective heating system. The calculation of the performance (life cycle) is performed with the previously introduced software AKZ SimaPro (Pré Consultants, 2009) version 7.1 and the database software Ecoinvent version 2.1. This takes into account the entire life cycle of the system from production through the operation and for the removal and disposal.

Table 6. Results of the eco-efficiency for buildings in 1970

	Scenario	Primary Energy Consumption	Global Warming Potential	Performance (life cycle)
		kWh/m²a	kg CO_2 eq	-
0	Basis (old Oil Boiler)	401.4	35,320	267.6
1	Redwell Infrared Heaters	107.2	8,059	89.4
2	Redwell Infrared Heaters + Solar Collectors	74.0	5,570	68.1
3	Redwell IH + Solar Collectors + PV-System	27.0	2,030	36.8
4	Air/Water Heat Pump with Floor Heating	141.6	8,323	92.3
5	Water/Water Heat Pump with Floor Heating	110.6	10,654	112.6
6	Direct Electric Heating	146.2	11,000	115.3
7	New Oil Boiler	86.7	8,618	86.1
8	New Oil Boiler + Solar Collectors	53.6	5,124	66.1
9	New Gas Boiler	83.9	7,040	74.5
10	New Gas Boiler + Solar Collectors	50.8	4,547	53.0

Table 6. shows again that only the gas heating system (new gas boiler) reached about -5% lower power factor then reached by the Redwell Infrared Heater, all other heating systems, such as air/water heat pump, direct electrical heating and oil-fired boilers are significantly less favourable than Redwell Infrared Heating systems.

5. Economic analysis

Based on Tables 7. and 8., in which the costs of the different systems are represented, both for renovation and for new construction, was then the economic efficiency calculation realised for all systems (Illustration 4-8).

The profitability calculations were based on following assumptions:

- Energy costs as of April 2010, Germany
- Inflation rate: 1.5%
- Capital costs: 2.0%
- Period under review: 20 years (projection of operating costs over 20 years)
- Savings are compared with an old oil boiler (no additional thermal insulation measures were taken into account)

Table 7. Cost expression - renovation scenario (in EUR)

	Redwell IRH	Redwell IRH + Solar Coll.	Redwell IRH + Solar + PV	Air/Water Heat Pump	Water/Water Heat Pump	Dir. Electrical Heating	New Oil Boiler	New Oil Boiler + Solar	New Gas Boiler	New Gas Boiler + Solar
Investment costs (one-off)										
Heater	14,500	14,500	14,500	18,000	21,000	9,500	4,000	4,000	4,500	4,500
Piping for Floor Heating	-	-	-	11,500	11,500	-	-	-	-	-
Installation Solar Coll.	-	12,000	12,000	-	-	-	-	12,000	-	12,000
Installation PV-System	-	-	24,500	-	-	-	-	-	-	-
Total Investment Costs	**14,500**	**26,500**	**51,000**	**29,500**	**32,500**	**9,500**	**4,000**	**16,000**	**4,500**	**16,500**
Operational costs (on going)										
Plus Energy Costs PV-System	-	-	9,100	-	-	-	-	-	-	-
Energy Costs	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.63 €/l	0.63 €/l	5.5 cent/kWh	5.5 cent/kWh
Maintenance Costs	-	100 €/year	200 €/year	100 €/year	100 €/year	-	150 €/year	250 €/year	150 €/year	250 €/year
Total Operational Costs	3,132	2,164	-6,936	4,140	3,234	4,275	3,044	1,524	2,904	1,335
Total 20 Years	**-88,002**	**-79,649**	**107,467**	**-129,016**	**-109,751**	**-111,828**	**-78,972**	**-57,634**	**-76,186**	**-53,709**

Table 8. Cost analysis – new construction scenario (in EUR)

	Redwell IRH	Redwell IH + Solar Coll.	Redwell IH + Solar + PV	Air/Water Heat Pump	Water/Water Heat Pump	Dir. Electrical Heating	New Oil Boiler	New Oil Boiler + Solar	New Gas Boiler	New Gas Boiler + Solar
Investment costs (one-off)										
Heater	14,500	14,500	14,500	18,000	21,000	9,500	4,000	4,000	4,500	4,500
Piping	-	-	-	-	-	-	8,500	9,000	8,500	9,000
Heating Device	-	-	-	-	-	-	4,200	4,200	4,200	4,200
Piping for Floor Heating	-	-	-	11,500	11,500	-	-	-	-	-
Boiler Room + Chimney	-	-	-	-	-	-	6,000	6,000	6,000	6,000
Installation Solar	-	12,000	12,000	-	-	-	-	12,000	-	12,000
Installation PV-System	-	-	24,500	-	-	-	-	-	-	-
Total Investment Costs	**14,500**	**26,500**	**51,000**	**29,500**	**32,500**	**9,500**	**4,000**	**16,000**	**4,500**	**16,500**
Operational costs (on going)										
Plus Energy Costs PV-System	-	-	9,100	-	-	-	-	-	-	-
Energy Costs	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.193 €/kWh	0.63 €/l	0.63 €/l	5.5 cent/kWh	5.5 cent/kWh
Maintenance Costs	-	100 €/year	200 €/year	100 €/year	100 €/year	-	150 €/year	250 €/year	150 €/year	250 €/year
Total Operational Costs	2,261	1,560	-8,311	2,500	2,368	3,521	2,493	1,358	2,171	1,128
Total 20 Years	**-67,577**	**-65,470**	**139,756**	**-98,512**	**-89,429**	**-92,140**	**-66,029**	**-53,749**	**-60,477**	**-48,842**

From tables 7 & 8, it can be seen that Redwell Infrared Heaters are a lot more economic in the renovation scenario, than other forms of heating such as heat pumps or direct electric heating systems. Here, too, only oil- and gas boiler operated with fossil fuels are more favourable. In the new build scenario, Redwell Infrared Heaters are by far the best overall model (capital and operating costs), when used in conjunction with photovoltaic, and a high total yield can be achieved due to the high total returns from electricity sales and far above all other heating systems.

The reduction in performance for heat pumps with increasing service life has been taken into account, as well as the reduced performance of all systems tested. This is another great benefit of Redwell Infrared Heaters, and this has an going effect – they are maintenance-free and have no output reduction over the life cycle of the system.

The examination of the operating costs of different heating systems for the existing building is shown in illustration 4 and in the following. While smaller values correspond to better performance and indicate a more sufficient system (illustration 4-7).

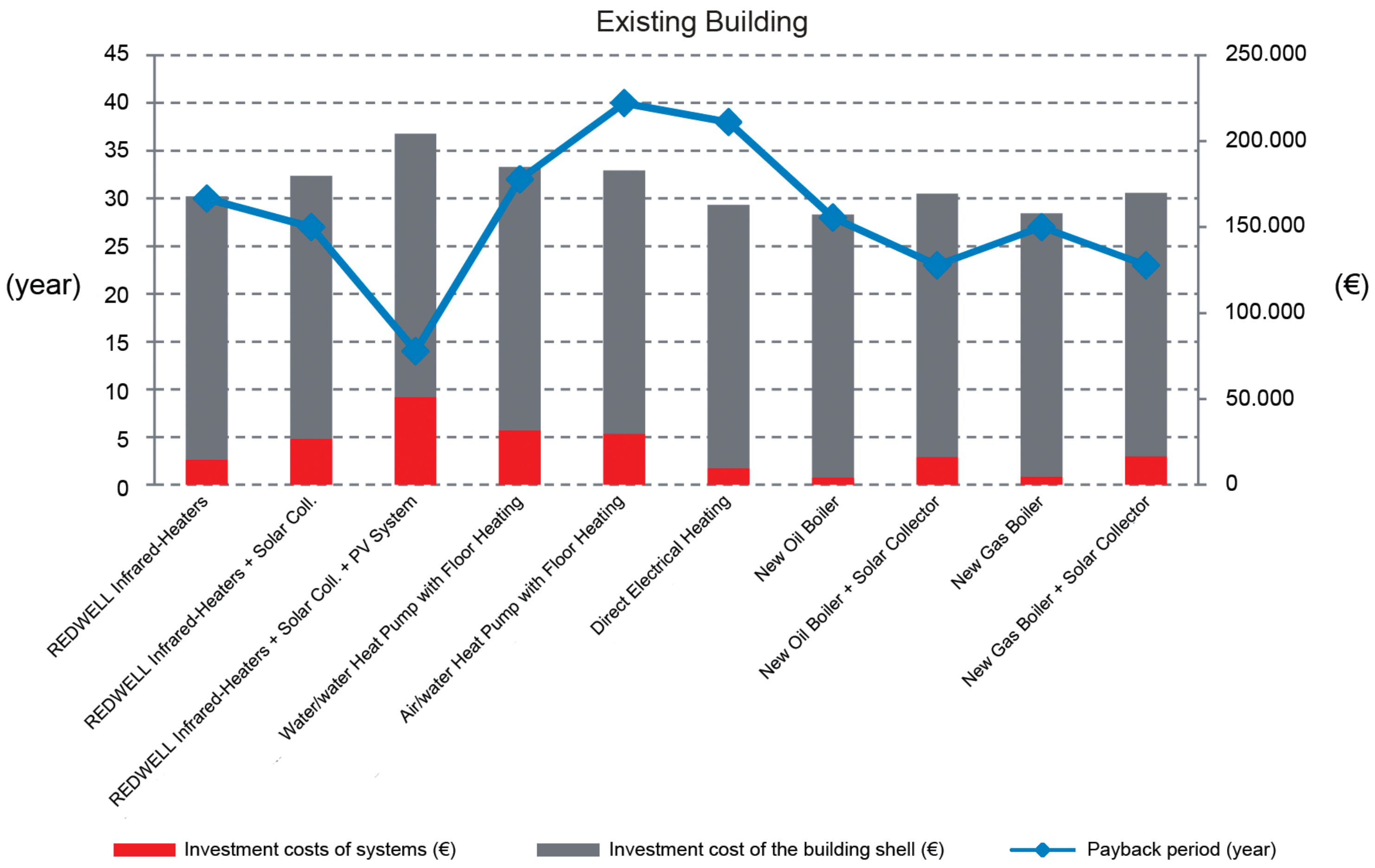

Figure 4. Total investment cost representation of the heating systems (1970's building) including building insulation

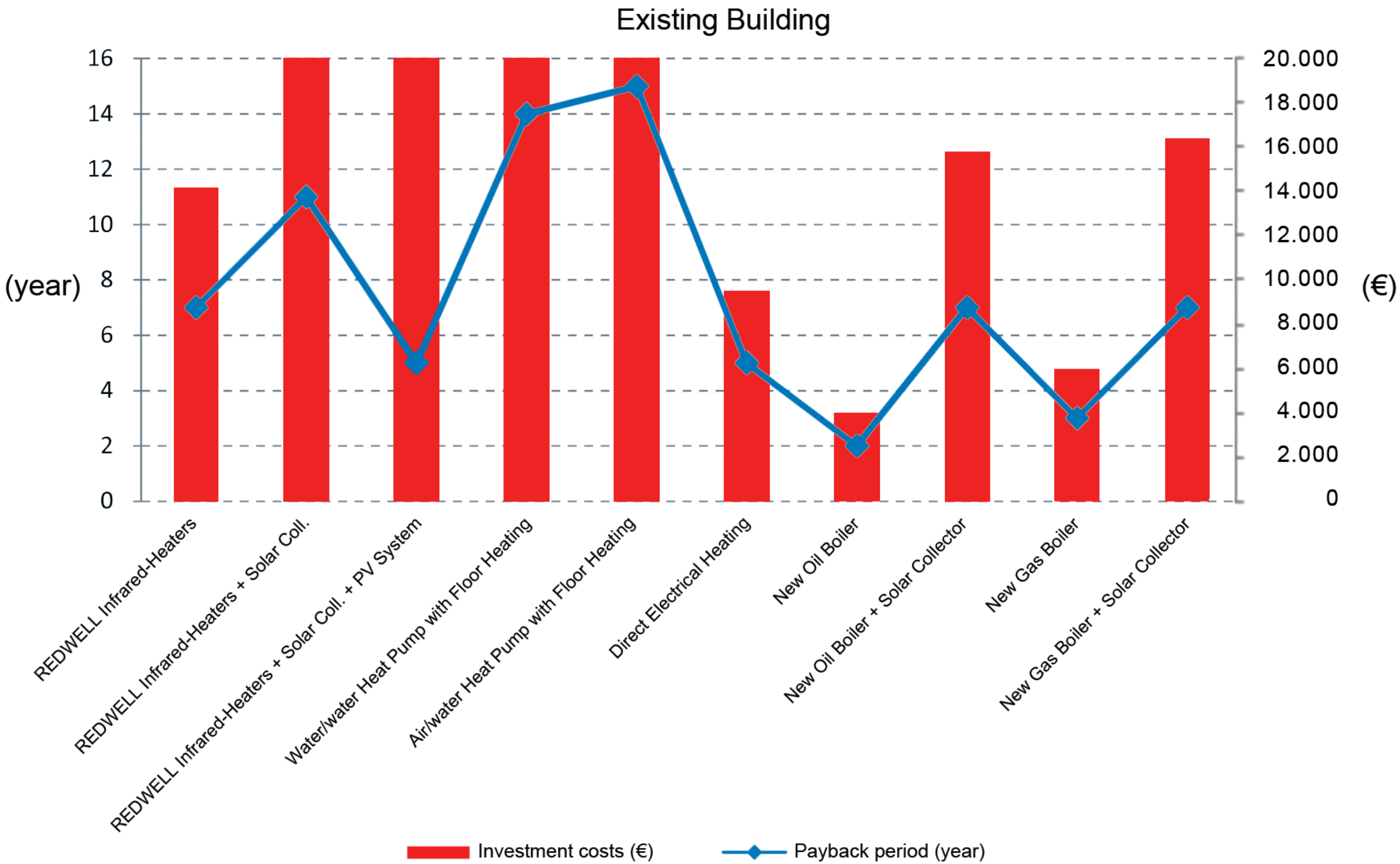

Figure 5. Economic evaluation of the investment cost on heating systems (1970's building) - renovation scenario

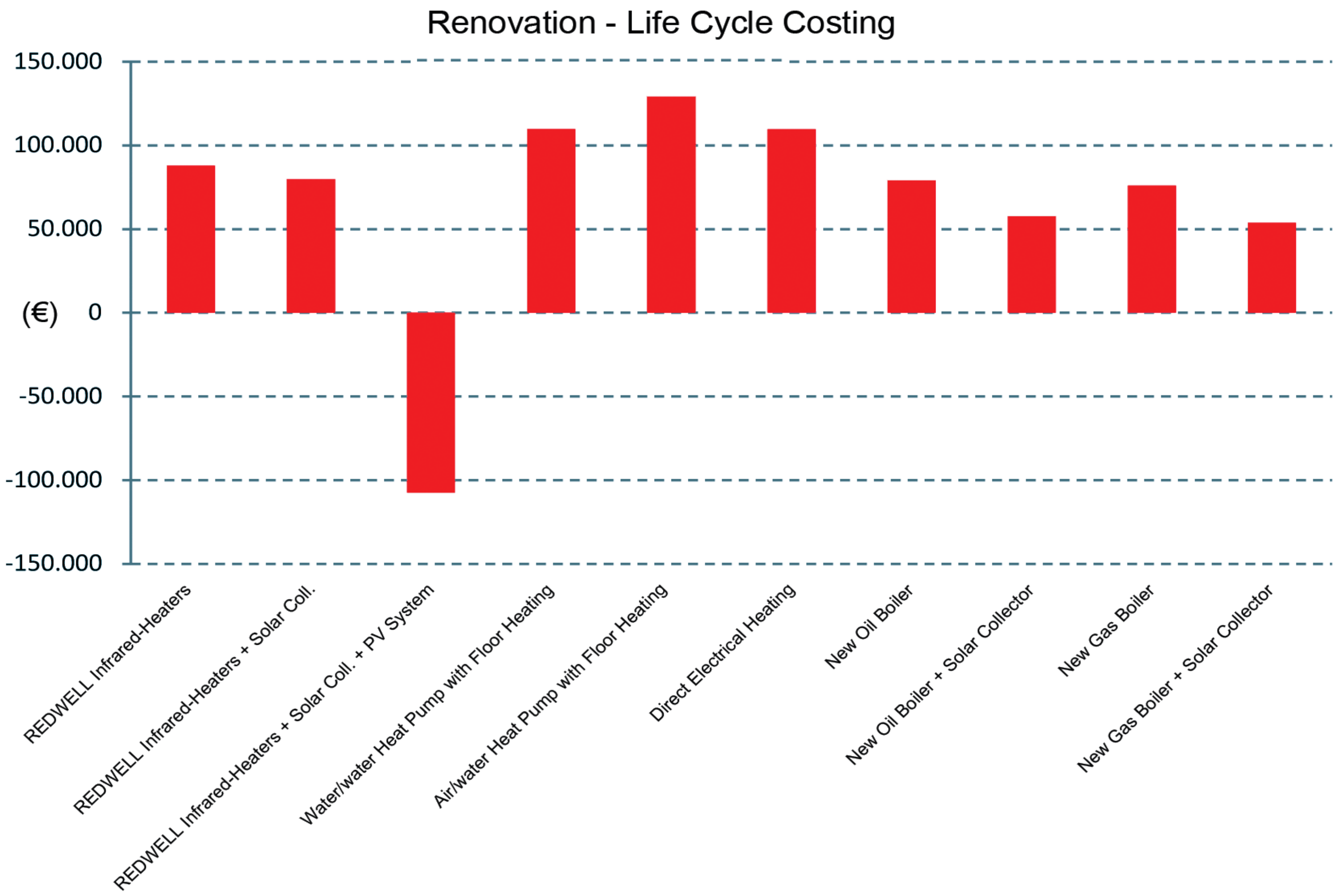

Figure 6. Holistic view of the heating costs (1970's building) + operating costs (20 years) renovation scenario

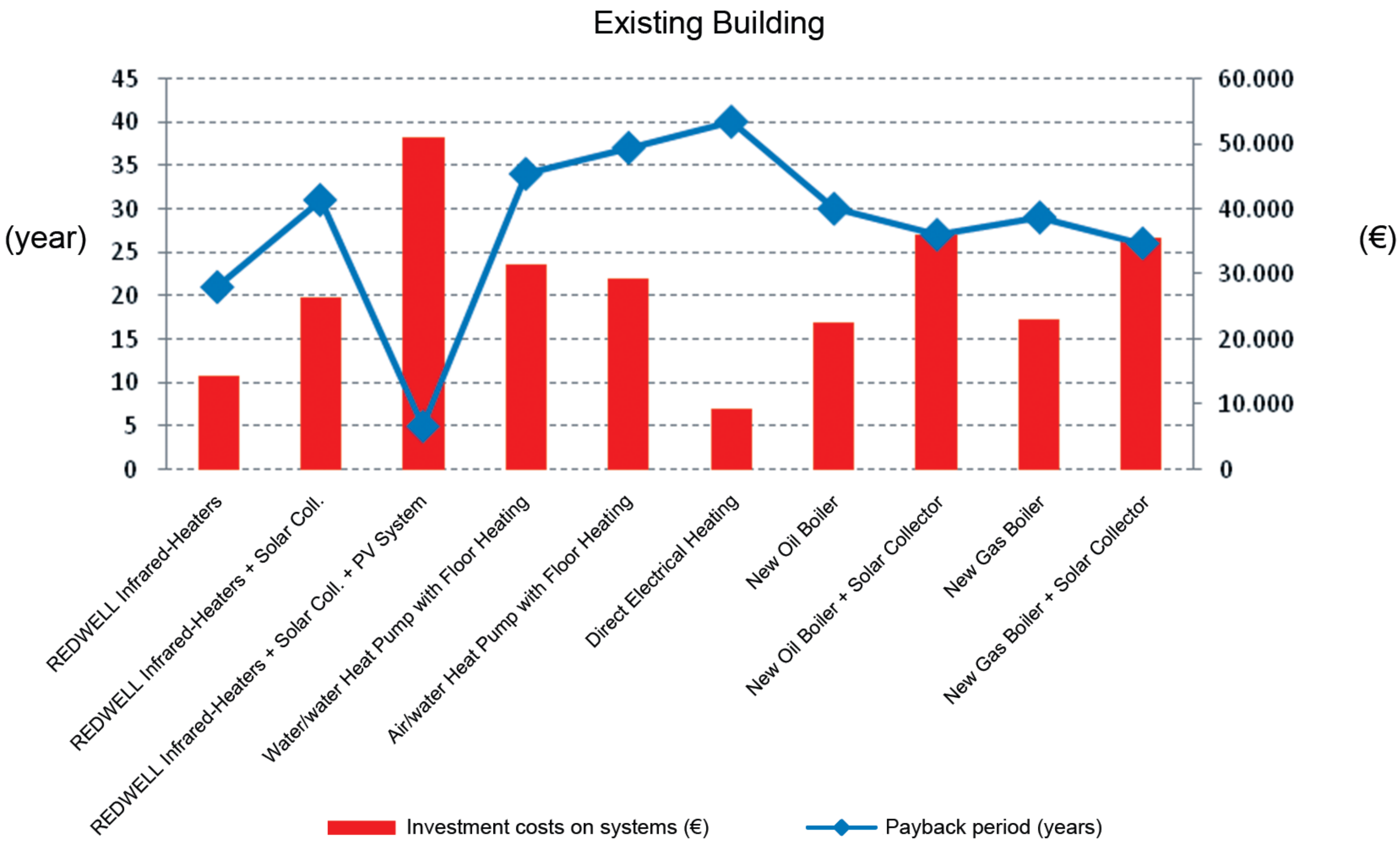

Figure 7. Economic evaluation of the investment cost on heating systems (1970's building) new construction scenario

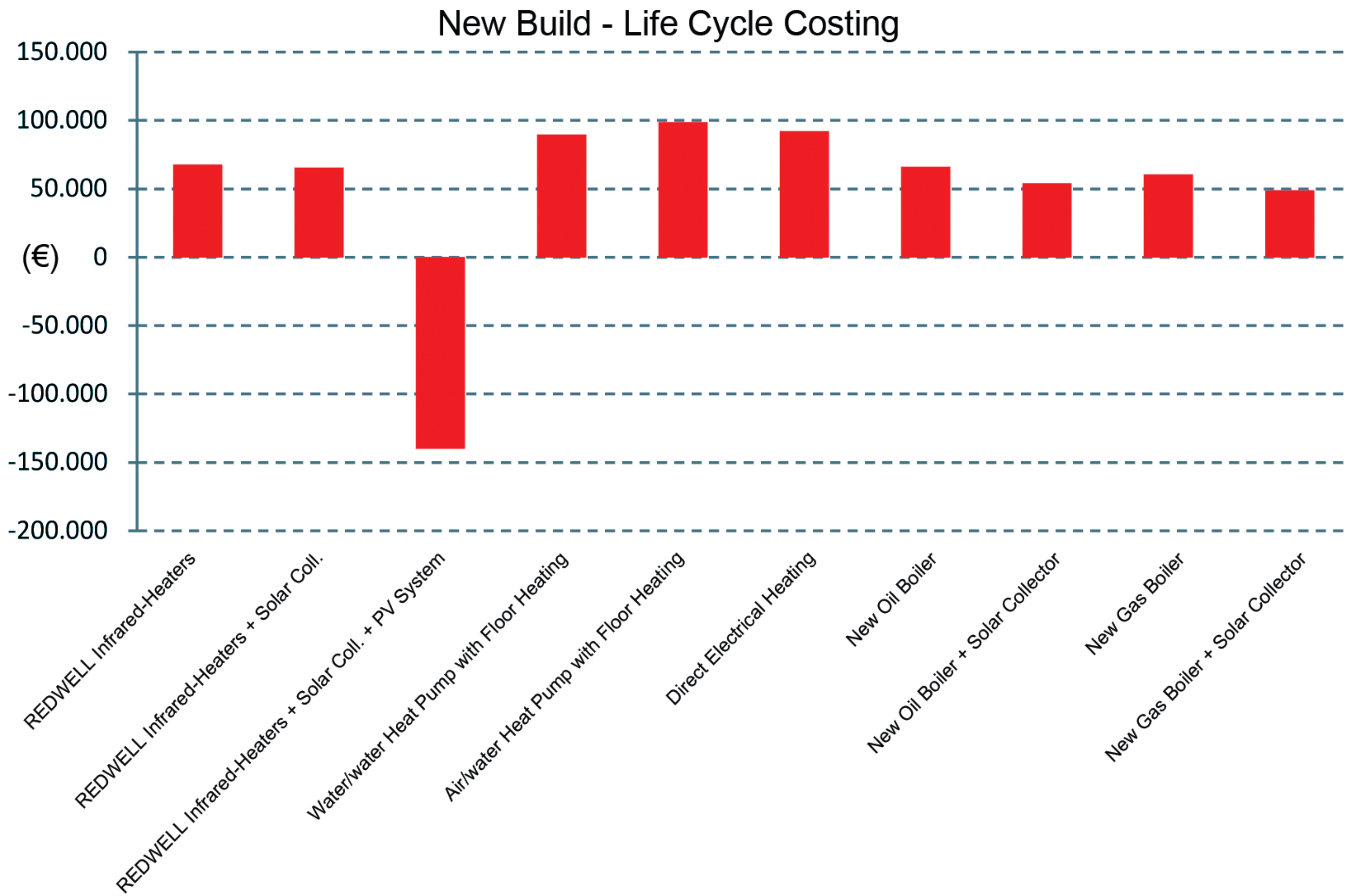

Figure 8. Holistic view of the heating costs (1970's building) + operating costs (20 years) new construction scenario

6. Thermal comfort

The comfort in a room is largely determined by the relative air humidity. Valid as a hygienic compromise between the different requirements in general, are the limit values of 40% and 60%. This prevents the following risks:

- Reducing the feeling of sultriness and at the same time reducing susceptibility to bacterial infection,
- Reduction of odours,
- Increasing the defence capability of the skin to microbes, and preventing electrostatic charge.
- Prevention of mould and fungus growth.

To illustrate the process of interaction between the physiological processes in the body and the physical exchange with the environment, Prof. Poul Ole Fanger [Fanger 1972] in 1969 developed a statistical and mathematical method for the objectified representation of thermal comfort. This is basically the fulfilment of thermal comfort seen as an energy service, which is to be provided by the building and its home automation services.

Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)

ÖNORM EN ISO 7730 [EN ISO 7730:2006] defines thermal comfort as the feeling which expresses satisfaction with the ambient air. Dissatisfaction can be expressed as discomfort in the body as a whole, due to the impact of heat or cold.

From these factors Fanger developed in the 60s, known as the "Predicted Mean Vote" through large-scale field trials. This is a value that determines the statistical average vote of a group of people. The basic heat balance is, as usual expressed in the technical sense, of input, thus heat production, and output, so heat dissipation. The relationship between PMV and PPD in it is that if this balance is zero, the body does not need to undertake any effort to achieve a balance. When this difference comes off zero balance, the organism must now alter to compensate and this is perceived as discomfort. If the calculation comes into the negative range, then these conditions are perceived as too cold, and secondly, that the predicted percentage change increases discontent. This can be seen in the PPD index when the PMV-index is positive, except when that the area was felt to be too warm.

Figure 9. Shows this relationship:

PMV: "Predicted Mean Vote" = predicted average assessment of the climate

PPD: "Predicted Percentage of Dissatisfied" = means predicted percentage of dissatisfied population with the climate.

Optimum, i.e. a small number of malcontents, which is defined by Fanger with at best 5%, is achieved when the calculation of the average predicted vote results equal to zero.

Explanation	Fenger - Scale	% Dissatisfaction
Cold	-3	99,1
Cool	-2	76,8
A little Cool	-1	26,1
Neutral	0	5,0
A little Warm	1	26,1
Warm	2	76,8
Hot	3	99,1

Figure 9. The Relationship between PMV and PPD and the corresponding perception according to ÖNORM 7730 [ÖNORM 7730:2006, p. 6]

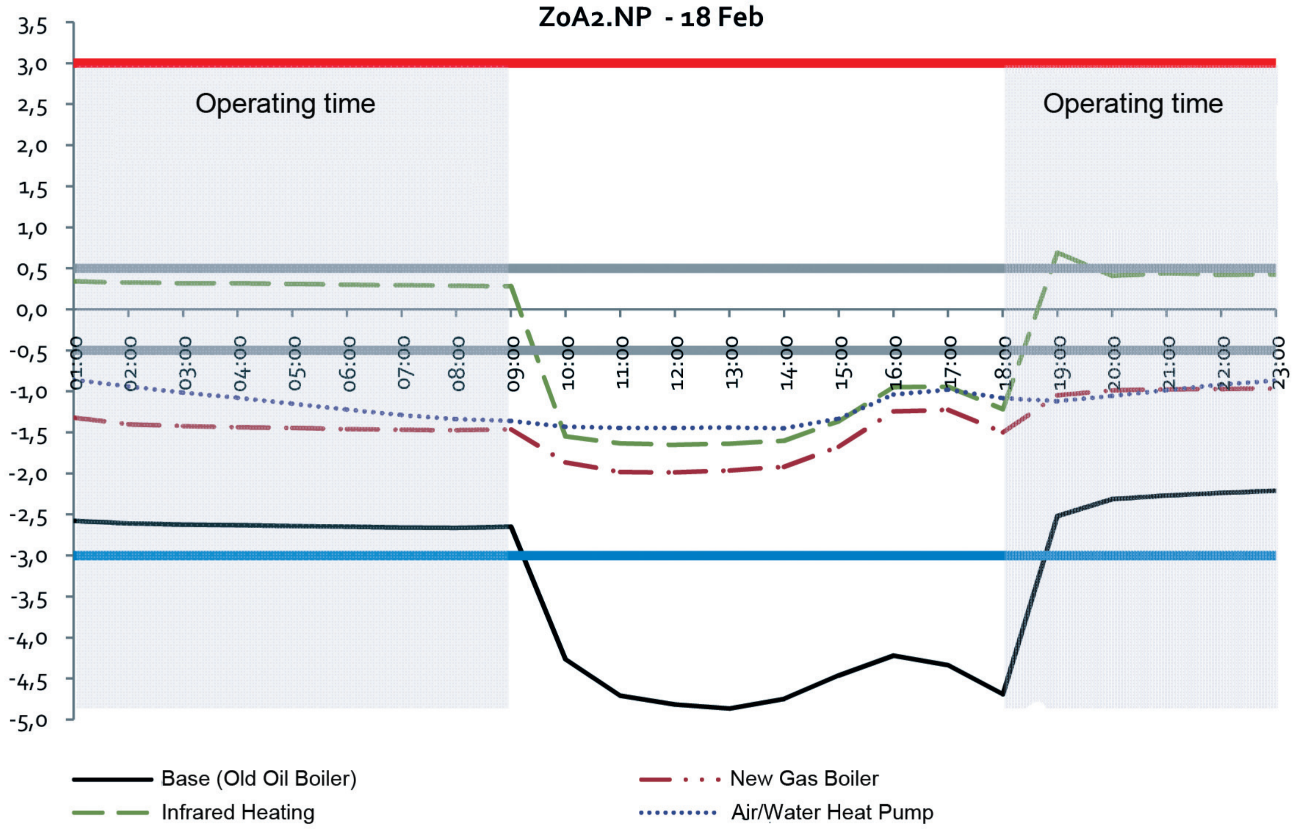

Figure 10. PMV Rate (Building Year 1970)

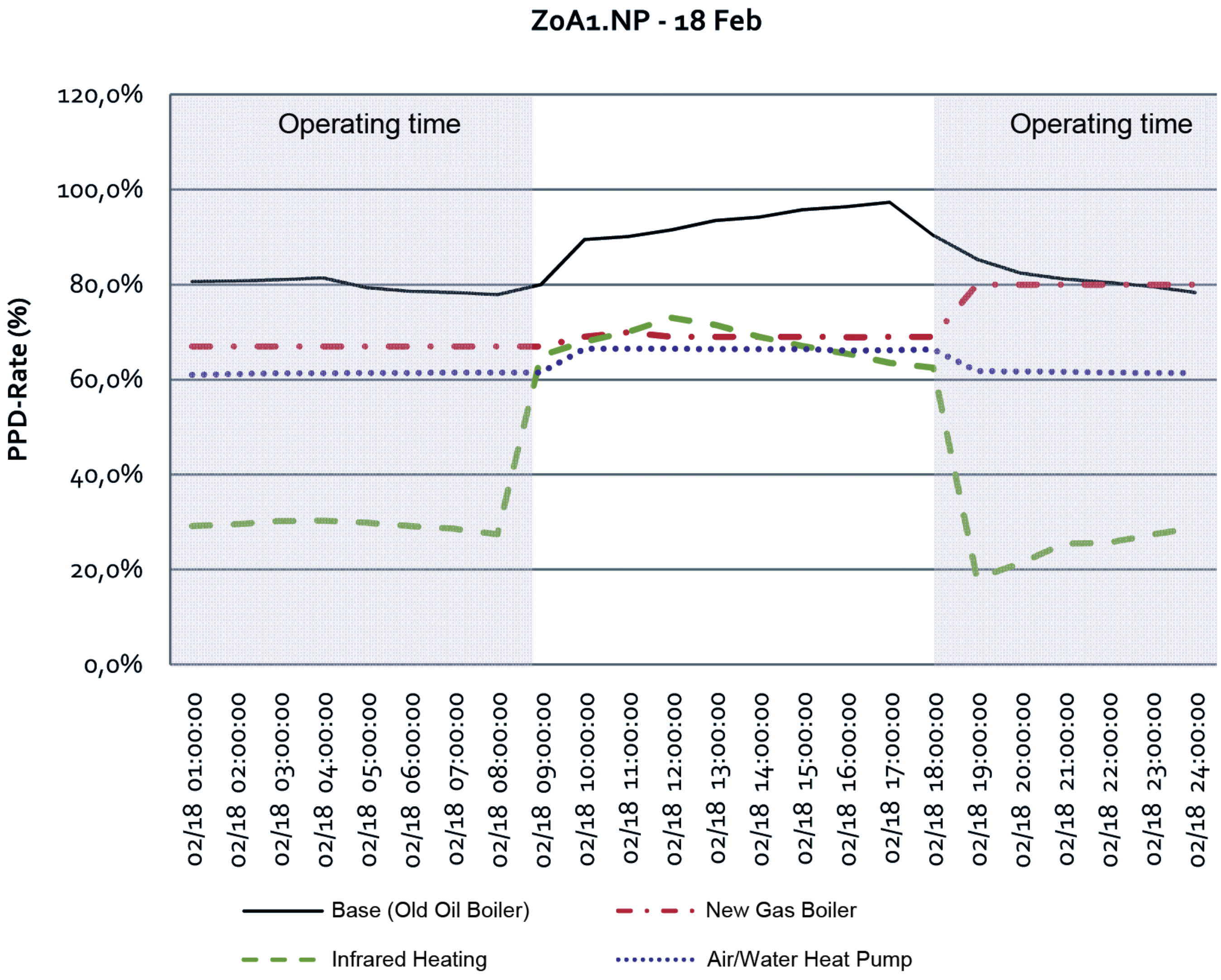

Figure 11. PPD Rate (Building Year 1970)

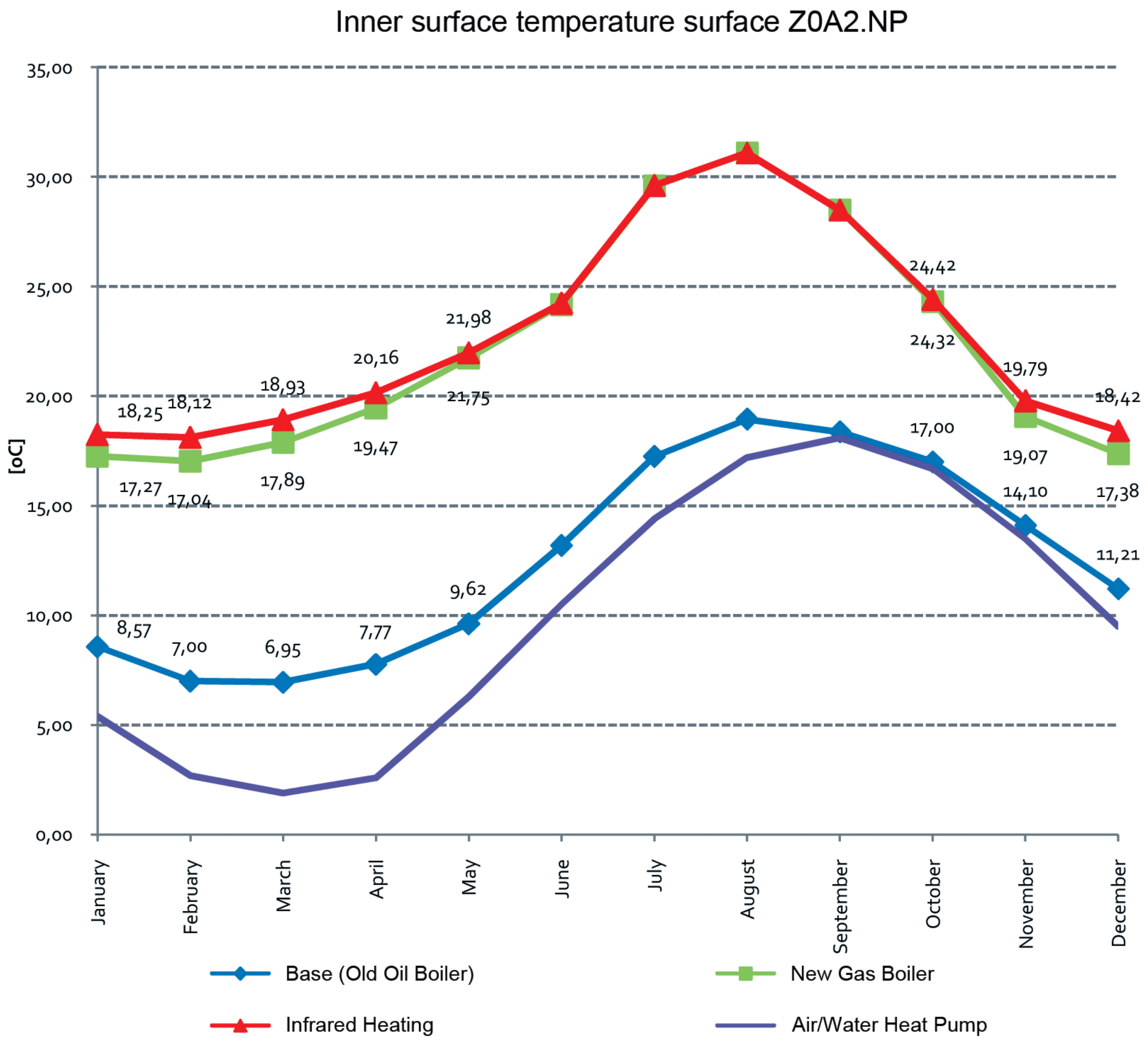

Figure 12. Inside interior surface temperatures of a typical basement wall (Building Year 1970)

With reference to Figure 10 for the 1970 building, it was perceptible that during the operation only Redwell Infrared Heaters reach the thermal comfort limits and it is with reference to Figure 11., Redwell Infrared Heaters come closest to the optimum 0% PPD-Rate.

Criteria of the local comfort

In addition to the statistical criteria of comfort, further criteria should be established to determine the thermal comfort. In this context, the monthly mean temperature change was investigated on certain surfaces and shown in Figure 12. The values represent the mean of surface temperatures for all floors toward the replacement work for the building from year 1970.

It became apparent that during the operation of the Redwell Infrared Heaters in general, that the surface temperature of the inside walls were 0.5 to 1.5o C higher than the surface temperature when the heater was a new gas boiler. Here is the curve for Redwell Infrared Heaters which are equal for all wall surfaces of a room, whereas the curves given for the gas boiler system for the immediate area around the heater wall are valid, all of the other wall surfaces remained cold. This situation contributes significantly to the improvement of thermal comfort by the use of Redwell Infrared Heaters.

Summary

In terms of energy use, Redwell Infrared Heaters are extremely efficient and effective as can be seen from the comparison with conventional heating systems. Here the Redwell Infrared Heaters rank highly both in terms of primary energy demand and the eco-efficiency throughout the entire life cycle. Also in the cost and economic comparisons with conventional heating systems, Redwell Infrared Heaters provided very impressive results.

With regard to thermal comfort, the Redwell Infrared Heater is in principle superior to all conventional heating systems which provide convective heating. Provided that the building is very well insulated similarly, when compared with under floor heating systems with large thermal inertia, this can outweigh the benefits of Redwell Infrared Heaters. All Redwell Infrared heating systems are extremely stable in performance and output (currently all Redwell Infrared Heaters are covered by an unlimited factory warranty guaranteed for 5 years) Redwell Infrared Heaters can display all relevant quality labels and test certificates.

The use of Redwell Infrared Heaters in well-insulated buildings met in every case the existing requirements of EnEV 2009 extremely well.

A combination of Redwell Infrared Heaters with solar thermal and photovoltaic creates an environmentally, economically and energetically optimal solution, which currently no other heating system can outperform. Especially in old buildings, the use Redwell Infrared Heaters is the best economic solution for the owner. But even in new construction, the Redwell Infrared Heater is a very efficient and an economically viable alternative to conventional heating systems.

Conclusion

The study shows that Redwell Infrared Heaters are clearly superior to all the other heating systems such as direct electrical heating, oil and gas heating and air/water heat pumps, taking into account all economic, environmental and economic aspects. Therefore, we strongly recommend that Redwell Infrared Heaters are defined in their own separate class due to their high energy efficiency and performance within the scheme of EnEV 2009.