Summary - Research project „IR BAU“
Potential of infrared heating systems for highly efficient residential buildings

On April 1st 2017, the starting shot was given for the following project of the HTWG Konstanz, Department of Energy Efficient Building, in Germany which lasted for 30 months.

The basic question was whether an infrared heating system can be an ecological and economical alternative to the heat pump in very well insulated residential buildings.

Three scientific methods were used for the investigation:
1. Scientific support for the residential building pilot project K76 in Darmstadt (Germany)
2. measurements in laboratory rooms
3. Creation of simulation models of the laboratory rooms

In the course of the project, some important key questions on the subject of infrared heating were answered.
In the following, a brief overview of the examination methods is given and the most important findings are presented.

For a better understanding, some **thermodynamic principles** of infrared radiation and other important parameters are recorded at the beginning:

Every body above the absolute zero point of -273.15 °C emits electromagnetic waves.
Our body can absorb a certain part of these electromagnetic waves as heat through the skin, the so-called infrared radiation.
There is always an exchange of radiation between two bodies. When one body is warmer, it releases this energy in the form of radiation to the other body = radiant power.
The radiation power (how well a body can emit heat as heat radiation) depends on various factors: the area of the radiating and irradiated body, the temperature of both the radiating and the irradiated body and the emissivity of the radiating and irradiated body.

The temperature of the heat-emitting surface plays an important role in infrared heating. The higher the surface temperature, the higher the radiation power per square meter. If the surface temperature is lower, the infrared heater can emit the same radiation power, but the heat-emitting surface has to be relatively larger.

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The radiant power should not be confused with the radiation efficiency of an infrared heater.

The radiation efficiency is the parameter for the radiation capacity of an IR heater and describes what percentage of the electrical power supplied is emitted in form of infrared radiation.
Every IR heater emits heat in form of convection and radiation. The proportion of radiation should be maximized in order to achieve high radiation efficiency. This can mainly be achieved through the design and construction and positioning of the heater.
There is currently no standard, but an IR heater should have a radiation efficiency of at least 51%.

Plate-shaped infrared heaters emit the radiation diffusely over an angle of 120°, and the radiation intensity depends on the distance from the radiating body to the irradiated body. The intensity of the radiation decreases with increasing distance.

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1. Accompanying scientific research of the residential building pilot project K76 in Darmstadt

The multi-family house K76 in Darmstadt was completed in the summer of 2017. The building technology system should be constructed with little material and space and should be decentralized, low-maintenance, flexible and durable.
The infrared heating system was therefore chosen for the heat supply, whereby depending on the size of the apartment, panels of different sizes were installed on the ceiling, which are controlled by thermostats in each room.
The domestic hot water is heated by continuous flow heaters, and a 36 kWp PV system provides energy for partly self-consumption (13% for IR heating from the PV system). To minimize energy consumption a ventilation system with heat recovery was installed.

1,360m² of habitable surface offer space for 40 residents and 15 residential units between 50 and 120m².

The accompanying research is based on one hand on the data from the measurements of the energy consumption of the individual residential units during two heating periods (2017/18 and 2018/19) and on the other hand on the user survey about the individual comfort.

The most important results at a glance:

	EnEV-calculation	Heating period 2017/18	Heating period 2018/19
Final energy requirement	36,9kWh/m²a	32,3kWh/m²a	28,6kWh/m²a

(wheater adjusted)

The specific total energy requirement for IR heating, ventilation and hot water is significantly below the value calculated by the EnEV (German Energy Saving Regulation).
The reduction in the final energy requirement from the first to the second heating period could be related to the increasing drying of the building mass. Errors in the operation of the ventilation system or the thermostat settings were also optimized by the users in the second year of use, so that the heating power consumption was further reduced.

In the course of the project, further options were considered as possibilities to reduce the energy consumption, such as increasing the degree of self-use of the PV system. The conversion of hot water generation from flow-type heaters to decentralized hot water boilers with storage tanks could have reduction potential, since the flow-type heaters often cause high load peaks at times without solar radiation.

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The use of a power storage could also contribute to increase the self-sufficiency through the PV system.

The comfort and user-friendliness of the infrared heating system was determined by anonymized online questionnaires at different times over three heating periods. Basic hypotheses were confirmed:
- A comfortable room climate can be created with infrared radiation heating.
- The control technology is easy to use.
- A slightly lower room air temperature than in the previous living situation was classified as comfortable.

Based on the scientific investigation on the real object K76 it can be said in summary that the concept of „direct current heating“ works very well in thermally insulated new buildings.

2. Laboratory measurements

On the former site of barracks from the 1960s 4 identical rooms were built to carry out laboratory measurements.

Each room has a size of 32.8 m² and is equipped with different heat generators.The following setups were carried out:
- Room 1: water-based underfloor heating (Buderus air-water heat pump with 7.6kW output)
- Room 2: electric underfloor heating Devi / Danfoss (2.8kW power)
- Room 3: Redwell infrared heating (2 panels with 1.3 kW output) - ceiling mounting
- Room 4: Redwell infrared heating (2 panels with 1.3 kW output) - wall mounting (on the inside oft he outer wall)

All rooms were equipped with decentralized individual fans in order to obtain a realistic air exchange, since the rooms are uninhabited. An extensive measurement and control system in and around the test rooms was used to examine the various systems and the mode of operation of the Redwell heaters during four measurement phases.

The following questions were answered:

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Differences in electricity requirements of various heat generators in real operation

The heat consumption of the ceiling-mounted Redwell IR heaters is lower than that of the heat pump during all measurement phases, as shown in Figure 68.

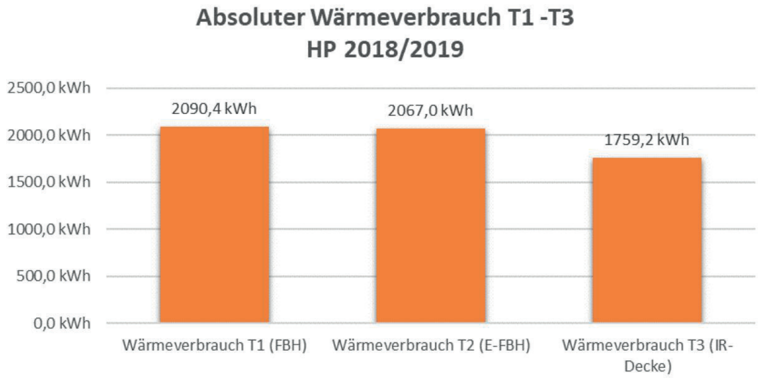

Abb. 68 Wärmeverbrauch Raum T1-T3, Messphase 1-4, Heizperiode 2018/2019

The positioning and the hysteresis of the control always have an influence on the electricity and heat consumption of the IR heating.
From the measurements it can said that it is better if the IR heater is mounted on the ceiling (less convection), the hysteresis is 0.5K and the room is ventilated by a ventilation system with a heat exchanger.

Indoor surface temperatures for IR heaters

The measurements of the laboratory rooms showed that the average surface temperature in the room with the two Redwell infrared panels, together with the heating surfaces, is on average 0.6K higher than in the room with underfloor heating. These results also occurred in the object K76 in the measurements of the inner surface temperatures.

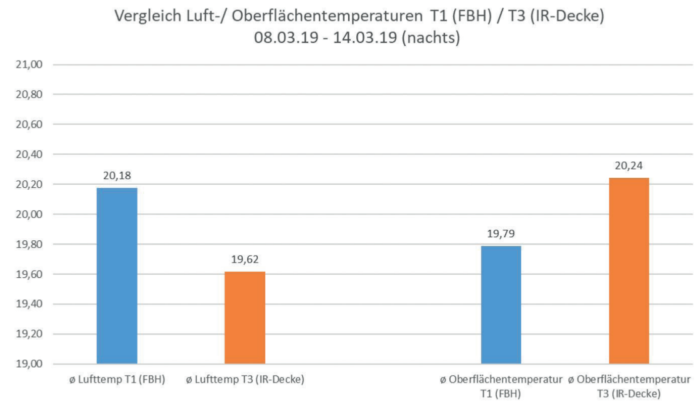

Abb. 74 Vergleich der nächtlichen Luft – und Oberflächentemperaturen zwischen Raum T1 (WP/FBH) und Raum T3 (IR-Decke) in Messphase 3 HP 2018/2019

Behavior of air temperature with IR heaters

In contrast to the surface temperature, the air temperature in the room heated with Redwell infrared heaters is on average about 0.6K lower than a room heated with underfloor heating. Thus, the room temperature can be reduced with the same comfort with the help of infrared heating and therefore the ventilation heat losses decrease, which in turn can save energy costs.

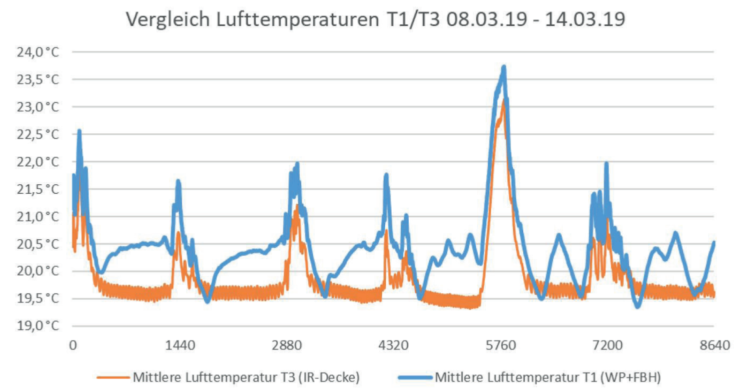

Abb. 85 Verlauf der Lufttemperaturen in Raum T1 (WP/FBH) / T3 (IR-Decke) bei Regelung nach operativer Temperatur, MP 08.03.19 – 14.03.2019

Savings through flexible control of the IR heaters

Contrary to inert underfloor heating systems, Redwell heaters can regulate the temperature in the room very quickly. This means that the heat given off by the heating can respond optimally to the heat demand.

In the measurements carried out, consumption differences between the underfloor heating and the Redwell infrared heatings of more than 15% were achieved. (see table 21).

Berechnete Differenzen im Wärmeverbrauch zwischen Raum T1 (WP/FBH) und Raum T3 (IR-Decke):

	Raum T1 (WP/FBH)	Raum T3 (IR-Decke)	Differenz
Differenz aufgrund niedrigerer Lufttemperatur nachts in Raum T3	10,17 kWh	9,82 kWh	0,36 kWh
Differenz aufgrund niedrigerer Transmissions-wärmeverluste in Raum T3	85,18 kWh	68,49 kWh	16,69 kWh
Differenz aufgrund höherer Übertemperatur tagsüber in Raum T1	25,86 kWh	22,49 kWh	3,38 kWh
Summe berechneter Differenzen im Wärmeverbrauch:			**20,42 kWh**
Gemessene Differenz im Wärmeverbrauch:			**21,90 kWh**

Tabelle 21 Berechnete Differenzen im Wärmeverbrauch zwischen Raum T1 (WP/FBH) und Raum T3 (IR-Decke)

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Radiation efficiency of IR heaters

Since the radiation efficiency of an IR heater determines what percentage of the supplied electrical energy is emitted to the room in the form of radiant heat, it is a decisive factor for the efficiency of an infrared heating system.
Measurements from various models are available on the market and showed large differences in the radiation efficiency of 40-70%. A standardization for this is still missing, so that a general definition can determine the quality of an IR heater.

3. Simulations of the laboratory rooms

Since the laboratory rooms have some special features (south-facing, uninhabitated...) a digital simulation model of the laboratory rooms was created in order to be able to transfer the measured values to standard buildings.

The simulation model was tested in three different validation phases to see whether the reality is represented correctly. The following questions were examined using the simulation model:

Transfer losses of an infrared heater

The laboratory measurements and the simulations show that compared to the Redwell heating system used, the transfer losses of a water-based underfloor heating system are approximately 50% higher. The fast reactivity and the low thermal inertia are only two main advantages of the infrared heating system.

Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) over 50 years - comparison of infrared heating and heat pumps

An infrared heating system, especially in combination with a PV system, delivers significant better parameters than a conventional heat pump system when it comes to the overall ecological life-cycle analysis, including production, maintenance and disposal. (see Figure 155)

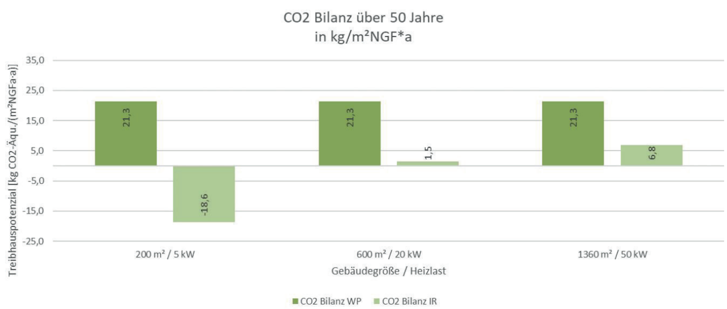

Abb. 155 Änderungen der CO2 Bilanz bei Verringerung der Gebäudegröße

	200 m² / 5 kW	600 m² / 20 kW	1360 m² / 50 kW
Wärmepumpe	21,3 kg CO2/m²a	21,3 kg CO2/m²a	21,3 kg CO2/m²a
IR-Heizung + PV	-18,6 kg CO2/m²a	1,5 kg CO2/m²a	6,8 kg CO2/m²a
Abweichung IR+PV	**-4088%**	**-1413%**	**-313%**

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Regarding the cost-effectiveness the heat pump variant generates higher investment, operating and repair costs, but lower consumption costs. With an infrared heating system in combination with a PV system (example K76), the operating costs are reduced significantly with the same or even lower investment. This option is therefore more cost-effective than the pure heat pump concept over a calculation period of 50 years.

The simulations allow the conclusion that the concept with a Redwell IR heating system with PV system clearly has economic and ecological advantages. The smaller and better insulated the building, the greater the benefits of the IR heating. (see Figure 154).

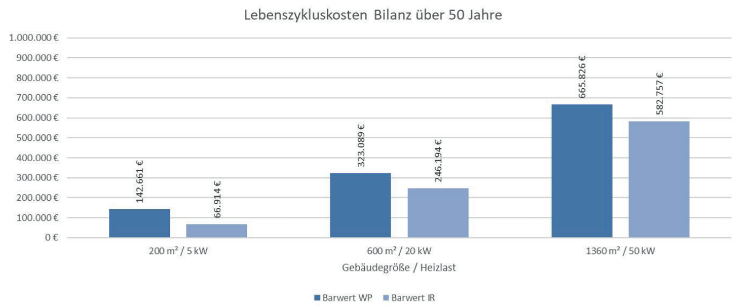

Abb. 154 Änderungen der Wirtschaftlichkeit bei Verringerung der Gebäudegröße

	200 m² / 5 kW	600 m² / 20 kW	1360 m² / 50 kW
Barwert Wärmepumpe	142.661 €	323.089 €	665.826 €
Barwert IR-Heizung	66.914 €	246.194 €	582.757 €
Abweichung IR	**-53%**	**-24%**	**-12%**

Can infrared heaters be an alternative to heat pump?

The advantages of a Redwell infrared heating (installation, monitoring, operability, investment,...) contribute to the fact that the electricity-based heating thanks to the local generation of renewable electricity is perfectly in tune with the energy transition. New single or multi-family houses or the modification of existing houses with a Redwell infrared heating system in combination with a PV system can drive forward the expansion of renewable energy. Besides it is less cost-intensive for the homeowner than installing a heat pump system. The project shows that it is possible to have the same or even lower use of electricity as a heat pump system, with the infrared heating system including a PV system which is also optimized for self-consumption.

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4. Conclusion

The IR construction project, in which the Redwell Manufaktur GmbH participated as a partner, with its diverse research approaches was able to demonstrate some advantages of infrared heating compared to underfloor heating.

Although a heat pump is the more efficient system for heat generation and also has a lower power requirement, this is offset by the significantly lower investment costs of an infrared heater. A Redwell infrared heating system combined with a PV system can also make a profit by covering its own needs in winter and electricity excess in summer.

The combination of infrared heating as a heat generator with a photovoltaic system as a regenerative energy source should become the standard in order to take full advantage of the ecological and economic advantages of both systems. The falling price development for PV systems could further improve these advantages in the future. If the hot water is also heated using an electric boiler or decentralized domestic hot water heat pumps and a further combination of an electricity storage system, the infrared system, together with its very flexible control, offers great potential.

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