Energy and Costs Savings by Re-Fitting Individual Room Temperature Control Systems for Floor Heating

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1. Introduction

The stipulations of the Act on Energy Savings in Buildings (EnEG, 1976, 1980) require individual room temperature control for pump hot-water heating systems. Furthermore, for heating elements the requirement for re-fitting of heating systems applies. For floor heating systems, individual room temperature control was not required until German Heating Systems Regulation (HeizAnlVO) went into effect in 1994.

From 1989 to 2003, 5.62 million housing units (HU) were completed, of which 2.8 million HU were in single-family homes (SFH) and two-family homes (TFH) and 1.2 million were owner-occupied HU in multi-family houses (MFH) [1]. At a conservative estimate, this results in a potential of approximately 2 million housing units with hot-water floor heating systems [2]. The resulting consolidated potential for re-fitting with individual room temperature controls is approximately 1 million hot-water floor-heating systems.

The German "Bundesverband Flächenheizungen und Flächenkühlungen e.V." (BVF) tasked the Technical University Dresden with determining the energy savings potential of individual room temperature controls for surface heating systems [3]. Goal of the analysis was to characterize the savings potential with individual room control processes in comparison to systems without individual room control. The analysis was conducted using a typical single-family home. The system used for analysis was a poured floor system according to DIN EN 1264 [4] (16mm pipe plus 45 mm floor pavement cover via cement screed). The heat insulation level of the building adheres to the conditions in the Heat Insulation Ordinance of 1977 (WSVO77) [5].

2. Analysis

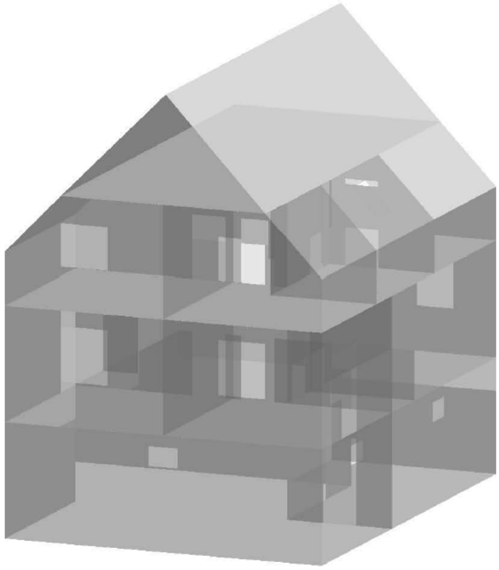

Figure 1.1. Schematic illustration of the examined one-family home

Two scenarios were examined for the central operational regime of the system:

- Continuous heating operation throughout the entire heating period without centralized and de-centralized lowering of temperature
- Lowered heating operation during the time from 11:00 p.m. until 05:00 a.m. respectively.

On the central side, meaning there was a weather guided inlet temperature control according to the heating curve. Locally, room temperature control via two-position controller and non-controlled systems were examined. The exact parameters for these variations can be extracted from the following list:

System parameters:

- Floor heating: according to DIN EN 1264 (system A / wet system) [4]
- Valve drives: thermoelectric, 180 s response time
- Two-position controller differential gap: X_{sd} = 0,5 K
- Non-controlled system: adjustment of the standard mass flow
- Inlet temperature: weather guided according to heating curve
- Nominal temperatures: $\vartheta_{op;soll}$ = 20 °C – normal rooms; $\vartheta_{op;soll}$ = 24 °C - bathroom
- Design temperature level: ϑ_V /ϑ_R/ϑ_i = 50°C/ 40°C/ 20°C

Operating parameters:

- Reduced temperature phases - central: 11:00 p.m. – 05:00 a.m.
- Heat-up phase - central: 05:00 a.m. - 07:00 a.m.
- Reduced temperature phases - local: none

2.1. Model description

2.2. Analysis Software

Within the framework of the analysis the thermal building simulation program TRNSYS [6] was applied. TRNSYS stands for "Transient System Simulation Program" and was developed at the University of Wisconsin, Madison (USA) in the 1970s. See comprehensive description of details in [3]. The building model was largely expanded and improved at the Institute for Thermodynamics and TGA and at the Institute for Energy Technology at the TU Dresden. Within the framework of IEA task 22 [7] and [8], [9] and [10] the implemented modules were extensively expanded and validated.

2.3. Heat Distribution System

It is also necessary to base the calculations upon a representative structure concerning the heat distribution system. For the analysis of surface heating systems, a star-shaped laying according to figure 2.1 was used. Within the net, the zones 14 (basement hallway) and 10 (bathroom) were provided with a free heating surface. This was necessary, since floor heating cannot supply the required heating load of the above-mentioned zones due to limited surface use. All examined types of laying were subjected to a complete hydraulic alignment. The dimensioning of heating elements and floor heating included an additional allowance of 15% in the functional rooms. For the bathroom and basement (staircase), an over-sizing of the local heat carrier by 50% was planned.

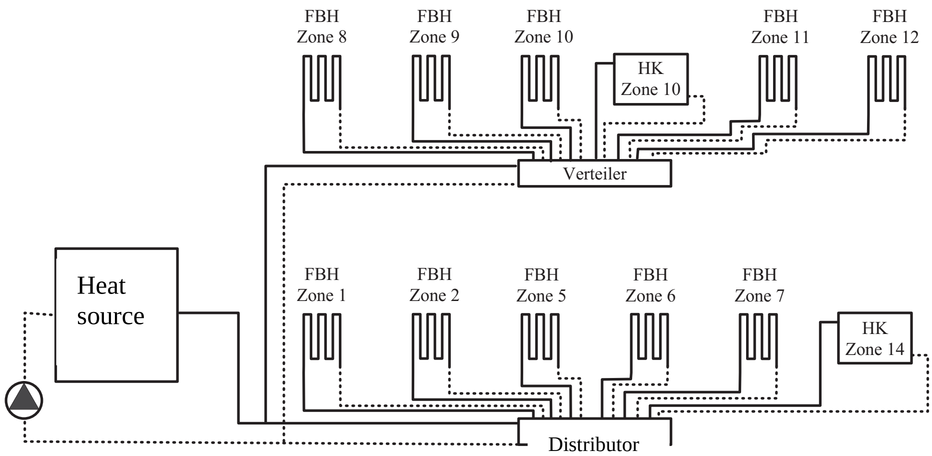

Figure 2.1. Star-shaped distribution for a mixed system with floor heating and free heating surfaces (basic principle)

2.4. Marginal Conditions

The following paragraph documents the applied external and internal marginal conditions of the numerical simulation. Weather data according to the specifications in [11] were used for input data for the external thermal marginal conditions. Specifically, the data set for the test reference year 04 (TRY-04) was used, which is representative of the "Lowlands in North-Eastern Germany". All data deposited in TRY-04 are calculated values originating from a large number of different performance data. In order to be able to assess the degree of deviations of these data from the values of local weather stations, selected TRY-04 data were compared to those of the weather station Potsdam (30-year mean) in figure 2.2. The diagram shows a large degree of concurrence. The analyzed balance period was selected based up the TRY-04 [11] weather data. Basis for the selection process was the median daytime temperature according to [12]. The heating period was limited by a median daytime temperature of a = 15 °C (compare [13]), which was exceeded on three consecutive days. According to this definition, the result is the heating period shown in figure 2.3.

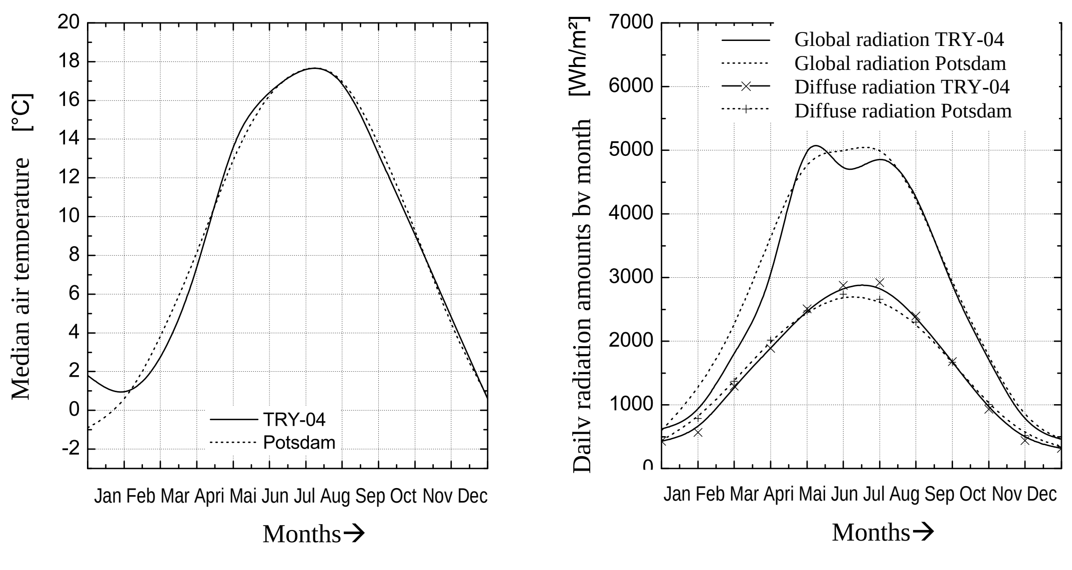

Figure 2.2. Weather data of the test reference year 04 in comparison according to [11]

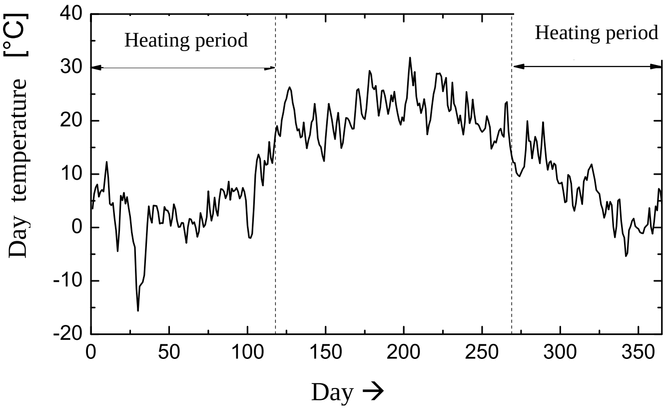

Figure 2.3. Mean day temperature / heating period for the period of analysis

2.5. Model Description

Within the program, the balance period (heating period) as such was preceded by a two-month oscillation phase in the building model, in order to reach suitable thermal start conditions in the perimeter construction. The values documented in table 2.1 were used as basis for the internal loads in the individual rooms. A typical daily routine was simulated. The respective profiles are provided in [3]. The described internal heat gains were agreed upon, 50% as convective gain and 50% as radiative gain, respectively.

Room	Performance [W]	Specific Load [W/m^2]	Sources / standard
Person (normal activity)	126.0	-	EN ISO 7730 [14]
Person (resting)	82.8	-	EN ISO 7730 [14]
TV	100	-	blanket assumption VDI
Illumination	-	10	2078 [15] blanket
Other equipment	50	-	assumption

Table 2.1. Load assumptions in the room according to VDI 2078 [15] /EN ISO 7730 [14]

Next to the internal gain, different time dependent air exchange rates were defined for the individual rooms. These are also documented in [3] and no further comments are included at this point. The object of investigation for the basic option was a usage profile with heat reduction at night, requesting a nominal temperature of $\vartheta_{op,nom}$ = 20 °C for the functional rooms and a nominal temperature of $\vartheta_{op,nom}$ = 24 °C for the bathroom.

3. Results of Analysis

Table 3.1 shows the energetic results of the analysis. Here, the parameters were divided according to the requirement chain: heat dissipation of the distribution system (Q_{RLu} / Q_{RLb}), heat dissipation of local room heating surfaces (Q_{FBH} / Q_{HK}) and total energetic expenditure (Q_{tot}). In addition, table 3.1 shows the resulting additional energetic expenditures for locally non-controlled systems in comparison to locally controlled systems. Here, three different valve adjustments for the regulation of standard mass flow were assessed for the non-controlled system.

Option	**Qtot [kWh]**	**$Q_{RL,u}$ [kWh]**	**$Q_{RL,b}$ [kWh]**	**Q_{FBH} [kWh]**	**Q_{HK} [kWh]**	**Δ_{Qtot} [%]**
Intermittent operation						
controlled	33399	127	1648	27641	3983	-
non-contr. (H_{vent}= 0.25)	36426	124	1657	30977	3667	9.1
non-contr. (H_{vent}= 0.5)	37076	124	1655	31663	3634	11
non-contr. (H_{vent}= 1.0)	37274	124	1654	31876	3620	11.6
continuous operation						
controlled	34117	142	1795	27702	4478	-
non-contr. (H_{vent}= 0.25)	40354	135	1814	34645	3759	18.3
non-contr. (H_{vent}= 0.5)	41071	135	1811	35419	3705	20.4
non-contr. (H_{vent}= 1.0)	41289	136	1811	35658	2930	21

Table 3.1. Energetic characteristics of the analyzed control options

The energetic characteristics in table 3.1 show that there are significant energetic differences between the controlled and the non-controlled options. For the intermittent operation, energetic differences regarding heating requirements of up to 11.6% were determined. For continuous operation, the respective values are around 21.0% additional expenditure in comparison of a non-controlled to a controlled local heat input. There were only minor energetic differences between the non-controlled options, since the valves were of sufficiently large dimension. In addition to the energetic statements, figures 3.1 and 3.2 document the average values of operational room temperatures for the most important usage zones during intermittent operation. The pictured curved lines show that the nominal values of the operational room temperatures in the main usage zones were very well met. The values for cases where the system was not equipped with an independent local control device show an operational room temperature that is approx. 1.5 - 2 K higher. The situation in the bathroom proved to be critical (figure 3.2). Here an operational room temperature of op = 24 °C cannot be guaranteed, especially during transition time. This is essentially because the applied heating curve has a low end of 20 °C. On the other hand, dynamic heating-up processes and internal heat loss to the neighboring rooms played a role.

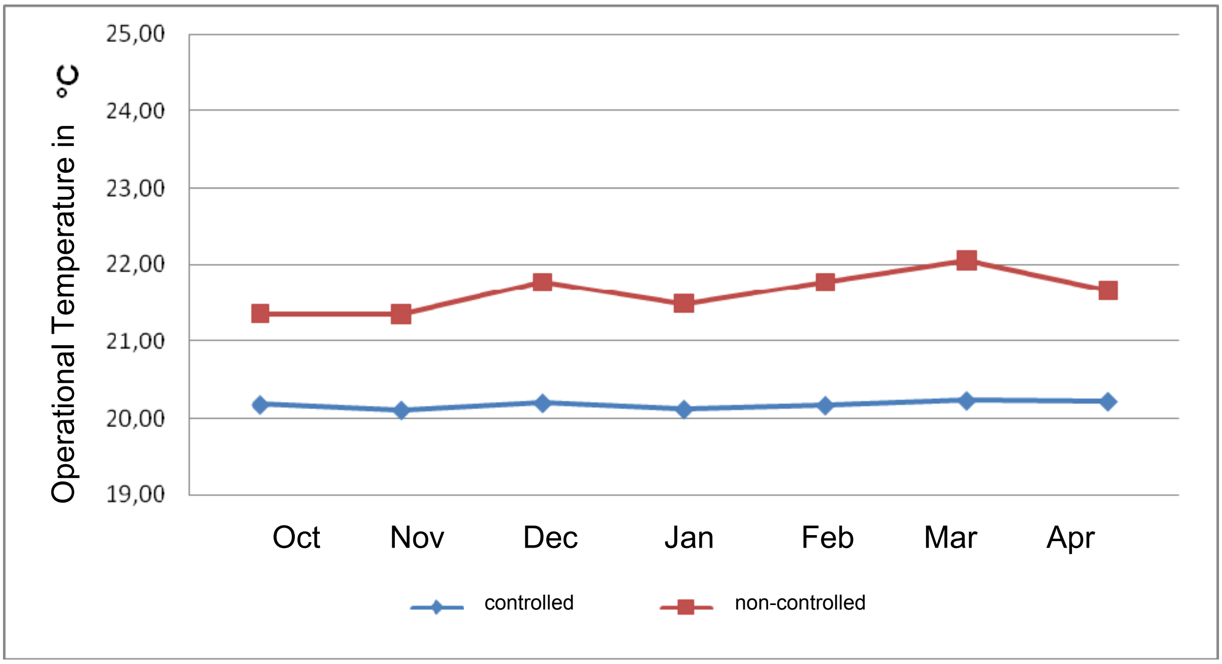

Figure 3.1. Monthly average values of operational room temperature in zones 1, 2, 5, 6, 8, 9, 11 (contolled / non-controlled option H_{vent} = 1.0; intermittent operation)

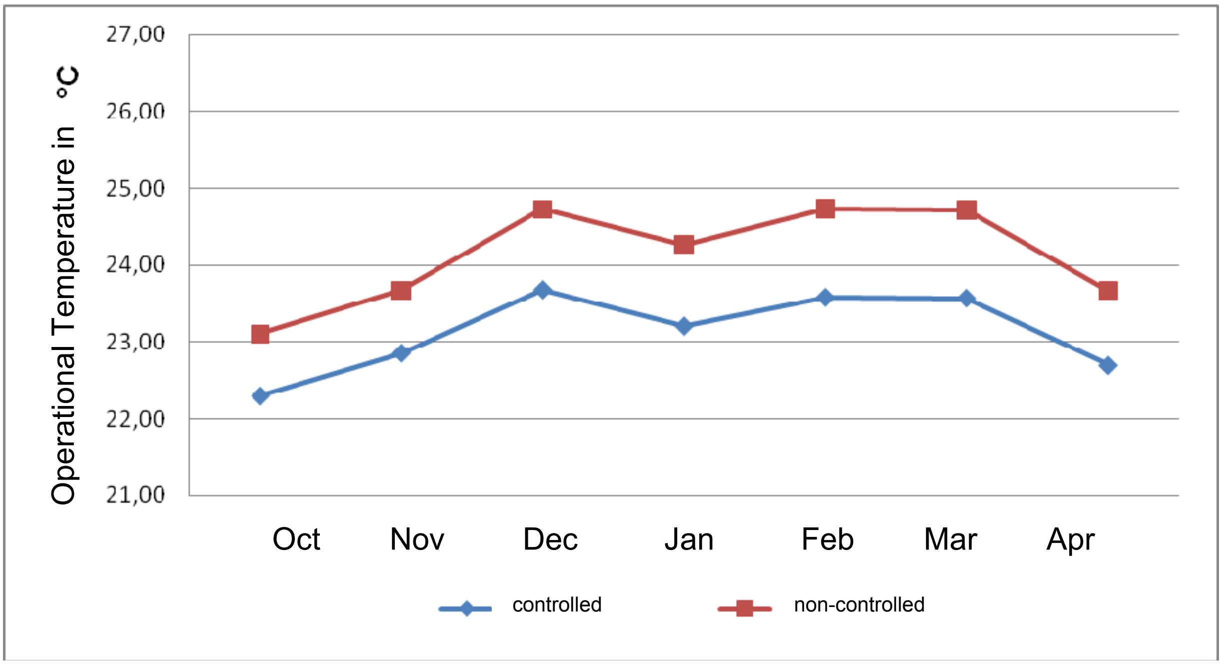

Figure 3.2. Monthly average values of operational room temperature in zone 10 (controlled / non-controlled option H_{vent} = 1.0; intermittent operation)

The respective operational room temperatures for continuous operation can be extracted from figure 3.3 and 3.4. For the controlled options in zones with a nominal temperature of 20 °C, the conditions determined were almost identical with those for intermittent operation. There is a clear difference in the level of operational room temperature in non-controlled operation. Here the operational room temperatures were around 1 - 1.5 K higher than during intermittent operation. Especially in the bathroom, there were no periods with predicted undercut of nominal values here.

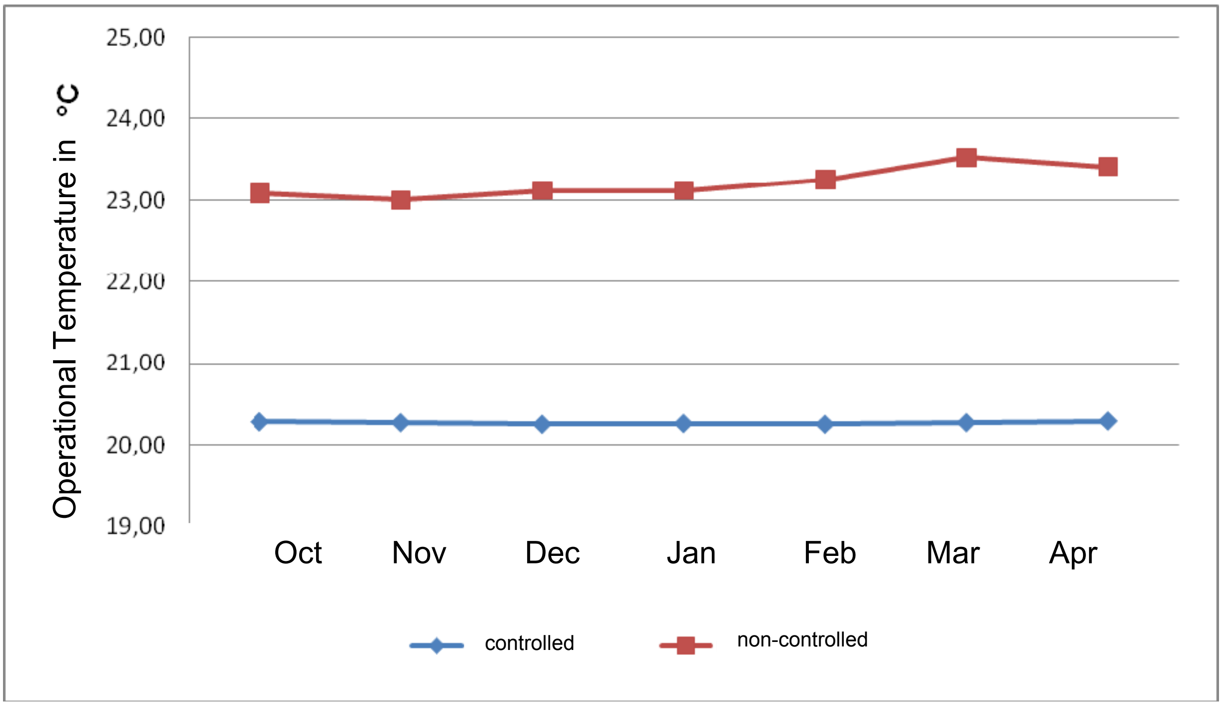

Figure 3.3. Monthly average values of operational room temperature in zones 1, 2, 5, 6, 8, 9, 11 (contolled / non-controlled option H_{vent} = 1.0; continuous operation)

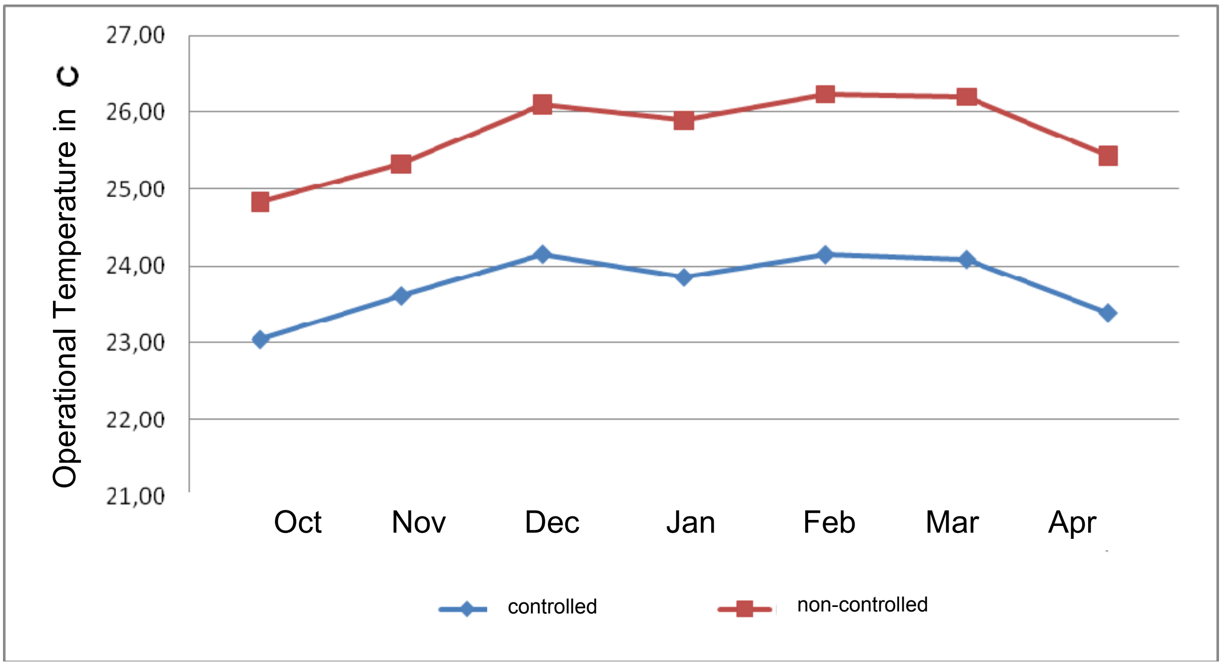

Figure 3.4. Monthly average values of operational room temperature in zone 10 (controlled / non-controlled option H_{vent} = 1.0; continuous operation)

Figures 3.5 and 3.6 show the operational room temperatures and, as a final item, the cumulative frequencies within the usage time for the selected options. For the controlled options with intermittent operating method it becomes apparent, that the nominal temperatures cannot be fully met, a fact that is essentially based upon the sluggishness of modeled floor heating systems. Upon conclusion of the heating-up phase after lowering the temperatures at night, the floor heating system could not reach the nominal temperatures in all rooms. The difference compared to the stated nominal value, however, is small.

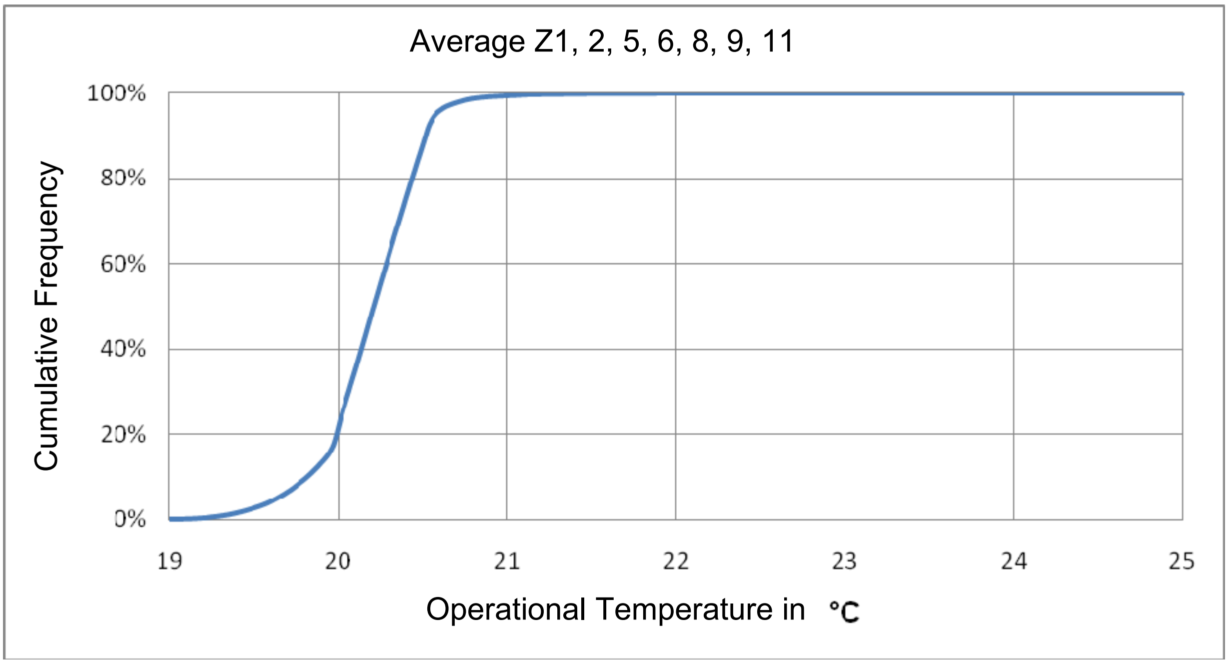

Figure 3.5. Cumulative Frequency of Room Temperature (Average Value in Zones 1, 2, 5, 6, 8, 9, 11; intermittent operation; controlled option)

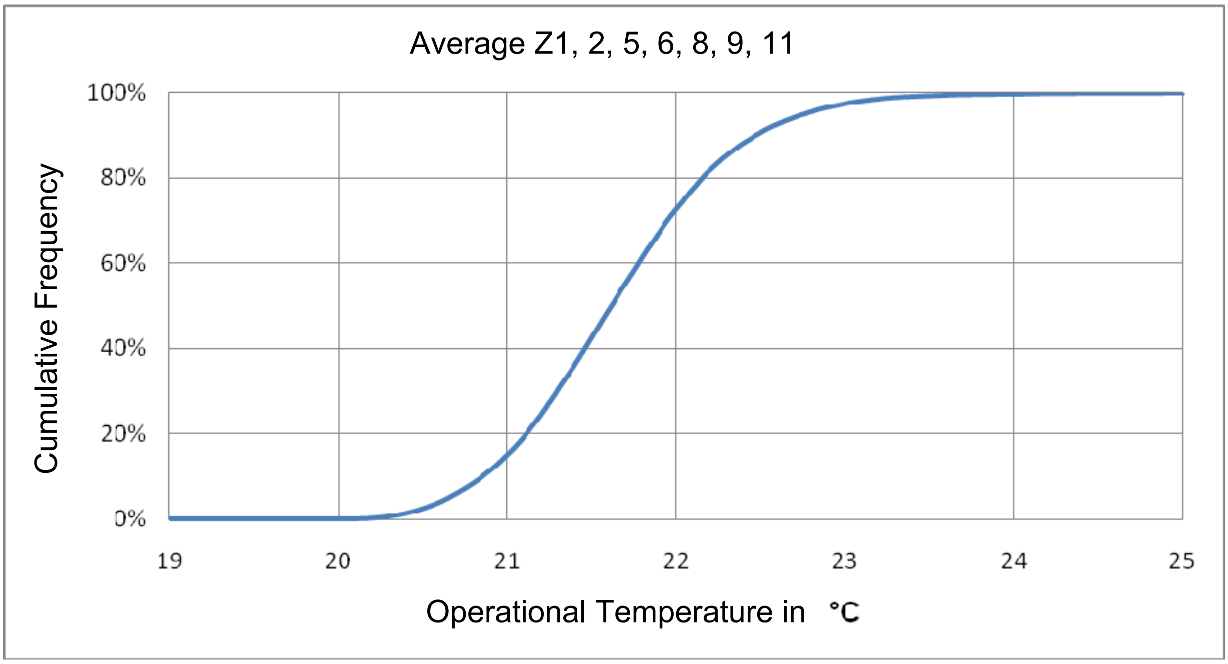

Figure 3.6. Cumulative Frequency of Room Temperature (Average Value in Zones 1, 2, 5, 6, 8, 9, 11; intermittierender Betrieb; non-controlled option H_{vent} = 1; 0)

For the comparable non-controlled case (figure 3.6), the rooms showed a higher median room temperature. A lack of comfort is not to be expected. At an average, the operational room temperatures were at least op = 1K higher than the operational room temperatures of the controlled option (figure 3.5). As a final item, figures 3.7 and 3.8 document the cumulative frequencies of the operational room temperature for continuous operation. Especially for the controlled option, undercutting of nominal values could not be detected. The cumulative frequencies for the non-controlled case were considerably higher than those for the intermittent operation. At an average, room temperatures of more than op = 22 °C were achieved.

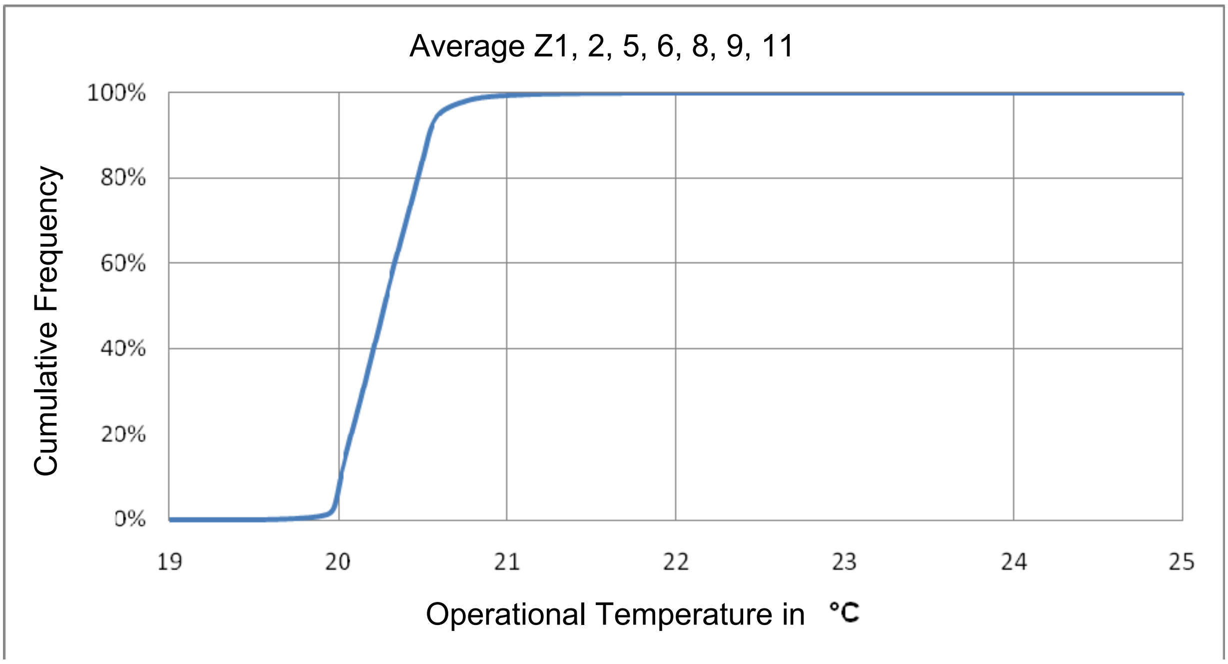

Figure 3.7. Cumulative frequency of room temperature (average value in zones 1, 2, 5, 6, 8, 9, 11; intermittent operation; controlled option)

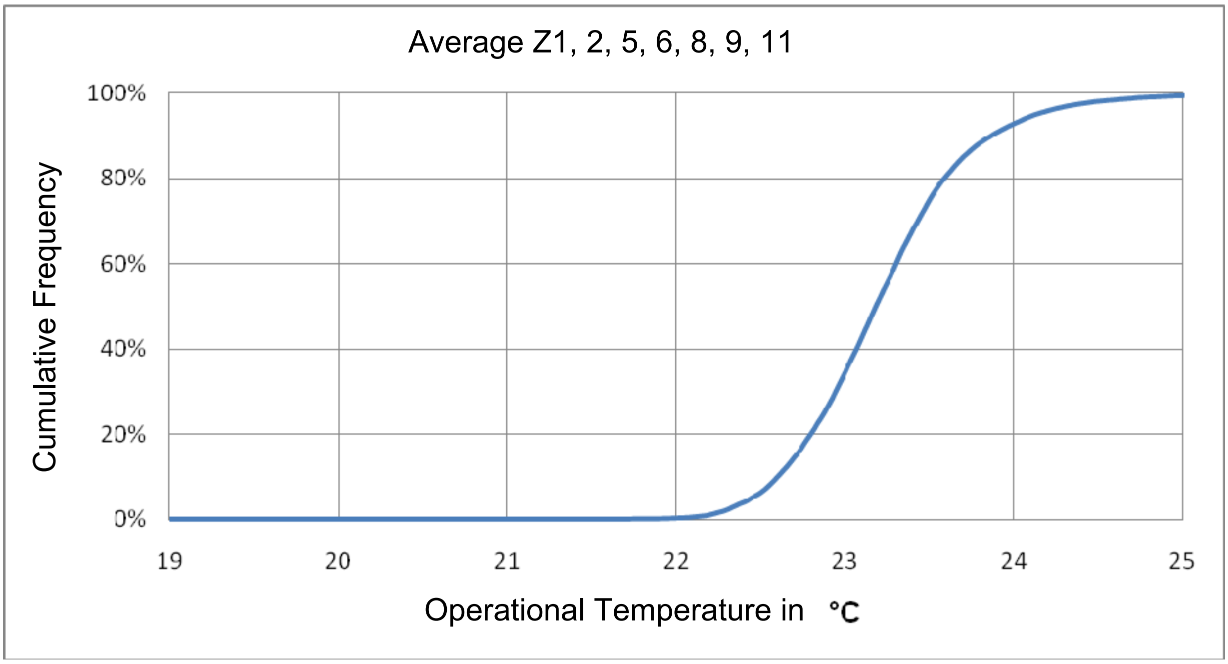

Figure 3.8. Cumulative frequency of room temperature (average value in zones 1, 2, 5, 6, 8, 9, 11; intermittent operation; non-controlled operation H_{vent} = 1; 0)

Table 3.2 documents the energetic and heat physiological explanations and, as a final item, the median surface temperatures for the main usage zones. In principal, it became apparent, that lower median surface temperatures were determined for the intermittent operation than for the continuous operation. The maximum difference is here up to $\Delta\vartheta_{OF}$ = 3K. From the perspective of absolute values, of course, significantly higher surface temperatures were achieved in the bathroom. Here, the median values listed in table 3.2 were within the framework of permissible maximum values according to DIN EN ISO 7730 [14]. For the medium surface temperatures in the functional rooms the permissible maximum values according to DIN EN ISO 7730 [14] were not achieved.

Option	**Surface temperature [°C]**	
	Functional Rooms (zones 1, 2, 5, 6, 8, 9, 11)	**Bathroom (zone 10)**
Intermittent operation		
controlled	23.60	28.43
non-contr. (H_{vent} = 0.25)	24.83	28.76
non-contr. (H_{vent} = 0.5)	25.15	28.90
non-contr. (H_{vent} = 1.0)	25.25	28.94
continuous operation		
controlled	23.95	30.42
non-contr. (H_{vent} = 0.25)	26.91	31.27
non-contr. (H_{vent} = 0.5)	27.27	31.43
non-contr. (H_{vent} = 1.0)	27.38	31.46

Table 3.2. Median surface temperature of floor heating

These median surface temperatures are also interesting with view upon assessment of self-regulation effects for surface heating systems. The self-regulation effect, meaning the limitation of heat dissipation, is considerably dependent upon the excess temperature (temperature difference surface - room air). When using the values in table 3.2 as a basis, the surface temperatures (rooms with op = 20 °C, intermittent operation) were at an average 2.5 K over the operational room temperature. For the non-controlled option with H_{vent} = 1.0 a temperature difference compared with room temperature of 3.4 K was determined. This means that internal gains can better be used via an individual room control method, since the temperature difference that needs to overcome is smaller.

4. Conclusion of Energetic Considerations

Within the framework of this study, individual room control systems were assessed from an energetic point of view. A system that was not equipped with independent local control units was assessed as a comparative case. The analysis was based upon a typical freestanding single-family home with a net floor space of 160 m^2. The single-family home met the requirements of WSVO77.

The energetic results showed that local individual room control systems that relate directly to the room temperature have considerable energetic advantages in comparison with not continuously controlled systems. Within the framework of this study, energetic advantages of up to 11.6% were proven during intermittent operation. For continuous operation the energetic advantages of a individual room control system was up to 21.0%. A reduction of the valve position during the non-controlled operation enables the reduction of additional energetic expenditures. In these cases, the maximum additional energetic expenditures were around 9.3% (intermittent operation) or 18.3% (continuous operation). Therefore, the results of this study show that a local independent control can unlock high energy savings potentials for floor heating systems. At this point we would like to point out, that the purely percentile details of potential savings only apply to the analyzed class of buildings. An economical efficiency analysis, however, will always require the use of the absolute energetic savings potentials. In this case these ranged between 25 - 44 kWh/m^2a as it relates to the least favorable case without independent individual room control. The results of this study are also interesting in view upon the assessment of the "self regulation effect", which is often controversially discussed among specialists. The use of individual room temperature control systems reduces the temperature difference between surface temperature of the heating system and of the room. This results in better utilization of internal thermal gains. I. e., the "self regulation effect" is better utilized in case of surface heating systems with individual room temperature controls than in case of those without independent local control devices.

5. Economic Efficiency of Re-Fitting with Individual Room Temperature Controls

An assessment of the economic efficiency in case of re-fitting of old floor heating systems with individual room control systems was conducted against the backdrop of the above mentioned energetic assessment. Basis for this evaluation was the calculated savings potential according to table 3.1, visualized in figure 5.1.

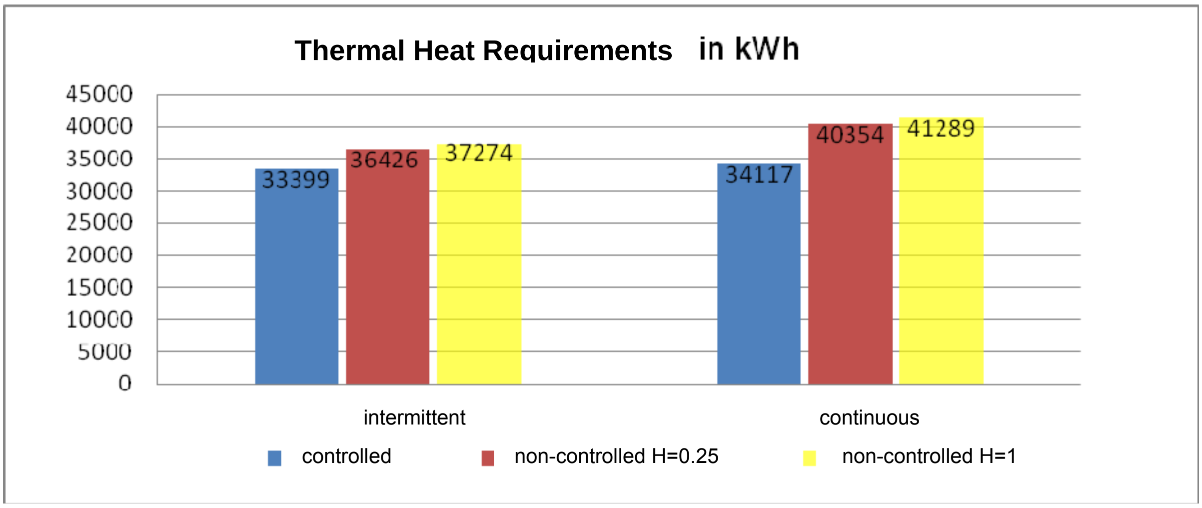

Figure 5.1 Thermal heat requirements in kWh/year under various operating conditions

5.1. Energy Cost

Based upon information provided by the German Federal Statistical Office, the price per kWh heating energy, produced from natural gas, for private households was 6.47 cent for the 1st half-year of 2009

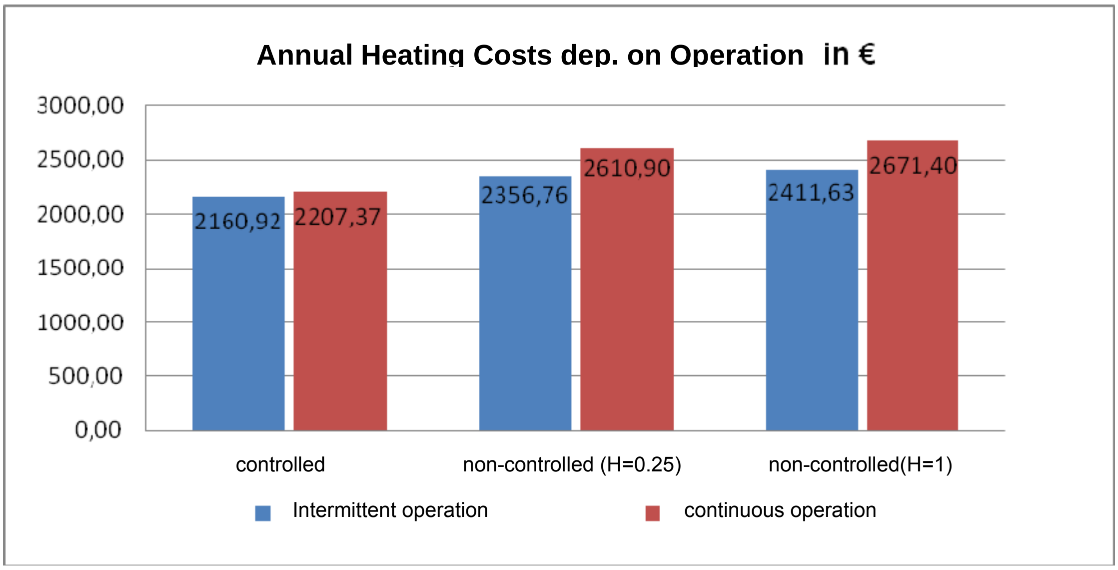

Figure 5.2 Annual heating cost in €/year under various operating conditions

Figure. 5.2 shows that use of individual room temperature controls in comparison with non-controlled operation results in considerable savings. Comparable savings could be achieved for continuous and intermittent operation, respectively. In case of comparison of the non-controlled condition (H=1) with the controlled condition for continuous operation, for example, the savings amount to € 464.03 annually. The annual cost savings for the intermittent operation during comparison of the same operation modes amounts to € 250.71. An alignment of valve adjustment during non-controlled operation (comp. H=0.25 / H=1) can result in additional savings in the operation modes, but to a lesser extent. Basically, this leads to the conclusion that the lowest heating costs result from intermittent operation of the heating source in conjunction with the use of individual room temperature controls.

5.2. Purchase Costs in Case of Re-Fitting with a Individual Room Control

The simplest type of re-fitting, and one that is realized with minimal effort, is the use of a radio-controlled individual room temperature control solution. This type of system makes wire connections between room temperature controls and receiver units in the distribution box of the heating circuit obsolete. Therefore, these systems are very well suited for re-fitting. The following components are needed to equip the single-family home examined in the analysis (see figure 1.1), according to the schematic diagram of the heating system in figure 2.1:

10 pieces radio room temperature control (1 each per controlled room)

2 pieces receiver units (one each per heating circuit distributor)

10 pieces Actuators (one each per controlled heating circuit)

The material cost for such individual room temperature control solution, at an average, amount to € 1700 incl. VAT. This figure is based upon average prices of systems by reputable manufacturers, which are available on the market. The labor costs for installations were estimated to be € 200 incl. VAT (rounded). This corresponds to approx. 4 work hours with an hourly rate of approx. € 40, consistent with the rate for an average specialist. The purchase costs were estimated to amount to a total of € 1900.

5.3. Reduction of CO_2 Emissions via Individual Room Temperature Control

Based upon the result data of the GEMIS project by the Federal Environment Ministry, production of one kWh heating energy from natural gas produces 0.23 kg/kWh CO_2.
Consideration of the operational modes shown in chapter 5.1 (H = 0.25) as astarting points from this point of view, results in the following CO_2 emission reductions per calendar year for the sample system, under consideration of figure 5.1:

a. 6237 kWh/a for intermittent operation of the heat source
   6237 kWh/a x 0.23 kg/kWh = 1434.5 kg CO_2/a
b. 3027 kWh/a for intermittent operation of the heat source
   3027 kWh/a x 0.23 kg/kWh = 696.2 kg CO_2/a

Considering a re-fitting potential of one million non-controlled hot-water floor heating systems nationwide (Germany) (also see chapter 1), results in a possible annual total emission reduction of 1,434,500 tons CO_2/a for continuous operation, as it pertains to natural gas. After all, for intermittent operation 696.200 t CO_2/a could be saved this way as well.
Since April 1, 2009, the Federal Government has been granting an allowance of 25% within the framework of the KfW special subsidy (431) “energy efficient redevelopment”. This supports special measures to reduce the CO_2-emissions of existing housing units. This also includes the optimization of heat dissipation through improvement of control technology of existing heating systems.

5.4. Payback Period Individual Room Temperature Control

Basis for the calculation of the payback period was the non-controlled condition (H=0.25) as start condition, since here the maximum possible optimization has already been achieved through hydraulic adjustment. Furthermore, the KFW subsidy mentioned in chapter 5.3 was included in the calculations.

One-time KFW subsidy on the purchase price: 25% of € 1900 = € 475 ! Therefore an investment sum of € 1425 remains to be raised. Based upon this and under consideration of the respective annual savings, the following payback periods result in the respective operation modes in case of re-fitting with a individual room temperature control:

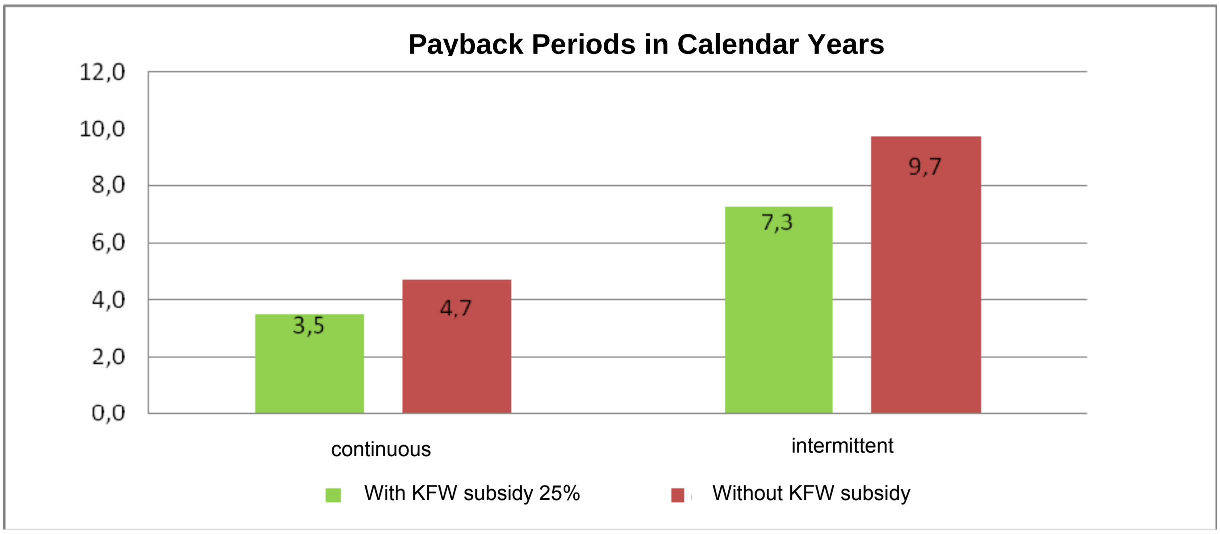

Figure 5.3 Payback periods for the retro-fitting with radio individual room controls

Figure. 5.3 clearly shows that re-fitting with individual room temperature controls pays back especially fast in systems that do not allow, for example, programming of times where temperature is lowered for the intermittent operation. In view of the tendency toward rising energy costs, an even faster payoff can be anticipated for such investments.

6. Conclusion of Economical and Environmental Considerations

Against the backdrop of the proven savings potential, the retrofitting with radio individual room controls in existing floor heating systems constitutes a modernization goal of highest priority. Especially in older buildings, the necessary investments pay off under consideration of the KfW subsidy and continuous heating operation within a time period of 3.5 years and for intermittent operation within 7.3 years.

For the examined model building, the ecological advantages through retro-fitting add up to a CO_2-emission savings or 1434.5 kg CO_2 per year for continuous operation of the heat source. For intermittent operation 696.2 kg less CO_2 is emitted per year. The total CO_2-reduction potential for old systems in the Federal Republic of Germany is 1,434,500 tons CO_2/a for continuous operation. For intermittent operation 696,200 t CO_2/a could be saved.

In addition to the described economical and environmental reasons, ease of usability when choosing the individual room temperature and heating time and the increase of thermal comfort speak for retro-installation of radio individual room temperature controls. Interesting, new areas of activity open up for planners and installation firms.

Bibliography

[1] German Federal Statistical Office: Construction activity and apartments. Mikrozensus-Zusatzerhebung 2002, Bestand und Struktur der Wohneinheiten, Wohnsituation der Haushalte. Wiesbaden 2002

[2] Deutsche Gebäudetypologie, Systematik und Datensätze. Institut Wohnen und Umwelt GmbH, Darmstadt 2003

[3] Unpublished final report. Bundesverband Flächenheizungen und Flächenkühlungen e.V., Hagen. 2009

[4] Deutsches Institut für Normung e.V.: DIN EN 1264 : Room surface integrated heating and cooling systems with water flow part 1-5. 2007. Beuth Verlag GmbH, Berlin

[5] WSVO 1977: Ordinance regarding energy conserving heat insulation for buildings (Heat Insulation Ordinance). August 1977. Bonn: Federal Government

[6] Klein, S.A. et al.: TRNSYS 14.2 A Transient System Simulation Program. University of Wisconsin, Madison USA, 1996

[7] Felsmann, F. ; Gritzki, R. ; Le, H.: Joint project: Building Energy Analysis Tools, Solarbau, TK2: German collaboration in the partial project IEA-SHC-Task22: Simulation programs for NEH / Institute for Thermodynamics and TGA, TU Dresden.

[8] Perschk, A.: Building systems situation under consideration of the hygric processes in building walls, Faculty for Mechanical Engineering, TU Dresden, dissertation, 2000

[9] Gritzki, R.: Bestimmung der Effektivität nutzerbedingter Fensterlüftung mit Hilfe numerischer Simulationsverfahren, Technische Universität Dresden, Dissertation, 2001

[10] Seifert, J.: Zum Einfluss von Luftströmungen auf die thermischen und aerodynamischen Verhältnisse in und an Gebäuden, Fakultät für Maschinenwesen, Technische Universität Dresden, Dissertation, Oktober 2005

[11] Christoffer, J. ; Deutschländer, T. ; Webs, M.: Test reference years from Germany for medium and extreme weather conditions TRY. Deutscher Wetterdienst, 2004. - ISBN 3-88148-398-5

[12] Recknagel, E. ; Schramek, E. (Hrsg.): Pocket book for heating and air conditioning technology. Munich: 72. Ausgabe, R. Oldenbourg Verlag GmbH, 2005. - ISBN 3-486-26534-2

[13] Verein Deutscher Ingenieure: VDI 3808: Energy assessment criteria for heating systems. January

1993
[14] Deutsches Institut für Normung e.V.: DIN EN ISO 7730 Ergonomics of the ambient atmosphere - Analytical determination and interpretation of thermal comfort via calculation of the PMV and PPD index and criterial of local thermal comfort. 2006. - Beuth Verlag GmbH, Berlin 2001. Forschungsbericht
[15] Verein Deutscher Ingenieure: VDI 2078: Calculation of cooling loads of air conditioned rooms - VDI cooling load rules. 1996. - VDI - Room air technology handbook

Symbols / abbreviations

H_{vent}	Valve lift	%
Q	Heat	kWh
Q	Performance	W
X_{sd}	Differential gap	K
ϑ	Temperature	°C
ϑ_a	External temperature	°C
$\vartheta_{op;soll}$	Operational nominal temperature	°C
ϑ_V	Inlet temperature	°C
ϑ_R	Return temperature	°C
ϑ_i	Interior temperature	°C
$\Delta\vartheta_{OF}$	Temperature difference floor heating	K
Q_{RLu}	Heat dissipation of the distribution system pertaining to unheated room	kWh
Q_{RLb}	Heat dissipation of the distribution system pertaining to heated room	kWh
Q_{FBH}	Heat dissipation of the local room heating surface floor heating	kWh
Q_{HK}	Heat dissipation of the local room heating surface heating elements	kWh
$Qges$	Total energetic expenditure	kWh