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On the influence of local and zonal hydraulic balancing of heating system on energy savings in existing buildings – Long term experimental research

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ABSTRACT

The application of regulation valves in new and existing buildings allows for proper hydraulic balance of the heating system and in this way it may increase the energy efficiency of heating installation. Unfortunately, to the best of authors' knowledge, there are no long-term field studies that present the level of energy savings achieved by means of commonly used valves in engineering practice, such as thermostatic radiator valves (TRVs), under risers differential pressure control valves (DPCVs), pressure independent balancing radiator valves (PIBRVs), as well as a combination of them.

This article presents the results of field research conducted during 6 heating seasons in 16 multi-family buildings assigned to four groups, depending on the type of heating system modernization. The buildings in the first group had existing on-off valves located near the radiator that were replaced with TRVs, and hydraulic balancing of the heating system was performed by means of a pre-set. The second group of buildings was characterized by the installation of DPCVs under the risers of heating installation which was already equipped with TRVs; the third group encompasses the buildings with simultaneous installation of TRVs and DPCVs. The final group consisted of buildings in which the existing TRVs were replaced by pressure independent balancing radiator valves. The energy savings were calculated based on average heat consumption before and after modernization and ranged between 14.6% and 23.8%, depending on the type of the installed valves or their combination. The calculated payback time for the analyzed modernization actions was in the range between 1.4 and 4.9 heating seasons.

1. Introduction

Nowadays, one of the very important issues is the energy efficiency in buildings, due to the highest share of buildings in the overall energy use and requirements described in EU-Directive 2012/27/EU [1]. That is why there is still large potential of energy savings which could be obtained particularly in the existing buildings [2].

There are many studies in which different refurbishment strategies for buildings are proposed but focused mainly on the thermal insulation of buildings partitions [3–5]. In this regard, there are studies in which the new insulation materials based on thermal plaster [6], aerogel technology [7] or VIPs [8] are presented or the optimal insulation thickness is proposed [9], however the payback period, in this case, ranging from 5.5 to 12.1 years was estimated [10]. Another simple and inexpensive retrofit solution to obtain energy saving and benefits regarding the indoor thermal comfort may be applying innovative surface finishes on interior and exterior surfaces of the existing buildings [11]. However, while designing the building envelope refurbishment, it is worth using a cost-optimal methodology [12], in order to properly select the energy efficiency measures.

On the other hand, energy saving may also be achieved using proper control equipment or advanced control strategy in the existing heating system [13–18]. For example, the potential energy savings of zoned versus non-zoned control were estimated at the average level of 20% [19].

One of such commonly used solutions for local heating control is the thermostatic radiator valve (TRV) with a pre-set which allows local regulation of indoor air temperature in a heated room and is used for hydraulic balancing of the heating installation using its preliminary setting, which may generate energy savings [20–27].

However, there is no simulation or experimental research taking into account the energy savings, which may be obtained thanks to

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Table 1
General characteristics of the analyzed buildings.

Building	Year of construction	Heated floor surface area [m^2]	Number of apartments	Number of radiators
A1	1976	1685	38	102
A2	1977	1685	38	102
A3	1988	1218	30	86
B1	1980	2188	44	128
B2	1980	2174	44	128
B3	1992	2599	52	163
B4	1990	2595	52	162
B5	1990	2595	52	162
B6	1961	1866	40	110
C1	1960	1250	30	87
C2	1967	1450	34	96
C3	1959	1415	32	90
C4	1971	1142	28	80
C5	1973	1162	28	80
C6	1970	1150	28	80
D1	1991	2672	54	166

hydraulic balanced heating system, especially in large heating installation where the use of TRVs is insufficient for proper hydraulic balance.

This work shows field data from sixteen multi-family buildings and quantifies the actual energy savings resulting from the use of four configurations of commonly used valves for hydraulic balance of the heating system such as thermostatic radiator valves (TRVs), differential pressure control valves (DPCVs) and pressure independent balancing radiator valves (PIBRVs).

2. Materials and methods

For the purpose of assessing the impact of the commonly used hydraulic balancing devices of heating systems on the achieved level of energy savings, 16 multi-family buildings located in Lublin (Poland) were selected. The designed outdoor temperature for winter in Lublin is equal to −20 °C and the standard heating season lasts for 222 days per year. The buildings selected for analysis (Table 1) had 5 heated storeys and were built with similar construction between 1959 and 1992.

All the analyzed multi-family buildings were subjected to thermal insulation prior to the beginning of this analysis and were characterized by already insulated ceilings ($U = 0.390\,W\ m^{-2}\ K^{-1}$) and new double-glazed windows ($U = 1.8\,W\ m^{-2}\ K^{-1}$). In the case of external walls, the analyzed buildings were insulated with styrofoam ($\lambda = 0.045\,W\ m^{-1}\ K^{-1}$, 10 cm thick) and therefore their heat transfer coefficients were $U = 0.323\,W\ m^{-2}\ K^{-1}$.

The exceptions were buildings B4, B5 and B6 (Table 1), where there was no external wall insulation and the heat transfer coefficient of these partitions was at the level of $U = 1.15\,W\ m^{-2}\ K^{-1}$ by their thickness of 54 cm.

For the analyzed buildings, the heating energy was supplied from the high temperature district heating system, where the heat exchanger was used in individual thermal stations (located in the basement of each building) to transfer heat from the primary loop to the secondary loop. The supply temperature and the return temperature were controlled at 80 °C and 60 °C.

The individual thermal station in each building was equipped with a variable-speed pump and central control system based on the outdoor weather conditions, which allowed for adjusting the amount of heat supplied for heating according to the outdoor conditions.

The heating system in the analyzed buildings is a traditional central heating installation with horizontal, thermally insulated pipes (in the basement) connecting the thermal station with the thermally non-insulated risers (vertical pipes). Moreover, the connecting pipes between the risers and the radiators (installed on the external walls under the windows) in the heated rooms were not thermally insulated.

Due to the different range of modernization actions of the heating system in multi-family buildings (Fig. 1), they were divided into 4 groups (i.e., A, B, C and D), which was aimed at exposing the influence of commonly used control valves on the heat consumption in existing buildings.

Three buildings (A1, A2 and A3) were qualified to group A, in which the TRVs with the thermostatic head were installed in place of existing on/off valves on the supply connecting pipe (close to the radiator), and a hydraulic balance of the central heating installation by means of preliminary settings on TRVs was made. The utilized TRVs are characterized by the nominal diameter of 15 mm, 8 presetting options and the recommended differential pressure between 5 kPa and 25 kPa. In turn, the thermostatic heads had the built-in gas thermostatic sensors, which enable to regulate the room temperature in the range between 16 °C and 26 °C and to close the TRVs at a sensor temperature which is 2 °C higher than stated on the temperature scales.

In Group B, there are 6 buildings (B1, B2, B3, B4, B5 and B6), where differential pressure control valves (DPCVs) were installed under every riser of the heating system, which provide stable pressure difference in the riser for the existing TRVs. The used DPCVs had the nominal diameter equal to 15 mm and the differential pressure setting amounting to 10 kPa. Group B buildings were already equipped with the TRVs before the start of the field research. Group C comprises 6 buildings (C1, C2, C3, C4, C5 and C6), in which the DPCVs were installed simultaneously on each riser of the heating system with the TRVs on the supply connecting pipe of each radiator (instead of existing on/off valves) as well as hydraulic balancing with the installed valves (TRVs and DPCVs) was conducted. The technical characteristic of applied TRVs and DCPVs were similar to the valves installed in the case of group A and group B, respectively.

In turn, only one building was qualified to group D (due to the lack of other buildings with this range of modernization in the analyzed location), marked as D1, in which the PIBRVs were installed in place of the existing TRVs. The used PIBRVs were characterized by the nominal diameter equal to 15 mm, recommended differential pressure between 10 kPa and 60 kPa and 8 presetting options, which enabled to set the flow rate of heating medium between 20 and 125 dm^3 per hour. These valves act as the TRVs and provide stable pressure difference before the valve, similarly to the DPCVs.

The field research in the buildings included 6 full heating seasons (from the beginning of October to the end of April) and involved measuring the actual heat delivered to the analyzed buildings (Q_{supply}) at monthly intervals, using calibrated heat meters in-