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Actual energy savings from the use of thermostatic radiator valves in residential buildings – Long term field evaluation

Tomasz Cholewa [a,*], Alicja Siuta-Olcha [a], Constantinos A. Balaras [b]

[a] Faculty of Environmental Engineering, Lublin University of Technology, Nadbystrzycka 40B, 20-618 Lublin, Poland
[b] Institute for Environmental Research & Sustainable Development, National Observatory of Athens, I. Metaxa & Vas. Pavlou, GR-15236 Athens, Greece

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ABSTRACT

The use of pre-set thermostatic radiator valves (TRVs) contributes to the reduction of energy consumption and the increase of the energy efficiency of the existing heating systems in buildings. However, there are limited long-term experimental studies that document the level of energy savings achieved by the use of TRVs, quantified for three different options of their utilisation.

Long-term field data were collected over several heating seasons from nine existing multifamily residential buildings organized into three groups characterized by different modernization activities using TRVs. The first group includes the cases where the buildings are equipped with TRVs without hydraulic balance of the heating system with pre-set TRVs; the second group encompasses buildings that were already equipped with TRVs and then a hydraulic balancing of the heating system was performed by means of a pre-set; finally, the third group of buildings considers the simultaneous installation of TRVs and hydraulic balancing of the heating system using pre-set TRVs. The energy savings ranged between 7.1% and 23.3%, depending on the range of modernization activities using TRVs with or without hydraulic balance. The payback time was less than 2.5 heating seasons in all cases.

1. Introduction

The reduction of energy consumption in the residential sector is one of the priorities in developed countries, which is related to the requirements described in EU-Directive 2012/27/EU [1]. Taking this into account, the main actions focus on the reduction of energy consumption in existing buildings, because new buildings are already energy efficient in most cases. This may be achieved by modernization of building envelopes [2], raising the awareness of energy users [3–5] or application of additional control equipment in the existing heating system [6–8].

In new buildings, the control strategy of the heating systems utilises at least the central regulation based on weather conditions and some kind of local regulation such as thermostatic radiator valves or another kind of devices, which allow to control the indoor air temperature in a heated room. A more advanced control solution may use, for example, the model predictive control (MPC) [9,10], which contributes not only to energy savings [11], but also to energy peak reductions [12].

However, the energy retrofit activity in existing buildings should be widely applicable and offer low payback time of investment costs [13]. One such solution is the thermostatic radiator valve (TRV) with a pre-set, which is the most commonly used local heating control device. TRVs are utilised to control the indoor air temperature by regulating the flow of heating medium into a radiator and for hydraulic balancing of the heating installation by using its preliminary setting.

Tahersima et al. [14] designed a controller which is based on the proposed linear parameter varying (LPV), implemented in order to improve the stability of radiators under the low demand conditions. Xu et al. [15] developed a model for simulating the thermal and hydraulic behaviour of space heating systems with radiators controlled by TRVs in multi-family buildings. Then, they continued the research in this aspect [16] and proposed a control strategy, in which the supply water temperature is adjusted daily according to the flow performance of the system. Seifert et al. [17] proposed an analytical solution of the room temperature control loop which required only small a number of input parameters.

The aspects of energy savings achieved by the use of TRVs are also reported in the literature [13,18–20], but these results are mostly obtained from simulations. On the other hand, there is no long-term experimental research in existing buildings on energy savings achieved with different possibilities of TRVs utilization. This

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* Corresponding author.
E-mail address: t.cholewa@wis.pol.lublin.pl (T. Cholewa).

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Table 1
Characteristics of the analysed buildings.

Building	Year of construction	Heated floor surface area [m^2]	Number of flats	Number of radiators
A1	1951	762	20	57
A2	1951	980	19	56
A3	1951	762	12	48
B1	1951	762	12	48
B2	1959	2555	51	178
B3	1952	1139	28	80
C1	1969	793	22	60
C2	1965	2342	60	170
C3	1952	1169	29	86

work presents field data from nine multifamily buildings and quantifies actual energy savings resulting from the use of TRVs with a pre-set option.

2. Materials and methods

The work considers actual operating data from nine five-storey residential buildings located in Lublin (a city in Eastern Poland) which are connected to a high temperature district heating network. The data analysis was carried out during 6 heating seasons which were representative for modernization activities performed in selected buildings. The heating season for the analysed buildings started at the beginning of October and finished at the end of April.

The analysed buildings (Table 1) were built between 1951 and 1969, employing similar construction practices and heating installations. The external walls of the buildings

($U = 1.15\,W\,m^{-2}K^{-1}$, 54 cm thick) have no thermal insulation and consist of solid, ceramic bricks ($\lambda = 0.770\,W\,m^{-1}K^{-1}$, 51 cm thick) as well as cement-lime plaster ($\lambda = 0.820\,W\,m^{-1}K^{-1}$, 1.5 cm thick). The flat roofs ($U = 0.391\,W\,m^{-2}K^{-1}$, 40 cm thick) are prefabricated constructions with a layer of mineral wool ($\lambda = 0.052\,W\,m^{-1}K^{-1}$, 12 cm thick) covered by roofing felt. All windows in each building were replaced with new double-glazed ones ($U = 1.8\,W\,m^{-2}K^{-1}$) before the data collection and analysis had started. The occupants of the considered buildings remained the same in the course of the analysis.

Individual thermal stations were located in the basement of each building, where the high temperature heating medium was converted by means of a heat exchanger to lower the temperature (80/60 °C). Then the heating medium was transported to convective radiators located in each heated room of the flats by means of a traditional, central heating installation with vertical pipes, the scheme of which is shown in Fig. 1. Convective radiators in the heated rooms were installed on the external walls, about 10 cm under the window sill and about 10 cm above the floor.

Each individual thermal station was regulated by a central control system based on weather conditions, which enabled the proper temperature adjustment of the heating medium that was supplied to the heating system. The central decrease of the heat supplied to the building's heating system was not programmed to occur during the night.

The risers and pipes connecting the risers with radiators were not thermally insulated, in contrast to the horizontal pipes (in the basement) connecting the main thermal station with the risers.

Considering the different extent of modernization activities which may appear in the engineering practice related to the use of TRVs, the analysed buildings were divided into 3 groups (i.e. A, B, and C).

Group A includes buildings A1, A2 and A3. In this group of buildings, the thermostatic radiator valves were installed without hydraulic balancing of the heating system by means of preliminary settings of TRVs.

Group B includes buildings B1, B2 and B3, in which TRVs were previously installed without hydraulic balancing and operated so for several years. After 8 years of operation, the correct hydraulic balancing of central heating installation was performed by means of preliminary settings on the TRVs.

Group C includes buildings C1, C2 and C3, in which TRVs were simultaneously installed on all radiators in each apartment, followed by a hydraulic balance of the central heating installation by means of preliminary settings on TRVs.

All buildings were already equipped with variable speed pumps, in order to adapt the heating medium flow and maintain the hydraulic pressure throughout the installation maintained at the established range. In the buildings assigned to group A and C, the TRVs replaced the existing on/off valves. Additionally, thermostatic heads were installed on each TRV, enabling the regulation of indoor air temperature by the users of individual flats. The building occupants were educated simultaneously on how to operate a thermostatic head and what kind of problems may occur as a result of using TRVs. The information was prepared in the form of special informative bulletin delivered by the housing association to each occupant and also during the annual meeting organized during the summer by the housing association.

The heat supplied to each building for space heating was measured at individual thermal substations (Fig. 1) on a monthly basis, using a calibrated heat meter ($Q_{building}$). However, given the large amount of data, the analysis was based on the data aggregated for an entire heating season. For the buildings from the group A and C, a total of 6 heating seasons were considered in the analysis, i.e. 2 heating seasons before and 4 heating seasons after the analysed modernization activity. However, for buildings from group B, taking into consideration the limited number of measurements for these buildings, 4 heating seasons (i.e. 1 heating season before the modernization and 3 heating seasons after the modernization) were analysed.

The modernization activities, i.e. the installation of TRVs in Group A buildings, the hydraulic balancing in Group B buildings, and the installation of TRVs and hydraulic balancing in Group C buildings, were always performed during summer. In this way there was no interruption of the system operation during the heating season.

The mean outdoor air temperatures were equal to 4.2 °C, 3.0 °C, 4.4 °C, 3.2 °C, 1.0 °C, 1.8 °C, respectively, for the 6 analysed heating seasons. Therefore, in order to include a meaningful pre/post retrofit analysis, the actual heat consumption of each building ($Q_{building}$) is normalized with respect to heating degree days (HDD) by use of correction coefficient for a given heating season (φ) to obtain the weather-normalized heat used in the building (Q_{HDD}) per square metre of heated floor surface area ($A_{building}$), which is described in Eq. (1).

$$Q_{HDD} = \frac{\left(Q_{building} \cdot \varphi\right)}{A_{building}} \tag{1}$$