CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2024; 34 (3): 0001-0015
DOI: 10.59440/ceer/190249
Original Research Article

CENTRAL HEATING CONTROL CHARTS FOR THE ECONOMIC USE OF ENERGY IN RESIDENTIAL BUILDINGS

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Abstract

Methods and types (qualitative, quantitative or mixed) of control of central heating installations in residential buildings are presented. Measurements were made for a radiator in a central heating system that was powered by a heating node substation. The output temperature of the heat node supplying the residential building, in which the test stand was located, was compared with the measured supply and return temperature. Indoor room temperature, outdoor air temperature, inflow and outflow temperature on the vertical supplying the heater were also recorded and analysed. These data were compared with the control charts of the heat networks allowing for direct readings of the required feed water temperature for a given outdoor temperature according to the Heat Energy Enterprises data. The differences are accordingly presented. The actual measurements, read at the test stand located on the 2nd floor of the 4-storey building with input parameters of 90/70 °C during the entire month of December 2022, are recorded every 6 hours and are tabulated and displayed in comparison charts with the calculated parameters. Inflow and outflow temperatures values on the vertical supplying the heater and the values of outdoor temperature measured by a sensor were analysed. The temperatures supplied to the radiators in the apartments were also compared with the requirements of electronic heating cost allocators contained in the PN EN 834 standard. New design temperatures for the central heating installation were proposed due to the requirements of the electronic heating cost allocator.

Keywords: heater, thermal power, heating system, supply temperature, control diagrams

1. INTRODUCTION

Economic and technological development leads to a growing energy demand (Fig. 1). Heat generation accounts for a large proportion of greenhouse gas emissions. Decarbonising heat depends on changes at the point of use and may require millions of homes to replace their gas or oil-fired boilers with a new technology. There is no one-size-fits-all solution, as the fuel mix and the means of delivery to the end-

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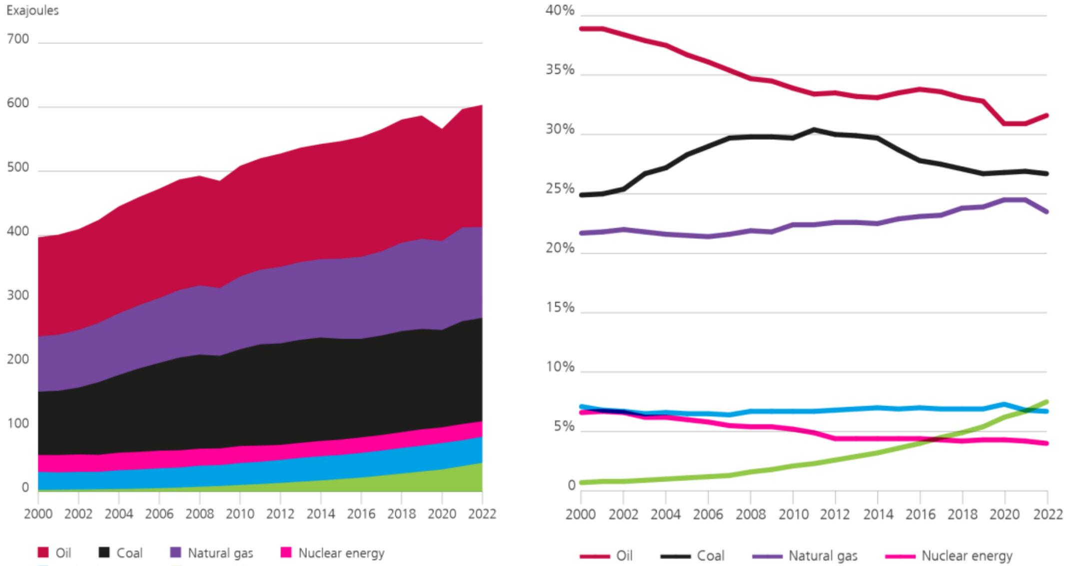
user vary widely between countries. Thus, a multiple-technology approach towards is most required, resulting in a variety of pathways [1]. Heat energy efficiency is a key for emissions reductions.



a) b)

Fig. 1. Primary energy world consumption, a) world consumption, b) share of global primary energy [1]

In residential buildings, in a temperate European climate, energy consumption for space heating and domestic hot water accounts for as much as four-fifths of total energy consumption [2] or even more, 87% [3, 4].

The demand for heat [5, 6] by individual consumers varies during the day and in subsequent months of the year. It depends mainly on the outside temperature [7], but also on the settings of the indoor temperature controllers and the operating time of heating devices. We change the amount of heat supplied by controlling the heat input. The following types of control can be mentioned:

a) central control i.e. supplies temperature control, so-called qualitative control at the heat source
b) local control i.e. flow rate control, so-called quantitative control at the receivers.

In most cases, both types of control are used together. Central control without local control is used when the type of heat collection is the same for all consumers, for example, central heating of an estate or city. Both types of control together are more frequently used for very branched and long heat networks, while the central control is adapted to the needs of the largest number of consumers, for example, central heating in residential buildings. Local control is used to adjust to other heat consumers because the consumers are diverse: central heating, ventilation, domestic hot water, technological needs. Therefore, central control is insufficient and additional local control is necessary, i.e. control at the receiver.

Heat exchange in heat exchangers is related to heat losses to the environment and flow resistance through the device. Typically, water at a temperature of 115°C is sent from a thermal power plant to the district heating substation and from this place the central heating 70/50°C and hot water installation 45÷55°C is powered [5, 8, 9]. Heating and cooling networks (Fig. 2) can provide a viable low-carbon solution to the heat demand issues. The use of geothermal sources seems particularly promising, also in combination with solar energy collectors [11] for passive houses. The average temperature of geothermal waters in Poland ranges from 45°C to 76°C [12] and higher [13]. Three schemes of geothermal centralized heat supply for geothermal waters of selected wells from Lviv region are proposed [14]. To increase the coolant temperature of the heating system after the intermediate heat exchangers, depending on the length of the heat pipelines in the schemes, it is proposed to use a central or individual heat pump [14].

Unlike electricity, heat cannot be transmitted over significant distances. The amount of heat received by any heating device is determined according to the following formulas:

$$\dot{Q}' = c\,\dot{G}'\,(t_V' - t_R')\,n\ [Wh] \tag{1.1}$$

$$\dot{Q}' = F\,K'\,\Delta t'\,n\ [Wh] \tag{1.2}$$

where:
F – is the heating surface in m^2,
K = $C\left(\frac{t_V+t_R}{2} - t_L\right)^m$ – heat transfer coefficient W/(m^2K),
m = 1/3 or 1/4 depending on the Rayleigh number [15].
In general, the range $0 \le m < 0.85$ includes radiant and convector heaters [5 p. 800, 16]. If the true value of the radiator exponent is not available, m = 1.3 can be used [17],
$\dot{G}$ – mass flow rate, kg/s,
t_V – flow temperature of the radiator, °C,
t_R – return temperature of the radiator, °C,
n – device operating time (h),
c - specific heat of water for the average temperature value in the range t_V, t_R, $\left[\frac{J}{kg\,K}\right]$,
Δt – logarithmic excess temperature of the heating medium with respect to t_L (°C or K), calculated from the measured values as follows:

$$\Delta t = \frac{t_V - t_R}{\ln\frac{t_V - t_L}{t_R - t_L}}\ [°C] \tag{1.3}$$

t_L – reference air temperature of the radiator in accordance with 5.1 [17], °C. It can be assumed that this is the air temperature in the room t_i,
$'$ – upper indicator for current values.
Equations 1.1. and 1.2. are true if in the period "n" the values of physical quantities are constant or averaged. They concern quasi-state conditions and do not apply to moments after turning the heater on or off. Equations 1.1 and 2.2 show that the amount of heat emitted by a heating device can be adjusted by changing each of the components of the following formulas:

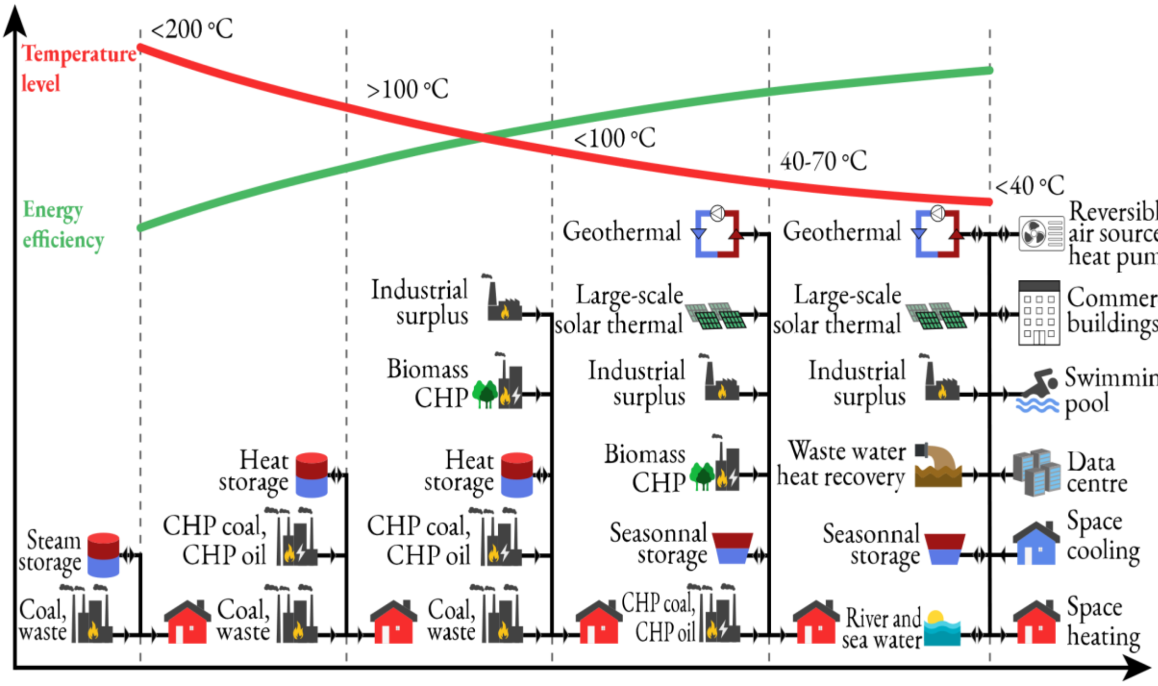
- the heating surface area F of heating device,
- the value of the heat transfer coefficient K,
- the value of the flow temperature t_V, (qualitative control),
- the value of the logarithmic excess temperature Δt, °C,
- the value of the mass flow rate G, (quantitative control; modulating control - mass flow rate is modulated),
- breaks in the device's operation (n) by changing the operating time (on/off control).

The most commonly used central control system in water heating networks is the control of the temperature of heating medium (in the supply), known as the qualitative control.

The aim of this article is to analyse central heating control charts in terms of providing heat to living spaces:

– thermal comfort,
– appropriate conditions for the recording of heat consumption by cost allocators.

Due to the ease of continuous regulation of water heating installations, on/off regulation is recommended in the case of installations with minimal, almost zero heat load power or in the case of steam-powered heating installations. In the case of minimal thermal loads, mass flow regulation (quantitative regulation) can switch to on/off regulation.



1st Generation 1880-1930	**2nd Generation** 1930-1980	**3rd Generation** 1980-2020	**4th Generation** 2020-2050	**5th Generation** >2020
Steam system: Steam pipes in concrete ducts	Pressurised hotwater system Heavy equipment	Pre-insulated pipes Industrial compact substations	Low energy demands Smart energy: optimum interaction of energy sources, distribution and consumption	Bidirectional: Heating & cooling supply Almost no thermal losses Uninsulated plastic pipes Modular expansion

Fig. 2. Development of district heating and cooling networks. The abscissa shows the development through five different generations and the ordinate shows the corresponding temperature level and energy efficiency. Black lines in each generation represent the pipe network, while arrows indicate the direction of heat flow [10]

2. QUALITATIVE CONTROL AT THE HEAT SOURCE (constant mass flow rate)

With qualitative control ($\dot{G}$ = const), constant hydraulic conditions of the network operation are maintained by a constant mass flow rate in the pipes. To maintain a constant temperature in the rooms, the heat release is controlled depending on the outside temperature by changing the temperature in a supply pipe.

The heat transferred through a heating network can be presented in three forms:

1. As heat supplied to the building by the heating network

$$\dot{Q}' = c\ \dot{G}\ \left(\tau_1{}' - \tau_2{}'\right)\quad [W] \tag{2.1}$$

2. As a sum of heat transferred by a radiator with surface areas F and heat transfer coefficients K to a room with logarithmic excess temperature of the heating medium with respect to t_L

$$\dot{Q}' = K'\ F\ \Delta t'\quad [W] \tag{2.2}$$

3. As heat loss by the building to the environment

$$\dot{Q}' = V\ q\ (t_i - t_e')\ \ [W] \tag{2.3}$$

where:

V - is the volume of heated buildings (m^3),
q - thermal characteristics of buildings ($W/(m^3\ K)$),
τ_1 - τ_2 - supply and return temperatures of network water (°C),
t_i – design indoor temperature (°C),
t_e – design outside air temperature (°C),
$'$ – upper indicator for current values.

These three equations can be expressed in the form of a heat balance system of equations. For assumed steady conditions, the thermal power supplied to the radiator is equal to the heat losses of the room, ignoring heat flows to adjacent rooms through internal partitions and heat losses in pipelines. The above equations can be written as follows:

$$\dot{Q}' = c\ \dot{G}\ \left(t_V{}' - t_R{}'\right) = K'\ F\ \Delta t'\ = V\ q\ \left(t_i - t_e{}'\right)\ [W]. \tag{2.4}$$

The value of the K coefficient for radiators is variable it contains a power exponent m depending on the type of radiator [19] and the actual control diagram is not straight [5, 20]. In control practice, instead of using a graph, numerical tables are used. This allows for direct reading of the required supply water temperature for a given outside temperature. The supply and return temperatures of network water and exemplary central heating systems depending on the outdoor air temperature $t_e{}'$ are shown in Table 1 for the design outdoor air temperature t_e = -20°C [5].

Table 1. Supply and return temperatures for water heating depending on the outdoor temperature t_e' according to SPEC data [5] (constant indoor temperature t_i = 20°C, climate zone IV, t_e = 20°C)

t_e'	$\varphi = \frac{t_i - t_e'}{t_i - t_e}$	Pump heating								Thermal network		Gravity heating 90/70° C	
		Radiators, Cast iron radiators						Surface heating		Temperature 150/130° C			
		110/70° C		95/70° C		90/70° C		55/45° C					
		τ_z	τ_p	τ_z	τ_p	**τ_z**	**τ_p**	τ_z	τ_p	τ_z	τ_p	τ_z	τ_p
-20	1,000	110,0	70,0	95,0	70,0	**90,0**	**70,0**	55,0	45,0	150,0	130,0	90,0	70,0
-19	0,975	108,2	69,2	93,5	69,1	**88,7**	**69,2**	54,2	44,4	147,2	127,6	88,0	69,0
-18	0,950	106,3	68,3	92,0	68,2	**87,3**	**68,3**	53,4	43,8	144,2	125,2	87,5	68,1
-17	0,925	104,5	67,5	90,5	67,3	**85,8**	**67,3**	52,6	43,3	141,4	122,8	86,2	67,0
-16	0,900	102,6	66,6	89,0	66,9	**84,4**	**66,4**	51,7	42,6	138,4	120,4	84,8	66,0
-15	0,975	100,7	65,7	87,4	65,5	**83,0**	**65,5**	50,9	42,1	135,0	118,0	83,6	65,0
-14	0,850	98,9	64,9	85,9	64,6	**81,6**	**64,6**	50,0	41,6	132,6	115,6	82,3	63,9
-13	0,825	97,0	64,0	84,4	63,7	**80,0**	**63,5**	49,2	41,0	129,8	113,2	80,8	62,8
-12	0,800	95,1	63,1	82,8	62,8	**78,7**	**62,7**	48,4	40,4	126,8	110,8	79,5	61,8
-11	0,775	93,2	62,2	81,3	61,8	**77,2**	**61,7**	47,6	39,8	123,9	108,4	78,1	60,7
-10	0,750	91,3	61,2	79,7	60,8	**75,7**	**60,7**	46,7	39,2	120,8	105,9	75,8	59,6
-9	0,725	89,3	60,3	78,0	59,8	**74,3**	**59,8**	45,9	38,6	118,0	103,4	75,5	58,7
-8	0,700	87,4	59,5	76,5	58,9	**72,9**	**58,9**	45,0	38,0	114,9	101,0	74,1	57,7
-7	0,675	85,5	58,6	74,8	57,9	**71,4**	**57,9**	44,2	37,4	112,0	98,5	72,8	56,6
-6	0,650	83,5	57,6	73,2	56,9	**70,0**	**57,0**	43,4	36,9	108,9	96,0	71,4	55,6
-5	0,625	81,5	56,3	71,6	55,9	**68,4**	**55,9**	42,6	36,3	106,0	93,5	70,0	54,6
-4	0,600	79,5	55,5	69,9	54,9	**66,9**	**54,9**	41,1	35,7	102,8	91,0	68,5	53,3
-3	0,575	77,5	54,5	68,2	53,8	**65,4**	**53,9**	40,8	35,1	99,9	88,4	67,1	52,3
-2	0,550	75,5	53,4	66,6	52,8	**63,9**	**52,9**	40,0	34,5	97,7	85,9	65,6	51,2
-1	0,525	73,4	52,4	64,9	51,7	**62,3**	**51,8**	39,2	33,9	93,8	83,3	64,1	50,1
0	0,500	71,3	51,3	63,1	50,6	**60,7**	**50,7**	39,3	33,3	90,5	80,7	63,5	48,9
1	0,475	69,4	50,3	61,6	49,6	**59,2**	**49,7**	37,4	32,7	87,7	78,2	61,0	47,8
2	0,450	67,2	49,1	59,7	48,5	**57,5**	**48,5**	36,6	32,1	84,4	75,5	59,4	46,6
3	0,425	65,1	48,0	58,0	47,4	**55,8**	**47,3**	35,8	31,5	81,5	72,9	57,8	45,4
4	0,400	62,9	46,8	56,2	46,1	**54,1**	**46,1**	34,9	30,8	78,2	70,3	56,1	44,1
5	0,375	60,8	45,7	54,4	45,0	**52,4**	**44,9**	34,0	30,3	75,2	67,7	54,2	42,9
6	0,350	58,6	44,5	52,6	43,8	**50,8**	**43,8**	33,1	29,6	71,8	65,0	53,2	41,7
7	0,325	56,1	43,0	50,8	42,6	**49,0**	**42,5**	32,3	29,0	68,7	62,2	51,2	40,5
8	0,300	54,2	42,0	48,9	41,3	**47,3**	**41,3**	31,4	28,4	65,3	59,5	49,4	39,2
9	0,275	51,9	40,7	46,9	40,0	**45,5**	**40,0**	30,5	27,7	62,2	57,7	47,1	37,9
10	0,250	49,5	39,4	45,0	38,1	**43,7**	**38,7**	29,7	27,1	58,7	53,5	45,8	36,6
11	0,225	47,1	38,0	43,0	37,3	**41,5**	**37,8**	28,7	26,5	55,0	51,0	43,8	35,4
12	0,200	44,7	36,6	41,0	36,0	**39,3**	**36,0**	27,8	25,8	52,1	48,1	41,7	33,8

3. QUANTITATIVE CONTROL (constant supply temperature)

With quantitative control, the amount of heat transported through the network is controlled by the amount of the transferred heating medium. In heating networks, the temperature of the supply medium (usually water but also steam) is maintained constant, and the mass flow of the heating medium is controlled by changing the efficiency of the circulation pumps or by using a throttling valve. The temperature of the return water will change. There are the following dependencies [5]:

$$\varphi = \frac{\dot{\mathrm{Q}}'}{\dot{\mathrm{Q}}} = \frac{\mathrm{t_i} - \mathrm{t_e}'}{\mathrm{t_i} - \mathrm{t_e}} = \frac{\mathrm{G}'}{\mathrm{G}} \cdot \frac{\tau_1 - \tau'_2}{\tau_1 - \tau_2} = \frac{\mathrm{K}'}{\mathrm{K}} \cdot \frac{\mathrm{t_V} + \mathrm{t_R}' - 2\mathrm{t_i}}{\mathrm{t_V} + \mathrm{t_R} - 2\mathrm{t_i}} \tag{3.1}$$

where:

φ - heat load factor, i.e. the quotient of the momentary thermal power demand for heating the object to the calculated power demand.

The logarithmic mean temperature difference (equations 1.2, 2.2) is quite well approximated by the arithmetic mean:

$$\Delta \mathrm{t_{ar}} = \frac{\mathrm{t_V} + \mathrm{t_R}}{2} - \mathrm{t_i} \tag{3.2}$$

and it was used in the equation (3.1). The return water temperature as a function of $\mathrm{t_e}'$ can be calculated from the equation:

$$\tau'_2\left(\mathrm{t_e}'\right) = 2\mathrm{t}_i - \tau_1 + \left(\frac{\mathrm{t_i} - \mathrm{t_e}'}{\mathrm{t_i} - \mathrm{t_e}}\right)^{\frac{1}{m+1}} \left(\mathrm{t_V} - \mathrm{t_R} + 2(\tau_2 - \mathrm{t}_i)\right). \tag{3.3}$$

and

$$\tau'_2\left(\mathrm{t_e}'\right) \geq \mathrm{t_i} \tag{3.4}$$

Quantitative control applies to steam-powered heating systems and heating networks in which the temperature of the supply water cannot be reduced below a specified value due to the preparation of domestic hot water or other technical requirements.

The equation for the quantitative control of a central heating installation is the following:

$$\mathrm{t}'_\mathrm{R}\left(\mathrm{t_e}'\right) = 2\mathrm{t}_i - \mathrm{t_V} + \left(\frac{\mathrm{t_i} - \mathrm{t_e}'}{\mathrm{t_i} - \mathrm{t_e}}\right)^{\frac{1}{m+1}} (\mathrm{t_V} + \mathrm{t_R} - 2\mathrm{t_i}). \tag{3.5}$$

and

$$\mathrm{t}'_\mathrm{R}\left(\mathrm{t_e}'\right) \geq \mathrm{t_i} \tag{3.6}$$

4. MIXED CONTROL

Central quality control is basically set for heating purposes. If there is a heat demand for heating domestic hot water, quality control is not sufficient. The supply network water temperature cannot fall below a certain value, e.g. 70°C, due to the required domestic hot water temperature of approximately 60°C, and then quantitative control is performed. Periodically, rooms may be overheated and sometimes they may not be heated enough. Slight changes in the internal temperature in rooms are mild because the thermal capacity of the building and thermostatic radiator valves work together to maintain temperature uniformity. Control systems with outdoor air temperature prediction help to reduce heat consumption. The work [21] presents existing, corrected and optimized control charts for a building in northern Poland. Such a chart is shown in Figure 3.

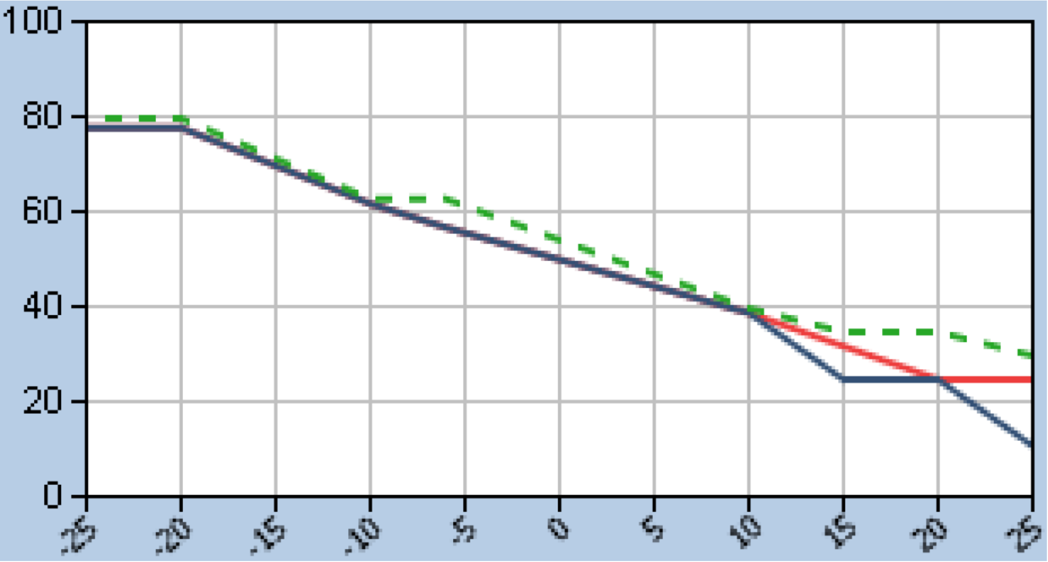


Fig. 3. Existing (green line), corrected (blue line) and optimized (red line) control charts for a building in northern Poland. The supply temperature of a central heating system vs. the outdoor air temperature [21]

Internal temperature deviations in rooms with radiators powered by an independent heat source caused by disturbances:

- in the temperature of the water supplying the radiator $\Delta t_V = t'_V - t_V$
- changes in the water mass flow through the radiator $\Delta G = G' - G$
- oversizing of the radiator with respect to the design value $\delta F = F'/F$

can be calculated from the equation [20]:

$$\Delta t_i = \frac{t_i - t_{zew}}{t_V - t_e}\left[\Delta t_V + \frac{\varphi\,(t_V - t_R)}{2}\,\frac{\Delta G}{G} + \varphi\,\Delta t_{ar}\,(1 - \delta F)\right] \tag{4.1}$$

The work [22] also presents the influence of other external factors (wind speed, sunlight, cloud cover) and internal factors (the users' behaviour and preferences) on the demand for thermal power for heating purposes and recommends the most accurate way to take these factors into account for heating multi-family and public buildings. The scope of the dissertation includes the presentation of selected options for reducing energy consumption in existing buildings and methods that are used for modelling, forecasting and controlling the heat supply for heating buildings. The experiences from the installation, operation, and maintenance of the forecast control system for HEAT in a multi-family building and an office building located in Poland were elaborated in works [23, 24]. New network control concepts are implemented based on individual mathematical models describing the operation of the network under real weather conditions in a given area, i.e. the created models [21, 25] take into account the specific behaviour of the end users for a given heating network, thus laying the foundations for intelligent heating networks. The aim is to fully automate the heat nodes according to the plan or idea of the network operation. Renewable and low-temperature heat sources support the decentralization of heating systems [26, 27].

5. DATA AND MEASUREMENTS

Figure 4 shows the controlled temperatures of a network water of a group node supplying the analysed building and the temperatures of a central heating installation. The analysis of this graph shows that the input temperatures of 115/55 °C, heating node supplying the tested building, are sufficient to meet the requirements of the design temperatures of 90/70 °C at the node output. Measuring stand (Fig. 5) was located on the third floor of a 4-storey building in Bialystok. Some of the recorded data are shown in Figure 6.

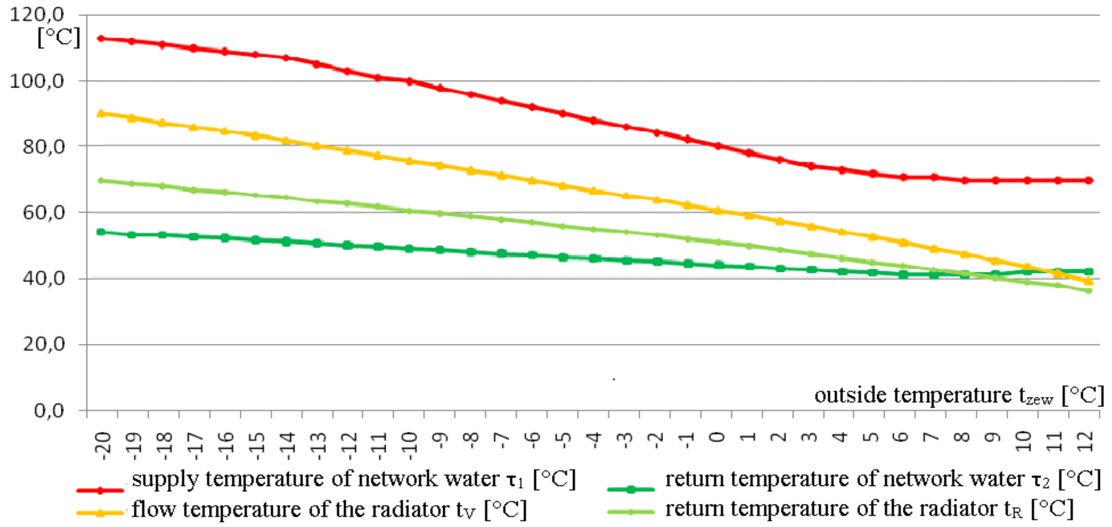


Fig. 4 Controlled temperatures of the network water of a group node supplying the analysed building and the temperatures of a central heating installation versus outdoor temperature t_e' (climate zone t_e = -22 °C, indoor temperature: 20 °C).

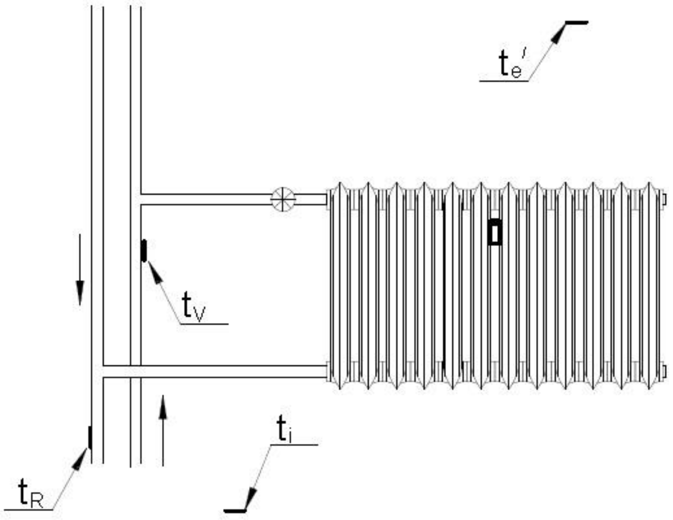


Fig. 5. The schematic diagram of the experimental apparatus. The location of the sensors and a heat cost allocator are marked

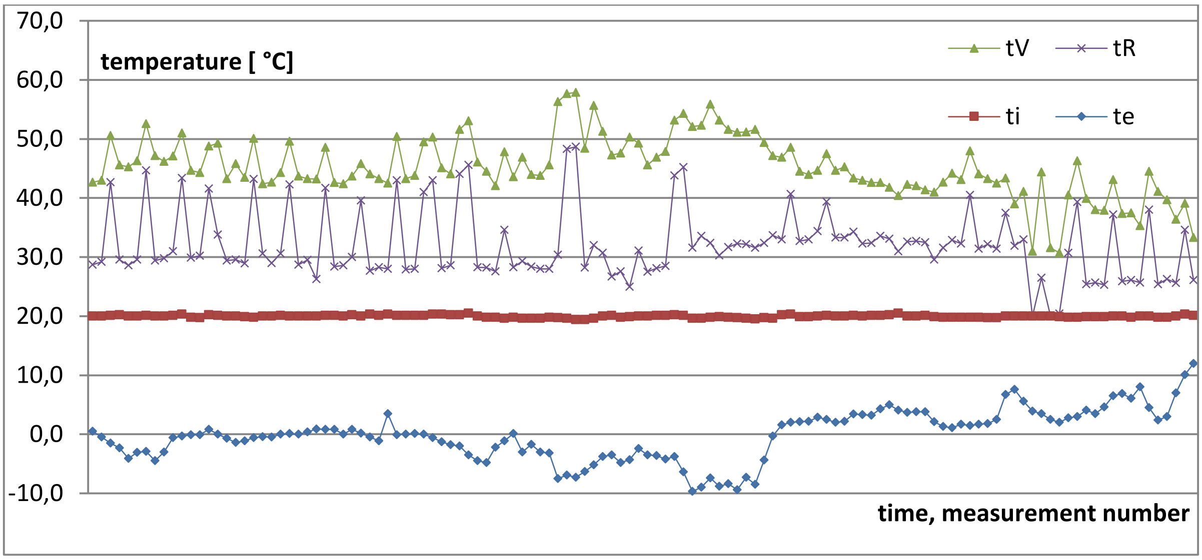


Fig. 6. Graphical presentation of some of the recorded temperature values as a function of time for the coldest period of the year

The recorded values are in the range:

- outdoor air temperature from -9.7 to 12.0 °C,
- indoor air temperature in the room from 19.4 to 20.5 °C,
- supply temperature from 30.7 to 57.9 °C,
- and return temperature from 20 to 48.7 °C.

Generally, in heating, engineering calculations ignore the dependence of the specific heat (1.1, 2.1, 2.4) of water on temperature. Thermodynamic tables give the properties of chemically pure water at saturation pressure. Water circulating in pipelines is kept above saturation pressure and contains chemical compounds, mineral deposits and corrosion products. In the considered water temperature range from 20 to 150°C, the specific heat of water varies from 4.174 to 4.313 kJ/(kg· K). This is (4.24±0.07) kJ/(kg· K) or ±1,6%. Pt 500 sensors with an accuracy of 0.5K [28] are usually used to measure temperature in district heating. 1-Wire Digital Thermometers DS1820 with an accuracy of 0.5 K [29] were used to measure the temperatures in the test stand in the room and the outside air temperature. The temperature measurements do not count the actual temperature profile in the liquid stream, disturbances of heat loss to the environment due to the thermal conductivity of the sensor and other factors. It can be assumed that the temperature difference t_V-t_R is calculated with an error of 1 K. For t_V-t_R = 20K this gives a relative error of 5%, and for t_V-t_R = 10K this gives a relative error of 10%.

6. RESULTS ANALYSIS

The measurement results versus the outdoor air temperature are presented in Figure 7. The Figure 7 also shows the supply t_V and return t_R temperatures in accordance with the declared control chart: 90/70 °C values of temperature. It is visible that the actual supply and return temperatures are lower than the values included in the control chart.

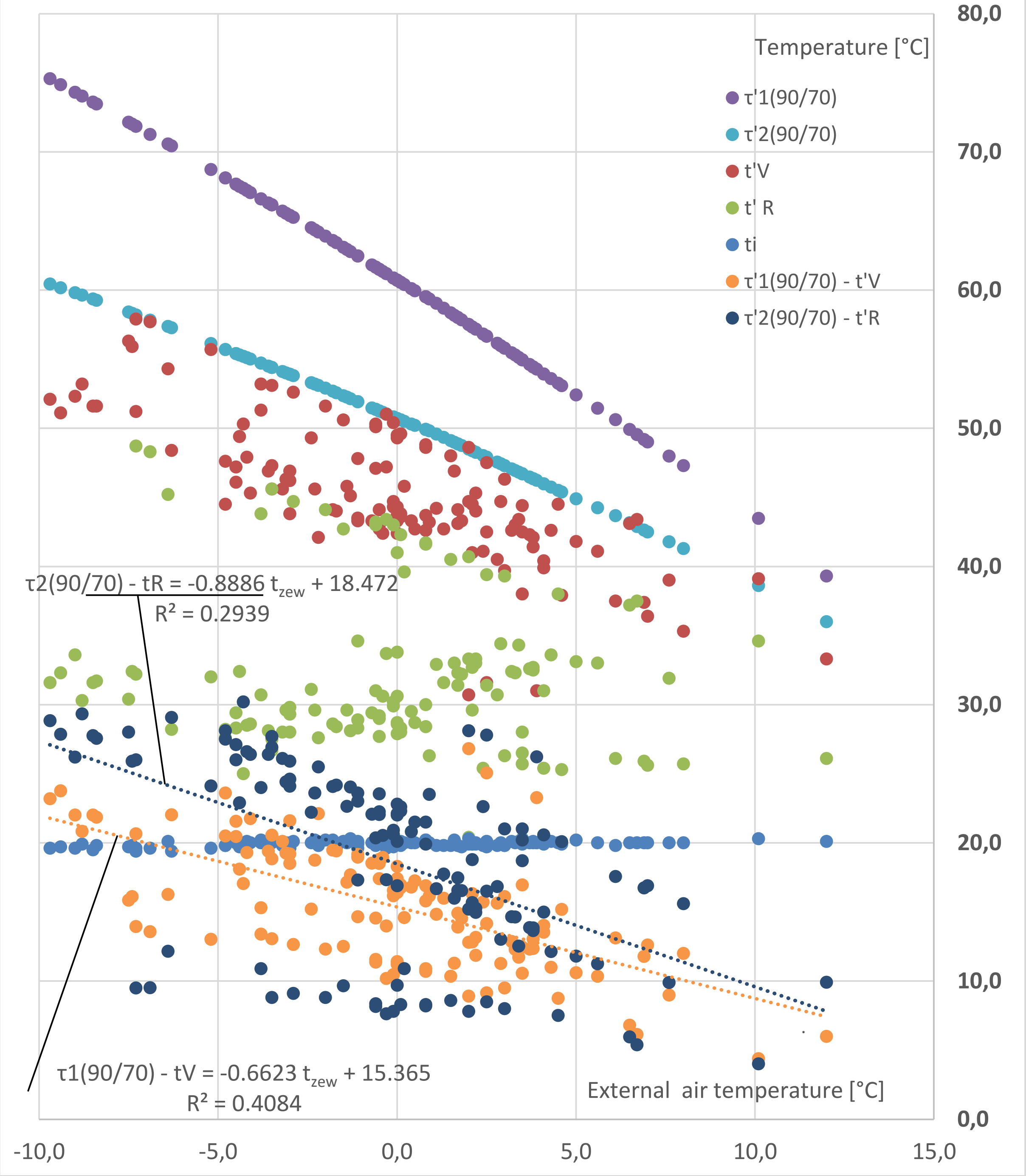


Fig. 7. The supply τ_1 and return τ_2 temperatures declared by the heat supplier for the tested building with the design temperatures of the central heating installation 90/70 °C, the measured values t_V, t_R and the values of the temperature differences between the declared and measured temperatures $\tau_1 - t_V$, $\tau_2 - t_R$ depending on the outdoor air temperature t_i

Temperature differences between the declared and measured values were approximated by the linear equations depending on the outdoor air temperature:

$$\tau_1 - t_V = -0.6623\, t_{zew} + 15.365 \text{ and } R^2 = 0.4084 \tag{6.1}$$

$$\tau_2 - t_R = -0.8886\, t_{zew} + 18.472 \text{ and } R^2 = 0.2939 \tag{6.2}$$

Due to the low values of the R^2 parameters, it can be assumed that the influence of the outside air temperature on these differences of temperature values is insignificant. Other factors are more important. Analogously to the chart $t_V(t_R)$ given in the standard [30], measurement values and declared temperature values based on central heating control charts were plotted [Fig. 8].

A significant part of the measurement points is above the line corresponding to the base state conditions. The rest of the measurement points are on the line corresponding to the base conditions.

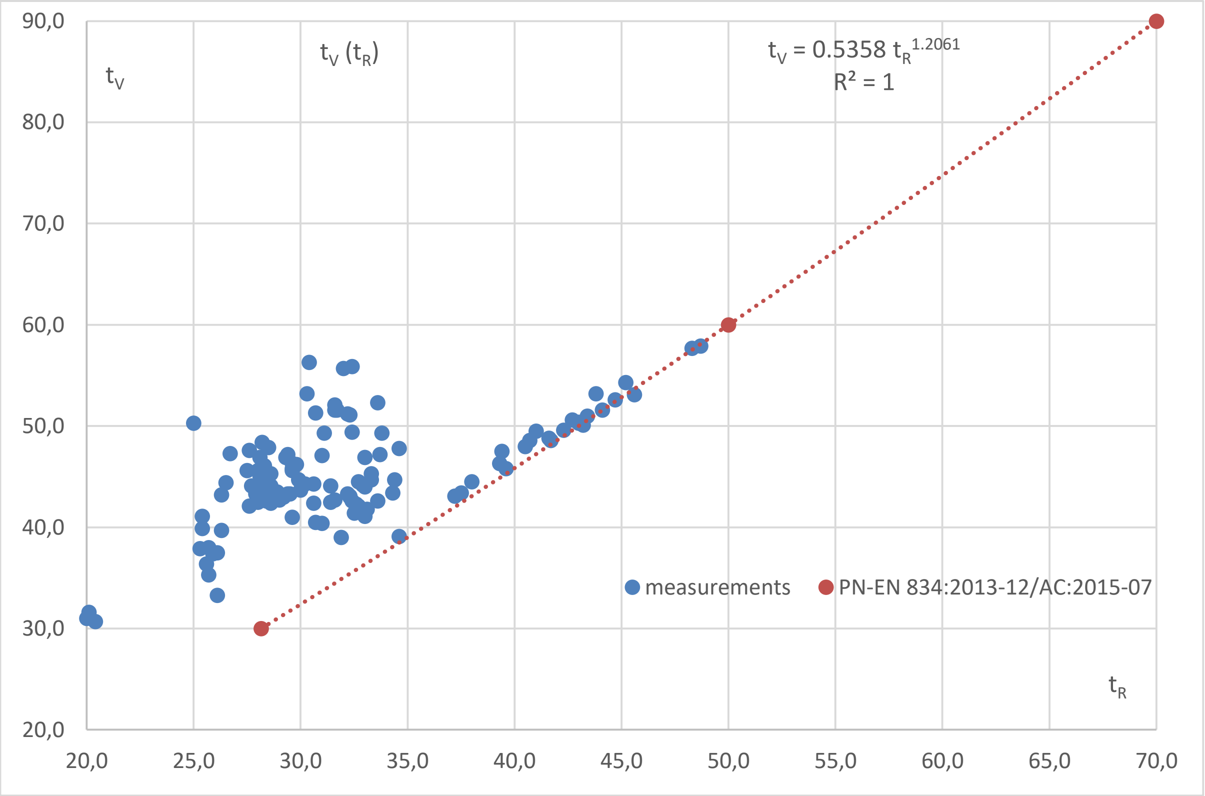


Fig. 8. Comparison of flow t_V and return t_R temperatures at base state [17] and measured conditions

7. CONCLUSIONS

1. The supplied heat ensured an appropriate (about 20 °C) and stable air temperature in the room.
2. Increasing the supply temperature means greater certainty that there are no underheated rooms in the building and a flow rate of the network water is lower, which reduces the work of pumps and electricity used for pumping the heating medium. However, this increases heat losses in the distribution pipelines.

3. Lowering the temperature of the heating medium in the supply means lower heat losses in the heat distribution pipes. However, the possibility of underheating the rooms increases. Higher heating medium flows mean higher flow resistance and higher power consumption of the circulation pumps.
4. The temperature of the heating medium also affects the noise level of the installation and the durability of pumps, valves, pipelines and radiators.
5. Figure 6 shows that the highest daily temperatures, higher by approximately 5 °C than the previous values, occurred around 6 p.m. This time of day also corresponds to the highest daily return temperatures. About 12 to 20 °C higher than the previous values. The phenomena described here result from the implementation of the daily cycle set by the programmer in the heating substation. Almost all the points located on the $t_V(t_R)$ line in Fig. 8 represent the measurement values recorded at 6 p.m.
6. Points located to the left of the $t_v(t_R)$ line (Fig. 8) can be brought to this line by increasing the flow through the radiator with a thermostatic valve. This action would cause the room to overheat.
7. Over the years, the design temperatures of the central heating installation have been lowered while maintaining the design temperature difference $t_V – t_R$ = 20 °C or 25 °C, and the following values are used: 80/60 °C, 70/50 °C, 60/40 °C or 85/60 °C, 75/50 °C, 65/40 °C. To enable the heater to operate in basic conditions, the following calculation of temperatures should be appropriately used: 78/62 °C, 66/54 °C, 54/46 °C, and 81/64, 69/56, 57/48 (tab. 2). The operation of the radiator in the basic state should enable to correct registration of the heat consumed by the electronic allocators.

Table 2. List of designed temperatures for central heating enabling the radiator to be operated in basic conditions

t_V / t_R / t_i	Applied design temperatures		Δt_{ar} [°C]	Proposed design temperatures due to Δt_{ar} values		Δt_{ar} [°C]	Proposed design parameters due to Δt_{ar} values	$\Delta t = t_V - t_R$ [°C]
$\Delta t = t_V - t_R$ = 20°C	t_V [°C]	t_R [°C]		t_V [°C]	t_R [°C]			
80/60/20 °C	80	60	50	77.9	62.1	50.0	78/62/20 °C	16
70/50/20 °C	70	50	40	65.9	54.1	40.0	66/54/20 °C	12
60/40/20 °C	60	40	30	54.1	45.9	30.0	54/46/20 °C	8
$\Delta t = t_V - t_R$ = 25°C								
85/60/20 °C	85	60	52.5	80.9	64.1	52.5	81/64/20 °C	17
75/50/20 °C	75	50	42.5	68.9	56.1	42.5	69/56/20 °C	13
65/40/20 °C	65	40	32.5	57.1	48.0	32.5	57/48/20 °C	9

ADDITIONAL INFORMATION

This article was elaborated in the framework of the grant No. W/WB-IIŚ/2/2022 of Bialystok University of Technology from the Ministry of Education and Science in Poland.

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