DETERMINATION OF AN OPTIMAL TEMPERATURE FOR THE CENTRAL HEATING INSTALLATION IN DWELLINGS

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Received: 15.05.2009; Revised: 29.06.2009; Accepted: 25.09.2009

Abstract

Improving of building thermal protection, improving of energy efficiency of heat supply systems for room heating in building and enabling effective use of renewable heat sources create appropriate indoor conditions and, at the same time, extort the need for application of heating installations with accurately determined nominal temperature of heating medium.
The paper presents results of investigations and analysis aiming at determination of the optimal nominal temperature of water-based heating installation in function of a heat source type and building thermal protection condition.
In the investigations mainly authors' own method and computer program based on this method were used. The program was used to determine simultaneously the optimal thermal protection, installation and the heat source. The method applied uses the goal function in the form of total, discounted, average annual costs related to building thermal protection, installation and heat source for a dwelling – the total costs to fulfil required thermal conditions in the building. In the initial analysis the limit values for the nominal temperature of heating installation were defined depending on the heater type and the building thermal protection condition.

Streszczenie

Doskonalenie ochrony cieplnej budynku, poprawa sprawności energetycznej układów zaopatrzenia w ciepło ogrzewanych pomieszczeń budynku, umożliwienie efektywnego wykorzystania odnawialnych źródeł ciepła stwarzają warunki i jednocześnie wymuszają potrzebę stosowania instalacji grzewczych z odpowiednio dobraną temperaturą nominalną czynnika grzewczego.
W artykule przedstawiono rozważania i wyniki badań zmierzających do określenia optymalnej temperatury nominalnej wodnej instalacji centralnego ogrzewania w funkcji rodzaju źródła ciepła i stanu ochrony cieplnej budynku mieszkalnego. W badaniach wykorzystano głównie własną metodę i zbudowany w oparciu o nią programy komputerowy służący do jednoczesnego wyznaczania optymalnej ochrony cieplnej budynku, instalacji i źródła ciepła. Przyjęta metoda wykorzystuje funkcję celu w postaci zdyskontowanych przeciętnych rocznych kosztów całkowitych dotyczących ochrony cieplnej, instalacji i źródła ciepła dla budynku mieszkalnego – kosztów całkowitych uzyskania wymaganych warunków cieplnych w budynku. W analizie wstępnej określono wartości graniczne temperatury nominalnej instalacji centralnego ogrzewania w zależności od rodzaju stosowanych grzejników i stanu ochrony cieplnej ogrzewanego budynku.

Keywords: **Optimization; Central heating; Dwelling-house; Nominal temperature of heating installation.**

1. INTRODUCTION

The building use requires existence of a proper indoor environment including thermal comfort and indoor air quality. Overall comfort of building use is related also to the availability of hot tap water. Creation of comfortable indoor conditions as well as preparation of a required amount of warm water at a proper temperature requires heat. In this paper state of the indoor environment and availability of the domestic heat water will be referred as thermal conditions of a building use.

Improvement of a building thermal protection, improvement of energy efficiency of the systems for the heat supply to the rooms in building, enabling effective use of renewable heat sources create comfortable conditions and, at the same time, extort the need for application of heating installations with accurately determined nominal temperature of heating medium. This selection should be realized by means of complex optimization process aiming at determination of the most appropriate thermal protection level, installation and heat source for a newly designed dwelling or for thermomodernization of an existing dwelling. In case of a central heating system this process should also determine the most appropriate nominal temperature for the heater type selected.

The method for such optimization has been developed [3] and computer program "Multival" was created [2]. In this method the goal function in the form of total, discounted, average annual costs related to the building thermal protection, installation and heat source for the dwelling was set (i.e. total costs to fulfil required thermal conditions). This function includes several partial criteria related to first costs, consumption of fossil fuels and pollution emission. Investigation of such a complex function confirms interconnections existing between the parameters determining state of the thermal protection and heating installation type as well as the heat source. Therefore, there is a need to determine simultaneously all parameters influencing the state of thermal protection.

The lower thermal resistance values for the walls the stronger interconnection is observed. Only in case when the source consists of one component (as regards to component type) and its energy efficiency is constant, the initial costs are negligibly small or proportional to the nominal power, and at the same time annual building heat demand is proportional to the nominal heat demand, the optimal operational states can be determined separately: first the thermal protection and then the heat source and the installation. In case if the conditions mentioned above are not fulfilled, the optimal states can be determined by method of successive approximations. In the goal function defined in this way the variables are general parameters of continuous and discrete nature. An appropriate combination of the following methods: gradient method for continuous variables, method of viewing intervals, method of successive approximations and method of successive comparisons for the discrete variables, allows, although with some difficulties, to determine simultaneously optimal parameters investigated.

2. TYPES OF CENTRAL HEATING INSTALLATIONS

There are water-based and air heating installations used. Majority of installations are water-based heating installations. In these installations compact heaters (radiant, convection, convector), surface heaters (floor, wall, ceiling) or their combinations can be applied. In case of the surface heaters thermal comfort is obtained with lower t_i [1]. Large surface heaters allow lower temperature of the heating media to be used. Because of the thermal comfort requirements the surface heaters often have low unit thermal efficiency.

Substantial time variability of the heat demand caused by low heat losses through well insulated outer walls raised tendency to use installations and heaters with low water and thermal capacity.

Surface heaters are characterized by large water and thermal capacity. Difficulties in fast regulation of thermal output diminishes to some extend their ability for self-regulation. This leads to obtaining higher than required indoor air temperature, which results in increase of heat consumption of the heating installation.

In order to decrease thermal capacity and to obtain required thermal output at relatively low heating medium temperature, new types of heaters are being developed. An example of such heaters are surface heaters using capillary mats [9] containing plastic (polypropylene) tubes with diameters ca 4 mm located 10 to 30 mm from each other, placed several millimetres below floor, wall or ceiling surface. This allows to obtain thermal output approximately 80 W/m^2 already at the temperature difference between heating medium and indoor air of 10 K. Disadvantages of these heaters are low tube resistance for gas diffusion and difficulties for smooth thermal output regulation related to low thermal pressure (difference in heating medium temperature and indoor air temperature).

In the past also construction of the compact low temperature heaters were modified and improved. This was achieved by minimizing their thermal capacity and proper formation of the outer surface in order to obtain equilibrium of heat transfer through long wave radiation in the direction to the window and located the heater located below, and through generation of the convective flow which is strong enough to balance the downward air flow along the window.

Table 1.
Relative change of heat output for compact heaters in function of nominal heat medium temperature for t_i=20°C and $t_{1^x}^N / t_{2^x}^N$ = 90°/70°C

	$\frac{\dot{Q}_g^x}{\dot{Q}_g}$			
	$t_{1^x}^N / t_{2^x}^N$ =90°/70°C	$t_{1^x}^N / t_{2^x}^N$ =70°/55°C	$t_{1^x}^N / t_{2^x}^N$ =55°/45°C	$t_{1^x}^N / t_{2^x}^N$ =35°/25°C
m=0.25	1.0	0.746	0.420	0.106
m=0.33	1.0	0.736	0.398	0.092
m=0.50	1.0	0.704	0.353	0.068

3. RESULTS AND DISCUSSION

Determination of the most appropriate nominal temperature for central heating installation was considered within two groups of problems:

- determination of lower limits for nominal temperature,
- investigation of optimal nominal temperature.

Within the analysis of the first issue the influence of the building thermal protection on nominal temperature limits and relation between thermal output and nominal temperature for different heaters in water based heating installation were studied.

For the second issue, the optimal nominal temperature in water based heating installation equipped with panel heaters and surface heaters (floor heating) was determined as a function of heat source type used. In this process already mention method and computer program [2,3] were applied.

3.1. Nominal temperature limit for water-based central heating installation dependence on the building thermal protection

In the existing central heating installations, especially in buildings with poor thermal protection and mainly water-based installations, typical nominal temperatures of heating medium equal 85°/65°, 90°/70° and 95/75°C. Lower temperatures and smaller differences were selected for installations in high buildings to diminish the influence of changing gravitational pressure on the heating medium flow through particular heaters during the heating season. Newer installations are designed for parameters close to 70°/55°C or lower. The level of nominal temperature selected is related to the state of the thermal protection of heated room and to the heater type used. Determination of optimal nominal temperature is related to the investigation of nominal temperature lower than the parameters mentioned above. Theoretical lower limit of the heating medium in the central heating installation is the required indoor air temperature. Lowering the heating medium temperature always changes heater's thermal output. Thermal output of the heater $\dot{Q}_g^x$ is a function of supply and return temperature: $t_{1^x}^N, t_{2^x}^N$ respectively, can be described by the following equation:

$$\frac{\dot{Q}_g^x}{\dot{Q}_g} = \left[\frac{0,5\cdot(t_{1^x}^N + t_{2^x}^N) - t_i}{0,5\cdot(t_1^N + t_2^N) - t_i}\right]^{1+m}$$

where

$t_1^N,\ t_2^N,\ t_{1^x}^N,\ t_{2^x}^N$ - nominal heating medium temperatures for the two states

$\dot{Q}_g^x$ heater's thermal output for supply and return temperatures $t_1^N,\ t_2^N$

t_i – indoor air temperature

m – exponent dependent on heater type. Indicatory exponent values are: m=0.25 – for panel heaters, m=0.33 – for sectional heaters m=0.35 – for surface heaters.

An exact values of m exponent depend on the particular heater solutions, e.g. presence of fins on the sectional heaters, surface and inlet and outlet armament in the casing of convector heaters.

In Tables 1 and 2 relative changes of thermal output for panel heaters are presented in the function of nominal heating medium temperature.

The most influenced by changes in heating medium temperature heaters are convector heaters (m=0.5). Lowering nominal temperature from 70°/55°C to 35°/25°C in case of these heaters is related to the necessity of enlarging their surface area 10 times to obtain the same thermal output. Under the same conditions for panel heaters (m=0.25) the surface should be enlarged 7 times. For panel heaters

Table 2.
Relative change of heat output for floor heaters (m=0.07) in function of nominal heat medium temperature and tube spacing for t_i=20°C and $t_{1^x}^N / t_{2^x}^N$ =90°/70°C

	$\frac{\dot{Q}_g^x}{\dot{Q}_g}$		
	$t_{1^x}^N / t_{2^x}^N$ =55°/45°C	$t_{1^x}^N / t_{2^x}^N$ =45°/35°C	$t_{1^x}^N / t_{2^x}^N$ =35°/25°C
b=0.10	1.0	0.655	0.316
b=0.20	0.753	0.494	0.241
b=0.30	0.592	0.391	0.190

Table 3.
Minimal nominal temperatures for central heating installation equipped with convection heaters or/and floor, wall heaters for typical dwellings located in 3rd climatic zone

Heater type	Building complying with requirements [4]	Building complying with requirements [5]	Building complying with requirements [6]	Building complying with requirements [7]	Building with optimal thermal protection
convection heaters mounted below window	80°/65°C, 75°/60°C – with thermal insulation	70°/55°C, 65°/50°C – with thermal insulation	60°/50°C	55°/45°C	50°/40°C
convection heaters mounted along external wall	60°/45°C, 55°/45°C – with thermal insulation	55°/40°C, 50°/40°C – with thermal insulation	50°/40°C	50°/40°C	40°/30°C
Typical floor heaters with convection heaters	55°/45°C – with thermal insulation	50°/40°C	45°/35°C	40°/30°C	35°/25°C
Typical floor heaters	-	-	50°/40°C	43°/35°C	37°/30°C
Floor heaters with capillary tube mats placed shallow	-	-	30°/27°C	29°/25°C	29°/25°C
Typical wall heaters	-	-	-	35°/25°C	<35°/25°C
Wall heaters with capillar tubes mats	-	-	-	27°/24°C	<27°/24°C

such a change can be realized by using multi-panel heaters instead of heaters with single panel. The change of heat output ($\left[\dot{Q}_g\right]_n$) for 0.6 m high heaters built of n panels in relation to the single plate heater ($\left[\dot{Q}_g\right]_1$ can be approximated by means of the equation: $\left[\dot{Q}_g\right]_n = \left[\dot{Q}_g\right]_1 \cdot n^{0,84}$. Lack of changes or insignificant changes of heaters' length and height should not cause additional difficulties for installing the heaters or deteriorate heaters' esthetics. In a similar way, i.e. without changing the heater's external dimensions, in many other situations for surface heaters the nominal temperature can be lowered. This can be realized by more dense arrangement of heating tubes – decreasing tube spacing scale (Table 2). This is, however, possible only for well insulated rooms. In other cases obtaining the same heating power would require increasing the heating surface area by connecting floor and wall heaters or by applying additional compact heaters.

In Figure 1 and Table 3 nominal temperature limits for central heating installation are expressed by function of heater type and thermal protection level of a dwelling located in 3rd climate zone.

In case of compact heaters it was assumed that the limitation of the heater's length is the length of a window or of an external wall with window. It was also assumed that there was no limitation for the heater surface area (size) in bathrooms, because, in extreme case different heater types can be used simultaneously: floor, convection and radiant heaters mounted under the window or on the outer wall, and tube

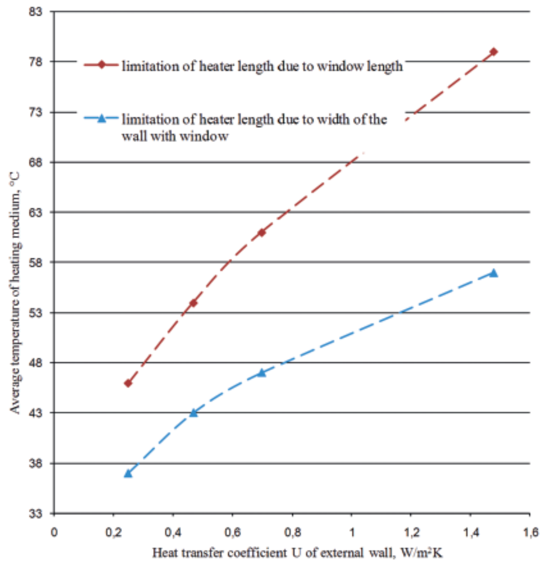

Figure 1.
Relation between minimal (limited by the allowed length of the panel heater) average nominal temperature of heating medium and heat transfer coefficient *U* of external walls for typical multifamily building

(bathroom) heaters. For compact heaters the lowest temperature combination considered was 35/25°C. In the following the partial insulation is understood as an insulation of a ceiling under unheated attic and above unheated basement, and installation of windows with heat transfer coefficient of U<1.5 W/m^{2}K; window replacement means replacement of windows with heat transfer coefficient of U<2.5 W/m^{2}K by windows with U<1.5 W/m^{2}K (to fulfil requirements given in [8]). At the same time it was assumed that wall heaters are mounted on the outer wall only in case of buildings with high insulation level. Such a solution is, however, connected to increase of the heat loss through the outer walls. In order to minimize such a heat loss it is necessary to apply additional insulation layers, typically under the heater, on the inner side of the outer wall. Advantages of the low nominal temperatures in relation to the indoor environment in heated rooms are:

- increase of the spatial uniformity of long wave heat radiation, temperature and indoor air velocity,
- increase of average inner surface temperature of walls, also due to increase of long wave radiant heat exchange contribution in heated rooms,
- decrease of intensity of dust dry distillation on heating surfaces and dust raising

Lowering the nominal temperature of heating medium leads also to the following benefits in building heat management:

- decrease of heat losses from the pipeline between the heat source and heated rooms,
- decreasing heat losses from the pipeline during breaks in heat supply caused by the automatic control system,
- increase of efficiency of heat emission to the heated room by decreasing heat losses from the heater to the wall (usually outer wall) on which the heater is installed. In case of the low-temperature compact heaters usually multi-layer panel heaters are used, therefore the surface of heat exchange between heater and wall does not change with the decreased supply temperature,
- increase of the internal heat gains utilization,
- increase of self-regulation of thermal output (especially of plane heaters), which should lead to increase of the efficiency of heat supply regulation.

The disadvantages are:

- necessity of increasing heater surface area (and first costs for the installation) and often deterioration of room aesthetics,
- increase of water capacity (but also heat capacity) of the heating installation and of medium flow resistance due to multi-panel or multi-section heater solutions,
- worsening the regulation properties of the installation by strengthening the tendency to only two-position operation mode of thermostatic valves,
- increased sensitivity of heat output regulation to imprecise setting of a current (exploitation) medium temperature. The sensitivity to sizing of the heating surface area is, however, decreased.

Impact of lowering nominal temperature of heating medium on the construction features of heating installation is expressed through: lowering limitations in selecting pipeline materials, simplification of installation due to decreasing thermal elongation of the straight lines – fewer expansion pipe joints needed, decreasing heating medium expansion – smaller expansion tank, decreasing thermal insulation thickness for installation parts.

In the analysis concerning dwellings (with low rooms, mainly with natural ventilation) ceiling heaters were neglected. Warm air heating was also omitted in the analysis, although in buildings with high thermal protection an interesting possibility occurs to combine air heating with mechanical ventilation installation. If such installation is designed for low air exchange rate, then, despite low unit heat demand, the nomi-

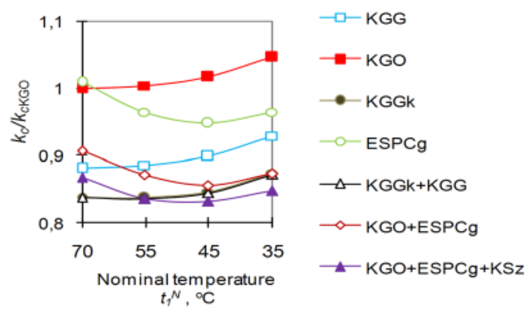

Figure 2.
Relative average annual total cost (k_c/k_cKGO) of multifamily house thermomodernization (final thermal protection condition designate optimal thermal protection) in function of nominal supply temperature in installation with convective heaters presented for different heat sources

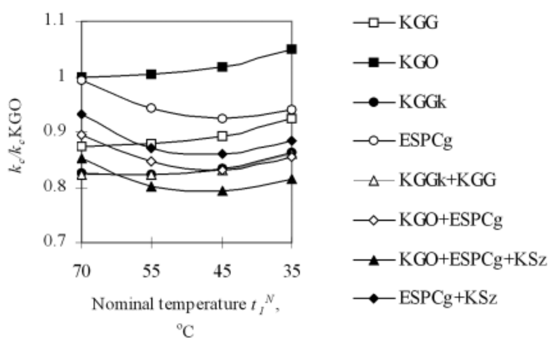

Figure 3.
Relative total cost k_c of thermomodernization (windows, central heating installation, heat source) of multifamily building with *U*-value for walls according to requirements from year 2002 [7] in function of t_1^N for convection heater and different heat sources

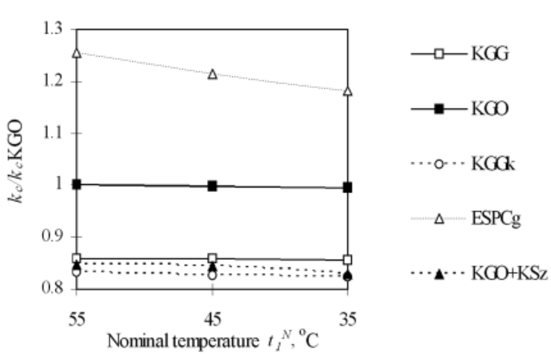

Figure 4.
Relative k_c of thermomodernization of single-family building with optimal thermal insulation in function of nominal temperature of heating installation with floor heating and different heat sources

nal temperature of supply air is close to 40°C. In case of small rooms this can cause substantial non-uniformity in temperature distribution.

3.2 Optimal nominal temperature of water-based central heating installation dependence on the heat source

In order to determine optimal nominal temperature the computer program "Multival" was used.

Optimal temperatures were defined based on total costs of the heat source, the central heating installation kc and thermal insulation for single-family and multi-family buildings. Considered thermal protection conditions were set based on the limit values given in [4-7] and defined as optimal values indicated by "Multival" program. Various individual heat sources were considered: non-condensing oil-fired boilers (KGO) and gas boilers (KGG), condensing boilers (KGGk), bivalent configurations of these boilers, electric compressor heat pumps (ESPCg), bivalent configurations of heat pumps (ESPCg+KGO), electric heating with floor heaters (OEL), multivalent systems using solar collectors (KS)-(ESPCg+KGO+KS).

For the building that fulfilled thermal protection requirements since year 2002 the cost of insulation was not taken into account in total costs calculations. In the heat source analysis with condensing boiler a linear change of efficiency in a function of return medium temperature was assumed. Nominal temperatures t_1^N=70°, 55°, 45°, 35°C given in Figures 2, 3 and 4 represent the following sets of nominal temperatures: 70°/55°, 55°/45°, 45°/35°, 35°/27°C. Priority for preparation of tap hot water was assumed for all heat sources analyzed. In case of monovalent heat sources with ESPCg, calculations for nominal temperature t_1^N =70°C were performed after linear extrapolation of heat pump characteristics given in catalogue to the temperature 7°C, i.e. of the medium leaving the condenser. In heat sources containing KGO+ESPCg+KS in case of t_1^N =70°C only KGO and KS were present. For the purpose of analysis prices in year 2006 were used.

In case of multi-family house with optimal thermal protection or well insulated the most beneficial, as regards to total costs, nominal temperatures of heating medium in central heating installation equipped with convective heaters are close to 50°/40° – 45°/35°C for heat sources with heat pump. For heat sources with condensing boilers a weak minimum occurs in the temperature range 70°/55° – 55°/45°C. If heating installation contains classic floor heaters and a single-family house is considered, then the optimal nominal temperatures are close to 35°/25°C for the source with heat pump. It should be noted, that application of floor heaters instead of convective heaters allow to decrease seasonal heat demand for heating by approximately 5%, when similar level of thermal comfort is maintained.

4. CONCLUSIONS

Determination of optimal nominal temperature for central heating installation is linked with determination of nominal temperature lower than currently used temperatures. Decreasing nominal temperature has impact on: construction features of heating installation, energy efficiency of the installation, thermal comfort, hygienic conditions in heated rooms, energy efficiency of the heat source, type of components and organization of heat source operation, system complexity of heat transported from the heat source to the installations (output and supply temperature regulation). Decreasing nominal temperature results in improved thermal comfort and, typically, in better hygienic conditions in heated rooms. Optimal nominal temperatures based on the unit total costs required to fulfil requirements for thermal conditions were determined in the present study. Total costs considered also energy efficiency of heating installation and its heat source. In buildings with good thermal protection the optimal nominal temperatures of heating installation equipped with panel heaters, heat source whose energy efficiency of heat source components depend strongly on the water temperature, are close to 50°/40° – 45°/35°C. For heat sources with condensing boilers a weak minimum occurs in the temperature range from 70°/55° to 55°/45°C. If such as installation in single-family house consists of classic floor heaters, then optimal nominal temperatures of heating medium are close to 35°/25°C for the heat source with a heat pump.

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