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Heat Supply Systems of Renovated Residential Buildings

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Abstract. Since 2010 in Latvia energy efficiency improvement measures in residential buildings have been actively implemented with an aim to reduce heat energy consumption and heating costs in houses. The aim of the study is to find optimal solutions for reducing energy consumption and increasing energy efficiency indicators of heating and domestic hot water systems. In the framework of the study heat consumption analysis of the domestic hot water supply systems in residential buildings was carried out. The results showed that heat energy savings and home energy efficiency theoretically and optimistically predicted by the renovation project after three years of operation of renovated houses were not reached. It was concluded after a thorough analysis that the external enclosing construction insulation reached predicted energy savings. Energy efficiency of the heat supply system was low, thermal energy consumption was higher than expected. Central heating systems are hydraulically unstable because heat in apartments is regulated emotionally, exceeding the regulated operating mode. The domestic hot water supply systems low energy efficiency causes relatively large thermal energy losses in hot water distribution and in circulation pipelines. The project was implemented in 2014; after three heating seasons of operation data monitoring, fixation of project deficiency and correction of solutions were carried out. According to the operation data monitoring, this innovative system is the most functional and energy efficient, corresponding to installed requirements of the project. After the assembly was completed the system was tuned to work in calculation mode and put into operation. During operation while heat consumption regime is changing, the functional efficiency does not change. Apartment heating system heat output is automatically regulated according to the room temperature. Preparation of hot water is provided in every apartment`s boiler capacity (in local space heaters) with the combined heating system heat transmission at 70 ° C temperature. It provides hot water heating to 60°C close to the final user and prevents the growth of microorganisms in hot water distribution system pipelines of the end user.

Keywords – massiveness, heating, heating season, hot domestic water supply

Introduction

Renovation of buildings

Terminology used in the article

Partial renovation – selectively renovated completely dilapidated engineering systems or building elements whose further qualitative operation is not possible.

Complex renovation – replacement of engineering systems; performance of the renovation or replacement of dilapidated parts of the building, if possible.

Traditional central heating system – unified single-pipe heating system of the whole house with vertical risers functioning in a unified hydraulic and heat-output mode.

Innovative central heating system – unified hydraulic supply system of a house divided into apartment autonomous subsystems, which functions autonomously without affecting the total building functional quality and the hydraulic and heat-output mode.

Massiveness of building elements – the ability of building to accumulate heat.

The aim of the study is to find optimal solutions for reducing energy consumption and increasing energy efficiency indicators of heating and domestic hot water systems. In the framework of the study heat consumption analysis of the domestic hot water supply systems in residential buildings was carried out.

On the basis of the EU energy policy guidelines and using the EU co-financing, since 2010 in Latvia improvement of existing low energy efficiency (up to 160 – 240 kWh /m^2 in a heating period) in privatized multi-apartment residential buildings have been actively implemented in order to reduce heat energy costs and heat supply costs for these buildings.

The priority in the projects was given to the renovation of dilapidated external deteriorated constructions and arrangement of building elements along with the renovation of physically and morally, partly or completely dilapidated thermal energy consuming engineering systems of houses: central heating, hot water supply and ventilation systems by performing partial or complex renovation, accordingly.

In the time period from 1960 to 1990 multi-apartment residential buildings were built quickly and cheaply using the existing material base and construction technologies. They belonged to the state and were rented to residents. In the 90s of the previous century, these houses were privatized and apartment renters became apartment owners. House building elements and engineering systems (heating, ventilation, water supply, and sewerage) were defined as the common ownership of all privatized apartments. Home apartment owners were jointly responsible for the qualitative operation of building elements and engineering systems. Central heating systems such as a traditional single-pipe heating system with vertical risers for water heating systems, with horizontal flow and reverse heat dividing transfer mains were located in the attics and the basement of buildings.

Centralized hot water supply system for water preparation takes place in heating substation, from where it is supplied to the apartments through the recirculation pipe with the circulation pump. The negative side of hot water systems is that there is a waste of hot water.

Ventilation has a natural gravity system. The extract is arranged from the upper area of the room through the vent channels. The inflow is provided through special openings in the window leaf through ventilations panes, special air supply devices, which were installed in outside walls under the windows. The cold outside air, which flows inside, is heated with increased warmth of heaters from the heating systems. Central heating systems of old apartment buildings have successfully fulfilled their functions, but they have to be changed due to their depreciation.

Results

The study analysed 18 multi-apartment residential houses in different cities of Latvia: Liepaja, Talsi, Stende. Their renovation was carried out in different time periods. Data is collected from non-renovated houses (written in black), insulated houses (written in blue Italic) and fully renovated houses (written in red Bold) according to the heat consumption in kWh/m2 in the heating season. Table 1 shows the data of the heat energy consumption of houses.

TABLE 1

Data of the 7 most typical houses for thermal energy consumption.

House No.	heated area, m^2	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
1.	1,850	116.3	***65.4***	**55.2**	**38.5**	**41.9**	**38.7**	**39.1**	**40.7**
2.	3,186	136.5	143.9	117.2	133.6	111.2	**51.8**	**56.8**	**63.6**
3.	3,259	133.9	127.8	125.7	***91.4***	***111.4***	**66.9**	**71.7**	**81.7**
4.	1,610	143.6	153.3	**62.5**	**68.4**	**57.7**	**59.3**	**64.3**	**67.9**
5.	1,001	202.1	204.5	189.4	***115.3***	**83.12**	**79.6**	**72.1**	**78.4**
6.	967	171.4	170.9	178.7	147.7	***67.8***	**55.2**	**56.9**	**62.8**
7.	973	169.9	160.1	132.2	159.8	***70.97***	**58.4**	**56.9**	**62.9**

The actual heat losses of the building at t_{inside}=+18°C and $t_{outside}$= -20°C exceeded the project's previously calculated losses, as a result thermal discomfort was observed during the operation of the building. The improperly operated traditional central heating system was inefficient with high energy consumption and losses. This is partly due to the lack of understanding of the owners of the apartments about the operation of the system.

Depreciation of 50 years old houses which have been functioning insufficiently was close to 100%, so they had to undergo complex renovation. The evaluation of achieved energy efficiency was carried out after 3 years of operation of renovated houses in 2013. Having comprehensively and thoroughly analysed the summarized evaluation results, the conclusion was made that in most cases partially renovated houses have not reached the previously estimated energy efficiency results, corresponding energy saving and economic efficiency. After the analysis it was possible to conclude that the energy saving reached due to the insulation of the external enclosing structure of buildings was in accordance with the predicted results. Heat energy consumption of renovated houses was affected by non-renovated or partially renovated central heating systems. Their functional quality was unsatisfactory.

Partially renovated or completely renovated traditional central heating system solutions do not radically improve the operation of the system, but makes it more expensive to operate. Efficiently insulated multi-apartment residential building solutions for traditional heating systems are not functional and economically effective in the conditions of Latvian seaside climate [1]. Climate conditions are a determining factor for the quality operation of traditional central heating systems and the economic efficiency.

In order to ensure that the room is at standard or comfortable temperature, traditional central heating system`s heat output in renovated non-heated houses is regulated depending on the outdoor temperature and the corresponding loss of house heat.

Thermal conductivity of exterior walls and upper floors of non-heated houses is rationed at 1.0–0.8 W/m^2°C. The outdoor temperature fluctuations quickly affect thermal comfort of a house. Automation of heating system`s heat output control either raises or lowers circulating heat flow temperature in central heating system accordingly.

Such a method of regulating heat output in non-heated houses with traditional central heating system was recognized as effective [2]. In non-heated and heated standard houses heat conduction coefficient U-values of building constructions heat transfer is shown in Table 2.

TABLE 2

Heat conduction U-values

Building element	**Non-renovated house U, W/m2*K**	**Renovated house U, W/m^2*K**
Outer wall of facade	1.02	0.29
Covering	0.86	0.19
Floor on soil	0.23	0.2
Door	4.53	2.0
Windows	3.23	1.8

However, such a heat-regulating technique is not economically efficient for insulated houses with high massiveness D [3]. The climate of Latvia is characterized by rapid fluctuations in outdoor temperature during a heating season in early hours and in the evenings, when a range of temperature variation can reach 15 - 20 ° C within 4-6 hours. In late evening hours when the temperature outside drops sharply, efficiently insulated buildings equipped with traditional, partially modernized central heating systems and their heat-regulating automation, increase the heat output of the central heating system that compensates heat loss according to the outside temperature. The massiveness D of efficiently insulated houses, which can continuously recoup the increasing heat loss, maintains normal thermal comfort at home. Houses are "overheated", heat energy consumption increases because people have to ventilate rooms.

In early morning hours, the outside temperature rises rapidly, as the heat loss of buildings decreases, the central heating system practically does not work, because the accumulated heat can be sufficient to maintain thermal comfort. The proper operation of houses` central heating system is ensured by a proper operation of the system.

The massiveness of a building is determined by the potential for accumulation of heat in buildings. It is calculated using the following formulas:

$$D = R \cdot S, \tag{1}$$

where

R – coefficient of thermal resistance of building elements Rn= δn / λn, (m2*K)/W;

S – thermal conductivity or heat absorption coefficient of the external building structure, W/(m2·K). The building absorption coefficient is calculated according to the formula:

$$S_m = 0.27\sqrt{\left(\lambda_m * \rho_m * (C_0 + 0.0419 * \omega_0)\right)} \tag{2}$$

where

λ_m - thermal conductivity of the building element material layer, W/(m*K); ρ_m – the volume density of the building element material layer, kg/m3;

Co - the specific heat capacity of an absolutely dry (ωo=0%) material layer of a building element, kJ/(kg*K); ω_o – layer weight humidity of building element material, %.

The empirical coefficient of 0.27 is applied in the permanent heating mode following materials and physical properties of the building elements used [4].

If the building structure is multi-layered of different materials, then "S" must be calculated for each layer according to formula 3:

$$Dn = R1 \cdot S1 + R2 \cdot S2 + \ldots + Rn \cdot Sn. \tag{3}$$

Taking into account the building area of each building, the total massiveness of the building was calculated:

$$D_e = \frac{D_1 \cdot F_1 + D_2 \cdot F_2 + \ldots + D_n \cdot F_n}{F_1 + F_2 + \ldots + F_n}, \tag{4}$$

where

D1,D2, ... Dn – the massiveness of building construction; F1, F2, ... Fn – the area of building construction, m2.

The massiveness of houses and building elements is determined by 4 levels [5]:

1) D ≥ 7 – high massiveness building;
2) 7>D ≥ 4 – medium massiveness building;
3) 4>D ≥ 1.5 – low massiveness building;
4) D < 1.5 – building without massiveness.

Using the formulas 1, 2, 3, 4 the massiveness of building elements of residential buildings was calculated. Calculation data for the house No.7 for heat inertia are summarized in Table 3.

TABLE 3

Calculation of massiveness of building elements for the house No.7

Building element	Total massiveness "D" of the building element	Total area of the building element, m^2
Walls	8.86	1,904
Upper floor cover	4.30	973
Windows	5.49	738

$$D_e = \frac{8{,}86 \cdot 1904 + 4{,}30 \cdot 973 + 5{,}49 \cdot 738}{1904 + 973 + 738} = 6.94 \cdot 1.1 = 7.64$$

The coefficient 1.1 refers to the accumulation of heat in premises, increasing the heat inertia. The particular house after the insulation is with a large massiveness D ≥7.

The heating season of an effectively heated building begins when internal heat releases do not compensate for heat losses. As a result, the length of the heating season and the heat consumption of the heating season change. Graph 1 shows the internal heat dissipation of the non-insulated and insulated houses, the heat loss and the duration of the heating period [6]. A heating season begins, when internal heat releases do not compensate for building heat losses. The building’s heat losses Qx at outside normative temperature t2 are calculated:

$$Qx = Q - 20\,(t1 - tx) / (t1 - t2), \quad (5)$$

where:

Q – Specific heat losses at normative outside temperature t2 (in Riga -20°C), W/m2; t1 – building’s internal temperature, °C; t2 - outside normative temperature, °C; tx – outside temperature for beginning of the heating season, °C.

Heating season begins for internal comfort temperature of apartments, when specific heat losses of building Qx and specific heat releases are equal to 11 W/m2, but the outside temperature is 1.5°C. The graphical calculation of the heating period is shown in Figure 1.

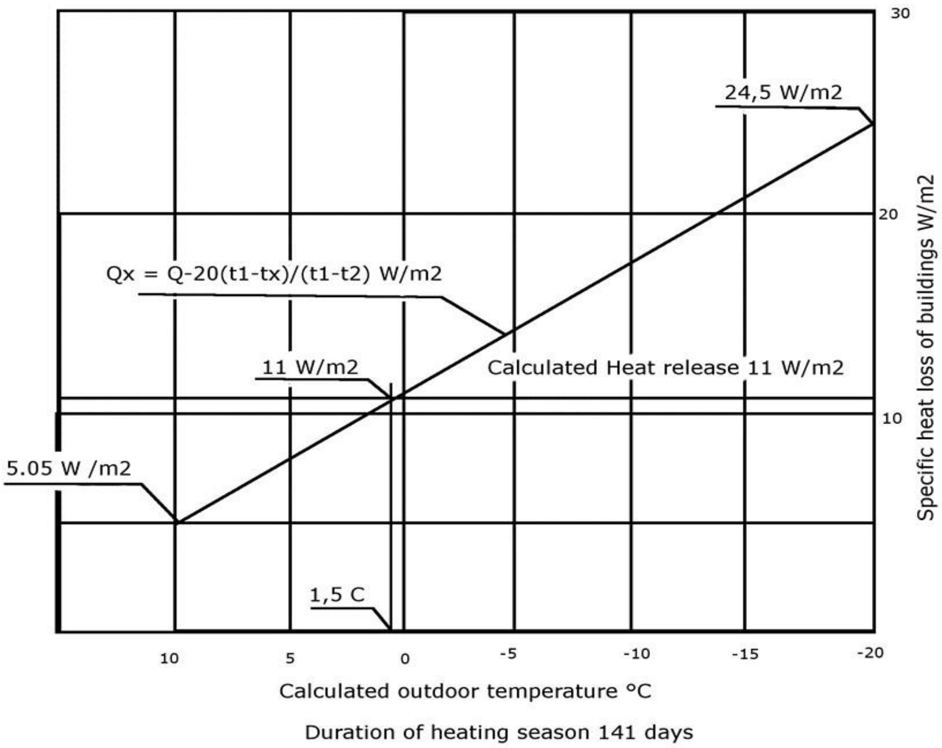
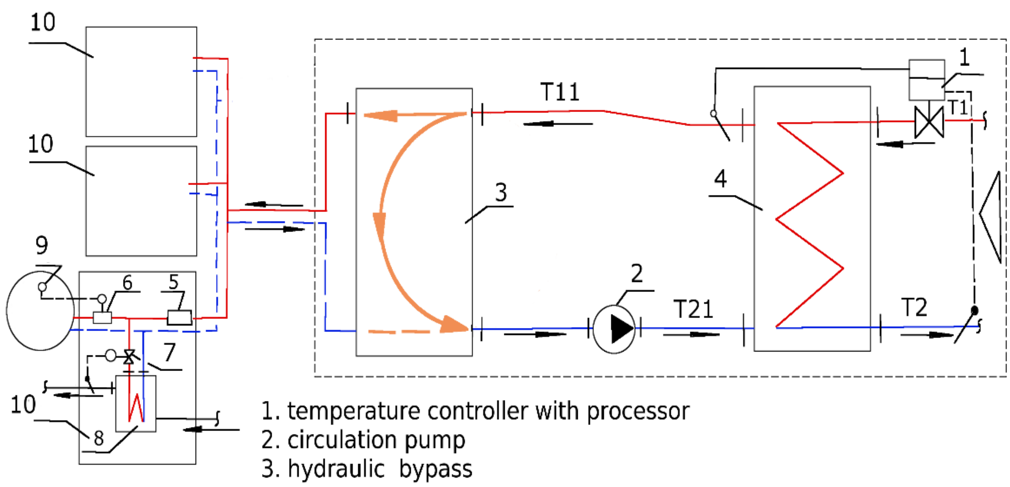


Fig. 1. Calculation of duration of heating season.

The duration of the heating season is determined using the monthly temperature fluctuation schedules for the heating period. Before the heating season the heating system of the house was hydraulically balanced and adjusted, so that all apartments and auxiliary spaces are provided with normative or required thermal comfort. In view of the decrease in outdoor temperature, it was planned in the heating system projects to increase its heat output and raise the temperature in the premises by 2-3 ° C above the normative temperature. Such a possibility for the population to regulate the heat supply of heaters themselves created the misbalance of the hydraulic and heat output of all heating systems and reduction of functional efficiency [7].

Insulated houses with a traditional heating system were compared to (heat flow adjustment based on outdoor temperature, centralized preparation of hot water for the whole house at the heat supply control point) the same houses with a new innovative autonomous heating system with hot water autonomous preparation in apartments. The functional operation of autonomous heating and a hot water system is regulated in the apartments' heating substation.

The functional operation of autonomous heating systems is regulated by indoor normative or required temperature provision and temperature fluctuations in apartments. Temperature sensors are installed in apartments. When fixing the temperature mismatch with the normative one, the command to the thermostatic valve "is given" to stop or restart the heat flow supply to the system. As soon as the temperature in the room meets the standard or falls to the limit, the sensor "gives command" to the thermostat valve to open and the heat flow circulation in the system and the return of heat in the premises restarts [8]. The schematic image of the innovative heating system is shown in Figure 2.



1. temperature controller with processor
2. circulation pump
3. hydraulic bypass
4. heat exchanger
5. hot water consumption heat meter for the apartment
6. thermostatic valve for capacity control of heating system of the apartament
7. regulator for hot domestic water
8. boiler for hot domestic water
9. temperature sensor in the apartment
10. apartament heating system

T1;T2 – heat supply and return from district heating system
T11;T21 – heat supply and return in the building heating system

Fig. 2. The functional schema of the innovative heating system

The central heating secondary heat supply system of a house operates in low pressure mode up to 3 bars. It is connected to a high pressure centralized heat supply system that is separated by an appropriate heat exchanger.

The duration of the system`s shutdown depends on several factors, however, essential is the thermal inertia of the building, ventilation, heat release in the room, insulation through the windows on sunny days and on the south side of the building.

The entire thermal system of the building is regulated quantitatively, but it does not affect the quality of all the apartment heating systems in the house. The hydraulic stability of the house`s heating system is provided by a hydraulic bypass in the heat substation of the house. Such systems can only be used in efficiently renovated houses with low heat energy consumption of 60-100 kWh / m2 during the heating season [8]. The heat flow supply and reverse temperature of 70°C / 30°C is constant in winter and summer. Such flow of temperature provides low heat loss from system pipelines. Stable heat flow temperature prepares hot water up to 60°C in heaters directly in an apartment with less heat loss. It provides hot water heating close to the final user and prevents the growth of microorganisms in hot water distribution system pipelines of the end user.

A standard temperature schedule of 80°C / 60°C was used until the reconstruction. It increased the heating area of the heating system and heat output potential in case the outside temperature fell below the calculated temperature. This created an increase in the loss of heat in the house.

An inventory of the heat consumption of an innovative heating system is carried out at the apartment's heating substation, using simple hot water consumption meters with the temperature limit to 70°C. The entire house`s heating system`s record can be seen in the heating substation.

Conclusions

Since 2010 in Latvia improvement of existing low energy efficiency (up to 160 – 240 kWh /m2 in a heating period) in privatized multi-apartment residential buildings has been implemented. After efficient renovation in residential buildings heat energy consumption decreased to 40-100 kWh / m2 during the heating season.

In order to improve the energy efficiency of the house heating system, the study was carried out and a new central heating system project was developed. It was implemented in the heating season of 2013/2014. Economic efficiency evaluation was performed after 4 years of operation and monitoring of the new non-traditional heating system.

Energy consumption in the heating season of 4 buildings before renovation, after partly renovation and after complex renovation is shown in Figure 3.

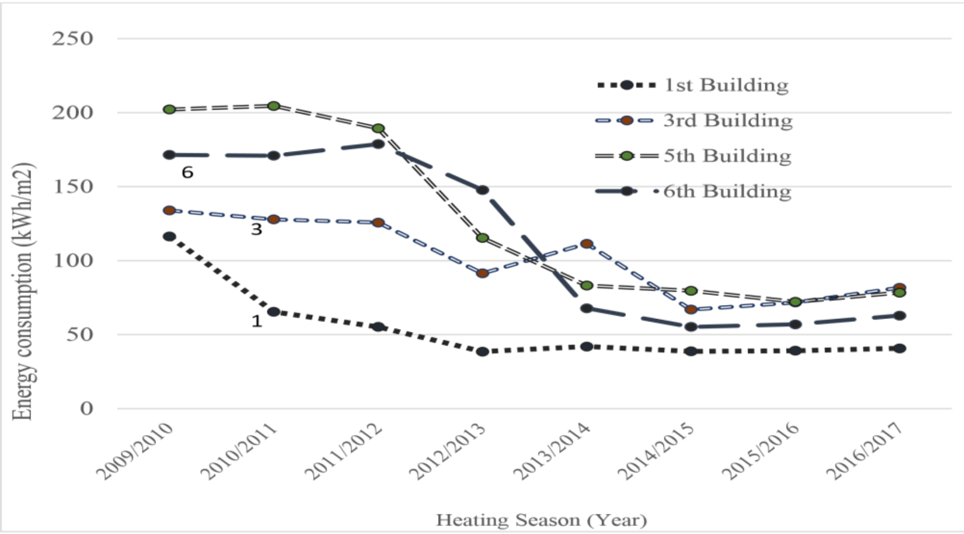


Fig. 3. Energy consumption of buildings, kWh/m^2 in 8 heating seasons.

After estimating the functional quality of operation and economic efficiency of the given heating innovative system during 3 years of operating data, it is evaluated as functionally and economically efficient compared to the traditional heating system and can be recommended for renovated, energy-efficient homes in the climatic conditions of Latvia. Heat energy consumption kWh/m^2 decreased by 60-70%.

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