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Energy performance of domestic hot water systems

Энергетические характеристики систем бытовой горячей воды

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Abstract. Residential sector consumes 70 % of the district heat. The domestic hot water system consumes 27 % of the total thermal energy consumption in these buildings in Riga. According to the mandate of the European Committee for Standardization (CEN) European standards for assessment of the energy performance of buildings have been developed. CEN standards give different methods and default values for calculations and procedures for energy performance assessment. Taking into account national or regional regulations and climatic conditions for all CEN standards application a national annex is required. CEN standards adapted to the status of Latvian standards (LVS) are not complemented with national annexes that are required for high grade use of standards at the national level. The target of this paper is assessment the suitability of CEN standards for the calculation of energy performance of the domestic hot water systems and search for the optimal solutions (methods and default values) for Latvian conditions. In this study there is performed assessment of the consumption of the heat energy in the apartment buildings for heating and hot water system, including: 1) assessment of the DHW volume and necessary energy amount; 2) assessment of the heat losses in the hot water distribution system during heating and non-heating seasons; 3) assessment of the auxiliary energy of the DHW system. The results of this paper give possible evaluation of economic feasibility and energy impact for improvements of domestic hot water systems. The method corresponding to CEN standards suitable for Latvian conditions is proposed.

Аннотация. Жилой сектор потребляет 70 % тепловой энергии. Внутренняя система горячего водоснабжения потребляет 27 % от общего потребления тепловой энергии в этих зданиях в Риге. В соответствии с документом Европейского комитета по стандартизации были разработаны европейские стандарты оценки энергетических характеристик зданий. Данные стандарты содержат принятые по умолчанию методы и значения для расчетов и процедур оценки эффективности использования энергии. Принимая во внимание национальные или региональные правила и климатические условия для применения стандартов, требуется национальное приложение. Стандарты, адаптированные под статус латвийских стандартов, не дополняются национальными приложениями, которые необходимы для высококачественного использования стандартов на национальном уровне. Целью настоящего документа является оценка пригодности стандартов, принятых Европейским комитетом, для расчета энергетических характеристик бытовых систем горячего водоснабжения и поиск оптимальных решений (методов и значений по умолчанию) для латвийских условий. В этом исследовании проводится оценка потребления тепловой энергии в многоквартирных домах для систем отопления и горячего водоснабжения, в том числе: 1) оценка объема ГВС и необходимого количества энергии; 2) оценка потерь тепла в системе распределения горячей воды во время нагрева и ненагрева; 3) оценка вспомогательной энергии системы ГВС. Результаты этой работы дают возможность оценить экономическую осуществимость и энергетическое воздействие для улучшения бытовых систем горячего водоснабжения. Предложен метод, соответствующий стандартам Европейского комитета, подходящий для латвийских условий.

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Introduction

Multi-apartment buildings are one of the largest group of district heat users in Latvia. The residential sector consumes 70 % from the total heat produced in district heating systems in Latvia. The amount of energy consumed in domestic hot water (DHW) systems represents an average of 51 kWh per square meter of apartment's heated area annually or 27 % of the total heat energy consumption in those buildings.

To implement the goals of the European energy policy has adopted the Energy Performance of Buildings Directive that introduced energy performance certification of the buildings. According to European Commission mandate M480 there are a lot of developed and adopted European standards (CEN) for assessment of the energy performance of buildings – EPBD standards. The EPBD standards prescribe that EU member states shall adopt the standards on national or regional level, taking into consideration local climatic conditions. The EPBD standards adopted for Latvia (LVS) are not supplemented with national annexes necessary for full application of the standards on national level.

Previous studies [1–4] carried out in various European countries, China, Japan, USA, Canada point out many differences in DHW usage and consumption as well the tendency to change over time due to a global increase of energy prices, changes in technologies, introducing of individual metering, as well as wide variety of other factors that may appear on local or regional level.

Researches in Estonia [5] show that household hot water consumption has decreased for more than three times during last 30 years, which is caused by the implementation of the water consumption metering, increase in energy price and implementation of energy efficiency measures in the buildings.

The Latvian researchers study [6–13] on DHW consumption profiles in apartment buildings found that the actual consumption of DHW is twice lower than the normative. Energy needs for the DHW represents significant part of energy balance of residential and some other sectors of buildings. Significant amount of energy demand can be formed by both – DHW consumption needs as well DHW circulation losses.

The scientific and technical articles [14–18] provide wide and overall information on DHW systems, consumption profiles, technologies and technical solutions. Taking into consideration changeable political, economic, technological circumstances and legal conditions as well as local or regional factors the necessity for more and more new researches on DHW systems investigation still exists.

In articles [19–21] the analysis and solutions of problems of hot water systems were produced. The authors offer various methods of studying of problems of domestic hot waters in residential buildings.

Research studies [22–25] present the main architectural-planning, spatial and constructive solutions aimed at energy saving and enhancing energy efficiency of residential buildings. It is shown that the determining factors for low-level consumption in buildings thermal energy for heating are: high level of thermal insulation of external enclosing structures, integrity of the outer shell of the building and its compactness. Lists the possible measures to reduce costs for DHW.

The goal of this paper is to assess the applicability of EPBD standards for Latvian conditions and to find the right solutions for calculation the energy performance indicators of the DHW system for energy certification of the building.

Materials and Methods

Within this study, there are analyzed heat energy and hot water consumption in multi-apartment buildings with many apartments. This approach smoothes out the differences and gives higher validity of results to characterize the apartment housing sector. Selected multi-apartment buildings have a typical annual heat consumption for Latvian climate conditions. The buildings have been operating for a long time without any reconstruction, except automatic heating units that improved about 10 to 15 years ago in most buildings. The annual thermal energy consumption in the analyzed buildings ranges from 164 to 225 kWh/m^2 in Riga and from 155 to 245 kWh/m^2 in Bauska (both calculated on total dwelling area). The investigated buildings are built according to standard type designs from sixties to nineties of 20th century. Usually apartment buildings have a single heat meter for both heating and DHW in Latvia. Therefore, to calculate energy performance indicators of the building it is necessary to assess the volumes of the DHW, the energy required for DHW heat at the required temperature and thermal losses in the DHW distribution and circulation pipelines. Estimated indicators of residential areas are presented in Table 1.

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Table 1. Indicators of residential areas

	Riga	Bauska
Number of buildings	39	57
Number of stores	3–12	
Total heated area (m^2)	158 194	91 001
Number of dwellings	3359	3167
Number of inhabitants	7139	no reliable information

All investigated buildings are connected to the district heating network. All buildings have the automatic heating unit equipped with the single heat meter for heating and DHW as well as hot water and cold-water meters. Automatic heating control unit ensures DHW temperature of about 50 to 55 °C during the water taping. The draw of DHW distribution systems with circulation is shown on Figure 1. For most of the standard design type buildings (except for 12 storied destine type No 104) the DHW distribution system have several circulation loops with bottom distribution supply pipes from basement, branch pipes from supply pipes in dwellings and downward return pipes.

The DHW distribution system of 12 storied destine type No 104 buildings have one upwards supply pipe from basement to building top (attic) and several downward return pipes with branch pipes in dwellings.

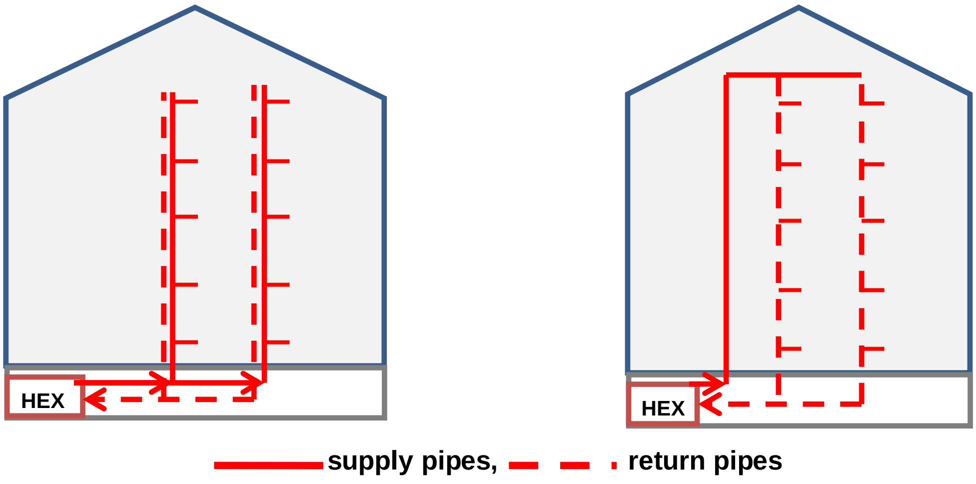


Figure 1. DHW distribution system with circulation loop. The bottom distribution (on the left), the upper distribution (on the right).

The CEN standards for energy performance of buildings provide concept and common methods for preparing energy performance certification and energy inspections of buildings. Calculation model for energy performance assessment of DHW systems described by the standards:

1) EN 15316-1 – Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 1: General (EN 15316-1);

2) EN 15316-3-1 – Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 3-1: Domestic hot water systems, characterization of needs (tapping requirements) (EN 15316-3-1);

3) EN 15316-3-2 – Heating systems in buildings - Method for calculation of system energy requirements and system efficiencies – Part 3-2: Domestic hot water systems, distribution (EN 15316-3-2).

Results and discussion

Assessment of energy performance of the DHW systems of the apartment buildings

Characteristics of the domestic water consumption

The assessment of the consumption data per dwelling area in 22 buildings in Riga shows that average annual consumption of water in the investigated buildings is 3.64 liters per m^2 daily, of which

2.12 liters cold water and 1.52 liters hot water. The average daily consumption of domestic cold water and DHW per m^2 per day shown in Fig. 2. The chart shown that consumption of the hot water decreased but consumption cold water increased during the summer.

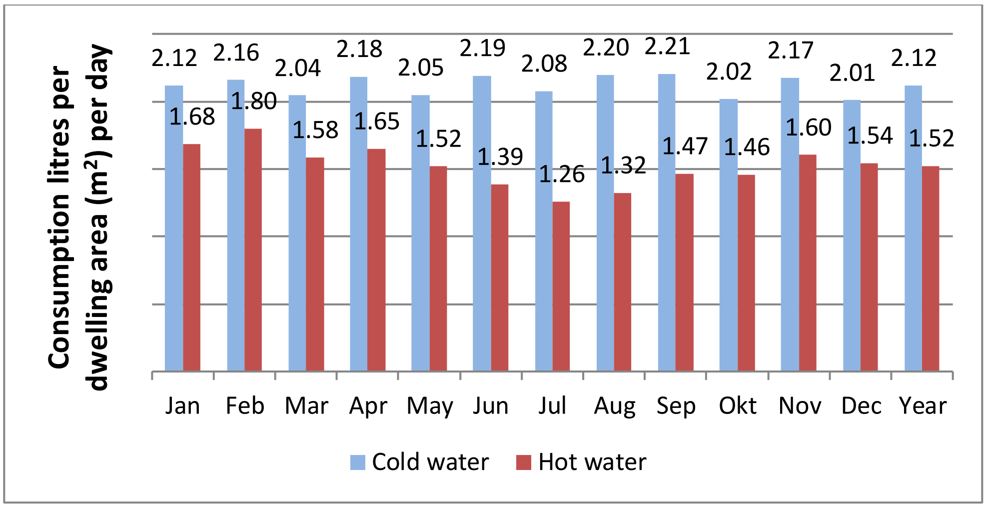


Figure 2. Average daily consumption of domestic cold water (DCW) and domestic hot water (DHW) in apartment buildings (liters per m^2 per day) by months and yearly

The average DHW consumption ratio is 41.8 % of total annual water consumption while seasonally it is 43.9 % during heating season and 39.4 % during non-heating season. The Figure 3 shows DHW consumption ratios of total and inlet water average temperature variations per months. The monthly differences of hot water consumption ratio are caused by variation of temperature of inlet cold water during a year. When supplied cold-water temperate increases (in summer) necessary hot water amount decreases whereas when supplied cold-water temperature decreases (in winter) the necessary hot water amount increases. DHW consumption is 94 % of annual average in the non-heating season and 106 % of annual average in the heating season.

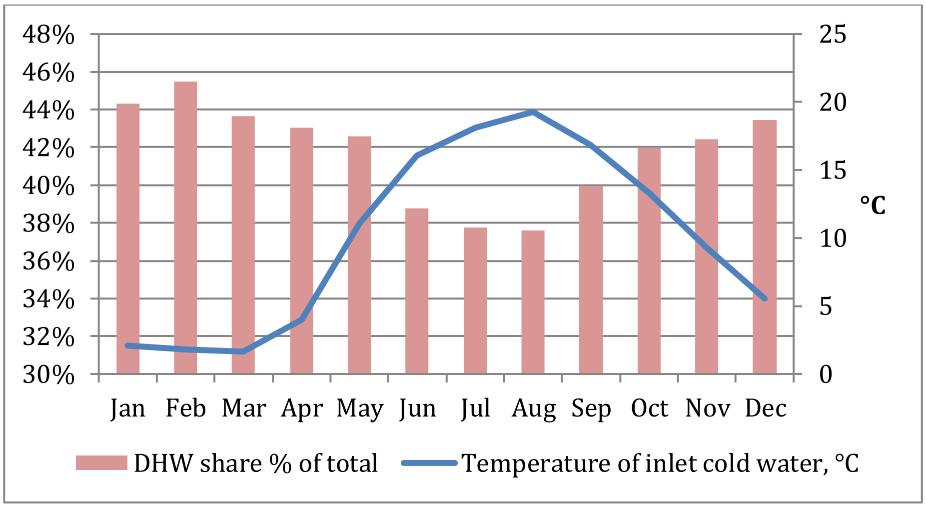


Figure 3. The ratio (%) of consumption of DHW to the total consumption in apartment buildings and average temperature of inlet cold water per month

The study shows specific indicators for a better understanding of DHW consumption (Table 2).

The coefficient of determination R has used to explain how much variability of one factor can be caused by its relationship to another factor (if the coefficient is closer to 1 then the relationship is closer). Consequently, the DHW consumption per one inhabitant has the highest coefficient of determination (R^2=0.94).

Table 2. DHW consumption indicators

		Minimum	Maximum	Average	Coefficient of determination R^2
Consumption of DHW, liters per day					
Per m² of dwelling area	Riga	1.10	2.73	1.86	0.90
	Bauska	1.01	3.53	1.54	0.84
per dwelling (household)	Riga	55.7	142.6	94.0	0.88
	Bauska	40.0	121.3	73.1	0.81
per person	**Riga**	24.2	60.2	41.0	**0.94**

By comparing DHW consumption indicators in the investigated buildings to default values set out in Annex A of standard EN 15316-3-1 the authors found out that average DHW consumption of 41.0 liters per person per day is close to the default value 36 liters per person per day in Table A.1 'Tapping program No. 1'. In addition, DHW consumption significantly differs from the values set out in Latvian Construction standard LBN 221-15 "Internal Water-main and Sewage of Buildings". The paragraphs 1.6 to 1.8 of Annex 4 of LBN 221-15 set out DHW consumption normative values 85 until 105 liters per person per day.

The average values of DHW consumption 94.0 litres per dwelling in Riga and 73.1 litres per dwelling in Bauska are less than default values of 100.2 liters per dwelling, determined in Table A.2 ('Tapping program No. 2.') and is very different from the default value of 199.8 liters per dwelling, determined in Table A.3 ('Tapping program No. 3.').

Assessment of energy consumption for DHW subsystems

To calculate energy used for DHW needs and DHW circulation, there is used data on heat energy consumption in the buildings during non-heating season (May to September).

In general, the total heat energy consumption Q in the analyzed building is the sum of energy for heating, DHW needs and heat losses in the DHW distribution circulation loop.

$$Q = Q_H + Q_W + Q_{W,cirk}, \tag{1.2.1}$$

where Q – the total energy consumption for heating and for DHW system, kWh;

Q_H – the energy consumption for space heating, kWh;

Q_W – the energy consumption for DHW needs, kWh;

$Q_{W,\,cirk}$ – the thermal losses from pipes of DHW distribution circulation loop, kWh.

The energy need for DHW heating Q_w is calculated as follows:

$$Q_W = V_W \frac{\rho_W c_W}{3600} \cdot \left(\theta_{w,dbl} - \theta_{w,o}\right), \tag{1.2.2}$$

where Q_w – the energy need for DHW, kWh;

V_w – the volume of water (in the respective period), m^3;

ρ_w – the density of water, kg/m^3;

C_w – the specific heat capacity, J/(kg·K);

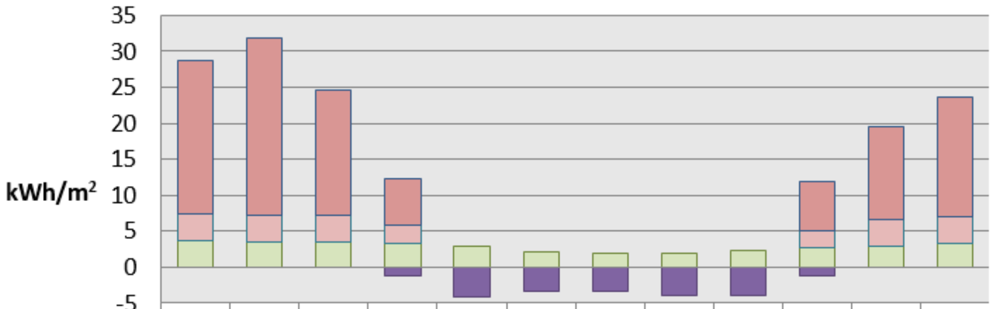
$\theta_{w,del}$ – the average cold water inlet temperature, °C;

$\theta_{w,o}$ – the average DHW delivery temperature, °C;

3600 – the factor of conversion from megajoules to kilowatt-hours.

The calculations on the study based on actual monthly average cold water temperatures. For comparison, the calculations based on seasonal (heating and non-heating season) average cold water temperatures or default cold water temperatures from LBN 221, have impact the results within 2%. The calculation with average annual default cold-water temperature (either LBN 221 or EN 15316-3-1) affect the results more higher and error may exceed 10 %.

Based on data of necessary energy for DHW needs during non -heating season it is possible to calculate the energy losses on DHW distribution circulation loop. The calculated monthly data of energy consumption for DHW needs (consumption), the thermal loses on DHW circulation loop and the energy for heating system per dwelling area of buildings in Riga shown in Figure 4.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heating needs	21.29	24.68	17.29	6.49						6.77	12.98	16.59
Recoverable DHW circulation losses (heat gains)	3.74	3.74	3.74	2.49						2.49	3.74	3.74
Non-recoverable DHW circulation losses				-1.25	-4.12	-3.40	-3.37	-3.93	-3.88	-1.25		
DHW needs	3.66	3.42	3.55	3.26	2.82	2.19	1.95	2.00	2.23	2.63	2.89	3.32

Figure 4. Heat energy average values per m^2 of heated dwelling area per month for heating, DHW needs, DHW circulation (data on 39 building in Riga)

The total thermal losses of a DHW distribution circulation loop range from 28.9 to 65.2 kWh per m^2 per dwelling area annually for different standard design buildings. The average thermal losses of a DHW distribution circulation loop is 45.4 kWh per m^2 dwelling area annually for buildings in Riga and 53.5 kWh per m^2 dwelling area annually for buildings in Bauska.

The assessment of thermal losses in DHW circulation loop in different standard design buildings per apartment give values ranges from 1.1 to 3.0 MWh per annum or 0.1 to 0.25 MWh per month. For buildings in Riga the average value is 2.28 MWh per apartment per annum or 0.18 MWh per month, for buildings in Bauska the average value is 2.58 MWh per apartment per annum or 0.21 MWh per month. In most buildings, monthly thermal losses in DHW circulation loop significantly exceed default value (0.1 MWh per apartment per month) recommended for settlement calculations in Riga city.

During heating season, the heat losses from the DHW circulation loop are recoverable for heating needs. Thus, during the heating season the heat losses in DHW circulation system are heat gains as part of total heating balance of the building.

During non-heating season, all thermal energy consumption used only in DHW system of building. The study shows that share of heat losses in DHW circulation loop ranges from 35 % till 79 % (in average 56 %) from total energy consumption or from 14.9 till 25.6 (in average 20.2) kWh per m^2 annually during non-heating season in investigated buildings in Riga.

Heat losses in the DHW circulation system have close correlation to the heated area of the building, but there is also a correlation in relation to the number of apartments, as well as number of circulation loops. Simultaneously the study shows that there is no correlation between heat loss in DHW circulation loop and such characteristic of building as: dwelling area, number of apartments, number of inhabitants (Fig. 5), i.e. the variables that have a close correlation to DHW consumption.

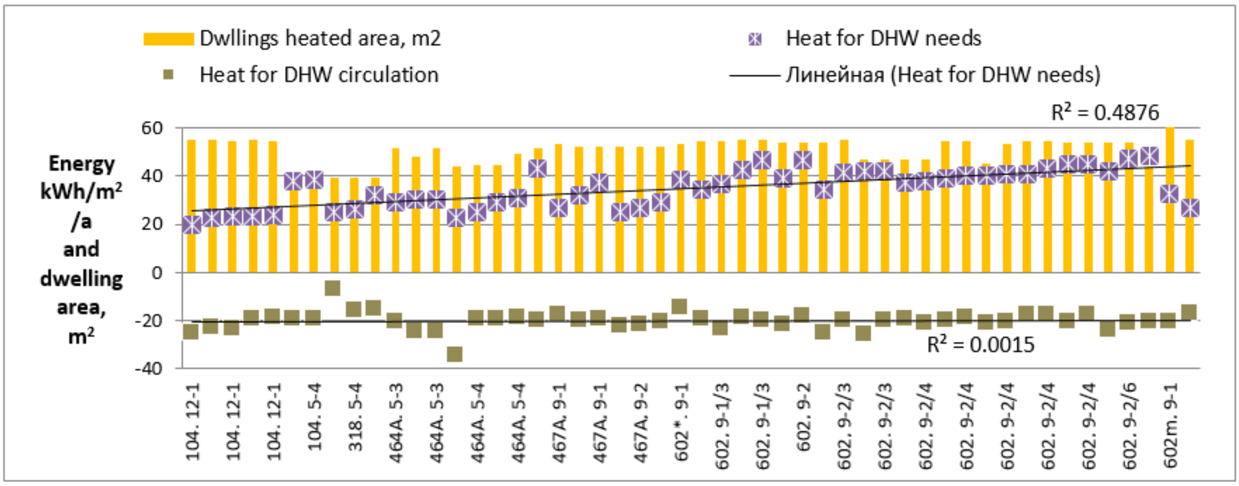


Figure 5. Heat consumption for DHW needs and DHW circulation losses and average space area of households (data on 39 buildings in Riga arranged by heat consumption for DHW needs)

Calculation of the heat energy losses based on DHW pipes actual physical characteristics

Estimation of the thermal energy losses in the DHW distribution system (experimental data), which assessed based on actual measured data for heating and DHW volume consumption in the building (see the section 1.2), in the study compared with the results obtained according to the methods:

1. Calculation of thermal losses based on the DHW pipeline physical characteristics according to 6.3.3. of the standard EN 15316-3-2;

2. Calculation of thermal losses based on DHW pipeline physical characteristics according to 6.3.3. of the standard EN 15316-3-2 using standard values provided in Annex D of the standard.

The general determination of thermal losses of a circulation loop comprising several pipe sections *I* is given by:

$$Q_{w,dis,ls,col} = \sum_i Q_{w,dis,ls,col,i} = \sum_i \Psi_{W,i} \cdot L_{W,i} \cdot (\theta_{W,dis,avg,i} - \theta_{amb,i}) \cdot t_W; \qquad (1.3.1.)$$

where $Q_{w,dis,ls,col,i}$ – specific energy losses of the distribution of pipe section *i*, Wh;

$\Psi_{w,i}$ – linear thermal transmittance of the respective pipe section *I*, W/(m·K);

$L_{w,i}$ – length of the distribution pipe section *i* (m);

$\Theta_{w,dis,avg,i}$ – mean inner temperature (water temperature) of pipe section *i* (°C);

$\Theta_{amb,i}$ – ambient temperature for the pipe section *i* (°C);

t_w – period of the time that the heat loss shall be calculated for $\Theta_{w,dis,avg,i}$ (hours).

The DHW circulation system of investigated buildings has the following features:

a) vertical distribution with known number of circulation loops in building section for each building type;

b) he circulation loops run continuously all the time; c) each apartment has one towel rail on the circulation loop.

The DHW distribution system comprises three different pipe sections:

V – distribution pipes from heat exchanger to the vertical supply pipes on basement;

S – main supply pipes on building heated area comprise: vertical pipes (S1) and individual tower rails in the apartments (S2);

I – individual branching pipes to the user outlets on dwellings. Heat losses from individual branching pipes are not affect overall circulation losses. Heat losses from individual branching pipes is part of the heat energy for DHW consumption needs.

The authors have worked out unified formulas for calculation of length of circulation loop sections for investigated buildings. The values and unified formulas for calculation of pipe length of each DHW circulations loop section based on technical design of different standard buildings are shown in Table 3.

For comparison in the Table 3. are shown default values and formulas of Annex D of standard EN 15316-3-2. To compare different calculation models the calculations use equal temperature characteristics for both the DHW temperature in the pipe sections and the ambient temperate around pipe sections. This approach allows in more accurately compare the authors' calculation method with the methods of standard EN 151316-3-2.

Table 3. The values and formulas for calculation of thermal losses of the domestic hot water distribution pipe sections

Author's calculation model	**Default values from Annex D of standard EN 15316-3-2**
Technical characteristics of distribution pipes	
V - insulated, steel, Ψ=0.4 (W/(m·K)) S_1, $S_{1,up}$, $S_{1,down}$ – non insulated, steel, Ψ=1.0 (W/(m·K)) S_2 – non-insulated, steel towel rails, Ψ=1.0 (W/(m·K))	V – insulated, Ψ=0.4 (W/(m·K)) S – non-insulated, external, Ψ=1.0 (W/(m·K))
Length of pipe section (m)	
FOR ALL TYPE OF STANDARD DESIGN, EXCEPT DESIGN NO 104 OF 12-STORE BUILDINGS: $L_V = 2 \times L_B + B_B \times n_{B,dis,col}$ $L_{S,1} = 2 \times L_B \times n_f \times h_f \times n_{B,dis,col}$ $L_{S,2} = n_{dwelling} \times L_{towel\,rail}$ 12-store 104. serial: $L_V = L_B + B_B \times n_{B,dis,col}$ (One) up distribution pipe $L_{S1,up}$ $L_{S1,up} = L_B \times n_f \times h_f \times 1$ Down distribution pipes $L_{S1,down}$ $L_{S1,down} = L_B \times n_f \times h_f \times n_{B,dis,col}$ $L_{S2} = n_{dwelling} \times L_{towel\,rail}$	For all buildings: $L_V = 2 \times L_B + 0.0125 \times L_B \times B_B$ $L_S = 0.075 \times L_B \times B_B \times n_f \times h_f$
Ψ – linear thermal transmittance of pipe section W/(m·K); L_B – the largest extended length of the building (m), B_B – the largest extended width of the building (m), N_F – the number of heated stores; $N_{B,DIS.COL}$ – the number of circulation loops in building; H_F – the height of the heated stores (m); $D_{WELLING}$ – the number of dwellings in building; $L_{TOWEL\,RAIL}$ – average length of the towel rails in dwellings (m).	
The following conditions are used in calculations: the average temperature of DHW circulation system +52°C, ambient temperature around DHW pipes +20°C, calculation time period: 162 days per 24 hours. *The CEN standards define the following default values: the average temperature of DHW circulation system +60°C, ambient temperature around DHW pipes +22°C. The standard values not been used on calculations.*	

According to the standard, the default linear thermal transmittance of pipe section should show respect to building area. The calculations with default values of the linear thermal transmittance (3.0 W/(m·K)) of main supply circulation pipe section on heated area of building give results which significantly (more than 4 times) differ from the result of actual assessment.

The results demonstrate that default values of the linear thermal transmittance set in standard EN 15316-3-2 is not applicable for assessment of the heat loss of DHW circulation subsystem. Thereby authors used input value 1.0 W/(m·K) as the closest to the actual value for calculation of the linear thermal transmittance of main supply circulation pipe section on heated area of investigated building. The comparison of the length of pipe sections by the actual and standard model shown that differences are less significant – length of the pipes located in the basement (section V) according to the standards have a length from 50% to 90% from the actual, while for other sections (S) the difference range from 110% to 320%. The calculation results for circulation losses by different assessment methods differs for standard type buildings with different technical design (Fig. 6)

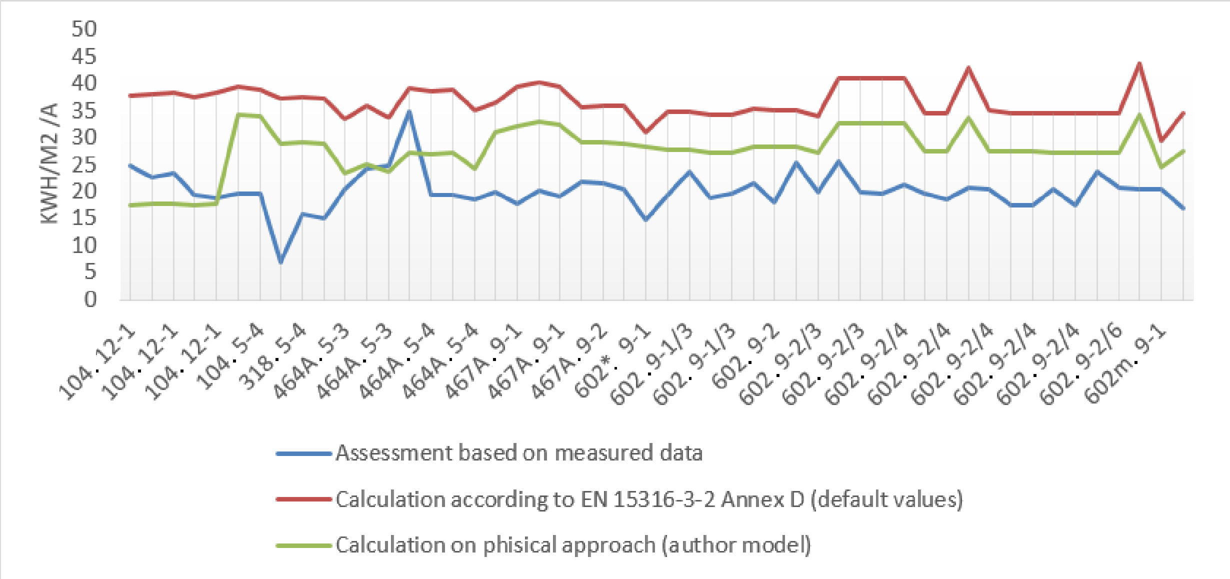


Figure 6. Calculation results for circulation losses by different assessment methods

The authors believe that most accurate results based on actual measured data of heat energy and DHW volume consumption. The calculations based on metered data shown that thermal losses of a circulation loop ranges from 14.9 to 25.6 (in average 20.1) kWh/m^2 per non-heating period (162 days) for buildings in Riga and from 12.8 to 36.7 (in average 23.7) kWh/ m^2 per non-heating period for buildings in Bauska. .

Based on the default values of technical characteristics of DHW system the calculation results in most cases significantly differ from the actual data (obtained during experiments).

The calculation of thermal losses based on the actual DHW pipeline physical characteristics and calculation using standard values of the standard EN 15316-3-2 gives highest results than experimentally based.

Theoretical calculations according to the authors methods gives closer results to the experimentally results that obtained on measured heat energy and DHW consumption. The assessment results based on authors' model differs from the experimental results range from 1 % to 88 % (in average 44 %) for different standard design buildings. In comparison, using default values and formulas for calculation, the difference is between 13 % and 147 % (in average 81 %) for buildings in Riga and from 11 % until 274 % (in average 98 %) for buildings in Bauska.

The authors consider that the biggest differences between the calculation results based on physical approach and metered results caused by the inappropriate default values of linear heat transmittance coefficient of pipe sections. Inaccuracy has formed, for example, due to embedding of pipes in the internal structures of the building. Therefore, the actual difference of the temperature of the pipeline and ambient temperature may significantly differ from the default data set up on standard. It is also known that some technical design of standard buildings has shared duct openings for DHW pipes and close sewage pipes that affect the surrounding temperature around the circulation pipes. Those errors can be prevented with correction (reduction) of the default linear heat transmittance coefficient for vertical pipe sections.

The breakdown of heat loss by DHW circulation loop sections

Additionally, the authors assessed circulation heat loss ratio of the DHW circulation systems by pipe sections during non-heating and heating seasons in different standard design buildings. This assessment based on physical approach with actual technical characteristics of DHW circulation system. The equal conditions used for calculations for heating and for non-heating seasons, with exception for average ambient temperature (+20 °C for the non-heating season and +10 °C for the heating season) around pips in the basement.

The heat losses of domestic water circulation loop outside the heating space (section V) are not recoverable during all the year (on heating and non-heating season), while it is acceptable that the heat losses from towels rails (S2 section) are useful heat gains for comfort in the bathrooms throughout the year. However, heat losses from the vertical distribution circulation pips (section S1) are useful heat gains (recoverable heat losses) during the heating season but not recoverable during non-heating season.

Based on the calculation model, the following rates obtained for different pipe sections of the DHW system:

1) for pipes in non-heated basement: from 10 % to 13 % during non-heating season and from 12% to 16 % during heating season for 5 to 12 storied buildings, from 19 % to 24 % during non-heating season and from 24 % to 29 % during heating season for 3 storied buildings and modified 4 storied buildings of standard design type No 103 in Bauska;

2) vertical distribution pipes: from 50 % to 60 % for 3-storied buildings, and from 55 % to 60 % for in 5-storied buildings, from 64 % to 67 % for 9 storied buildings, and from 48 to 49 % for 12-storied buildings;

3) for individual towel rails in dwellings: from 16 % to 27 % in 3-storied buildings, from 30 % to 33 % for 5-storied buildings, from 22 % to 24 % for 9 storied buildings, 38 % for 12-storied buildings.

The calculations shows that representative non-recoverable energy losses of DHW circulation loop ranges from 16 to 24 and in average 20 kWh per m^2 per year in investigated apartment buildings. The result is representative according to considerations that non-recoverable energy losses are in the basement during whole year, in vertical distribution pipes during non-heating season, but heat energy losses from towel rails are useful (not losses) during whole year.

The assessment of the auxiliary energy for DHW system

Auxiliary energy is one of the indicators that should be calculate during assessment of energy performance of the building. The auxiliary energy of DHW system can be calculated according to methods given in CEN or DIN[1] standards:

1) DIN V 18599-8:2007-02;

2) EN 15316-3-2:2008 (standard gives two methods: simplified and detailed);

3) European draft standards prEN 15316-1:2014 and prEN 15316-3:2014.

In the investigated buildings, the auxiliary energy for the DHW emission sub-system, generation sub-system and storage sub-system is zero. Thus, the study detailed calculations done only for auxiliary energy for DHW distribution sub-system.

According to the simplified calculation method, the auxiliary energy for the pump can be calculated by multiplying the pump power with the pump operational running time. According to the detailed calculation method, the assessment of the auxiliary energy of the DHW system takes into account hydraulic energy requirements during the operation, performance characteristics of the circulation pump as well as more than 20 other technical characteristics of the buildings and DHW system.

Results calculated according to both methods are shown in Table 4.

Table 4. Auxiliary energy by different calculation methods

	Auxiliary energy, kWh/m^2 per year					
	For DHW circulation system		For Heating system		**Total**	
Calculation method	Detailed	Simplified*	Detailed	Simplified	Detailed	Simplified
Average	0.44	*0.63/0.46*	1.18	*0.56/0.92*	**1.62**	***1.02/1.54***

* The auxiliary energy by simplified method calculated with the nominal power and maximum power of the pumps.

Discussion

The author S.V. Korniyenko in his work [26] find that actual DHW consumption represents an average of 71.5 kWh per square meter of apartment’s heated area annually or 34 % of the total heated consumption at 23-storey multi-apartment building in Russia.

[1] DIN – Deutsches Institut für Normung (German Institute for standartization)

In the study [27] it is mentioned that data based on static studies of the modes of operation of heating systems for DHW consumption of 10-storey building in Cheboksary is an average 32.2 kWh per heating period and 53.1 kWh per year and from 32 to 54 liters per inhabitant per day.

Research paper [28] concludes that DHW consumption of 32-storey building in Chogqing, a cooling dominated region in China, is 132 kWh per year. In case of DHW compouned with ground-source heat pump the simulation showed that the operation of DHW system could effectively reduce the ground temperature and improve the system performance to 89 kWh per year.

In the article [29] autors present the results of domestic hot water consumption measurements, which were done in a 32-appartament house in Riga. The results were worked up using the prescribed formulas of building normative LBN 221-98 and compose in average 44 liters per inhabitant per day.

The average value of the energy consumption for DHW system, obtained by the authors of this article, is 45.4 kWh per m^2 dwelling area annually for buildings in Riga and 53.5 kWh per m^2 dwelling area annually for buildings in Bauska The resulting discrepancy can be explained with heat losses from 50 % to 70 % for vertical distribution pipe sections and the fact that the present study covers building up to 12 floors.

In comparison with normative documents the actual DHW consumption (from 24.2 to 60.2 liters per inhabitant per day and in average 91.4. liters per households in Riga and 71.5 liters per housholds in Bauska) is less than specified in standard EN 15316-3-1 (from 100.2 to 199.8 liters per day per household) and in the Latvian Construction regulation LBN 221-15 (from 85 to 105 liters per inhabitant per day).

The actual DHW consumption from the energy point of view is significantly less that specified in Russian standard (135 kWh/m^2 per year).

Recommendations for energy performance calculation model for the DHW system

The study confirms that energy consumption of DHW system of apartment building have two distinctly independent correlative relationships:

1) Consumed volume of DHW and the required energy depend on number of inhabitants, dwelling area and number of apartments;

2) The thermal losses of DHW system circulation loop depend on heated areas of dwellings, number of apartments, number of circulation loop sections in dwellings.

The study shows and typical values the typical range for both correlative relationships. Nevertheless, the study shows differences for different standard design type buildings as well for buildings with the same design. In view of the findings authors suggest the method for energy performance assessment of DHW system of the building with unified accounting for heating and DHW needs. Detailed calculation should be carried out this way:

1. the accounting data shall be determined as:
a. the duration of the non-heating time period for month with no heating $t_{non\text{-}heating,count}$;
b. the total length of non-heating season $t_{non\text{-}heating}$,
c. the energy consumption Q_m for non-heating months m and the sum of energy consumption during months with no heating $Q_{non\text{-}heating,count} = \Sigma Q_m$;
d. the volume of DHW V_m consumed during non-heating months m and the sum of DHW volume consumed during months with no heating $V_{non\text{-}heating,count} = \Sigma V_m$;
(It is preferable to use the metering data from DHW meter of whole building instead of total sum of individual consumption data provided by the inhabitants of apartments);

2. The next step is the calculation of monthly energy consumption $Q_{W,m}$ necessary for DHW use during months with non-heating (see the formula 1.2.2. in section 1.2) and the sum for the months with non-heating

$$Q_{W,non-heating.count} = \sum Q_{W,m};$$

3. The next is the calculation of thermal losses in the DHW circulation loops $Q_{W,dis,non\text{-}heating.count}$ for non-heating months according the formula:

$$Q_{W,dis,non-heating.count} = Q_{non-heating.count} - Q_{W,non-heating.count}; \quad (2.1)$$

4. The energy for DHW needs $Q_{w,non\text{-}heating}$ and thermal energy losses in DHW circulation loop $Q_{W,dis,non\text{-}heating}$ for full non-heating season shall calculated as linear interpolation from the relevant data from months with non-heating according the formula:

$$Q_{W,non-heating} = Q_{W,non-heating.count}\frac{t_{non-heating}}{t_{non-heating.count}}; \tag{2.2}$$

$$Q_{W,dis,non-heating} = Q_{W,dis,non-heating.count}\frac{t_{non-heating}}{t_{non-heating.count}} \tag{2.3}$$

5. The difference of the DHW temperature ($\theta_{w,o}$) and inlet cold water temperature during heating ($\theta_{w,del,\ heating}$) and non-heating season ($\theta_{w,del,non\text{-}heating}$) should be taken into account to calculate the energy for DHW needs during heating season $Q_{w,heating}$ according to the formula:

$$Q_{W,heating} = Q_{W,non-heating.count}\frac{t_{heating}}{t_{non-heating.count}}\cdot\frac{(\theta_{W,o}-\theta_{w,del,heating})}{(\theta_{W,o}-\theta_{w,del,non-heating})} \tag{2.4}$$

6. The thermal losses of the DHW circulation loop $Q_{W,del,heating}$ depend on the temperature of the DHW in pipes sections i ($\Theta_{w,dis,avg,i}$) and the ambient temperature around the relevant DHW pipes sections i ($\Theta_{amb,i}$) during heating and non-heating seasons. Usually the temperature of the DHW in pipes have fixed value during heating and non-heating season. The average temperature around the pipes of sections on heated area of the building have equal value during heating and non-heating season, but the difference is caused by the pips outside the heated areas i.e. in non-heated basements and attics.

$$Q_{W,del,heating} = Q_{W,dis,non-heating.count}\frac{t_{heating}}{t_{non-heating.count}} \cdot\frac{\sum_i \Psi_{W,i}\cdot L_{W,i}\cdot(\theta_{W,cirk,i}-\theta_{amb,i,heating})}{\sum_i \Psi_{W,i}\cdot L_{W,i}\cdot(\theta_{W,cirk,i}-\theta_{amb,i,non-heating})}; \tag{2.5}$$

The calculations of the thermal losses in of the DHW circulation loop for the investigated buildings shows that the difference of ambient temperature during heating and non-heating season for the pipes outside the heating area affect the total circulation losses from 2% for twelve storied buildings, to 5 % for five storied buildings. This conclusion allows us to simplify the formula with substitution of the multiplier with differences of ambient temperatures with empiric coefficient K (with the values from 1.02 to 1.05).

$$Q_{W,dis,heating} = Q_{W,non-heating.count}\frac{t_{heating}}{t_{non-heating.count}}\cdot K; \tag{2.6}$$

The calculations according to the described method gives accurate energy performance indicators of the DHW system and gives the base to evaluate benefits of possible measures for the DHW system of the building.

To improve energy performance of the DHW system during energy audit of the building shall be considered implementation of the following measures:

- optimization of the operational settings by set up the day and night mode conditions, which include switching off during the night hours (for certain types of buildings switching off is possible also during holidays/weekends), the reduction of the temperature of DHW during the night hours;
- replacement of metal (steel or copper) pipes with the pipes with lower thermal conductivity;
- thermal insulation of the distribution pipes (effective for all uninsulated pipes);
- optimization of distribution network of the circulation pipes, for example, replacement of all or part of distribution pipes with one well insulated larger diameter central pipeline;
- installation of the hydraulic flow controllers (thermostatic, self-acting, proportional valves) on each section of the DHW circulation loop to ensure a balanced flow;
- replacement of the fixed power pump with demand controlled variable-speed pump that automatically adjusts to the hydraulic power needs and temperature settings;
- installation the waste water heat recovery system can be cost effective for the buildings with significant DHW consumption.

Economic impact of DHW system heat loss

The thermal losses of the DHW distribution circulation pipes system of the building consists of: thermal losses in the basement pipes during the whole year, thermal losses in the vertical distribution loop pipes during non-heating seasons. The thermal losses from the towel rails of the DHW distribution system gives comfort on bathrooms and may be useful throughout the whole year. As concluded in the section 1.4. characteristic thermal losses from the DHW circulation loop is average 20 kWh/m^2 per year for standard design type apartment buildings with originally installed DHW system steel pipes.

For a standard design type apartment building with total area of 4000 m^2 and typical thermal losses of the DHW systems (20 kWh/m^2 per year) the total thermal losses of the DHW systems is 80 MWh yearly and costs for the apartment owners is €4062 ([2]). After insulation (10 to 20 mm thickness with a thermal conduction 0.04 W/(m^2·K)) of the DHW pipes the linear thermal characteristic value of pipes range from 0.1 to 0.2 W/(m·K) or less. Such activities reduce the thermal losses from the DHW system for 70% or about 14 kWh/m^2/per year therefore yearly savings are 56 MWh of heat energy and costs € 2843.

According to the data of JSC "Ragas siltums" about 4000 apartment buildings with total heating area of 12 million m^2 connected to district heating network in Riga use heat energy for heating and DHW needs. Most of these buildings and their heating and DHW systems not improved since the building construction. The assessed thermal losses of DHW systems of these buildings are 240 GWh per year that cost € 12.2 million annually to apartment owners. The insulation of distribution pipes of the DHW systems of these buildings can save 168 GWh of heat energy and cost € 8.5 million annually.

As, a result of the research carried out it was found that

1. Frost heave occurs if the amount of the frozen and unfrozen water exceeds the volume of the soil interstices. Thus frost heaving normal stress is, on one hand, the function of the soil porosity on the other hand, it is the function of "excess moisture" resulting in the formation of "excess ice". "Excess ice" is the amount of ice exceeding the free interstice volume not filled with frozen and unfrozen film water after freezing.

2. The normal stresses in the open system prove to be more reasonable.

3. The formulas (10, 11) for the normal stresses of frost heaving in the open system as a function of excess moisture exceeding the free soil interstitial volume under freezing, and their results appear to be relevant to the tabular data of RF Code available and other authors' results. The expression obtained make it possible to define normal stress in any hydrogeological and climatic conditions.

Conclusions

The DHW systems of the apartment buildings has the following typical characteristics:

- DHW consumption
  - ranges from 24.2 to 60.2 (in average 41.0) liters per inhabitant per day;
  - ranges from 40.0 to 142.6 liters per day per household (dwelling), in average 91.4. liters for buildings in Riga and 71.5 liters for buildings in Bauska;
  - 1.52 liters per day per one square meter of dwelling;
- DHW share of the total domestic water consumption varies during a year: it is 41,8% in average during whole year, 43,9% during heating season, 39,4% during non-heating season;
- DHW consumption is 94% from the annual average consumption during non-heating season and 106% from the annual average consumption during heating season;
- the energy consumption for DHW system ranges from 19.8 to 48.2 (in average 34.5) kWh/m^2 annually.
- the actual DHW consumption is less than specified in standard EN 15316-3-1 (from 100.2 to 199.8 liters per day per household) and in the Latvian Construction regulation LBN 221-15 (from 85 to 105 liters per inhabitant per day). Therefore, the appropriate national annexes of standard EN 15316-3-1 should developed with DHW consumption characteristics suitable for Latvian conditions.

[2] JSC "Rīgas Siltums" heat energy prise was 45.33 € per MWh On March 2017 (www.sprk.gov.lv), 12% VAT rete for heat energy for housing, heat energy bruto prise 50.77 € per MWh.

The comparison of correlations of DHW consumption to miscellaneous technical indicators shows that closest correlation is between the DHW consumption to the number of the inhabitants (R^2=0.94), however close coloration (R^2=0.88) is to the housing area and to the number of the households (R^2=0.85). There is no correlation between the DHW consumption and thermal losses in the DHW circulation loop.

The temperature of inlet cold water for heating and non-heating seasons (or months) used in the calculations have impact to the energy consumption of the DHW system. The study shows that the most accurate result can be achieve if the mean monthly value of inlet cold water temperature or seasonal mean value cold water temperatures (+5°C on heating season, +15°C on non-heating season) from Latvian Construction regulation LBN 221-15 are used in calculations. The calculation using mean annual cold-water temperature (either LBN 221 (+10°C) or EN 15316-3-1 (+13°C)) may cause error more than 10%.

The thermal energy loses of DHW circulation loop varies from 0.1 to 0.28 MWh per month per dwelling for different standard design type buildings, in average 0.18 MWh per month for buildings in Riga and 0.21 MWh per month for buildings in Bauska. The study shows that actual thermal energy loses of DHW circulation loop significantly exceed 0.1 MWh – the value recommended by Riga city council for one dwelling per month (24 of August 2010 Instruction No.9).

The heat losses of the DHW circulation loop has the following typical characteristics on apartment buildings:

- Representative non-recoverable energy losses of DHW circulation loop ranges from 16 to 24 and in average 20 kWh per m^2 per year investigated apartment buildings. The result is representative according to considerations that non-recoverable energy losses are in the basement during whole year, in vertical distribution pipes during non-heating season, but heat energy losses from towel rails are useful (not losses) during whole year.

- The thermal losses of t from total heat energy consumption of the DHW system ranges from 35% to 79% (in average 56%) during non-heating season;

- The thermal losses in the DHW distribution system differs by different standard design types of buildings;

- The share of heat losses for different pipe sections breakdown is:

• from 10% to 25% for 5 and more storied buildings up to 28% for 3 storied buildings on pipe sections on non-heated basement;

• from 50% to 70% for vertical distribution pipe sections;

• from 20% to 30% for individual tower rails in dwellings.

The calculation of the auxiliary energy of the DHW system of the building by different CEN standard methods (simplified and detailed) gives similar results. The calculation according to simplified method shows that auxiliary energy of the DHW system ranges from 1.07 to 1.93 (in average 1.54) kWh/m^2 per year for different standard design type buildings, while calculation according to detailed method gives results from 1.54 to 1.82 (in average 1.62) kWh/m^2 per year. The authors find that detailed calculation method is too complicate and time consuming. Therefore, the simplified method is recommended for use for the buildings energy performance certification. As an alternative, the default value (for example, 2.0 kWh/m^2 per year) may adopted on national level.

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