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ON-SITE THERMAL DIAGNOSTICS OF HEATING AND DHW INSTALLATIONS

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Abstract
The requirements for the inspection of heating systems have been introduced in the Energy Performance Act. Thermal diagnostics of the system is an evaluation of the technical conditions of the heating and hot water installations, due to their energy efficiency and reliability of obtaining the required internal temperature in the building and delivery of the right amount of domestic hot water at the proper temperature. Data obtained from the diagnostics are useful for proper energy-efficient operation of the installation, for determining the energy performance of the building and executing the energy audit of the building for thermomodernization purposes. The paper describes the methodology of comprehensive inspection and diagnostics of heating and DHW systems and outlines the scope of basic activities that should be performed. The practical application of such diagnostics in several buildings is also presented.

Streszczenie
W ustawie o charakterystyce energetycznej budynków wprowadzono wymagania dotyczące przeprowadzania kontroli instalacji ogrzewczych. Diagnostyka cieplna instalacji grzewczych jest to ocena stanu technicznego systemów ogrzewania i c.w.u. ze względu na sprawność energetyczną i niezawodność uzyskania wymaganych warunków cieplnych w budynku oraz pokrycia potrzeb użytkowników w zakresie ciepłej wody użytkowej. Dane uzyskane z diagnostyki są przydatne dla właściwej, energooszczędnej eksploatacji instalacji, sporządzania charakterystyki energetycznej budynku oraz wykonania audytu energetycznego budynku na potrzeby termomodernizacji. W artykule opisano metodykę kompleksowej inspekcji i diagnostyki cieplnej instalacji ogrzewania i ciepłej wody użytkowej, oraz wyszczególniono zakres podstawowych działań, które powinny być wykonane podczas diagnostyki. Przedstawiono również praktyczne wykorzystanie diagnostyki w kilku budynkach.

Keywords: **Heating system; Hot water; Inspection; System efficiency; Thermal diagnostics.**

1. INTRODUCTION

According to the requirements of the energy performance act [1] there is an obligation to carry out periodic inspections of heating systems, which should include an evaluation of the energy efficiency and adapt the system to the heating needs of the building. The inspection is one of the stages of the energy diagnostics, consisting in the installation overview and actual state comparison with the available documentation and requirements of the technical conditions in buildings [2]. The detailed diagnostics including measurements should follow the inspection. The inspection of heating and domestic hot water (DHW) installations can be performed based on the guidelines included in standard for the inspection of boilers and heating systems [3]. This standard outlines the one-off heating system inspection procedure that is carried out in a building for the purpose of:

- verification of the proper performance, equipment and maintenance of the heating system to ensure optimum energy efficiency,
- estimation of the actual energy efficiency of the system,
- providing recommendations for the energy efficiency improvements of the system.

The inspection is carried out based on a local vision in the building using the following sources: building and installation design documentation, operation and maintenance data, facility book, previous inspection reports, fuel and energy bills and also information provided by the building administrator. In Standard [3] inspection procedures are described in a general way. Formulas of the reports from the inspection are included in Regulation [4].

The detailed method for diagnostics of heating and DHW systems is not described neither in legal or statutory requirements. Such a diagnostics was the part of Strategic Research Project (described in [5]) which included also the diagnostics of air-conditioning systems [6], heating and cooling sources [7]. The results of the measurements obtained during comprehensive diagnostics were used to determine the energy performance of the buildings [8-12]. The methodology of diagnostics of heating and DHW systems was described in the guidebook [13] and tested in several buildings [14].

During diagnostics of installations it is also necessary to check the correct operation of installations and their individual components as well as the compliance of the applied solutions with the technical requirements [2]. Assessment of the technical conditions is the basis for the estimation of energy efficiency and allows to formulate recommendations on the opportunities in order to improve performance and ensure optimum operation conditions.

The possibility of delivery the design heat load of the building and the thermal power for hot water preparation by the heat source is verified during the diagnostics of heat sources. This paper does not include diagnostics and methods for determining the efficiency of heat generation systems (heat sources and storages) for heating and hot water installations.

2. STAGES OF THERMAL DIAGNOSTICS OF HEATING AND DHW SYSTEMS

The diagnosis of heating and hot water systems includes the following stages:

a. identification of the system in order to determine any differences and deviations from the design state,
b. checking the quality of system operation, the maintenance of system and devices, the correctness of location and operation of measuring and control devices,
c. inspection of heating and DHW distribution of sub-systems,
d. inspection of space heating emission and control sub-system.

3. TASKS AND ACTIONS CARRIED OUT WITHIN THE FRAMEWORK OF DIAGNOSTICS OF HEATING AND DHW SYSTEMS

Many problems related to the operation of installations should be identified for the assessment of efficiency of existing heating and hot water installations. Appropriate actions should be taken in order to determine the optimal operating conditions of the installation and to formulate recommendations on the possibility of improving the energetic efficiency. An important purpose of energy diagnostics of the DHW system is also estimation of the amount of hot water used in the building. Such a value is useful for the assessment of correct installation operation and determination of the consumption of final energy required for hot water preparation in the building.

The main problems which should be identified and actions that should be undertaken in order to properly diagnose central heating system and DHW installation are presented in the Tables 1 and 2.

Table 1.
Tasks and actions carried out within the framework of diagnostics of the central heating installation

	Task	Description of the action
1	Carrying out a survey among users of a diagnosed building to get a general answer to the question:	The survey should be conducted during the heating season when the outdoor air temperature is low as this is a period of a potential malfunction of the system.
2	Verification of compatibility design and actual radiators' power; checking whether the installation was modernized after any changes in the building envelope (verification of the selection of the proper nominal parameters of the heating medium).	The degree of oversize of the radiators should be checked when the building envelope has been insulated, when the system of settlements of individual heating costs based on heat cost allocators is used in the building; in this case neglecting of radiators oversizing generate errors in the division of heating costs; the best way to correct the power of radiators after thermal modernization of the building is to replace them with new ones of a lower power.
3	Verification of the location of the radiators and whether they are correctly installed; identification of radiators' covers.	Determining the influence of verified factors on the total efficiency of the heat emission in the room space (using tables A.1÷A.8. from Standard [15]).
4	Check whether or not the correct automatic control of the installation has been applied.	Verification of compliance of used devices with the technical requirements [2] and their settings.
5	Inspection whether or not proper temperature sensors, control valves and controls are properly applied and installed.	Checking whether the measuring devices allow control the parameters on the manifolds and on the branches of the installation; verification of control valves' settings with design documentation.
6	Verification of the hydraulic balancing of the installation.	Checking the method of balancing and setting values of balancing valves (verification with the documentation), especially if the building envelope was modernized.
7	Verification of types of thermostatic radiator valves and selection of their settings.	If the valves are installed before the thermal insulation of the building envelope, check that the valve settings have been changed after the thermomodernization (whether the documentation of the hydraulic regulation of the installation after the thermo-modernization exists).
8	Evaluation of place and method of installation of thermostatic valves; possible covering of the valve heads influence the increased heat consumption.	Determining the impact of existing solutions on the total efficiency of the heat emission in the room space.
9	Evaluation of the operating conditions for thermostatic valves.	Verify that the balancing valves are used in the system and which are the operating parameters of the pump.
10	Evaluation of pumps used in the installation.	Description of the type of pumps, how they are controlled, check the operating parameters of the pumps: are they in accordance with the design assumptions?
11	Checking the division of the installation into zones (branches).	In the case of a large installation, it should be noted whether the appropriate zones of the installation are separated; parts of the building with a different way of use or with significantly different heat gains should be supplied with separate branches of the installation. Checking the operation of the controls and settings of the control valves in the individual zones of the system.
12	Verification of the venting of the heating installation, checking the technical condition of the automatic air vents.	Description of the real state and presentation of the effects of improper solutions (possibility of too low temperature in premises).
13	Verification of method of preventing against excessive pressure in the installation.	Checking the volume of the expansion vessel and the pressure in the device, checking the safety valve setting; presentation of possible threats.
14	Checking the level of contamination of the installation by sediments and assessment of technical condition of filters; whether the appropriate cleaning devices are installed, and whether they are properly operated.	a. selection of places for measuring the thickness of limescale, b. measurement of sediment layers in pipelines using a thickness gauge, c. description of an existing sediment layers and what should be done (the chemical cleaning or replacement of pipelines), d. description of the type and technical requirements of the cleaning equipment.

15	Checking the condition of the pipe insulation.	Description of the insulation type and thickness; estimation of insulation losses (may be a percentage) and identification of the location of insulation defects (for which the diameter of pipes); comparison with requirements concerning the insulation thickness according to the technical conditions [2].
16	Check whether the corrosion of components in the system exists – visual inspection of the pipelines; checking for leaks and frequency of water replenishment in the installation.	Description of the existing state, formulation of the hypothesis concerning installation tightness.
17	Verification of the method of preparing the water for filling and replenishment of water losses in the heating system.	Check whether there are specific requirements formulated by manufacturers of pipes and radiators used in the system with regard to the water quality. If not, then the water should meet the requirements of Standard [16]; description of the effects of improper water quality (possible damages to the devices).
18	Checking the application of the proper compensation of thermal expansion of pipelines and the method of fixing them to the partitions.	Description of the existing state and warning the user against potential threats (leaks or lack of water circulation).
19	Checking that it is possible to properly vent the installation and that pipes are conducted with a suitable inclination.	Description of the actual state and presentation of effects of improper solutions – wrong operation of installation.

Table 2.
Tasks and actions carried out within the framework of diagnostics of the DHW system

	Task	Description of the action
1	Conducting surveys among users of the diagnosed building to get answers to the questions: "whether the DHW installation fulfills its functions properly; is there always available hot water at the right temperature?"	The survey should be conducted separately during the heating season and in the rest of the year.
2	Checking the type and condition of the individual user outlets.	Checking the leaks and performance of user outlets.
3	Checking the temperature of water in user outlets; how long will it take before the temperature of water is appropriate?	Random tests of c.w.u. in user outlets in order to assess the actual state.
4	Verifying that the proper zoning of the installation is used.	Assessment of the correctness of the division into installation zones taking into account the pressure requirements within the zones and their equipment.
5	Check whether exists and what type is the circulation system (pump or gravity system).	Evaluation of the correctness of the circulation system with regard to the technical solution used.
6	Verify whether the hot water and circulation system are properly balanced and what kind of balancing devices is used.	Evaluation of the method of installation balancing - whether the type of control equipment is properly selected (orifices, control valves); verification whether the valves' settings are compatible with the documentation.
7	Checking whether the pumps in the installation are correctly selected.	Description of the type of pumps and control methods, check whether they are consistent with the design assumptions; evaluation of the circulation pump operation during the basic work and the possible thermal disinfection installation.
8	Checking the settlement system in the building (settlements with the water supplier and between the energy supplier and the customers).	Evaluation of the correctness of selection of the main cold water and/or hot water meter and hot water meters in the recipients' premises (in the case of DHW system and decentralized system of heating and hot water).
9	Checking the condition of hot water circulating pipes (contamination, corrosion, leaks).	a. checking the frequency of incidence of damages, places of occurrence and the possible causes, b. designation of sampling sites in the installation, c. measurement of the wall thickness of the pipes (in the extracted sections of the installation) and comparison with the ones included in the technical catalogs, d. presentation of further actions (eg. recommendation for replacement of the installation).

10	Checking the condition of the insulation of hot water and circulation pipes.	Description of insulation type and thickness, estimation of insulation losses (may be a percentage) and identification of the location of defects (for which the diameter of pipes); comparison with requirements of insulation thickness according to the technical conditions [2].
11	Verify whether the type of pipes is properly selected due to the thermal disinfection of the installation.	Description of the actual state, determining the relationship between the pipeline type, hot water temperature (possible thermal disinfection) and durability of the installation (corrosion, limescale, damages to the protective zinc coating of the pipeline because of high water temperature).
12	Verifying that the DHW disinfection system is used to protect against legionella contamination.	Evaluation whether disinfection of DHW installation is carried out correctly.
13	Check whether the plastic pipes are protected from overheating.	Verifying that the system uses protection against excess temperature and pressure limits for the type of plastic pipes applied in the installation.
14	Checking whether the system operates without noise.	Description of the actual state; the loud operation of the installation indicates that the water velocity in the pipes is greater than the maximum allowed and may cause the destruction of the inner protective layers in the pipelines.
15	Check that it is possible to properly vent the installation and that pipes are conducted with a suitable inclination.	Description of the actual state and presentation of the effects of improper solutions– wrong operation of the installation.
16	Checking the application of proper compensation of thermal expansion of pipelines and the method of fixing them to the partitions.	Description of the actual state and warning the user against potential threats (leaks or lack of water circulation).

The detailed procedures connected to the activities listed in Tables 1 and 2 are described in the guidebook [13]. Their practical application is presented in the guidebook [14].

The list of corrective actions recommended to use in order to improve the operation of the diagnosed installations should be done after the performed thermal diagnostics. This list shall be prepared as the report whose formula is set in Standard [3] and Regulation [4].

4. PRINCIPLES FOR DETERMINING THE EFFICIENCY OF HEATING AND DHW INSTALLATIONS

Direct measurement of the energy efficiency of installations in actual conditions in a building is practically impossible. For this reason, the efficiency of the various subsystems of the installation can be calculated based on the data from the performed energy diagnostics or contained in the tables in Regulation [17]. The efficiency values of the system are necessary for making the energy performance of the building and performing the energy audit of the building for thermo-modernization.

The total efficiency of the system is the product of the efficiencies of four subsystems: generation, accumulation, distribution and emission together with control. The first two efficiencies are related to the heat generation system and are not discussed in this paper.

Efficiencies related to the distribution and the emission including control are directly related to heating and DHW installations. They can be calculated based on the heat losses of system components, which are estimated as a result of thermal diagnosis or using tabular values.

The detailed methodology for calculating the efficiency of installations in accordance with the standards (EN 15 316) and Regulation [17] is presented in the Guidebook [13].

The rules for such calculations are described below.

4.1. Efficiency of distribution of heating sub-systems and DHW installations

In order to determine the distribution efficiency, heat losses from pipes and heat demand should be determined. In the central heating system, heat losses of supply and return pipes are calculated and they are dependent on the parameters of the heating medium. In the domestic hot water installation, heat losses of distribution and circulation pipes are considered.

The seasonal heat demand for heating (energy use for space heating) is determined based on Standard [18].The annual energy demand for heating up the required amount of hot water (energy need for domestic hot water) is calculated according to Standard [19].

The detailed equations included in Standards [20, 21] or the simplified indicators of unit heat losses shown in the tables in Regulation [17] can be used to calculate the heat losses of pipelines. The following data collected during energy diagnostics are the essential: length of pipes, outer and inner diameters of pipelines, insulation type and thickness, internal temperature in spaces where the pipes are fitted, number of tap openings per day, daily operating time of the circulation system, design temperatures of water in the installation and the method of the installation control.

4.2. Efficiency of emission sub-system including control of the heating installation

The efficiency of emission including control is connected with heat transfer losses to the heated space and depends on the type of radiators and the control of the heat emission to the premises. Methods for determining this efficiency in accordance with the procedures contained both in Standard [13] and Regulation [17] are based on the partial efficiencies included in the tables. The following data should be known: type of control equipment used in the installation, way of hydraulic balancing, type and location of radiators in rooms. Thorough inspection and diagnostics of the systems enables the selection of the appropriate values from the tables.

4.3. Efficiency of emission sub-system including control of the DHW installation

The efficiency of emission including control is related to heat losses from user outlets (e.g. taps, showerheads, thermostatic outlets or similar devices). Heat losses due to water outflow depend on the type of user outlets installed. The equation for calculating these losses is given in Standard [21]. Default values may be given in national annexes. In accordance with Polish Regulation [17] the emission efficiency should be equal to 1. This means that the heat losses from user outlets are omitted.

5. PRACTICAL APPLICATION OF ON-SITE DIAGNOSTICS IN BUILDINGS

The comprehensive thermal diagnostics including diagnostics of the heating and domestic hot water installations was conducted in seven different buildings (2 single-family, 2 multi-family, 1 school, 1 museum and 1 office). The types of heating and hot water systems in particular buildings are as follows:

1) building BJ I – the detached (single-family) house with the heated area of 147 m^2; the heating system supplied from the gas fired boiler; pipes are conducted in the floor and in the wall furrows; domestic water is prepared in the storage system; the cold water meter is installed in the building,
2) building BJ II – the detached (single-family) house with the heated area of 185 m^2; the floor heating system supplied from its own multi-source boiler house; domestic hot water prepared in the storage system with circulation pump; the cold water meter is installed in the building,
3) building BW-5 – 5-storey, multi-family building with the heated area of 1080 m^2; the central heating installation and the central hot water system with circulation loop are powered by the direct substation connected to the district heating network; insulated pipes are conducted in the basement; hot water meters installed in the flats,
4) building BW-11 – multi-family building with the heated area of 2880 m^2; the central heating system is supplied from the exchanger in the building; insulated pipes are conducted in the basement; domestic hot water is prepared individually in flats, using gas flow heaters; the main cold water meter is installed in the building,
5) school building BS with the heated area of 1406 m^2: the central heating installation is supplied from its own coal fired boiler house; insulated pipes are conducted in the basement; domestic hot water is prepared individually in flats, using electric heaters; the cold water meter is installed in the building,
6) museum building BM with the heated area of 615 m^2: the central heating system is supplied from the exchanger in the building; insulated pipes are conducted in the basement; domestic hot water is prepared using the storage electric heater; the cold water meter is installed in the building,
7) office building BB with the heated area of 1041 m^2: the heating system supplied from its own gas boiler house; insulated pipes are conducted in the basement; domestic hot water prepared in the storage system with circulation pump; the cold water meter is installed in the building,

The efficiencies of the heating and DHW installations were calculated based on the data obtained during the diagnostics in the studied buildings. Distribution efficiency in detached houses was determined only using the values from tables (from Regulation [17]), as the distribution pipes are con-

Table 3.
Results of the calculations based on the measurements, in accordance with Standards [15, 20] and Regulation [17]

	Hot water consumption, m^3/year		Distribution efficiency of the heating system, %			Emission and control efficiency of the heating system %	
Building	Measurements	Indicators [17]	Calculations EN 15 316- 2-3	Calculations [17]	Tables [17]	Tables EN 15 316-2-1	Tables [17]
BJ I	43	68	-	-	96	87	85
BJ II	52	85	-	-	96	93	91
BW-5	684	568	91	90	90	87	88
BW-11	1361	1514	97	95	90	87	88
BS	256	226	97	96	90	87	81
BM	54	55	94	95	90	87	88
BB	86	93	97	96	90	87	88

ducted in the floor and in the wall furrows – measurements were not possible.

Based on the analyzes carried out within the diagnostics of the DHW installation it was stated that the reliable assessment of water consumption in buildings based on the short measurements is not possible, due to the irregularity of water consumption during various periods of the year (month, week) and breaks related to the absence of users during holidays. The annual period allows for the objective assessment of the average water consumption, therefore the amount of water was calculated based on the annual consumption values (data received from owners and object managers).

In the multifamily building of 5-storey, domestic hot water is prepared centrally, but the main hot water meter is not installed. In order to estimate the consumption of hot water, the total consumption of domestic hot water in the dwellings was calculated based on the indications of hot water meters installed in flats. In the other buildings, the water was prepared individually and there were no hot water meters, so the hot water consumption was determined based on the main cold water meters installed on the cold water connections in the buildings. The appropriate percentage share of hot water consumption in the total amount of water supplied to the building was taken into account. This share was estimated in each building based on the analysis of the use of cold and hot water in the particular object. It was also modeled on the average consumption of water in other objects of similar use. The share of hot water consumption in total water consumption in the studied buildings was 20%÷30%.

Table 3 shows the comparison of measured and calculated (using indicators from Regulation [17]) hot water consumption and the comparison of efficiencies values of the heating systems in the studied buildings, determined by various methods, using data from carried out thermal diagnostics.

It should be noted that, in each test detached house three people reside, that means: the area per person in the building BJ I is 49 m^2, and in the building BJ II – 62 m^2. In multifamily buildings the calculated ratios are respectively: for BK-5 – 25.7 m^2/person, for BK-11 – 26.4 m^2/person. This means that the area per person is on average twice less than in the case of the single-family houses. This is not reflected in the indicators of unit water consumption in Regulation [17], where the water consumption rates are given respectively: for single-family houses – 1.4 $dm^3/(m^2 \cdot day)$, for multifamily houses, with individual consumption accounts – 1.6 $dm^3/(m^2 \cdot day)$. This is confirmed by the carried out diagnostics of DHW installations in studied residential buildings, where the differences in the hot water consumption compared to the measurements were as follows: 58% in the building BJ I, 63% in the building BJ II, -17% in the building BW-5 and 11% in the building BW-11. This means that the hot water consumption indicators given in the Regulation [17], referring to single-family houses are significantly overstated. If they are taken in the energy rating process, they affect the deterioration of the energy performance of buildings.

It can be seen that indicators of hot water consumption in the school building, office and museum, given in Regulation [17] quite well correspond to the actual values obtained from the measurements. In the school building BS the difference in consumption compared to the measurements was -12%, in the museum building BM – 2%, and in the office building BB – 8%.

Based on the analysis of the efficiency values shown in Table 3, it can be seen that there is no significant difference in distribution efficiency calculated based on the standards and the regulation, taking into account energy diagnostics data. However, there are big differences between the calculated values and adopted directly from the tables of the regulation. Improperly adopted efficiencies are another cause of the incorrect value of energy consumption in the energy performance certificate.

The values of emission and control efficiency determined using the values from the tables in the standards and the regulation are close to each other in almost all buildings.

6. SUMMARY

The paper presents the basic tasks and activities that should be performed during the energy diagnostics of heating and DHW systems.

Practical use of diagnostics to calculate the efficiency of heating and hot water consumption in seven buildings has been presented. It has been shown that the values calculated based on the diagnostic tests may vary considerably from the values obtained from the indicative and tabular data. Improperly calculated values affect the energy performance of a building.

Such a diagnostics may be used by engineers, energy consultants and auditors who perform:

- inspections of installations in accordance with the requirements for building managers in order to improve the quality of the installation's operation and thermal comfort in buildings.
- energy audits of buildings,
- energy performance certificates of buildings.

Due to the fact that the method of the thermal diagnostics of heating and hot water systems in terms of their energy efficiency, safety and work reliability have not yet been developed, the presented methodology is an important complement to this gap. The paper presents both the stages of inspection and diagnostics of the installation together with the tasks for their execution as well as points out the auxiliary materials for their implementation.

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