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COMPREHENSIVE ENERGY DIAGNOSTICS CARRIED OUT IN A RESIDENTIAL BUILDING – A CASE STUDY

Dorota BARTOSZ*

*PhD Eng.; Faculty of Energy and Environmental Engineering, The Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland
E-mail address: *dorota.bartosz@gmail.com*

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Abstract
The article presents the case study of the comprehensive diagnosis of an existing residential building with natural ventilation. The results of quick diagnostics of thermal insulation of the building, the heating system, ventilation, domestic hot water preparation and the quality of the environment in the rooms were presented. Based on the data obtained by measurements, the energy performance of the building was prepared using the building certification calculation method. The energy performance of the building was also prepared using the developed method of determining energy performance based on measurements.

Keywords: **Thermal diagnostics; Natural Ventilation; Domestic Hot Water; Indoor environment quality; Energy performance certificate.**

1. INTRODUCTION

The Polish National Center for Research and Development coordinated the implementation of the Strategic Research Project "Integrated System for Reduction of Energy Efficiency of Buildings", under which Research Task no. 4. "The development of thermal diagnostics of buildings" was predominantly carried out in the Department of Heating, Ventilation and Dust Removal at Silesian University of Technology. A detailed description of the scope of the project is given in [1].

In the first steps, the project group has developed quick methods of building diagnostics for different building components, i.e.: building insulation [2], heating and domestic hot water systems [3], ventilation and air conditioning systems [4], the indoor environmental quality [5] and energy performance certification [6]. Each method includes on-site inspection, diagnostic and computational analyses. The final stage of the 3-year project has focused on the practical application and validation of developed methodology in real buildings, described in detail in the published Handbook Vol.5 [7] and presented in scientific/research articles [8, 9, 10, 11, 12].

This paper presents the insights on a comprehensive *on-site* diagnostics based on an exemplary multi-family building. It gives practical information on how to properly conduct diagnostic measurements for an energy performance certification..

2. *ON-SITE* DIAGNOSTICS OF BUILDING THERMAL INSULATION

The 5-storey residential building (Fig. 1) selected for the study is located in the western suburb of Gliwice, surrounded by buildings of similar height. It consists of a basement, ground floor and 4 upper-ground floors. Each storey has 4 apartments of the area varying from 50 to 74 m^2. The total heated area of each floor is approximately 1350 m^2. On the ground floor, the area of 235 m^2 is used by the Housing Cooperative. The remaining space is purely residential.

Figure 1.
Tested building

The building has been built in the technology of a large slab (the pre-fabricated W-70 system) in the early 1980s. The three-layer construction has been used for 27-cm thick external reinforced concrete walls with wool insulation. Ceiling construction uses channel ceiling slabs with thickness of 24 cm. The ventilated roof is covered with a tar paper. Window joinery in the building is almost entirely replaced with a new one made of PVC–only two dwellings and a staircase do not have the listed windows. The heat transfer coefficients were identified based on measurements, and on the archival documentation in accordance with standard [13]. Table 1 gives a summary of the thermal specification of the building construction.

Detailed on-site heat measurement methodology, including equipment description, is shown in the Handbook Vol.1 [2].

The proposed value of the thermal bridge around the windows (Fig. 2) was $\psi = 0.03$ W/(m·K) and the linear bridge at the connections of wall panels (Fig.3) was $\psi = 0.08$ W/(m·K) (on the entire perimeter of the boards). The thermography studies on special places indicated local insulation discontinuities or a significant reduction in the insulation from slag wool on the entire height of the building. The value of the linear bridge was estimated as $\psi = 0.04$ W/(m·K). After taking into account thermal bridges, the proposed corrected value of the heat transfer coefficient for the entire side partition with 6-m. panels was U = 0.85 W/m^{2}K.

The values of heat transfer coefficients for window and door carpentry were adopted based on the catalogue: new PVC windows in residential rooms: $U = 2.4$W/(m^{2}K), old wooden windows $U = 3.0$ W/(m^{2}K), glazed entrance door in metal frames $U = 3.2$ W/(m^{2}K). Transparent and non-trans-

Table 1.
Calculation and measurement of heat transfer coefficients of building partitions

Description	d, m	λ, W/m·K	R, m^2·K/W	R, m^2·K/W	U, W/(m^{2}K)	
					Calculation (archival documentation)	On-site measurement
The ceiling above the basement – thickness d=29 cm						
Thermal resistance of internal surface			0.170	0.994	1.01	1.30
Cement plaster	0.03	1.000	0.030			
Expanded polystyrene	0.02	0.045	0.444			
Concrete slab	0.24	1.330	0.180			
Thermal resistance of external surface			0.017			
The ceiling above the last floor (Roof) – thickness d=32 cm						
Thermal resistance of internal surface			0.100	1.190	0.84	0.92
Concrete slab	0.04	1.000	0.040			
Mineral wool	0.04	0.052	0.769			
Concrete slab	0.24	1.330	0.180			
Thermal resistance of internal surface			0.100			
External wall – thickness d=27 cm						
Thermal resistance of internal surface			0.130	1.470	0.68	0.73
Cement plaster	0.005	0.82	0.006			
Concrete	0.15	2.30	0.061			
Mineral Wool	0.06	0.05	1.200			
Concrete	0.06	2.00	0.030			
Thermal resistance of external surface			0.040			

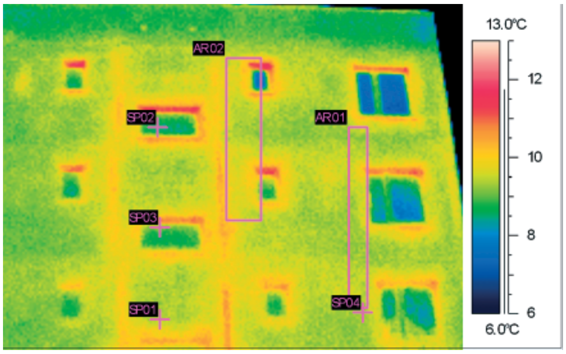

Figure 2.
Linear bridges around window and wall panel connections

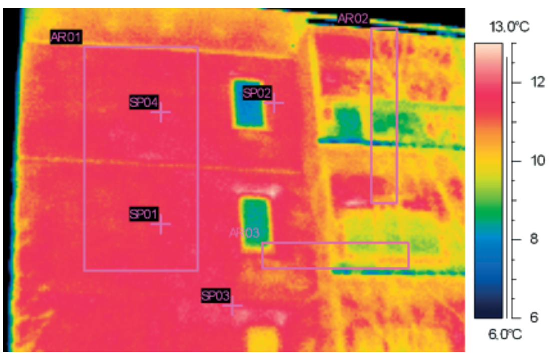

Figure 3.
Sidewall – low quality of thermal insulation in relation to other walls

parent glass barriers did not meet the criteria for thermal insulation requirements.

3. *ON-SITE* DIAGNOSTIC OF HEAT SOURCES

Central heating (CH) and domestic hot water (DHW) installations in the building are powered by a direct, low parameter heat centre located in the room in the building basement. The major modernization of the junction was carried out in 2005 despite the lack of thermo-modernization of the building.

This node is supplied with heat from a dual-function exchanger group node located outside the building. The nominal temperatures of the heating medium sent from the group node are 80°C/60°C, and the temperature of the heat source prepared for DHW is close to 58°C. The flow of heating medium in the supply lines of the CH system enforces circulation pump installed in a group node–CH installation is equipped with individual venting valves mounted on thide ends of the risers. A detailed description and equipment of the node together with the diagram can be found in Handbook Vol.2 [3].

Pipe network for CH installation was made of steel pipes, pipes for DHW installation and circulations lines were made of plastic lines. All pipes, including distributors, and valves, were thermally insulated with foamed polyethylene linings. Insulation thickness was ~15 mm, depending on the pipeline diameter. The insulation was in good technical condition. However, it did not meet the requirements given in [14] for all pipeline diameters. All branches within the room of the low-temperature node were hydraulically tight. The room has a window – no dedicated exhaust ventilation was in use. The inspection indicated that the direct node was in good technical condition and was appropriately operated (details in Handbook Vol.2 [3]). The mass flow rate of the heating medium deserves attention and correction – the flow of 0.75 kg/s is required, while the measured mass flow of the heating medium was 0.42 kg/s. Such a substantial difference in fluxes may indicate that the heating curve was incorrectly set for the CH installation. No damage was observed to the node elements that could significantly change the node's operation in relation to the conditions of its proper operation.

As part of the diagnostics, the actual required maximum thermal power of the node for supplying heat to the CH system was estimated. The ordered power, taking into account the constant efficiency of control and heat transfer through the heating system, should be 61.8 kW. The power ordered for the studied building was equal to 63.8 kW, which confirms the correctness of the hitherto accepted order power. The calculations made for the measurement data on March 29, 2012 (temperature of water on the supply and return, room temperature, heat source power, heat loss of CH and DHW pipes together with the fittings) allowed to determine the average daily efficiency of the heat source for CH at 98.2%. The seasonal efficiency of the node was estimated at 97.5% for CH supply and 97% for DHW supply.

4. *ON-SITE* DIAGNOSTIC OF HEATING INSTALLATION

The central heating installation is a two-pipe system with a lower distribution, in a traditional layout–flats are supplied with multiple connection points. The supply risers of the internal installation are supplied from two main branches run from the manifold. The operation parameters are 80/60°C.

The residential rooms have cast-iron heaters equipped with Danfoss thermostatic valves and heating cost allocators. Radiators made of finned tubes are used in the basement (workshop, laundry, drying room). The branches of the installation at the manifolds and under the verticals are fitted with ball screw-in stop valves (under the risers, additionally with the possibility of draining the water). The installation has automatic vents mounted on the top of the risers.

The installation is made of welded steel pipelines, carried out under the ceiling in the basement, while the risers in the apartments run by the walls. The pipelines outside the junction room were insulated with a mineral wool wrapper with a thickness of 2 to 5 cm – the whole installation was wrapped with a cover made of aluminum foil. Approaches for risers (50 to 60 cm long) and valves were not insulated (Fig. 4, 5). In the building, the room temperature control used thermostatic valves on radiators. The hydraulic adjustment was made by means of thermostatic valve settings.

The heat meter was installed at the heat sources node. The supply and return lines are equipped with manometers and temperature sensors connected to the heat meter.

Figure 4.
Collector

Figure 5.
Approaches for risers

As part of the modernization of the installation, a heat meter has been installed and an individual system for heat consumption settlements has been applied (a system based on liquid heat cost allocators). The venting network has been removed, and automatic vents have been installed at the highest points of the risers. Radiator valves and orifices has been replaced with thermostatic valves with double control strategy, while the right and oblique valves under the rises were exchange for ball valves and the orifices.

4.1. The results of the inspection and stocktaking of CH installation

The inspection was carried out in accordance with the principles set out in Handbook Vol.2 [3].

CH lines were in a good condition, protected by paint, without any visible corrosion or leakage. The lines insulation also was in a good condition. The thickness of old type insulation (mineral wool in aluminum foil cladding) was mostly compliant with the requirements in regulations [14], with the exception of local insulation creases. The thickness of the insulation of a new type (polyurethane foam) was half the thickness compared to the requirements of [14]. No insulation on approach to the risers has been installed. All thermostatic valves worked properly. The installation was not equipped with balancing valves. The maintenance documentations showed the filter is periodically cleaned. There were no major water losses in the CH installation.

Average seasonal efficiency of CH installation was calculated based on measured heat consumption of the building, lengths and diameters of pipelines and the condition of the insulation using the relationships given in the standards [15, 16, 17]. Calculated values are: distribution efficiency $\eta_d = 0.91$, efficiency of use and control $\eta_e = 0.87$. The efficiency determination procedure is given in Handbook Vol.2 [3]. The evaluated installation met the requirements of the regulations [14] regarding the possibility of individual room temperature control, settlements for used heat and hermitization of the CH installation. The CH installation did not meet the requirements of [14] in the field of pipeline insulation in unheated rooms–insulation thickness was insufficient at the part of pipeline and approach lines were uninsulated.

5. *ON-SITE* DIAGNOSTIC OF DOMESTIC HOT WATER INSTALLATION

Installation of domestic hot water in the analysed building was subjected to diagnostics according to the procedures described in the Handbook Vol.2 [3] and in [18]. Within the building, there is a central hot water installation with a circulating system. Installation of cold and hot water, and circulation is distributed in the basement in 8 plumbing divisions. In each apartment there are two installation sections – bathroom and kitchen. Cold and hot water pipelines in apartments are made of galvanized steel pipes and run in wall furrows. Just before the diagnostic took place, the building had underwent a modernization of the water installation and circulation, which included replacement of horizontal pipelines from galvanized steel pipes run in the basement with the PE pipes maintaining the original pipe diameters. The valves and sub-orifices in the circulation circuit has been replaced with TA balancing regulating valves (Fig. 6). In addition, three bathroom pipes has been changed into PE pipes with 1 cm thick polyurethane foam insulation. Other divisions of the DHW and circulation pipes carried out in installation ducts have not been replaced. They are made of galvanized steel pipes, which are uninsulated.

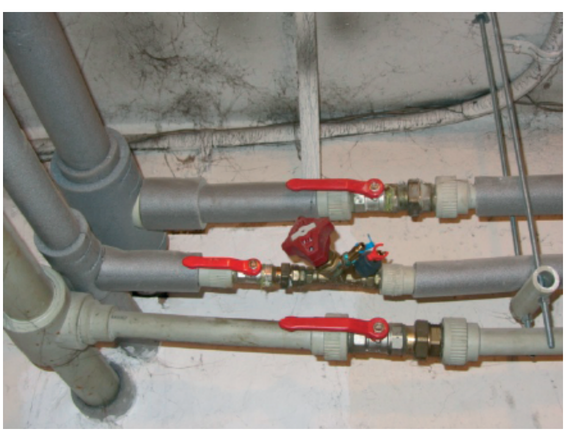

Figure 6.
Water supply pipes in the basement (from above) – hot and cold water, circulation

5.1. The results of the inspection and inventory of the DHW installation

Installation of cold and hot water was equipped with individual water meters, located in apartments (4 in total per each apartment – one set of two in the kitchen and second in the bathroom), a housing cooperative space and workshop. The settlement of all recipients in the building for water intake and its heating took place based on an indication of DHW meter located in a district heating node.

As part of the water supply system diagnostics, the correctness of water meter readings was verified by comparing the indications of the main water meter with the summary indications of individual water meters in 16 apartments, as well as the housing cooperative space and workshop. The main water meter were 6.7% higher than sum of individual readings, which taking into account the admissible error of the water meters, should be considered as a correct result.

DHW was balanced on the basis of the total indications of individual water meters. In the residential part, the total consumption of tap water (cold and hot) in 2011 was 1677 m^3, which means monthly average consumption of 139.8 m^3/month, and a daily average of 4.59 m^3/day. The total DHW consumption in 2011 of 875 m^3 translates into average monthly consumption of 72.9 m^3/month and daily average 2.4 m^3/day.

Measurements showed that the temperature of the DHW reaches a value of approx. 45°C. Because the actual temperature of hot water was lower than 55°C, the readings of water meters were corrected by the indicator k_t = 1.28 for further analysis [17], giving the final value of 683.6 m^3 for the residential space. It means that average monthly consumption was 57 m^3/month, and the daily average was 1.87 m^3/day. The water consumption standards given in the regulations [19] refer to the so-called reference units per person as an indicator for DHW. In the analysed case it was 44.6 dm^3/(person·day), which is 40.8% of total DHW consumption. Taking into account the regulations [20], where the reference unit is m^2, we get the index 1.73 dm^3/(m^2·day).

An analogous analysis was carried out for the building space occupied by a housing cooperative (including a workshop), constituting an independent technical and utilitarian part of building, total consumption of tap water (cold and hot) in 2011 was 82 m^3, and total consumption of DHW converted to 55°C is 21.1 m^3.

5.2. Assessment of the efficiency of the DHW installation

Specified based on measurements of water consumption, indicators of unitary daily consumption of hot water in the residential part of the building and in the housing cooperative were the basis for determining

Table 2.
Summary of cold and hot water consumption in the residential part of the building

	Source of data	The percentage of hot water in total water consumption	Water consumption indicator		Water consumption		Time of use in a year	Annual water consumption	
			Cold + hot water	Hot water	Cold + hot water	Hot water		Cold+hot	Hot
		%	dm^3/(person·day)		dm^3/day		day	m^3/yr	
Literature values									
1.	Dz.U.201.1240 [18]			38.4		1613	328.5		**529.8**
2.	Dz.U.2015.376 [19]			1.6*		1728	328.5		**567.7**
Measurements									
3.	Consumption in 2011 t_{DHW} = 45°C	52	109	57.1	4595	2397	365	**1677**	**875.0**
4.	Consumption in 2011 (corrected) t_{DHW} = 55°C	41	109	44.6	4595	1873	365	**1677**	**683.6**

* dm^3/m^2day

the annual demand for usable energy for heating hot water, and then determining the distribution efficiency of the DHW system together with circulation flow. The detailed equations included in Standards [16, 17] or the simplified indicators of unit heat losses shown in the tables in Regulation [19] 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. Two calculation methods were used for this purpose and the following values were obtained:

- according to the ordinance [19], the obtained distribution efficiency was $\eta_{W,d}$ = 0.44 without taking into account the armature, and $\eta_{W,d}$ = 0.42 including non-insulated fittings,
- according to the standard [17], the distribution efficiency was equal to $\eta_{W,d}$ = 0.35.

The procedure for determining distribution efficiency in accordance with the standard [17] only takes into account the heat loss of the pipes is given in Handbook Vol.2 [3].

5.3. Assessment of compliance of the existing solution and operation of the DHW system with current requirements

For the evaluation of the design and operation of the water supply system in the diagnosed building, the water consumption measured at the main cold water meter and individual water meters (cold and DHW) has been compared with the calculations based on ordinances [19, 20]. Table 2 shows the water consumption summary considering the real number of inhabitants in the building (42 people in the residential part and 10 people in the space used by the housing cooperative). An amendment to the method of preparing energy performance certificates of the regulations was introduced in 2015 [20], according to which the estimation of hot water consumption has been quite controversial. The changed methodology introduces consumption indicators depending on the heated area (m^2) of the building. It should be emphasized that the actual consumption of hot water is 20% higher than indicators required by updated regulations [19, 20]. The disclosed discrepancy between literature and empirical data confirms the need to measure water consumption in existing buildings.

A similar analysis was carried out for a part of the building occupied by a housing cooperative and workshop. Full results are given in Handbook Vol.5 [7].

To improve the operation of DHW systems and user safety (due to possible hot water infections with Legionella), the following steps were recommended:

- to raise the DHW temperature supplied from the heating system so that the temperature of the hot water in the taps was 55÷60°C,
- to carry out periodic disinfection of DHW systems and circulation,
- to install a water meter on the main circulation line,
- to increase the thickness of the insulation of DHW and circulation pipes in the basement and insulate the fittings.

6. *ON-SITE* DIAGNOSTIC OF NATURAL VENTILATION SYSTEM

The building is equipped with a natural gravity ventilation system. Each flat has 2 or 3 gravity conduits terminated from the side of the rooms with grates. In smaller apartments, one grille has been installed in the kitchen and one in the bathroom, while the larger apartments have an additional grille in the separate toilet. The number of discharge ducts is the same at the low and high floors. The apartments are equipped with rectangular or round grids of various sizes, i.e.: 16×16 cm, 17×17 cm, 10×12 cm, and Ø11 cm. Ventilation grilles are located under the ceiling of the rooms and are exposed.

Ventilation ducts in the building draw air out over the roof. Ducts are not equipped with chimney cowls and do not have inspection openings . Initial inspection showed that the ducts were unobstructed. With only a few exceptions, ventilation grilles were quite clean (Fig. 7). Small exhaust fans have been installed in few bathrooms and toilets (Fig. 8).

Figure 7.
Example dirty ventilation grille

Figure 8.
Exhaust fans in bathroom

Most windows in the building were fairly tight and had micro-ventilation feature. Only in two apartments there were few decades old wooden windows. None of the windows was equipped with air inlets. The entrance door to the building was not very tight, while the doors to the apartments were generally tight. The door to all toilets and bathrooms has been provided with free flow – sleeves or grilles in the door. There were leaks in the form of cracks in building construction and poorly sealed verticals of central heating in apartments. In some apartments, there were also noteworthy leaks at the joins of the walls. Diagnostic measurements included direct measurement of the ventilation air flow in the outlet grilles and leakage evaluation with a blower door test. Measurements were made in apartments M1 and M2 on the second floor and M15 on the fifth floor on 17 February 2012. The outside temperature was about 3.5°C, and the day was moderately windy (wind speed about 2.5 m/s). The measuring sleeve of the balometer was used for the measurement according to the methodology described in Handbook Vol.3 [4]. The air flow was measured at the closed windows without micro-ventilation. The results are summarized in Table 3. The number of exchanges was calculated from the sum of ventilation air flows in individual grids in the apartment.

Table 3.
The results of air flow measured in the air outlet

Flat		t_i, °C	Grilles dimension, cm	Air flow, m^3/h	Number of air exchanges h^{-1}
Floor 1	M1	20.7	16×16	32	0.25
			17×17	0	
	M2	21.2	16×16	30	0.61
			16×16	32	
			Ø 11	30	
Floor IV	M15	21.0	16×16	40	0.57
			16×16	30	
			17×17	35	

6.1. Airtightness measurements

The measurements of the building airtightness were conducted in accordance with standard PN-EN 13829:2002 [21], based on the fan pressurization

Table 4.
The results of airtightness measurements

Flat	Type of window	Micro ventilations of windows	Test conditions	V_{50}, m^3/h	n_{50}, h^{-1}	Exponent n	Correlation coefficient
M1	Wooden	no	Overpressure	425 ±0.6%	3.42	0.666 ±0.020	0.9964
			Underpressure	406 ±0.6%	3.26	0.663 ±0.020	0.9963
M2	PCV	no	Overpressure	240 ±0.9%	1.55	0.640 ±0.030	0.9915
			Underpressure	224 ±1.0%	1.44	0.680 ±0.034	0.9902
		yes	Underpressure	1372 ±0.7%	8.82	0.562 ±0.023	0.9934
M15	Wooden/PCV	no	Overpressure	751 ±1.6%	3.98	0.582 ±0.052	0.9691
			Underpressure	679 ±0.8%	3.60	0.600 ±0.028	0.9914
		yes	Underpressure	2037 ±1.0%	10.79	0.675 ±0.040	0.9865

method with the use of a Blower Door device. The method of determining the n_{50} value is described in details in the Handbook Vol.3 [4] and the paper [22]. Before performing the tests, it was necessary to seal some elements of the electrical system and the culverts of the central heating pipes. In the apartments where it was possible, the measurements were taken at closed windows and in the micro-ventilation mode (test only under pressure). Average n_{50} values were determined from the obtained n_{50} values in overpressure and underpressure conditions.

The results of the pressure tests are summarized in Table 4. In apartment M1 with old wooden windows, n_{50} was equal to 3.3 h^{-1}. The air tightness of n_{50} = 1.5 h^{-1} was obtained in the apartment M2 with new PVC windows and without micro-ventilation mode, which is interpreted as high airtightness. In the case of apartment M15 where both old wooden and new PVC windows have been installed, the n_{50} was equal to 3.8 h^{-1}. The measurement of the window gaps length made it possible to calculate window airtightness coefficients, which amounted to: a = 1.16 m^3/mhPa$^{0.67}$ in apartment M1, a = 0.54 m^3/mhPa$^{0.67}$ in M2 and a = 1.37 m^3/mhPa$^{0.67}$ in apartment M15.The determined flow exponent n was adjusted to 0.67 for the calculation needs.

The measurements carried out (using a balometer and a Blower Door device) and diagnostics of the natural ventilation system shows that in the analyzed residential building ventilation does not meet the requirements of the standard [23]. In flat M1 (1 kitchen and 1 bathroom), the air flows should be 120 m^3/h, while the measured value was 4 times smaller. An obstruction was detected in one of the grids, as the measurement showed no flow (Table 3). In the other flats covered by the measurements, the standard air flow should be not less than 150 m^3/h, while the measured exhaust air flow were 92 m^3/h and 105 m^3/h for M2 and M15 respectively. Both apartments did not deviate so much from the standards as apartment M1.

It is recommended to check and clean the ventilation grates in all flats and to check the patency of the ducts, use micro-ventilations in the windows or install automatically controlled air inlets in the windows or external walls and regular airing of the rooms.

7. *ON-SITE* DIAGNOSTIC OF INDOOR ENVIRONMENT

Diagnostic of the built environment was carried out in accordance with the guidelines described in the Handbook Vol.4 [5]. It consisted of long-term continuous measurements and survey study, on the basis of which the assessment of the quality of the thermal environment and the quality of the indoor air was carried out. Measurements of indoor environment parameters were carried out from February 11 to March 8 during the heating season. During this period the outside air temperature remained above 0°C, which did not meet the representativeness requirements of the thermal environment quality assessment for the heating period, The required outside temperature for this region is below -2.1°C. APAR AR 235 air temperature and relative humidity loggers, and SENSOTRON PS32 indoor air quality monitors were used for the measurements. The accuracy of the temperature measurement is 0.5°C in the range from 20°C to 30°C. In the remaining range it may vary in the range of 0.5÷1.8°C. Sensors have been calibrated before the start of the measurements. Sensors have been installed in 5 residential flats,

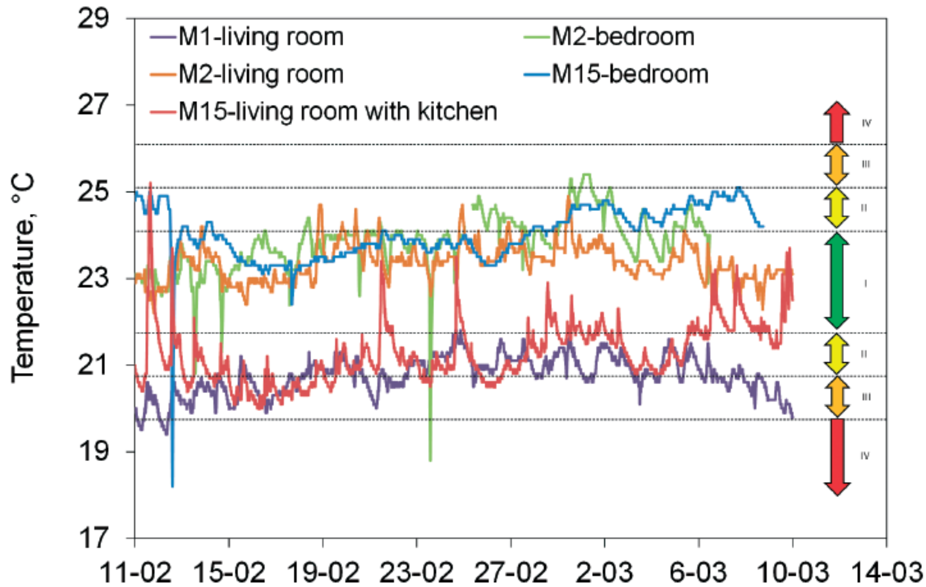

Figure 9.
The variability of air temperature in building and boundaries for the environment quality categories

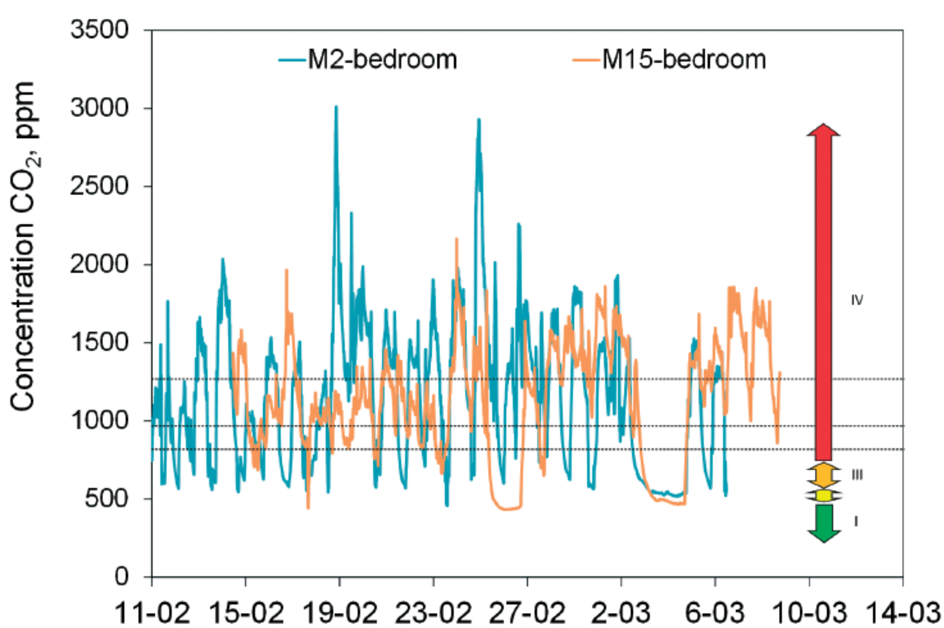

Figure 10.
Variability of carbon dioxide concentration and boundaries for the environment quality categories

mostly in bedrooms and living rooms. Additional sensors were placed in the basement and in the stairwell for the monitoring purposes, but these readings were omitted in the analysis of the indoor environmental quality.

Figure 9 shows the results of the thermal condition measurements and their quality categorization based on standard PN-EN 15251:2012 [25] and defining category of indoor air quality. The air temperature for most of the evaluation period varied from 20°C to 25°C. In both bedrooms (in M2 and M5) and in the living room located in the south-east direction (M2), the air temperature values recorded are in the range of 22.5÷25°C. The air temperature values recorded in living rooms in other apartments were ~3 K lower. The average daily temperature fluctuation of 1 K was observed within the whole facility. The relative humidity of the air during the measurement period fluctuated in the range of 20÷60%.

For the most part of the time the temperature in the rooms met the requirements of the second quality category, which corresponds to the recommended conditions for new buildings and after renovation. The questionnaire surveys also confirmed a high level of satisfaction with the thermal environment. Air quality assessed on the basis of indications of concentrations of metabolically discharged carbon dioxide indicates is shown in Figure 10. In the analyzed apartments, the concentration exceeded the level of the recommended category III for more than 40% of the occupied time, which indicates insufficient air exchange.

8. ENERGY CHARACTERISTIC OF THE BUILDING BASED ON MEASUREMENTS

Heat consumption for heating and ventilation in the standard heating season can be determined using the energy signature (ES) method described in the standard [25]. It applicates the linear regression to determine the empirical dependence of energy consumption on the outside temperature, and then to calculate the energy consumption in the heating or cooling season. Typically, this method assumes a constant value of the internal temperature, and that the outside air temperature is a parameter that has the greatest impact on energy consumption. In the analysis performed in this research task, the variability of the internal temperature values was taken into account in order to include heat depending on the internal heat gains, making heat demand dependent on the difference between the indoor and outdoor air temperature. This modified methodology is described in the Handbook Vol.6 [6] and articles [26, 27, 28]. In accordance with the adopted guidelines, the energy signature method can be used in the case of measurements of heat consumption in a period longer than one month–in our case, the measurement data from the whole heating season were available (212 days).

Discussed energy characteristics were based on measurements of heat demand and measurements of the external environment throughout the heating season of 2011/2012 (1.10.12-30.04.12) and measurements of indoor environmental conditions made in the period from March 14, 2012 to April 3, 2012. In order to apply the method, the following parameters were used:

- hourly average outdoor air temperature values measured by the meteorological station in Gliwice,
- weighted average daily values of indoor air temperature measured in representative rooms of the building (measured in the period from March 14, 2012, to April 3, 2012. The weighted average daily temperature values for the building were calculated from the measured values, where the weight factors were the areas of heated rooms compared to total heated area,
- average daily heating power delivered to the heating installation during the whole heating season 2011/2012 shared by Energy Company Gliwice.

The calculations were made for the standard climate date in Katowice where the average season temperature $t_{e,av,s.STD}$ was equal 2.7°C.

Fig. 11 shows the dependence average daily heating power in reference to the internal and external air temperature differences ($t_{i,av}$-$t_{e,av}$) in the heating season 2011/2012 (212 days). Based on the linear regression equation (a correlation coefficient of 0.96), the average heating power was calculated for the difference between the internal air temperature and the outside air temperature of the standard season ($dT_{av,s,STD}$ = 19 K). On the basis of the average heating power, the heat consumption in the heating standard season was calculated, taking into account the duration of the standard heating season L_s = 212 days (from October to April). The average seasonal indoor air temperature of the air was assumed 21.6°C (temperature calculated on the basis of measurements taken in the period of 14.03÷3.04.2012.

The final energy forecast for heating and ventilation

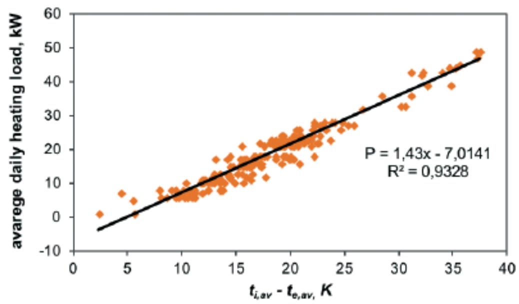

Figure 11.
Dependence of average daily power for heating on average daily temperature internal–external difference in the measurement period

in the standard heating season for Katowice is 368.4 GJ (102 330 kWh). This is the heat consumption for the standard outdoor climate conditions and for the actual conditions of use of the building, i.e., an internal temperature of 21.6°C with the actual infiltration rate and internal gains estimated for the whole heating season. The internal air temperature was higher than the normative value for residential buildings, while the ventilation air flows were lower than recommended in the ventilation standard [23].

Onsite diagnostic data has been used to extend the analysis, by which the energy performance evaluation was prepared in accordance with the regulations on the methodology of energy performance certification. The energy performance evaluation takes into account energy consumption for: heating and ventilation, hot water preparation and auxiliary energy. The data from measurements and indicators from the Regulation [17] were used:

- the final energy used for hot water purposes was calculated based on measurements: DHW consumption 1.73 dm^3/(m^2·day) for the residential part and 0.4 dm^3/(m^2·day) for housing cooperative. The efficiency at level of 0.4 was assumed ($\eta_{W,d}$ = 0.42, $\eta_{W,g}$ = 0.97) based on the local visual inspection and the regulations [20],
- the final energy consumed by auxiliary devices used in heating and DHW installations was calculated in accordance with the guidelines given in the regulations [19], adopting the catalogued capacity of inventoried auxiliary devices (circulating pump, circulating pump and weather regulator) and the duration of the heating season lasting 212 days (5088 hours),
- primary energy was determined using non-renewable primary energy input coefficients for heating and DHW systems from coal-fired heating plant (w_i in the value of 1.3 provided by the PEC Gliwice), and electricity (w_i equal to 3.0) given in the regulations [20].

Table 5 presents the final and primary energy consumption calculated on the basis of the carried out measurements, separately for the heating system, DHW system and auxiliary devices. The obtained energy indexes of 138 kWh/(m^{2}yr) for final energy and 182 kWh/(m^{2}yr) for primary energy assess the energy status of the building. As part of the analysis, the heat consumption for heating and ventilation was calculated using the calculation method described in Regulation [20]. However, the data obtained from the measurements was used for the calculation excluding heat demand. The calculated and measured heat transfer coefficients of the building partitions together with the identified thermal bridges and the designated heat sources efficiency were taken into account. The calculated efficiency of distribution

Table 5.
Designated indicators of the energy performance of the building

Thermal characteristic of the building							
		Based on measurement		Based on calculations [20]		Based on calculations [20]	
		$t_{i,m}$ = 21.6°C		$t_{i,m}$ = 21.6°C		$t_{i,st}$ = 20.0°C	
		Final energy	Primary energy	Final energy	Primary energy	Final energy	Primary energy
Heating and ventilations	kWh/yr	102 330	133 030	188 800	245 440	211 000	274 300
DHW	kWh/yr	82 030	106 640	82 030	106 640	82 030	106 640
Auxiliaries	kWh/yr	1 900	5 700	1 900	5 700	1 900	5 700
TOTAL	kWh/yr	186 260	245 370	272 730	257 780	294 930	386 640
Unit indicator	kWh/(m^2·yr)	138	182	202	265	218	286

and regulation of the CH and DHW systems were used together with measured actual consumption of hot water. Due to the insufficient number of measurements of ventilation air flows in the apartments, the results of these measurements were not taken into account. In addition, these values did not meet the comfort conditions and the normative (hygienic) use of residential premises. Due to the difference between the internal design temperature according to the regulations [20] ($t_{i,st}$ = 20°C) and the temperature obtained from measurements ($t_{i,m}$ = 21.6°C), both cases respectively were considered. Table 5 presents the calculated values of final and primary energy consumption divided into the needs of the heating system, DHW system, and auxiliary energy for heating and hot water preparation according to the Regulation [20].

When comparing the obtained energy performance results based on measurements and based on the methodology at the same indoor air temperature of 21.6°C, the final and primary energy indexes (202 kWh/(m^{2}yr) and 265 kWh/(m^{2}yr) respectively) are about 46% higher than measured values. On the other hand, the change of the calculation indoor air temperature to the nominal value of 20.0°C caused a further increase of 8%. It should be emphasized that the reason for such big differences is the increase in heat consumption for heating and ventilation purposes by almost 84%, and directly very poorly operation of natural ventilation, which does not provide nominal air exchange (as described in details in Chapter 6).

9. CONCLUSIONS

The comprehensive diagnosis of a residential building has indicated possible actions to improve the energy status of the building. The basic thermomodernization operation should include the insulation of external walls to the conditions that meet the current thermal insulation requirements. As part of the heat source diagnostics, CH and DHW installations should have adjusted heating curve and insulate the distribution pipes in the basement, along with insulating the fittings. Diagnosis of the DHW installation showed a 20% higher water consumption compared to the guidelines. Diagnostics of the internal environment showed above all that air temperature maintained in apartments is higher than the normative value and the air quality assessment indicates the problems with air exchange at the required level. This is confirmed by the diagnostics of the natural ventilation system, showing measurably too low air exchange in the flats and high airtightness. A malfunctioning natural ventilation system directly affects the designated energy performance of the building–measurements showed a 46% lower heat consumption for heating and ventilation than the value calculated according to the requirements. However, it should be emphasized that the presented method of determining energy performance based on measurements, in contrast to the method presented in [20], takes into account the estimation of energy consumption in relation to the standard season.

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