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AUTOMATION RETROFITTING AS A FIRST STAGE OF COMPLEX RENOVATION OF DISTRICT HEATING SUBSTATIONS IN PUBLIC BUILDINGS

ROZBUDOWA UKŁADÓW AUTOMATYKI JAKO PIERWSZY ETAP KOMPLEKSOWEJ MODERNIZACJI WĘZŁÓW CIEPŁA W OBIEKTACH UŻYTECZNOŚCI PUBLICZNEJ

A b s t r a c t

Automation systems modernization in selected district heating substations in university campus buildings were described in the article. Replacement of the control valves and application of heat meters for each circuits were the scope of the renovation. Local automation systems were integrated within Building Management System. Conclusions resulted from the operation of renovated heat substations will be used in the future for further complex and optimized heating substations modernization. Analysis of the work of the heating substations in buildings built in the past few years were also presented in the paper.

Keywords: *district heating substations*, *automation systems*, *thermal renovation*

S t r e s z c z e n i e

W artykule opisano proces rozbudowy układów automatyki w wybranych węzłach ciepła budynków uniwersyteckich. Zakres remontu obejmował wymianę zaworów regulacyjnych oraz zastosowanie liczników ciepła na poszczególnych obiegach instalacji grzewczych. Układy automatyki zintegrowano w systemie zarządzania BMS. Wnioski wynikające z eksploatacji zmodernizowanych węzłów mają w przyszłości posłużyć do dalszej, kompleksowej, zoptymalizowanej modernizacji węzłów ciepła. W artykule przedstawiono również analizę pracę węzłów obsługujących budynki wybudowane w ciągu ostatnich kilku lat

Słowa kluczowe: *węzły ciepła*, *układy automatyki*, *termomodernizacja*

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1. Introduction

In recent years many buildings were thermally renovated. Thermal insulation of external walls was improved, windows replaced, central heating (CH) and hot water distribution systems (DHW) modernized. Changes in heat bills, use of electronic heat cost allocators, and the heat meters along with billing of individual tenants, as well as public institutions, led to a more conscious operation of buildings, reduced heat demand for heating and hot water preparation.

The existing buildings technical documentation, after numerous modifications of buildings' envelopes and HVAC systems, is not a significant help in determining the actual buildings' heat demand. Analytical methods for existing buildings are affected by substantial errors [3]. Measurements of heat transfer coefficients or airtightness of buildings, although technically feasible, are seldom used. Very difficult to assess is the influence of natural ventilation and operation of the buildings.

Costs of delivered heat depend on the contracted heat demand, which is typically declared by the building administrator. Heat suppliers have precise knowledge of peak capacities, thanks to heat meters with the data transmitters. Unfortunately, this information is usually not available for the customers. A typical configuration of heating substation is equipped with only the main heat meter and no individual circuits are measured. Real heat demand is not known, that is why comprehensive modernizations of heating substations are difficult to conduct properly.

The solution is staged modernization. First step consists of replacing the automation control system, main actuators and valves; integrating it within the Building Management System (BMS) and installing heat meters. After one period of operation, knowing real heat demand, one can proceed to the second phase of modernization, which consists of replacing the substation's hydraulic components. This solution allows for a selection of a heating substation well-fitted to building needs, and results in distributing the financing in time.

2. Modernization of automation systems and metering of heating substations

In 2013, 12 heating substations in the Poznan University of Technology (PUT) campus were selected for modernization. Buildings are summarized in Table 1. Among them are dormitories (A11–A19), the canteen (A20), administration and educational buildings (the rest). Additionally, for comparative purposes, Mechatronics, Biomechanics and Nanoengineering R&D Centre (CM), built in 2011, are presented.

The heating substations have been in use since 1980/1990. The newest one was made in 2003. During this operation a number of fittings, valves, sensors and actuators have been replaced. They were equipped, only, with main heat meters (district heating circuit). Heating substations generally worked properly with weather based controls, but have the ability neither to remotely control the heating parameters, nor reading the circuits' heat consumption.

Staged modernization was proposed, with the first step consisting of the automation systems replacement and metering the substations circuits: CH, DHW, air handling units

Fig. 1. Analyzed PUT campus buildings (source: Google Maps)

heaters (VH) and hot water circulation (HWC). New valves with actuators for CH, VH and DHW circuits were installed; damaged fittings were replaced; and thermal insulation of pipelines completed.

The total net specific cost of upgrade was around 20 € per 1 kW of contracted heat demand.

3. Operation of retrofitted heating substations

Information about real peak heat demands is important to determine the modernization strategy for the campus buildings and is essential to reduce the contracted capacities as to decrease fixed costs associated with the heat delivery.

Minister of Economy ordinance [1] sets detailed rules for calculation of tariffs and settlements of heat supply. In accordance with §2.18 [1] contracted heat demand is set by the administrator of the building. It is the peak capacity calculated for design conditions. Heat suppliers enforce the contracted heat demand with use of flow limiters. In case of exceeding the contracted heat demand, heat suppliers may charge the customer twice the rates.

Heat demand is determined (§43.3 [1]) as 1/24 of the difference of the heat meter readings (MWh) made in a period of 24 hours. Contracted head demand is calculated as follows (§41.3 [1]):

$$N_C = \frac{Q_{dCH}}{24} \cdot \frac{t_i - t_e}{t_i - t_{av}} + \frac{Q_{dHW}}{24} \tag{1}$$

where:

Q_{dCH} – amount of heat supplied for CH+VH in 24 hours period [MWh],
Q_{dHW} – amount of heat supplied for DHW+HWC in 24 hours period [MWh],
N_C – calculated contracted heat demand [MW],

t_i – indoor temperature [ºC],
t_e – design temperature [ºC],
t_{av} – average ambient temperature for 24 hours period [ºC].

Q_{dCH} and Q_{dHW} values should be determined with use of dedicated heat meters. If only the main heat meter is available it is impossible to determine in practice the Q_{dHW} at ambient temperature t_{av}.

The impact of contracted heat demand on fixed heat costs is particularly evident in the case of new, low energy buildings connected to the district heating network. Connection heat demand defined in the application for connection to the network based on the HVAC design in general practice is often two or even three times higher than the actual heat demand, which occurs during operation. CM building, with measured specific heat demand for CH and VH of 26 W/m² and 14.000 m² of heated area is equipped with a substation of 1.21 MW heating capacity. With contracted heat demand set with the use of connection heat demand, instead of the real demand (about 400 kW), would result in an increase in total annual heat cost from 2.30 €/m²/annual to 4.00 €/m²/annual (data calculated for the year 2012). In many cases, technical and administrative heat customer staff, used to the higher specific heat costs for typical buildings, pay no special attention to low energy buildings heat costs.

Heat demand for an existing building can be estimated using the consumption readings from the main heat meter for longer time periods (e.g. monthly invoices), divided by the number of hours of the measurement period. It results in determination of heat capacity smaller than actual values, due to averaging of peak demands.

Accurate determination of the heat capacity of a substation is possible with use of long--term metering of heat power. It requires the use of individual heat meters for each circuit,

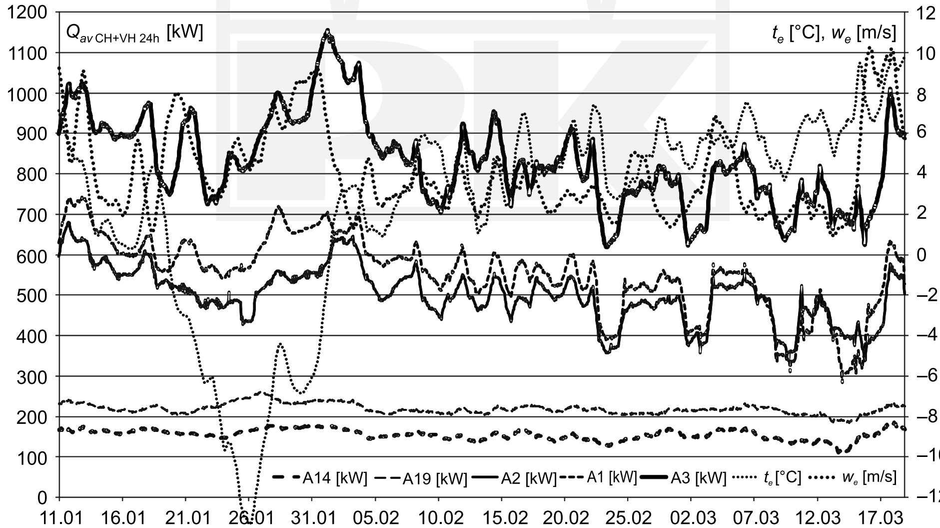

Fig. 2. Thermal capacities of selected buildings, averaged over 24-hour periods related to design conditions (t_e = –18ºC, t_i = 20ºC), wind speed (w_e) and outside temperature (t_e) for the analyzed period 10.01–18.03.2014

integrated into the BMS, which enables archiving of measured parameters. Substation heat demand is the sum of the maximum DHW+HWC demand and CH+VH demand, related to design conditions, selected from the list of 24-hour mean demands.

Figure 2 presents the thermal capacity measurements averaged over 24-hour periods and related to design conditions. The measurements were made using the CH and VH heat meters and archived in BMS.

Heat demand reduction observed on weekends for some buildings (B1, A2, A1, A3, C1) is the result of internal temperature setback. The analysis does not take into account lowered temperature in the rooms (assumed constant 20ºC). In dormitories (A14, A19) these reductions were not applied, what resulted in flat curves for the buildings.

Table 1

Contracted and estimated heat demands

object	A_f	N_{OH}	N_{24}			N_{MH}			ΔN_{OH}	ΔN_{MH}	q_{24}
		Σ	CH	HW	Σ	CH	HW	Σ			
	[m²]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[kW]	[%]	[%]	[W/m²]
A11	6560	**422**	374	66	**440**	355	31	**386**	–4	–12	**57**
A12	5420	**294**	235	73	**308**	209	47	**256**	–4	–17	**43**
A13	5420	**260**	188	54	**242**	154	40	**193**	8	–20	**35**
A14	5420	**256**	187	69	**256**	155	47	**202**	0	–21	**35**
A18	7180	**526**	256	86	**341**	172	75	**247**	54	–28	36
A19	7180	**526**	261	88	**349**	218	69	**286**	51	–18	**36**
B1	4300	**487**	472	2	**474**	344	2	**347**	3	–27	**110**
A20	2000	**230**	134	15	**149**	98	12	**110**	55	–26	**67**
A2	6340	**586**	680	13	**693**	489	13	**502**	–16	–28	**107**
A1	13700	**788**	743	20	**763**	541	25	**566**	3	–26	54
A3	14900	**1005**	1155	19	**1173**	824	22	**845**	–14	–28	**77**
C1	3210	**318**	336	2	**339**	237	1	**238**	–6	–30	**105**
CM	14000	**400**	362	9	**371**	254	8	**262**	8	–29	**26**
Σ/śr.	**95630**	**6096**			**5897**			**4441**	**3.4**	**–24.7**	**61**

Abbreviations: A_f – heated area, CH – central heating (CH and VH taken into account), HW – hot water preparation (DHW and HWC taken into account), Σ – total power, N_{OH} – contracted heat demand, N_{24} – maximum heat power averaged over 24 hours periods, N_{MH} – maximum heat power averaged over monthly periods, ΔN_{OH} – contracted heat demand over-sizing relative to the actual value (N_{24}), ΔN_{MH} – maximum heat power excess averaged over monthly periods relative to the actual value (N_{24}), q_{24} – specific heat demand (CH+VH)

Due to the 24-hour averaging, capacity increases after the reduction period are not particularly noticeable on the chart. In practice, increased power periods last approximately a few hours.

For high-rise buildings (A1, A3) and for older buildings with poor airtightness (A2, B1, C1) the influence of wind, even in ambient temperature rising periods, can be clearly observed.

For the 10.01–18.03.2014 period analysis of the heat meters readings was conducted and presented in Table 1, which compares the ordered heat demand (subscript OH), heat power averaged in the 24 hours period (subscript 24) and during the month (subscript MH). Analysis was performed using the CH, VH, DHW and HWC circuits heat meters archived in the BMS database. Average ambient air temperature was 2.5ºC. CH and VH capacities were related to the design ambient temperature –18ºC.

It should be noted that determination of the heat demand using monthly averages (MH) results in underestimating the power of up to 30%, with average of almost 25%. Dormitories, thermally renovated in recent years, are characterized by a specific heat demand of 35–36 W/m^2 (with the exception of buildings A11 and A12 due to their different operation: adjacent sports hall and conference auditorium). Not thermally renovated buildings (C1, A2 and B1 – prohibited by Old Monuments Law), are characterized by a specific heat power demand of 105–110 W/m^2. Buildings A1 and A3, erected in the 70's, thermally renovated, but with large number of thermal bridges, exposure to wind and equipped with additional mechanical ventilation systems with poor controls (for A3) are characterized by an 54–77 W/m^2. Low energy building CM, erected in 2012, is characterized by the value of 26 W/m^2. Very good performance is the result of proper thermal insulation, good airtightness (measured n_{50} = 0.3 h^{-1}) and the demand controlled ventilation (DCV) all over the building.

By comparing the heat demand of A1 and A3 buildings, with the same structure and similar operation, attention was paid to, not metered so far and thus not conscious by the technical staff – the heat demand of the auditorium building located in between A1 and A3 buildings. The building is supplied with heat from A3 building substation, which includes the lecture halls, with an area of 1.200 m^2. Heat demand for CH+VH is nearly 400 kW, which represents about 40% of the heat demand of A3 building (with an area of 13.700 m^2). The reasons are: lack of insulation, high heat losses to the ground, low efficiency heating system and most of all primitive automation system often resulting in a continuous operation of air handling units, without dependence on the auditoriums' occupancy profile.

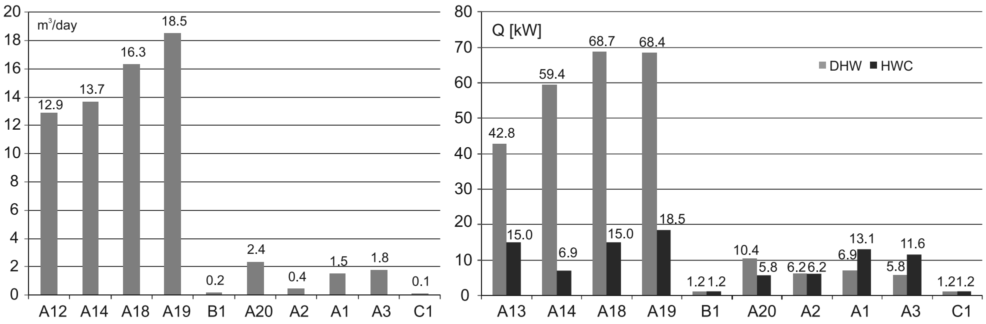

Fig. 3. Hot water consumption (left) and comparison of DHW and HWC heat demand (right) in selected PUT campus buildings

Measurements proved a very low consumption of DHW (100 to 400 dm³/day) in B1, A2 and C1 buildings. A change should be considered from central hot water preparation with circulation system to local electric water heating.

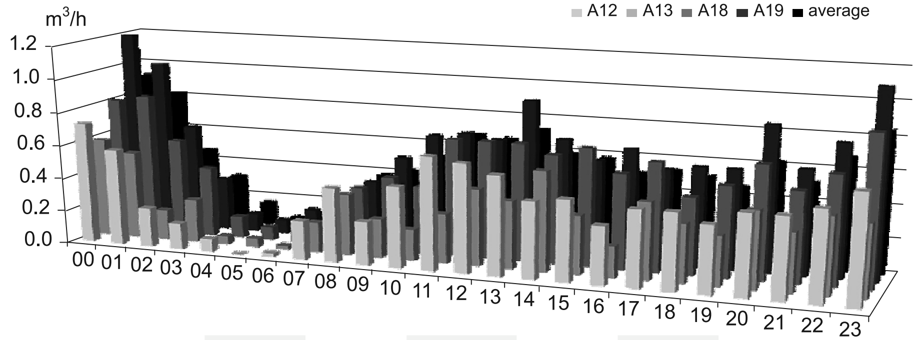

Fig. 4. Hourly averaged DHW consumption in selected dormitories

The higher hot water consumption compared to the buildings' floor area results in less HWC contribution in total DHW+HWC heat losses. For dormitories HWC ratio is about 18.3%, while for rest of the campus (except A20 – canteen) it exceeds 56%. Very large heat losses were observed in high-rise A1 and A3 buildings, where HWC ratio is more than 66%. As a result of the observations strict schedules and hot water temperature reductions (setbacks) were set for the DHW circulation systems.

In the dormitories, a reduction of hot water consumption was observed in the hours 3:00 –7:00. For the period temperature reduction to 45°C (compared to standard temperature of 55ºC) was set.

4. Conclusions

The paper presents the concept, scope and effects of the first stage of a complex retrofitting of heating substations for 12 buildings located on the PUT campus. Common problems of operation of the heating substations being in use for years were described. Capabilities of BMS control, schedules, reductions and the adjusting of parameters were also discussed.

Particular attention was paid to the method of estimating the contracted heat demand. It was concluded, that design oversizing of heat exchangers may indirectly and substantially increase the heat cost for low energy buildings. A number of heating substations operation phenomena, not noticed till now due to lack of instrumentation, were described and analyzed.

Benefits of automation systems retrofit, as a first stage of complex modernization was presented. Customer obtains knowledge of the peak heat demands, heat losses, hot water consumption and operation profiles. This is a very good step towards optimal complex retrofitting in next stages. BMS allows to control the operation parameters of heating substations, set schedules and reductions.

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