NATURAL GAS SAVING AND EMISSIONS DECREASE IN PUBLIC HEALTH CARE SECTOR – A CASE STUDY

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A b s t r a c t

A study on natural gas saving and emissions decrease in the public health care sector is presented. The analyzed hospital complex belongs to the largest ones in Slovakia and uses both hot water and water steam for heating purposes. Visual steam system inspection revealed serious inefficiencies, including steam venting, missing pipelines insulation and obsolete steam sources with dysfunctional blow-down system. Defined experiment with stepwise steam appliances shutdown enabled quantification of excess natural gas consumption due to these inefficiencies. Measures proposed for the solution of this state are inexpensive, with a short payback period. The expected natural gas savings amount up to 3200 MWh/year, which represents roughly 50% of the total natural gas consumption in the hospital complex.

Keywords: public building, health care sector, natural gas, emissions, heat loss

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1. INTRODUCTION

Energy consumption in the building sector amounts to between 20 to 40% of the total world energy consumption [1], [2]. The estimated energy saving potential in this sector is over 30% on average [3], which is often corroborated by related case studies and reviews [4] – [8]. However, the building retrofit rate is still very low, only about 3% in both USA and EU [9] and even lower is the new building construction rate, contributing together to only up to 5% incremental building energy efficiency investment in 2017 [2].

A brief examination of the current situation in case of the U.S.A. revealed that more than a half of the U.S. buildings will need extensive retrofits by 2050 to meet the goal to cut the energy use in buildings by half [10], [11]. This will require strong involvement of both government and municipalities to create further energy awareness programs, strengthen the role of buildings energy benchmarking and energy auditing and to overcome barriers to energy efficiency in this sector [12]. Implementation of smart metering and advanced energy saving systems will also aid in achieving this ambitious goal [6].

The 2010 Energy Performance of Buildings Directive [13] and the 2012 Energy Efficiency Directive [14] are the EU's main legislative instruments promoting improvement of the energy performance of buildings within EU providing a stable environment for investment decisions to be taken.

When the recast Directive was approved, many features of the original Directive were strengthened and new requirements were introduced; one of the most important is the final definition of nearly zero energy buildings (nZEB). General definition of a nearly zero energy building can be found in the work of Kurnitsky et al. [15].

The greatest potential for energy savings is in existing buildings, therefore they provide the greatest opportunity and challenge; no specific target has been set for their renovation [16]. However, Member States shall follow the lead of the public sector by developing policies and adopting measures (such as energy targets) to stimulate the transformation of refurbished buildings into very low energy buildings. Member States shall inform the Commission of their national plans [13]. The exact definition and the exact way of achieving this goal are left to the Member States. As presented in a recent report [17], many EU countries have difficulties to meet the expected 3% per year buildings renovation rate that should satisfy the goals set by the Directive.

National definitions of nZEBs have been transposed to the Slovak legislation and supplemented by the Slovak national standards and regulations. Act No. 300/2012 [18] provides a definition of nZEB according to which they are buildings with very high energy performance.

To achieve the nZEB parameters it is necessary to proceed from the acceptance and determination of three interrelated criteria:

- Reduction of specific heat demand for heating to minimum.
- Reduction of primary energy consumption for heating, cooling, ventilation, domestic hot water and lighting.
- Significant coverage of the overall primary demands by renewable energy sources [19], [20].

Energy demands are separated into five categories: heating, lighting, hot water, ventilation and total energy demand; providing scales of energy classes as a global indicator for different building types [21], [22]. The resulting energy performance indicator is called the "energy use". If the calculation methodology follows the rules of energy certification as defined in the Regulation 364/2012 Z.z. [23] and Regulation 324/2016 Z.z. [24], the heating system can be classified in one of the energy efficiency classes A to G. Tables 1 and 2 provide a numerical indicator classifying the energy use for heating and total energy use in selected types of buildings. The total energy use is calculated by a simple summation of the energy need and energy loss of heat emission and distribution systems.

Table 1. Energy classes classifying the energy use for heating [23] in kWh/m^2/year

Building types	Energy performance classes						
	A	B	C	D	E	F	G
Office buildings	≤ 28	29-56	57-84	85-112	113-140	141-168	> 168
Schools and educational facilities	≤ 28	29-56	57-84	85-112	113-140	141-168	> 168
Hospitals	≤ 35	36-70	71-105	106-140	141-175	176-210	> 210
Hotels and restaurants	≤ 36	37-71	72-107	108-142	143-178	219-213	> 213

Table 2. Total energy use [24] in kWh/m^2/year

Building types	Energy performance classes						
	A	B	C	D	E	F	G
Office buildings	≤ 53	64-125	126-179	180-232	233-291	292-350	> 350
Schools and educational facilities	≤ 43	44-86	87-125	126-163	164-204	205-245	> 245
Hospitals	≤ 104	105-207	208-300	301-393	394-491	492-590	> 590
Hotels and restaurants	≤ 94	95-187	188-275	276-363	364-454	455-545	> 545

Slovakia has a huge potential in existing buildings renovation to achieve the nZEB standard even if it is not obligatory. Renovated buildings are required to meet the nZEB standard only if it is technically, functionally and economically feasible [23].

Of the total number of non-residential buildings, 15 435 buildings were identified as owned by central and local government bodies between 1994 and 2003. Broken down by the built-up volume, 50.9% of these non-residential buildings were schools, 13.2% were healthcare facilities, 12.5% were administrative buildings

and 10.3% were accommodation facilities [25]. The advanced average age of these buildings is documented in Fig. 1.

Health care buildings belong to the most intensive energy consumers within the public buildings group, exhibiting on average 200 to 350 $kWh/m^2/year$ of the total energy consumption [29] – [29] which is over 60% higher than in other public buildings [30]. This is caused both by higher occupation compared to other public buildings as well as strict hygienic and microclimatic demands following the well-being of patients and personnel [28], [31].

Factors leading to such outcomes have been analyzed in detail in recent studies, including mathematical modelling and statistical analysis [27], [28], [31], providing relationships between individual factors and specific annual energy consumption.
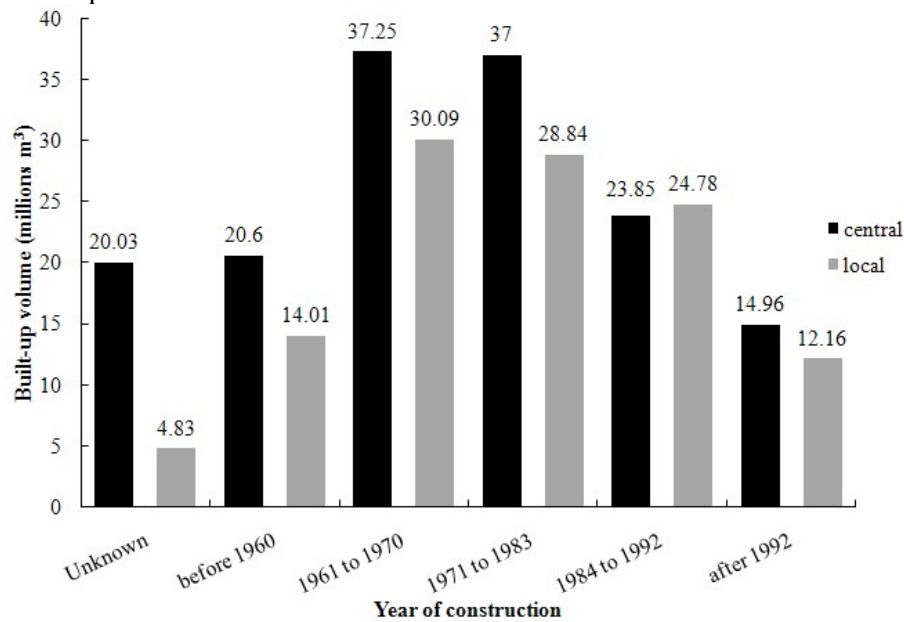

Fig. 1. Built-up volume of non-residential buildings owned by central (black) and local (grey) government bodies, by age [25]

Opportunities for energy consumption decrease in public health are tightly connected with the end use of energy in this sector. Nearly half of the energy consumption is typically consumed for building heating [20], [26], [32], followed by HVAC systems, lighting and other electric appliances. Thus, the majority of studies aimed at energy intensity decrease in this sector seek to lower the heating demands by proper building envelope retrofit, central heating unit upgrade, HVAC system modernization and regulation system improvement [4], [5], [33] – [35]. The role of hospital personnel awareness of energy efficient behaviour is

highlighted [36] – [37] with behavioural inertia being frequently identified as one of the barriers to substantial energy savings in this sector. A comprehensive analysis of all important barriers to energy efficiency in public health buildings is provided in [4], [5], [37], [38] where it is stated that the comparatively low priority of rational energy use in this sector is often overcome by other more urgent personnel activities and duties. Energy management introduction and energy performance contracting are seen as viable means towards energy savings [7], [39]. Parallel in-house activities aimed at personnel education have the potential to aid these processes [36]. Environmental effect of decreased energy consumption is dual: lower emissions released to cover the energy demand [26], [35] and improved working and living environment [40].

The advanced average age of Slovak hospitals (42 years, [41]) prompted the Slovak government to make a commitment to stepwise reconstruct and rehabilitate all large hospitals in Slovakia providing hundreds of millions euro to cover the associated financial expenses [42] – [45]. New hospital complexes are also to be built [41]. Investments to existing buildings are to be directed both to building envelopes modernization and new insulation as well as to internal equipment retrofit, including steam/hot water sources, HVAC units and chillers. In order to invest money into energy saving measures effectively, actual energy consumption has to be reviewed and non-investment options should be exploited to decrease the energy consumption which in turn should decrease the size and cost of the new equipment to be installed.

This study follows two goals:

1. Demonstrate the potential for low- or no-cost measures towards energy consumption decrease in the heat production and distribution system in a large hospital complex;

2. Provide a general methodology applicable to any hospital producing and consuming water steam to decrease the steam and heat losses by implementation of the best practice for steam and condensate systems applicable both for industrial and for residential systems [46], [47].

2. MATERIALS AND METHODS

2.1. Hospital complex

The hospital complex located in Bratislava belongs to the largest hospital complexes in Slovakia and serves for up to 700 thousand inhabitants of Bratislava city and adjacent regions. Heat delivery for its needs is ensured via two means: hot water for heating supplied from the municipal hot water network and steam production in natural gas fired steam boilers. Apart from the boiler room, natural gas is consumed in the kitchen for meals preparation. Table 3 shows the average

annual consumption of energies in this complex. Considering the total hospital complex area of 77300 m^2, the specific total energy consumption of nearly 250 kWh/m^2/year is obtained which fits within the corresponding data span in hospitals worldwide [26] – [29].

Table 3. Average annual energy consumption in hospital

Consumed energy	Hot water	Natural gas	Electric energy	Total
Consumption (MWh/year)	7860	6450	4870	19180
Share of total consumption (%)	41.0	33.6	25.4	100

Unlike many other studies that strive to propose and implement measures for heat consumption reduction generally, this study is focused on the natural gas solely. Apart from a very small fraction used in the hospital kitchen it is almost exclusively used in gas fired steam boilers. Steam production, transport and consumption are traditional topic of industrial energy efficiency measures but receive less attention in the residential sphere. As it is obvious from Table 1, the natural gas share of the total energy consumption of the hospital is roughly 33% which makes it a promising candidate for consumption reduction. The authors intend to provide the readers with a comprehensive and easily to be followed methodology for steam system energy efficiency increase.

2.2.   Steam production, delivery and consumption

The boiler room is equipped with three natural gas fired steam boilers. Boiler #1 is the oldest one, with rated steam production capacity of 4 t/h but it is out of order. Boiler #2 is also of advanced age (>30 years) with rated capacity of 6 t/h and is currently not in use. The newest boiler #3 of rated capacity of 2 t/h steam is the only one that can be operated for longer periods of time. All boilers produce saturated 800 kPa (g) steam that is throttled down to 300 kPa (g), delivered to steam header and distributed to end users partly at this pressure and partly after pressure reduction to 70 kPa (g). Schematic depiction of the steam production, delivery and consumption system is provided in Fig. 2.

Visual steam system inspection revealed the following defects that are often found in industrial steam systems as well [46], [47]:

-   dysfunctional steam to deaerator delivery regulation system causing steam loss from the deaerator and lower water deaeration quality
-   space heating in the boiler room was on
-   excessive boiler blow-down leading to both water and heat losses
-   boiler capacity was higher than system steam demand, which led to cyclical boiler operation and thus to lower boiler efficiency and higher breakdown probability

- steam and condensate pipelines were ill insulated or the insulation was completely missing
- majority of the steam traps were oversized and/or dysfunctional, which led to steam leaks to condensate pipelines
- flash steam from the condensate collection tank was vented to the atmosphere without use.

Daily and hourly averages of natural gas consumption in the boiler room were analyzed and the results are presented in Chapter 3 in Fig. 3, 4 a, b. To assess the portion of steam lost or condensed due to ill insulated steam mains, the following procedure was devised:

- stepwise closing of the valves depicted in Fig. 2 interrupting thus steam delivery into individual steam consuming appliances
- quantification of natural gas consumption decrease in the boiler room associated with closing of individual valves using online data analysis of natural gas volumetric flow. Results of this procedure are shown in Fig. 5.
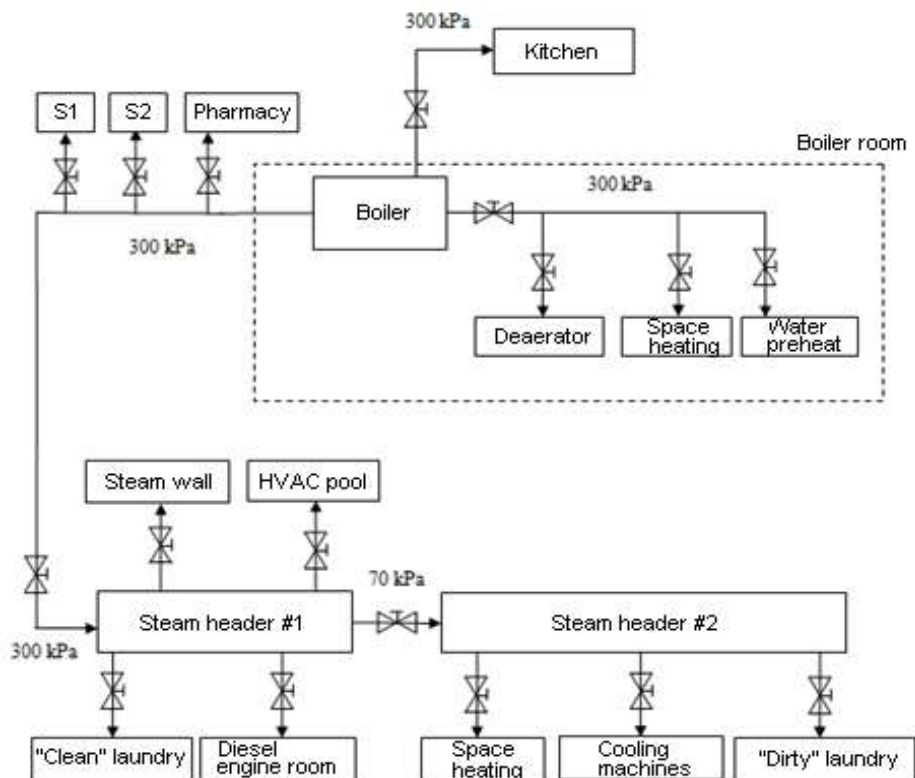

Fig. 2. Schematic depiction of the steam system. S1,2: Sterilizer units

In order to ensure that no troubles arise from performing this experiment, it was carried out during evening and night. Appliances / systems with short allowable steam delivery interruption were shut down as the last ones. Ambient air temperature was -15°C which meant that all space heaters and HVAC systems were in operation. Sterilizer units S1 and S2 operate batch-wise and were not in operation during the experiment.

2.3. Environmental impact assessment

Natural gas combustion produces lower emissions of harmful substances compared to other fossil fuels. Emission metering data for the hospital steam boilers were not available; thus the following data representing yearly averages for natural gas distributed in the Slovak Republic in 2018 [48] were applied:
- natural gas CO_2 emission factor of 55.9 t/TJ
- natural gas volumetric higher heating value of 10.74 kWh/m^3 (at 15°C and 101.325 kPa).

The representative value of nitrogen oxides emissions from natural gas fired boilers of 65.3 kg/TJ were used [49] yielding the following figures of volumetric emission factors for natural gas combustion in steam boilers:
- CO_2 : 2162 kg/1000 m^3
- NO_x : 2.52 kg/1000 m^3.

Considering the advanced age of the hospital boilers, these values represent the lower limit and can be used as conservative estimates for environmental impact assessment of potential natural gas consumption reduction. Emission reduction, R, of individual gases was estimated from Eq. (2.1) and (2.2),

$$R_{CO} \ (kg/year) = R_{NG}(m^3/h) \cdot 2.16 \ kg/m^3 \cdot 8760 \ h/year \qquad (2.1)$$

$$R_{NOx}(kg/year) = R_{NG}(m^3/h) \cdot \frac{2.52 kg}{1000 \ m^3} \cdot 8760 \ h/year \qquad (2.2)$$

where R_{NG} denotes the average potential natural gas savings quantified in Chapter 3 and 8760 h/year is the system operational time.

3. RESULTS AND DISCUSSION

Fig. 3 provides an overview of daily natural gas consumptions in 2018. It can be seen that the lowest natural gas consumption was roughly 50% of the highest one. Such natural gas consumption trend is applicable to a continuous heat demanding production process in the industrial sphere.

This, however, is not the case here. As it appears from Fig. 2, steam consumers are operated either cyclically regardless of the season (Sterilizers, Laundry) or during the heating season only. Hot tap water is produced using the hot water from the municipal hot water system and thus it does not contribute to the rather high natural gas consumption in summer. Occasional natural gas consumption increase highlighted in Fig. 3 results from short periods of municipal hot water supply unavailability when steam is used in certain HVAC / space heating units instead of hot water.

Analysis of hourly natural gas consumption provided in Fig. 4 a, b enables better insight into this matter. Peak and off peak periods associated with morning and evening/night hours respectively can clearly be recognized. They can be attributed to steam consuming appliances that are in operation in the morning and afternoon hours, such as Sterilizers and Laundry with relative peak height of around 20 m³/h of natural gas consumption.

Basic natural gas consumption is between 40 and 50 m³/h in summer and 60 to 110 m³/h in winter obviously depending on the temperature outside. There is almost no steam consumption during summer nights, thus it was anticipated that up to 40 m³/h of natural gas are consumed to cover heat and steam losses from the system. The experiment as described in Chapter 2.2 provided proof of this assumption and allowed quantifying the excess natural gas consumption.
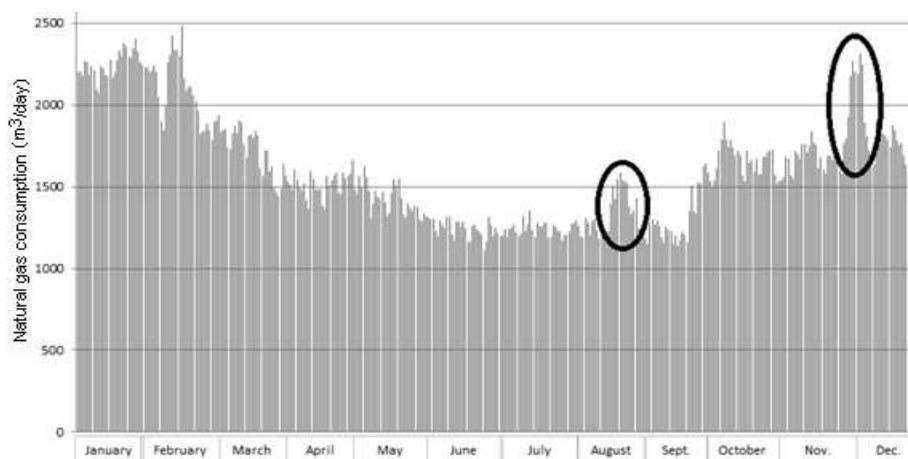

Fig. 3. Overview of daily natural gas consumption in the boiler room in 2018
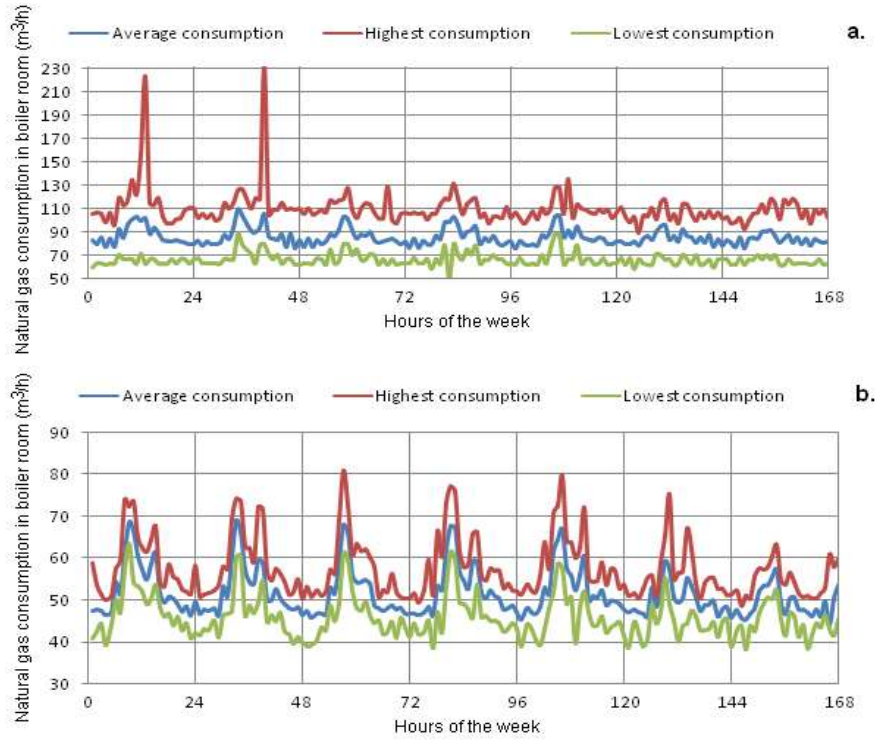
Fig. 4 a, b. Analysis of typical hourly natural gas consumption in the boiler room
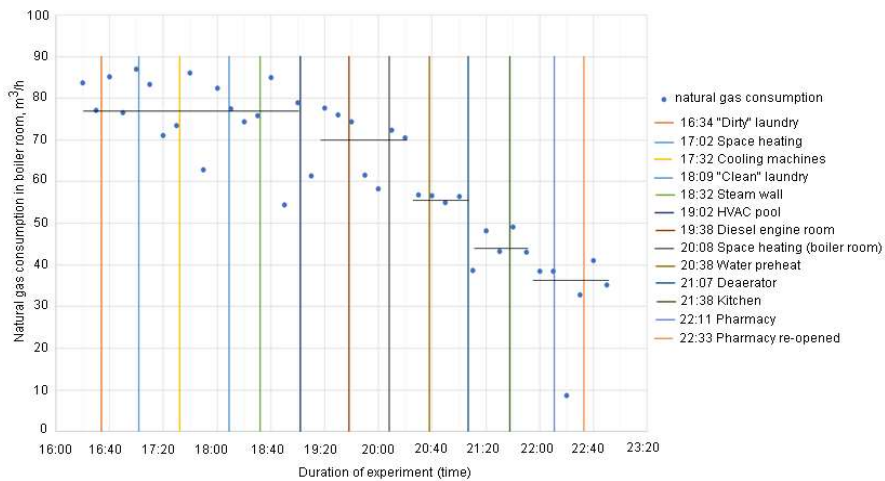in 2018: **a.** in winter and **b.** in summer

Fig. 5. Gradual natural gas consumption reduction during the experiment.
Natural gas volumetric flow is recalculated to 15°C and 101.325 kPa

Natural gas consumption trend during the experiment is shown in Fig. 5. It can be seen that natural gas consumption did not change substantially after closing all steam pipelines supplying the 70 kPa (g) steam to individual appliances. It could thus be concluded that steam and heat losses corresponding to the 70 kPa (g) steam system are insignificant. Natural gas consumption decreased gradually after closing further steam valves to the final value of around 35 m^3/h which represents the excess steam consumption used to cover steam and heat losses from the steam system only.

Furthermore, a 10 m^3/h natural gas consumption difference was observed after shutting down the deaerator steam supply. With properly working steam supply regulation this should not result in visible natural gas consumption decrease. In this particular case, the 10 m^3/h natural gas consumption decrease corresponded to steam vented from the deaerator when no cold water was supplied. It has to be stressed that the deaerator system, like the rest of the steam system, is fairly oversized and thus the cold water supply pump operates cyclically. With the deaeration steam supply malfunction, steam is consumed usefully only during cold water pumping; after the water in the deaerator is heated to the deaeration temperature, excess steam is vented into the atmosphere.

Based on the visual inspection and experiment results, the following measures for natural gas consumption reduction were recommended:

1. Installation of a functional deaeration steam regulation system able to save up to 10 m^3/h of natural gas;
2. Application of new insulation on steam and condensate pipelines, replacement of dysfunctional steam traps with new ones and regular monitoring of their performance;
3. Switching off space heating in the boiler room;
4. Repairing the currently dysfunctional boiler water conductivity measurement and reduce boiler blow-down.

All these measures require only moderate investment and exhibit both to our experience and according to literature [47], [48] a short pay-back period ranging from several months (regulation valve replacement, blow down reduction) up to one to two years (new insulation, new steam traps). By combination of all measures together, at least 35 m^3/h of natural gas can be saved, which represents the yearly energy saving potential of 3200 MWh or roughly 50% of the total natural gas consumption in the hospital. Considering an average household with the annual natural gas consumption of 1500 m^3/year, the expected 3200 MWh/year natural gas saving is equivalent to ca. 200 households.

Applying equations (2.1) and (2.2), the related emissions decrease can be estimated to amount to 644 ton of CO_2 and 0.75 ton of NO_x.

4. CONCLUSIONS

Public health sector worldwide has the potential for substantial energy intensity decrease that still remains largely untouched. As documented in this study, energy consumption cuts up to several tens % are possible with simple and easily applicable measures. The methodology for achievable savings estimation is readily transferable to other hospital complexes or any other public buildings employing steam systems. It should be incorporated into energy management systems in the public health sector as a simple and reliable means of steam system defects identification and quantification. Thereby, the public building sector energy efficiency can be improved and the ambitious carbon emission cut goals of the EU should be approached.

ADDITIONAL INFORMATION

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OGRANICZENIE ZUŻYCIA GAZU ZIEMNEGO I REDUKCJA EMISJI
W SEKTORZE ZDROWIA PUBLICZNEGO – STUDIUM PRZYPADKU

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

Niniejszy artykuł prezentuje studium przypadku na temat ograniczenia zużycia gazu ziemnego i emisji w sektorze zdrowia publicznego. Analizowany kompleks szpitalny należy do największych na Słowacji i używa do ogrzewania zarówno ciepłej wody użytkowej, jak i pary wodnej. Kompleks ten będzie w najbliższych latach poddany

renowacji, włącznie z instalacją dystrybucji mediów. Analiza obecnego systemu I wynikające z niej zaproponowane sposoby na zaoszczędzenie energii oferują redukcję kosztów powiązanych z przyszłą inwestycją. Wizualna ocena systemu dystrybucji pary wodnej ujawniła poważne wady tego systemu, w tym w odpowietrzaniu systemu, uszkodzonej bądź brakującej izolacji rur, przestarzałych bojlerach parowych z niedziałającym systemem usuwania zanieczyszczeń. Eksperyment ze stopniowym wyłączaniem urządzeń parowych umożliwił ilościowe określenie nadmiaru zużycia gazu ziemnego spowodowanego wspomnianymi niedostatkami. Metodologia takiego eksperymentu jest uniwersalna i łatwa w zastosowaniu w jakimkolwiek innym budynku użyteczności publicznej gdzie podobny system pary wodnej jest w użyciu. Zaproponowane rozwiązania dla poprawy takiego stanu są niedrogie i z krótkim czasem zwrotu inwestycji. Zastosowanie nowej izolacji rur, naprawa odwadniaczy oraz naprawa zaworów redukcyjno-regulacyjnych do odpowietrzania pary w odpowietrznikach są przedmiotem rozważań. Oczekiwana redukcja zużycia gazu ziemnego wynosi do 3200 MWh/rok, co stanowi około 50% rocznego zapotrzebowania tego gazu w kompleksie szpitalnym. Ocena środowiskowa zaproponowanych zmian pozwala oczekiwać redukcji emisji dwutlenku węgla na poziomie 644 ton rocznie oraz tlenków azotu na poziomie 0.75 ton rocznie.

Słowa kluczowe: budynek użyteczności publicznej, gaz ziemny, emisja, straty ciepła