Examples of the HVAC Systems’ Modernization in the Existing Schools and Kindergartens

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**Abstract.** The possibility to reduce energy consumption in a group of 30 public, education buildings located in Poland, by improvements in the HVAC systems, was analyzed. The study group included both: primary and secondary schools as well as kindergartens. 14\% of evaluated heating systems were found as having a proper efficiency and technical quality, while in a case of 86\% changes regarding heat regulation, distribution or generation were recommended. Theoretical reduction of energy for heating could reach a level of 5-18\% in buildings with water pipes systems.

1. **Introduction**

According to the Energy Performance of Buildings Directive, all new buildings in EU countries must be nearly zero-energy buildings by 31 December 2020 and a huge attention is paid on the public buildings. Majority of existing buildings were constructed prior to introducing any formal energy performance requirements, as a result of which the quality of the building stock is considerably below that which can be achieved today. Therefore, they need appropriate modernization, that is improvement of existing building technical features of a building which should lead first of all to reduction in energy demand. In Poland, nearly 37\% of total energy in non-residential buildings is consumed by heating, ventilation and air conditioning (HVAC) [1].

In Poland a huge part of energy is used for heating of buildings, in contrast to countries located in south Europe, like for example Spain, or Italy where much more energy usage is connected with cooling [2]. Energy situation of new buildings differs significantly from existing, old ones. For example the kindergarten that was built in 2014 as an energy efficient kindergarten, has a heating demand of approximately 35-40 [kWh/(m$^2\cdot$year)]. As described in [3] the building is heated with floor heating supplied by low-temperature natural gas boilers.

As shown in previous studies [1,4,5], the heating energy consumption factor in Polish existing schools and kindergartens was found between 133.5 [kWh/(m$^2\cdot$year)] and 261.1 [kWh/(m$^2\cdot$year)]. Thus, there is a possibility to apply solutions that can reduce energy consumption, such as retrofitting of envelope, replacing of windows by new ones with a low U value, as well as modernization of the HVAC system. Efficiency of the ventilation system on the overall energy consumption and the indoor air quality (IAQ) was described in [6,7]. Issues of efficiency of distribution network was discussed in [8].
In this paper several buildings of schools and kindergartens located in Bialystok, Poland were selected and possibility to improve HVAC systems was analysed, as well as a range of improvements applied last years was shown.

2. Description of buildings
The group of 30 kindergartens and schools located in Podlaskie Province, Poland was analysed. Buildings were constructed between 1919 and 1988, thus structures of walls and roofs were design to meet regulations regarding heat transfer coefficients that were effective these years. During the retrofitting process, to reduce heat losses through heat transfer, in case of most of buildings (87%) walls and roofs were isolated and external windows, doors replaces by new ones. These improvements allowed to reduce useful energy consumption in the buildings.

All buildings had heating systems, while there were no cooling systems in them, except few offices used temporary by buildings’ administration staff.

In all buildings natural ventilation was used in rooms for students and pupils, while a mechanical ventilation was used only in kitchens, if any.

3. Description of the HVAC systems and thermal comfort
Majority (29 of 30) of buildings had a water heating system with column and/or panel radiators, that is the most often used in Poland. Installations were supplied from the Central Town CHP (Combined Heat and Power) Centre. Heating systems were used continuously all months of the heating season, that lasts from September to April/May depending on the year.

The last building (the kindergarten located in a rural area dedicated for children living in villages in the nearest surrounding) was equipped in electric radiators, and according to information from a building owner the heating installation was used only in a kindergarten working hours (average 8 hours per day from Monday to Friday).

Installations with a water heating system were modernized during exploitation periods, whereas the range of improvements was different, as shown in Figure. 1.

![Figure 1. The range of improvements in the heating system.](image)

4. Indoor thermal comfort
Design temperature in Poland for classrooms and offices is set down as 20°C. In the analysed buildings the indoor temperature during normal usage of classes was found between 16.8°C and 21.2°C. The lowest value was recorded in the kindergarten with electrical heaters in the morning. In other buildings (with a water heating system) temperature didn’t fall away below 18.8°C.
It is very important to maintain a proper indoor temperature, as shown in many previous studies it influences people sensation and students aptitude for learning [9-13].

5. Evaluation of heating system efficiency and analyse of possible improvements
Firstly, buildings with a water heating system were considered.
According to Eq.1 the total efficiency of heating system depends of 4 factors.
\[
\mu_{\text{tot}} = \mu_r \mu_g \mu_d \mu_a .
\] (1)
where:
\( \mu_{\text{tot}} \) is total seasonal efficiency of the heating system,
\( \mu_r \) is the average seasonal efficiency of heat regulation and use in heated space, [−],
\( \mu_g \) is the average seasonal efficiency of heat production from an energy carrier or the energy supplied to a heat source, [−],
\( \mu_d \) is the average seasonal efficiency of heat transmission from a heat source to heated space, [−],
\( \mu_a \) is the average seasonal efficiency of heat accumulation in the inductance components of a heating system, [−].
Thus, the higher total efficiency of HVAC system is, the lower final energy consumption we obtain Eq.2:
\[
\frac{Q_{\text{nd}}}{Q_k} = \frac{Q_k}{\mu_{\text{tot}}} .
\] (2)
where:
\( Q_k \) – the annual demand for final energy supplied to a building or its part for the central heating system, [kWh/year],
\( Q_{\text{nd}} \) – the annual energy demand for heating space, [kWh/year].
Only in a case of 14% analysed buildings (Figure.1) no improvements are recommended, while for 86% of systems it is possible to improve their efficiency. Most of all it is recommended to install thermal valves in rooms where they are missing, to ensure stable indoor conditions and prevent from overheating. Moreover in most cases old radiators should be replaced by new panel ones with a low capacity, as well as old pipes and isolation. In all cases buildings were supplied by heat centres from district heating and it was not necessary to improve the energy source. It is worthy to note that is necessary also to consider possibility to improvements in regulation system even in buildings were thermostatic valves were installed, but they were old types and in many cases not working properly. As shown in [14] in another part of Poland actions to replace old thermostats with Danfoss radiator sensors and thermostatic valves in buildings managed by the city, e.g. in the schools, municipal facilities, city offices, and other socially important facilities, were taken. It is predicted that thanks to better temperature control in individual rooms, about 23 percent of energy could be saved. Moreover it would result in better indoor thermal comfort and would help to avoid situations when part of rooms of overheated while in the others indoor temperature is too low to meet requirements of students and teachers.

Secondly, for the kindergarten with electric radiators, due to a fact that the building used only in mornings and it is located far from a district heating network, it is highly recommended to install an air heat pump.

6. Summary
Improvements in water heating systems could result in 5-18% reduction of energy consumption while replacement of electrical radiators by the air heat pump would increase the system efficiency even 2-4 times, depending of its COP (coefficient of performance).

Findings are consistent with conclusions presented in [15], where analysis of 4 schools showed that in a case of buildings built before 1945, it was possible to improve the efficiency of the installation by about 17%, whereas in buildings built after 1970 - by about 5%.
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