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ANALYSIS OF THE ENERGY CONSUMPTION FOR HEATING IN SCHOOLS

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The aim of the study is to analyse energy consumption for heating in set of the school buildings. Data analysis includes three data sets – predictions from energy performance certificates (EPC), measured data from heat meters and measured climate corrected data. Data sets were statistically checked and processed and represented graphically. The actual energy consumption differs from the one stated in the EPCs in all cases, which means that schools consume on average 15 % more energy than it is stated in the EPC. Overall, the data reveal that the actual energy consumption differs from the theoretical consumption, with all schools having higher actual consumption than the theoretical values. The differences in the data sets are discussed, and possible improvements are suggested taking into account strong relation between energy consumption and indoor air quality.

Keywords: *Energy consumption, energy performance certificates, heating, school buildings.*

1. INTRODUCTION

Importance of the indoor air quality (IAQ) and thermal comfort in the educational buildings cannot be underestimated. According to the ASHRAE IAQ, upgrades can improve learning outcomes and mitigate the risk of transmission of airborne pathogens within the educational environment [1]. However, every school and its HVAC systems are unique and require certain efforts of a qualified professional in assessing each facility's unique characteristics. School buildings are considered to be one of the most diverse structures from the perspective of energy-efficient design and construction [2]. The current study is focused on the Latvian secondary education buildings with purpose to compare predicted energy demand according to the

energy performance certificates (EPC), actual energy consumption according to the heat meter data and actual consumption adjusted according to the degree days. It is important to discover the reasons of discrepancies between those mentioned data sources and provide possible solutions to improve data reliability.

This is important due to several reasons. First of all, it is necessary to understand whether it is possible to reduce energy consumption without lowering the indoor air quality and thermal comfort of the building users. Influence of building envelope properties on the energy efficiency is described in studies [3], [4]. The second reason is the fact that usually educational buildings are operated, maintained and paid or subsidised by municipalities or government. Finding the proper methods and strategies for the reduction of energy demand will provide considerable savings in terms of funds and primary energy consumption, which is beneficial for authorities to reach high European and national energy and climate targets. For example, in [5] it is stated that in Sweden the largest amount of energy is consumed in school buildings, i.e., where schools form the highest number of public properties (30 million m2). In total, schools consumed 4 222 GWh of district heating and about 3 GWh of electricity for heating and other purposes in 2020. Correlation of energy efficiency and thermal comfort based on simulation results is discussed in the studies [6]–[9], which show how window orientation and opening influence ventilation efficiency and thermal comfort. Many studies have already been performed across the world in order to analyse and compare energy consumption and conclude on further optimization steps [10], [11].

Authors of the study [12] argue that the methodology used for the evaluation of school buildings can be extended from public buildings to a commercial building stock, residential buildings and small houses. This can provide valuable information, in particular, for property owners whose buildings have been recently renovated or who intend to do so in the future. Renovation wave of the existing building stock of the European Union is spinning off, which means that the results of the study will be relevant for different stakeholders related to the building operation and management. In Canadian northern climate, researchers also conclude [13] that newer and renovated building consume less energy; however, electricity consumption is higher. Researchers from Korea [14] show that energy demand in school buildings is rising alongside with an increase in the use of interactive teaching methods, cooling and cooking options. It varies a lot between 67–240 [kWh/m^2/yr]; however, it should be mentioned that there is no significant difference in energy consumption per student.

However, some problems with moisture accumulation in the construction and best practice examples of retrofitting solutions are described in [15]–[18]. The design of the ventilation system in retrofitted buildings with passive use of solar energy is discussed in [19]–[21], showing how to avoid unnecessary overheating during summer months. While indoor air quality is a very important factor, it strongly depends and correlates with specific energy demand of the building. Study [22] reports the indoor air quality and overheating levels in eight recently built classrooms of two new low-carbon primary schools during heating and non-heating seasons. The analyses indicated that most of these classrooms had experienced overheating for more than 40 % of school hours, as well as revealing that CO2 concentration levels were above the maximum threshold of 1000 ppm for more than 60 % of school hours in heating and non-heating seasons.

Decentralised ventilation units can be proposed as a local solution; the efficiency of these units is described in [23], with precautions to use it, while delivering very poor heat recovery efficiency between 20 % and 50 %. The effect of CO_2 concentration on children's well-being during the process of learning is evaluated in [24]. Additionally, it is important to note that for renovated building rooms the concentration of volatile organic compounds (VOC) can be a problem, while any pollution requires additional ventilation rates and energy consumption for ventilation. The influence of renovation and pollution on the energy performance and ventilation rates is discussed in [25]–[27]. The paper [28] analyses a performance gap between predicted (calculated) and measured (actual) delivered energy for space heating in 185 school buildings. Considering the abovementioned information, it is important to perform evaluation of the energy demand in school buildings on a national or even a regional level with the aim to provide a basis for developing strategies and plans to improve energy efficiency both with passive and active methods.

2. METHODOLOGY

An analysis was conducted on the energy consumption of 25 public schools in Riga. The data used for analysis included the following parameters: monthly energy consumption from January 2020 to September 2022 for all 20 schools, climate data of Riga for the above-mentioned period and EPC for 11 schools. The 11 schools with EPC provided additional data, including information about the school address, area, heating system, hot water preparation, mechanical ventilation, lighting, cooling and additional features. All data sets were statistically evaluated and checked. A basic survey of the buildings was performed, such as visual inspection from the outside.

With this information, it was possible to compare three different types of heating energy consumption: theoretical (as provided in the EPC), actual (as provided in the monthly energy consumption reports) and degree day consumption, which was recalculated based on the external temperature for each year.

Out of 25 buildings, only for 20 of them data were fully available and reasonable for further evaluation. 20 buildings were divided into two groups, where 9 buildings were without existing EPC and 11 buildings were with EPCs. Thus, it was possible to make comparison between predicted EPC values and actual consumption data.

For further evaluation, the actual heat energy consumption data were processed using the following assumptions: all 20 buildings did not have data on hot water consumption, so heat energy consumption for the period outside the heating season was considered as consumption for domestic hot water (DHW) preparation. Note: these are not representative values during the summer months (June–August).

For the corrections of the climate influence the heating degree day (HDD) method was used and all heat energy consumption values associated only with heating needs were corrected by an actual climatic HDD factor for corresponding time periods. Climate data were obtained from the public web database of the official Centre of Environmental Geology and Meteorology of Latvia. Further data were processed and presented graphically.

3. RESULTS

Upon comparing the schools without EPC (a total of 9), the data demonstrated the following trends (summarised in Table 1): the total heating energy consumption for the 7 schools in Riga varied from 226.32 MWh in School 1 to 682.48 MWh in School 4 in 2021. Overall, there was a noticeable pattern of rising energy consumption from 2020 to 2021, as evidenced by the decreasing MWh values in most of the buildings, which could be attributed to 2021 being a colder year compared to 2020.

Table 1. Heating Energy Consumption (Schools without EPC)

	Heating energy consumption, MWh			Heating energy consumption (HDD corrected), MWh		
School	2020	2021	2022, until September	2020	2021	2022, until September
School 1	461.33	226.32	127.99	585.18	236.19	142.13
School 4	561.67	682.48	381.69	712.45	712.25	423.85
School 6	509.87	642.56	412.54	646.75	670.59	458.11
School 9	392.85	468.89	281.92	498.31	489.34	313.06
School 10	223.88	313.20	180.18	283.98	326.86	200.08
School 11	269.35	306.62	176.78	341.66	320.00	196.30
School 12	470.65	537.62	316.17	597.00	561.07	351.10
School 18	516.41	565.87	306.05	655.05	590.55	339.85
School 19	480.40	629.24	342.37	609.36	656.69	380.19

For instance, in School 4, the energy consumption increased from 561.67 MWh in 2020 to 682.48 MWh in 2021. Similarly, in School 6, the energy consumption increased from 509.87 MWh in 2020 to 642.46 MWh in 2021.

Data from schools with EPC show similar results. If degree days are included in the analysis of energy consumption, it is possible to see that 2021 is colder than 2020 (data summarised in Table 2).

Table 2. Heating Energy Consumption (Schools with EPC)

School	Heating energy consumption, MWh			Heating energy consumption (HDD corrected), MWh		
	2020	2021	2022, until September	2020	2021	2022, until September
School 5	311.23	396.20	218.28	394.78	413.49	242.39
School 7	495.78	593.92	334.27	628.88	619.83	371.20
School 8	549.51	626.11	326.02	697.03	653.42	362.03
School 13	226.49	362.51	212.79	287.29	378.32	236.30
School 14	602.01	710.62	395.34	763.63	741.62	439.01
School 15	433.29	519.87	387.67	549.61	542.55	430.49
School 21	468.52	503.45	330.66	594.29	525.41	367.19
School 22	590.30	760.23	390.97	748.77	793.39	434.16
School 23	544.85	521.32	278.02	691.12	544.06	308.73
School 24	435.58	490.72	344.49	552.52	512.13	382.54
School 25	408.58	485.24	280.60	518.27	506.40	311.59

Specifically, when considering degree days, half of the schools showed higher energy consumption in 2020 compared to 2021. For example, the consumption of School 4 in 2020 and 2021 was 561.67 MWh and 682.48 MWh, yet with degree days it was 712.45 and 712.25 MWh; consumption in 2020 increased by 28 % and in 2021 by 4.5 %.

4. CONCLUSIONS

From the preliminary analysis of the study, it can be concluded that the accounting of degree days has a significant impact on heat energy consumption. To illustrate this point further, schools such as School 8, School 14 and others show an increase of approximately 27 % in heating consumption in 2020. The consumption values changed from 549.51 MWh to 697.03 MWh and from 602.01 MWhto 763.63 MWh, respectively.

The summary of the results is presented in Fig. 1.

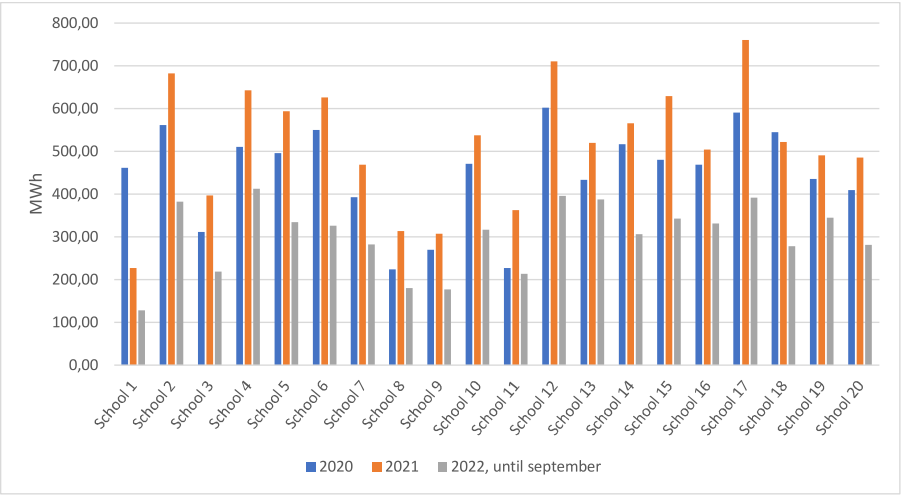


Fig. 1. Heat energy consumption.

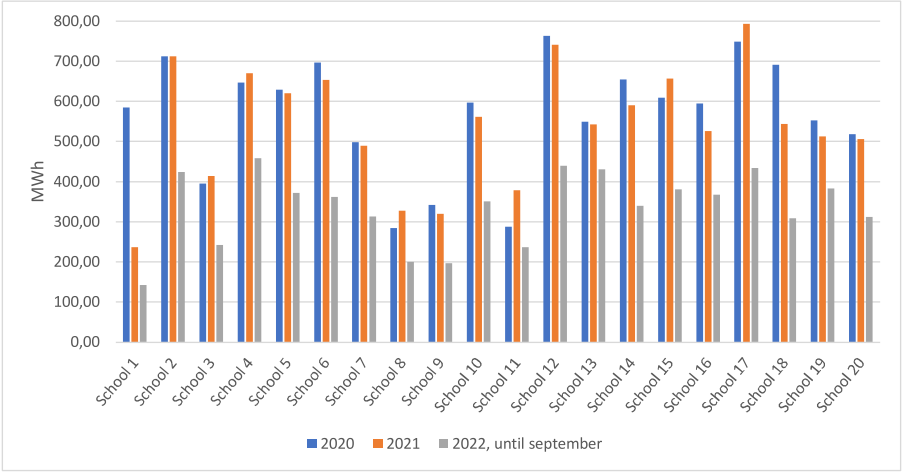


Fig. 2. Heat energy consumption adjusted according to HDD.

Upon examining the graphs, it becomes apparent that degree day adjustment helps to slightly even out the consumption patterns across the years, enabling a clearer view of the actual energy consumption.

Since more data were available for schools with EPC, including the area of the building and EPC, it facilitated a comparison of the heating energy consumption stated in the certificates and reports against the calculated consumption in kWh/m^2. The results are presented in Table 3.

Table 3. Heating Energy Consumption for m^2 (Schools with EPC)

Heating energy consumption, kWh/m^2				Heating energy consumption (HDD corrected), kWh/m^2		
School	2020	2021	2022, until September	2020	2021	2022, until September
School 5	60.53	77.05	42.45	76.78	80.41	47.14
School 7	48.27	57.82	32.54	61.22	60.34	36.14
School 8	54.34	61.91	32.24	68.92	64.61	35.80
School 13	47.90	76.67	45.00	60.76	80.01	49.97
School 14	60.15	71.00	39.50	76.30	74.10	43.86
School 15	42.63	51.15	38.14	54.08	53.38	42.36
School 21	91.56	98.39	64.62	116.15	102.68	71.76
School 22	58.57	75.44	38.80	74.30	78.73	43.08
School 23	52.23	49.97	26.65	66.25	52.15	29.60
School 24	83.36	93.91	65.92	105.74	98.01	73.21
School 25	89.58	106.38	61.52	113.63	111.02	68.31

As shown in Table 3, using degree day adjustment evens out heating consumption and allows seeing the real kWh/m^2 consumption regardless the temperature in the following year. Table 4 shows energy consumption that was stated in the EPC.

Table 4. Energy Consumption Data

School address	kWh/m^2
School 5	68.79
School 7	53.04
School 8	58.12
School 13	62.28
School 14	65.58
School 15	46.89
School 21	94.98
School 22	67.01
School 23	51.10
School 24	88.63
School 25	97.98

Figure 3 shows the comparison between the theoretical and actual HDD corrected heat energy consumption.

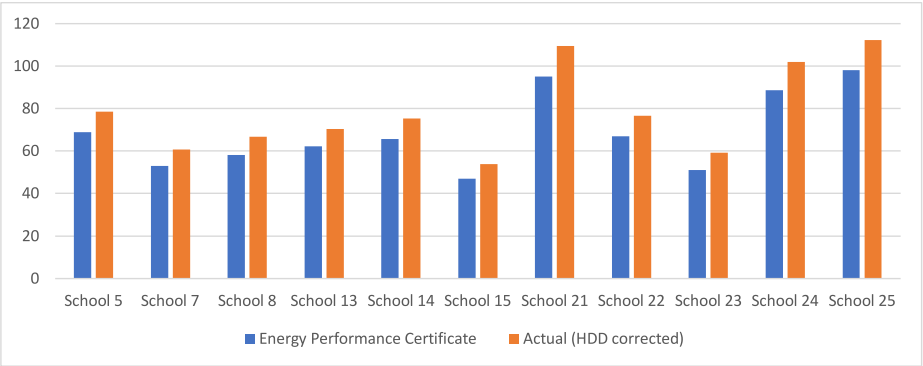


Fig. 3. Energy consumption comparison between EPC and actual heating consumption.

As it can be seen in the graph, the actual energy consumption differs from the one stated in the certificate in all cases, which means that schools consume on average 15 % more energy than it is stated in the EPC. The biggest difference occurred in the case of School 23, where actual consumption of energy for heating was 16 % higher than the theoretical consumption.

Overall, the data reveal that the actual energy consumption differs from the theoretical consumption, with all schools having higher actual consumption than the theoretical values, while possible reasons and solutions will be elaborated in further studies.

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