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Research paper

INDOOR ENVIRONMENTAL QUALITY IN SCHOOLS THROUGH THERMO TECHNICAL SYSTEM UPGRADES

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Abstract

Recent studies emphasize the importance of energy efficiency in public buildings, with particular attention to school facilities. While much research focuses on enhancing the thermal performance of building envelopes, it is equally crucial to analyze the indoor environment, especially thermal comfort. Since classrooms are designed for younger populations, ensuring optimal thermal conditions is essential for both well-being and productivity. Numerous studies indicate a strong correlation between thermal comfort and students' cognitive performance. This study examines the thermal comfort conditions in schools built in the first half of the 20th century. Representative model of these buildings is analyzed using energy simulations in DesignBuilder software. The research assesses thermal comfort levels and energy efficiency before and after the modernization of heating systems. Specifically, the study evaluates the replacement of traditional heating systems with heat pumps, which offer greater energy efficiency and lower environmental impact. Findings suggest that upgrading heating systems has a moderate impact on thermal comfort but significantly reduces energy consumption. The results also highlight the necessity of integrating energy-efficient solutions in school renovations to enhance indoor conditions and sustainability. Future research should further explore the interplay between modern HVAC systems, air quality, and overall indoor comfort in educational spaces. By implementing sustainable heating solutions, school buildings can provide healthier learning environments while contributing to broader energy conservation goals.

Key words: *schools, indoor environment, thermo-technical systems*

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1. INTRODUCTION

High energy consumption is one of the most serious problems facing global society today. Globally speaking, buildings are responsible for 50% of total energy consumption, which is mainly used for heating and cooling. The energy-efficient renovation of buildings is of great economic and environmental importance. If existing buildings, identified through analysis as requiring renovation, are properly retrofitted, energy consumption can be reduced by up to 90 % [1]. This involves improving the thermal characteristics of the building envelope and thermo technical systems. In this way, the so-called *Factor 10* can be achieved, which represents the enhancement of buildings with a resulting energy savings of 90 % [2].

The building's thermo technical system is a technical subsystem that includes installations, equipment, and devices for air conditioning, heating and cooling, as well as the domestic hot water (DHW) system [3].

There are many studies investigating the energy efficiency of school buildings [1], [4–9]. They mostly focus on seven key aspects of improving energy efficiency: improving the thermal envelope, HVAC systems, automation of heating, cooling, and lighting systems, maximizing the use of daylight, lighting control, use of geothermal water, and use of solar panels [10].

In 2017, the Republic of Serbia, in cooperation with the Republic of Germany, implemented an energy renovation initiative for public buildings, aiming to improve the energy efficiency of 30 to 40 school buildings. Besides reducing energy consumption, the project also aimed to improve comfort conditions in student spaces [11].

The main objective is to highlight the importance of energy renovation of a specific type of school buildings, focusing on improving thermo technical systems in existing buildings through the lens of thermal comfort in student spaces. From this main objective, the following tasks arise:

Analysis of renovation results for school buildings through dynamic simulations;

Identification, analysis, and calculation of possible interventions in thermo technical systems, particularly heating systems, to be applied to a specific type of school building in the Šumadija District.

The initial hypotheses were formed after a thorough examination of the research subject and an analysis of potential heating systems applicable to primary schools in the Šumadija District.

The main research hypothesis is:

By improving thermo technical systems and selecting appropriate heating systems, without addressing the thermal envelope of the building, it is possible to improve thermal comfort conditions in schools.

Additionally, the research is based on the following auxiliary hypotheses:

By using air-to-water heat pumps as improved systems compared to existing ones, it is possible to achieve energy savings of 20%.

The methodology established in this study and the proposed heating system improvement measures enable the identification of school types most suitable for implementing the proposed heating system in terms of energy savings and improved thermal comfort.

2. METHODOLOGY

This study is designed to proceed in three interconnected directions. The first involves a theoretical consideration of the issues related to the energy efficiency of school buildings, climatic characteristics, legislation, comfort conditions—with a particular focus on thermal comfort—and previous research concerning thermo technical systems and heating systems in school buildings in Serbia. The second direction consists of data collection and analysis of the existing condition of selected representative sample of school buildings in the Šumadija District. This building undergoes defined improvements of thermo-technical systems, specifically heating systems, without taking into account any enhancement of the building's thermal envelope. In order to achieve results and compare the existing condition of school building with the condition after the implementation of improved thermo technical systems, the third direction of the research is conducted. The comfort conditions of both the existing and improved states, as well as the energy consumption for heating, are examined.

The results are analyzed and calculated using dynamic simulations. Energy modeling and dynamic simulations of the buildings carried out by software package DesignBuilder, version 5.0.3.007.

2.1. Comfort conditions for school buildings

Comfort includes thermal conditions, visual perception, air quality, and appropriate noise levels. The concept of comfort encompasses thermal, visual (i.e., lighting), air quality, spatial, and acoustic aspects.

"Thermal comfort represents a psychological state that corresponds to a pleasant sensation of thermal conditions in the space, that is, when thermal equilibrium of the human body is achieved. The objective parameters of thermal comfort are: air temperature, mean radiant temperature of surfaces, air velocity, and air humidity" [3].

The main indicator of indoor environmental quality is the Predicted Percentage of Dissatisfied (PPD), which is determined for each category of comfort individually.

Certain standards define criteria and parameters for achieving optimal indoor environmental conditions. For each individual comfort aspect, specific standards were used during dynamic simulations:

Thermal comfort is addressed by three international standards:

SRPS EN ISO 7730 – *Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of PMV and PPD indices and local thermal criteria* [12],

ASHRAE Standard 55 [13],

CEN EN 15251 [14].

The CIBSE Guide A is a concise reference covering environmental conditions, energy efficiency, and methods of improving various types of spaces in terms of energy performance and achieving energy efficiency [15].

In Section 1.4 of the CIBSE Guide, Table 1.5 provides basic guidelines for all types of comfort as initial parameters for the design of thermotechnical systems in student spaces. Table 1 represents an excerpt from Table 1.5 of the CIBSE Guide A.

Table 1. Indoor environment for school buildings, Source: CIBSE Guide A [15]

Thermal space	Winter operational temperature and clothing level			Summer operational temperature and clothing level			Air level / Ls^{-1} per person	Light lux	Acoustic level dB
	Temp . ºC	Activity met	Clothing clo	Temp ºC	Activity met	Clothing clo			
School building									
amphi-theatre	19-21	1.4.	1.0.	21-23	1.4.	0.65	10	500	25-35
semminars	19-21	1.4.	1.0.	21-23	1.4.	0.65	10	300	25-35
classrooms	19-21	1.4.	1.0.	21-23	1.4.	0.65	10	300	25-35

3. REPRESENTATIVE MODELS OF SCHOOL BUILDINGS

The school building analyzed in terms of energy efficiency and potential measures for improving the heating system are full (eight-grade) primary schools in the Šumadija District, constructed in the first half of the 20th century. The analysis of the thermal envelope in both the existing and improved states, as well as the analysis of HVAC systems and comfort conditions in both states, was conducted through dynamic simulations. It should be noted that the thermal envelope is not treated as one of the measures for improving energy efficiency, but its analysis is essential in dynamic simulations.

The building analyzed in the study, both in their existing and improved states, belong to the type of facilities with compact layouts. This school is Category B school – buildings intended for primary education, Type I – facilities built before 1945 [16].

3.1. Dynamic Simulations

Modeling of the building in both existing and improved states in terms of thermo technical systems, as well as dynamic simulations—i.e., the analysis of thermal comfort conditions and energy consumption for heating, cooling, and lighting—was carried out using the DesignBuilder software package, version 5.03.007, with EnergyPlus 8.5, The Activity module defines the activity present within the building, based on which the number of hours or time spent in the space is determined. For both buildings, the selected module was *Teaching areas – student spaces*, with an occupancy rate of 0.55 per/m² (D1 Edu ClassRm:Occ).

The HVAC module represents the thermotechnical systems present in the building. As previously mentioned, this mainly refers to lighting and heating. In the existing state, this corresponds to the *Low Standard* module. There is no cooling system, and coal is used as the primary heating fuel. The Heating system seasonal CoP is 0.4.

3.1.1. Model S1- existing conditions

The primary school "Vuk Karadžić" in Knić, model S1, municipality of Knić, was built in 1938. The gross developed area of the school is 907.62 m². The surface area of the façade wall is 877.37 m², while the area of the openings is 244.22 m² (Figure 1).

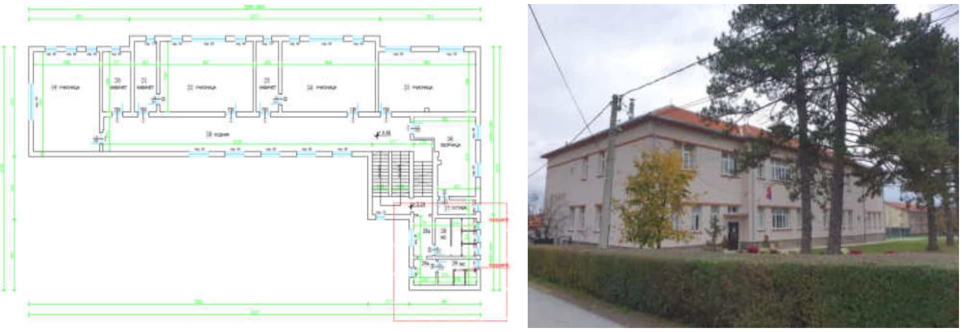

Figure 1. Model S1 School in Knić, Authors

The thermal envelope of building S1 and the maximum allowed values of the heat transfer coefficient U (W/m²K) according to the Regulation on Energy Efficiency of Buildings are presented in Table 2.

Table 2. Thermal envelope of S1

Thermal layers	Layers , δ (m)	U (W/m2K)	Umax (W/m2K)
External wall	Cement plaster 0,013 Polystirene 0,8 Brick 0,22 Gypsum plaster 0,013	0,309	0,9
Glass	Wooden frame Double glass	1,96	1,5
Ground floor	Urea formaldehid foam 0.13 Concrete 0.1 Screed 0.07 Wooden floor 0.03	0,25	0,4
Roof	Tile 0,025 Air 0,02 Wooden layer 0,005	2,9	0.2

Air conditioning, ventilation systems, and the domestic hot water preparation system are not present in the building. The original heating system consisted of wood and coal stoves. Through reconstruction and renovation of the building, a radiator heating system and an air-to-water heat pump were installed.

Simulations have shown that the annual energy consumption for heating is Qhnd 24.18 [kWh/m²a], indicating that the school, in its existing state, belongs to energy class B. The good thermal performance of the walls results in low heat losses, and the use of local stoves for heating as needed also demonstrates efficient energy consumption. Supplemental heating ensures that the school already meets the requirements for an appropriate energy class in its current state.

The heating design, including radiant and operative temperatures, as well as air and surrounding surface temperatures, is shown in Figure 2.

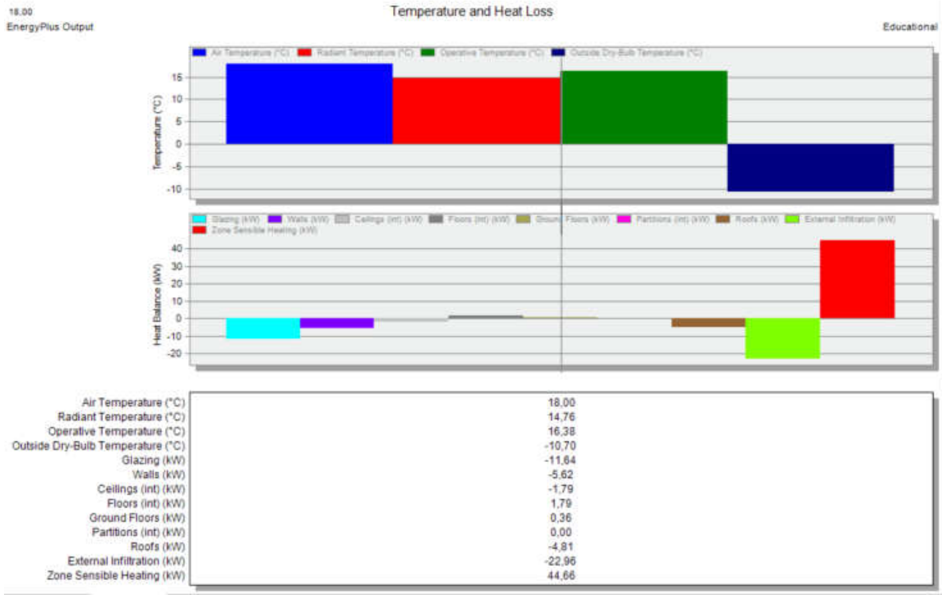

Figure 2. Heating design of S1, Design builder software

When calculating the thermal comfort values, the following comfort parameter values for student spaces were taken into account (Fig. 11). (ASHRAE 90.1)

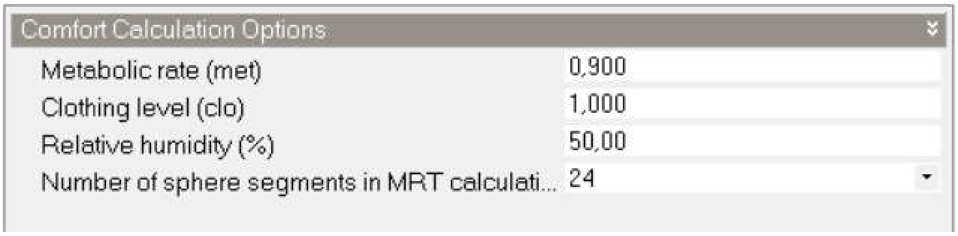

Figure 3. Comfort calculations, Design Builder, CFD Modul

In the classrooms, based on the results obtained from the simulations, the conditions for thermal comfort are met. The average radiant (comfort) temperature with the installed systems is in the range of 18.77ºC to 19.60ºC, which is considered very favorable (Fig. 4).

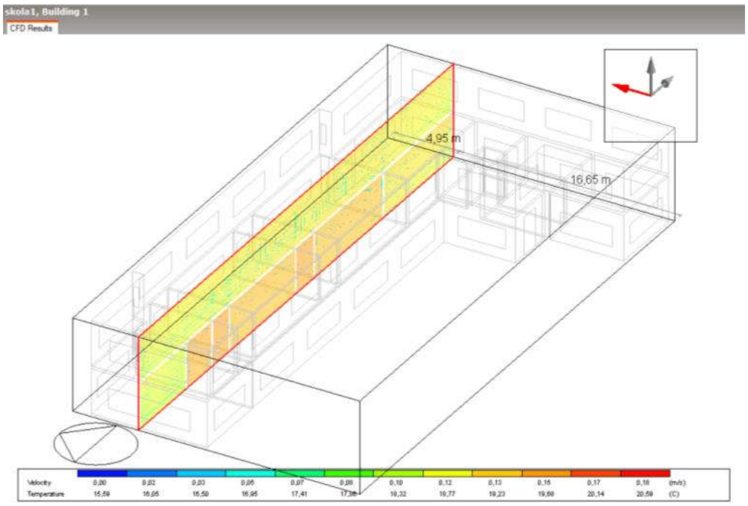

Figure 4. Comfort conditions in the classrooms of the S1, Authors

4. COMFORT CONDITIONS AFTER THERMOTECHNICAL SYSTEM UPGRADE

The building analyzed as case studies, S1 have a thermal envelope that fully complies with the parameters prescribed by the Regulation on Energy Efficiency of Buildings 61/2011 [17]. The thermal envelope was not altered in the improved state. The improvement was made by changing the heating system. In their existing state, the buildings used solid fuel stoves, burning coal and wood. The improved state involves replacing the heating system and installing air-to-water heat pumps. The modified state is represented through models S1N-

The model S1N (model S1 with improved systems) consumes Qhnd = 19.20 kWh/m²a annually, which places it in energy class A. The annual energy consumption for cooling is 94.20 kWh/m²a, which is not regulated by the Energy Efficiency Regulation of the Republic of Serbia and is considered irrelevant given the limited use of student spaces during the summer period, i.e., the summer break. The heating design is shown in Figure 5.

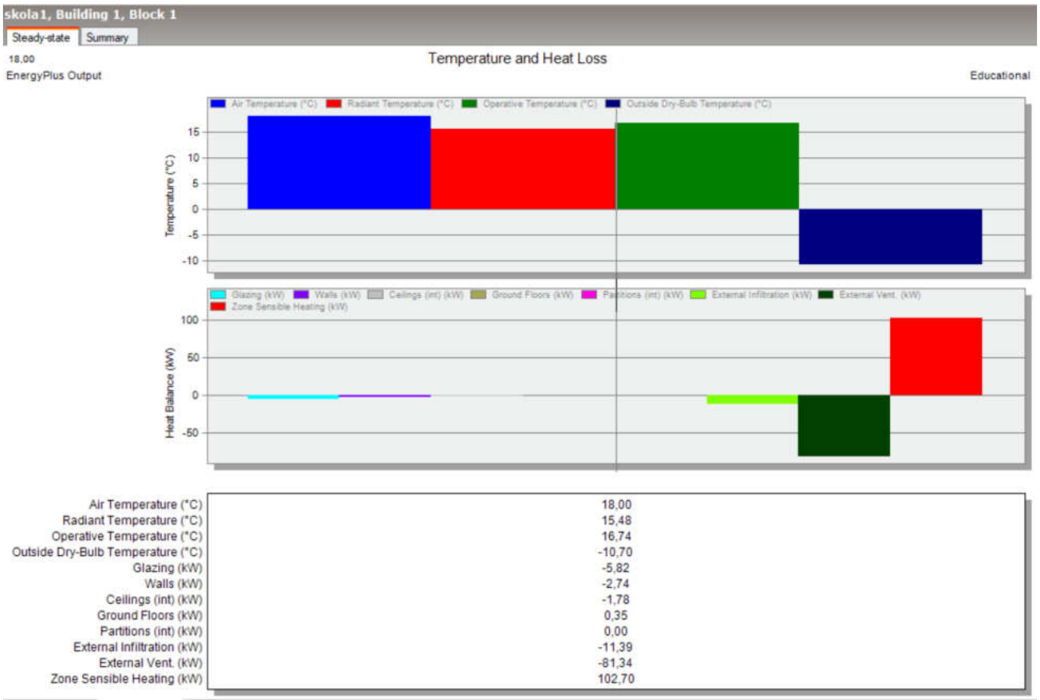

Figure 5. Design heating for S1H, Authors

4.1. Thermal comfort

PPD values for the model S1H for student spaces range from 46.17% to 98.18%. The working conditions during the winter period are acceptable, with an emphasis on colder conditions. PMV for the same spaces and the same time period ranges from -2.96 to -1.41. Additional heating is necessary for the children's workspaces. Electric heating is planned (Figure 6).

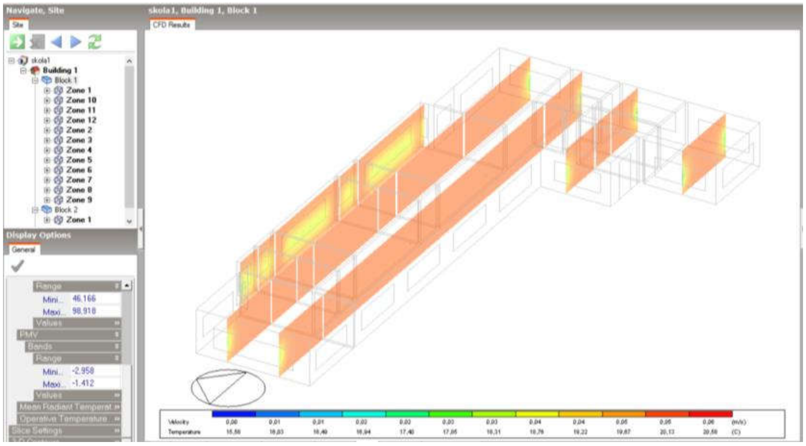

Figure 6. Thermal comfort for S1H model, Authors

4.1.1. Comparison of existing and upgraded model concerning thermal comfort

A comparative analysis of the obtained results regarding energy consumption for heating in the existing (S1) and improved states (S1N) of the school is presented in the table 3.

Table 3. Comparison of results for model S1 and S1H

Model	Heating energy Q_{hnd}[kWh/m^{2}a]
S1	24,18
S1H	19,20

Building S1, the "Vuk Karadžić" school, consumes 24.18 kWh/m²a annually for space heating, which places it in energy class B. By improving the existing heating system and installing air-to-water heat pumps, simulation results show a 20% improvement for model S1. As a result, the energy class of model S1 was improved by one level, which justifies the energy retrofit. A comparative analysis of the obtained results regarding thermal comfort for the existing and improved states of the model, S1 and S1N respectively, is presented in Table 4.

Table 4. Comfort for S1 and S1H model

Model	Comfort			
	PMV	PPD %	Radiant temperature T (ºC)	Operational temperature T (ºC)
S1	-1,96-1,47	49,03-74,95	20,00-20,00	18,83-19,96
S1H	-2,96-1,41	46,17- 98,92	13,93-20,00	14,82-20,00

Through analysis and dynamic simulations using the DesignBuilder software, specifically the CFD (Computational Fluid Dynamics) module, the results shown in Table 4 were obtained. According to SRPS EN 15251, such high PPD % values are permitted only for a limited period of time. Additional heating is required in all classrooms in the existing state According to the ASHRAE 55 standard, the acceptable PMV range is between -0.5

and +0.5, corresponding to a PPD of 10% (Table 4). Based on the results, there was no instance in which the conditions were suitable for children's occupancy. According to data from CIBSE Guide A, the operative temperature in classrooms should be in the range of 19–21 ºC. Simulations showed that the improved state leads to a less favorable indoor temperature. In the existing state, with local stoves and supplemental electric heating, the level of comfort is significantly better compared to the improved state. If we exclude the summer period and comfort conditions during the hottest months—due to the school break and adjusted activity (i.e., inactivity) in student spaces—comfort parameters were only slightly changed, with a 1% improvement resulting from the installation of the new heating systems.

8. CONCLUSION

Energy efficiency in buildings refers to the energy consumed during their lifecycle in relation to the useful output achieved, aiming to improve this ratio. Benefits of energy efficiency include improved indoor quality, reduced pollution, greater energy security, reduced emissions, and positive effects on climate change. It is especially important to evaluate comfort conditions in schools, as indoor air quality and temperature directly impact students' productivity and concentration.

This paper presents an analysis of thermal comfort conditions in student areas following improvements to the heating system. Simulations were conducted using DesignBuilder software (EnergyPlus 8.5), focusing on heating energy consumption and comfort conditions without altering the building envelope. The study analyzes representative school model (S1 and S1N) located in the Šumadija region, built before World War II. Improvement was made by replacing traditional coal/wood stoves with air-to-water heat pumps during reconstruction, and these changes were simulated without accounting for architectural upgrades to the thermal envelope.

The simulations show a 20 % improvement in heating energy consumption (from 24.18 to 19.20 kWh/m²a), upgrading the building from energy class B to A. However, thermal comfort conditions were only slightly improved (around 1%), and some classrooms still require supplementary heating.

The study concludes that while improvements in HVAC systems significantly reduce energy consumption, they offer limited enhancement of thermal comfort unless combined with improvements to the thermal envelope. Further real-world measurements and analysis of air movement and exchange are needed for a comprehensive assessment.

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