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UTICAJ KLIMATSKIH PROMJENA NA STEPEN DANE GRIJANJA I SPOLJAŠNJU PROJEKTNU TEMPERATURU

THE IMPACT OF CLIMATE CHANGE ON HEATING DEGREE DAYS AND OUTDOOR DESIGN TEMPERATURE

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Ovaj rad analizira promjene u stepen-danima i spoljašnjoj projektnoj temperaturi u različitim regionima Crne Gore tokom određenog vremenskog perioda usljed klimatskih promjena. Grijanje prostora je ključno za održavanje udobnih i bezbjednih uslova života, ali istovremeno predstavlja značajnu komponentu ukupne potrošnje energije. Glavni cilj istraživanja je da se identifikuju trendovi u stepen-danima grijanja i spoljašnjoj projektnoj temperaturi u odabranim gradovima i da se procijeni njihov uticaj na potrošnju energije i planiranje prilagođavanja klimatskim promjenama. Uprkos aktuelnim klimatskim promjenama, u posljednjih 30 godina nije izvršeno ponovno izračunavanje ovih parametara, iako oni direktno utiču na energetsko planiranje i projektovanje objekata. Zbog nepreciznih i zastarjelih vrijednosti, projektanti često prave nepotrebne greške. Rad naglašava važnost ažuriranja ovih parametara kako bi se obezbijedilo pouzdano predviđanje i razvoj održivih energetskih strategija u Crnoj Gori. Studija koristi podatke prikupljene tokom posljednjih 10 godina sa zvaničnih meteoroloških stanica u Crnoj Gori. Metode uključuju statističku obradu klimatskih podataka i poređenje sa zastarjelim referentnim vrijednostima koje se trenutno koriste u inženjerskoj praksi.

This paper analyzes the changes in degree days and outdoor design temperature across different regions of Montenegro over a defined period due to climate change. Space heating is essential for maintaining comfortable and safe living conditions, but at the same time, it represents a significant component of overall energy consumption. The main objective is to identify trends in heating degree days and outdoor design temperature in selected cities and assess their implications for energy consumption and climate adaptation planning. Despite ongoing climate change, no one did the recalculation of those parameters in the last 30 years and they affect energy planning and building design. Not being accurate enough, designers make unnecessary mistakes due to outdated values. The paper emphasizes the importance of updating these values to ensure reliable forecasting and the development of sustainable energy strategies in Montenegro. The study uses data collected over the past 10 years from official meteorological stations in Montenegro. Methods include statistical processing of climate data and comparison with outdated reference values currently used in engineering practice.

1. Introduction

1.1. The importance of research on energy consumption for heating purposes

Energy consumption for heating purposes represents one of the key factors in everyday life, both in households and in industry. Space heating is essential for maintaining comfortable and safe living conditions, but at the same time, it constitutes a significant portion of overall energy consumption. In order to optimize energy use, it is necessary to analyze the factors that influence heating demand, among which the outdoor design temperature stands out as particularly important. The outdoor design temperature is a critical parameter that determines the extent of a building's energy losses and the heating demand under specific climatic conditions. Accurate research and calculations related to this temperature enable the precise estimation of the energy required to maintain the desired indoor temperature. In this context, degree days play a critical role in accurately estimating the energy required for space heating. The higher the number of degree days, the greater the energy consumption required to maintain the desired indoor temperature. In today's society, with the increasing number of buildings and growing demands for energy efficiency, research into energy consumption for heating has become a key element in the planning, design, and maintenance of energy-efficient buildings

1.2. Contribution and aim of the paper

The aim of this paper is to investigate and analyze energy consumption for heating in Montenegro, taking into account the external design temperature and the importance of degree days. Through this analysis, factors influencing the energy efficiency of heating systems under different climatic conditions will be examined, with particular emphasis on the specific climate characteristics of Montenegro. The objective of this paper is to provide concrete calculations that can assist in optimizing energy consumption for heating in Montenegrin buildings, in order to achieve greater energy efficiency and reduce energy losses. Additionally, the goal is to highlight opportunities for improving existing methods of energy consumption calculation and to offer guidelines for further development of energy policy in this area. It will emphasize the need to revisit and update the currently used data, as its outdated nature may lead to inaccurate assessments and hinder effective planning. The results of this research may be valuable for architects, engineers in the energy sector, as well as for all those engaged in sustainability and energy efficiency issues.

2. Method

2.1. Fundamental definitions and terminology

To provide a better understanding of the subject matter, the key concepts essential for further analysis and discussion are explained.

Heating can be defined as the process of raising the temperature within a space to achieve and maintain thermal comfort, particularly during cold periods. The main purpose of heating is to ensure a pleasant indoor environment and to prevent potential damage caused by low temperatures, both to occupants and to building systems.

Thermal comfort conditions refer to a combination of physical and subjective factors that together enable an individual to feel comfortable in an enclosed space, without experiencing sensations of cold or overheating.

Heat losses represent the reduction of heat from the indoor environment as it escapes to the outside, mainly due to temperature differences between the interior and exterior. The most common are transmission losses, which occur through structural components of the building, such as walls, roof, floor, windows, and doors. Additional losses include those caused by ventilation and infiltration, resulting from air exchange with the external environment, whether intentional or unintentional. Furthermore, heat losses can occur through heating system components (e.g., uninsulated pipes) or due to improper system operation. All of these losses contribute to increased energy consumption, making their identification and reduction essential for efficient and economical heating.

Degree days are indicators used to estimate a building's energy demand during the heating season. This parameter represents how much the daily mean outdoor temperature is lower than a reference (indoor) temperature considered necessary for thermal comfort. The greater and longer the difference, the higher the heating demand and energy consumption.

Outdoor design temperature refers to the minimum outdoor air temperature used in the design of a building's heating system. It is determined based on climatic data specific to a given location, analyzing extreme temperature values over a defined historical period. Typically, the lowest average temperature recorded in the coldest month over the past ten years, along with the absolute minimum temperature during that period, are used. This allows engineers to design a heating system that can meet the building's needs under the most extreme weather conditions.

2.2. Principle of determining heating degree days

For practical applications, the following formula is used to calculate degree days (DD):

$$DD = Z * (t_i - t_{gg}) + \sum_{n=1}^{Z} (t_{gg} - t_{ad})$$

Z – number of days in heating period
t_i– average indoor temperature of the heated building
t_{gg}– threshold temperature marking the beginning and end of the heating season
t_{ad}– average daily temperature for each individual day during the heating period.

The beginning of the heating period is defined as the first instance of three consecutive days where the mean daily temperature is below the threshold temperature t_{gg}. The heating period ends when the mean daily temperature is above the threshold temperature for three consecutive days. The threshold temperature depends primarily on the function of the building (e.g., laboratories, hospitals, schools). According to [1], commonly used threshold values are 12°C, 14°C, 15°C, 16°C, 18°C, and 19°C.

2.3. Principle of determining outdoor design temperature

When determining the outdoor design temperature, the absolute minimum recorded temperature at a given location is not used, as such values are of short duration and represent extremely rare occurrences. Designing systems based on these minimums would lead to technically oversized and economically unjustifiable solutions, since the system would operate at full capacity only in exceptional cases. Instead, a method that considers more moderate yet representative climatic indicators is applied in practice. In Montenegro, the outdoor design temperature is determined based on the average temperature of the coldest month *(t_m)* and the absolute minimum temperature *(t_{min})* over a ten-year period. The relationship between these temperatures is defined by an appropriate formula taken from [1]:

$$t_s = 0,4 * t_m + 0,6 * t_{min}$$

3. Results and discussions

The analysis of the obtained results for the number of heating days and degree days across various cities in Montenegro confirms the presence of climate change, which directly affects the energy demand in the heating sector. A noticeable declining trend in both the duration of the heating season and the total number of degree days is evident in nearly all analyzed locations, indicating a rise in average outdoor temperatures during the winter months. This trend is most prominent in urban areas, such as Bar, where the number of heating days decreased from 124 to 98 (a reduction of 21%), while the value of degree days dropped by as much as 29%. A similar pattern is observed in Podgorica, with a 14.8% reduction in heating days and a 27% decrease in degree days. These changes may be partly attributed to a phenomenon where urban areas experience significantly higher temperatures than their rural surroundings, primarily due to human activities and land surface modifications. This temperature difference arises from the replacement of natural vegetation with heat-absorbing materials such as asphalt, concrete, and buildings, which store solar energy during the day and release it at night. Urban development significantly contributes to the rise in local temperatures through this effect. As cities expand and natural land surfaces are transformed into built environments, the capacity of the surface to regulate heat is reduced. The loss of green spaces and increased energy usage from transportation, buildings, and industrial activities contribute to localized warming. The concentration of infrastructure and human activity further intensifies the effect, especially in densely populated urban zones. In the northern, mountainous regions with a more continental climate, such as Pljevlja, Kolašin, and Žabljak, reductions are also observed, though with slightly less intensity. For example, Kolašin experienced a 13% decrease in degree days, while Pljevlja recorded a 10% drop. Although the heating season in these areas remains over 200 days long, the trend toward shorter and milder winters is noticeable even in these colder zones. A significant decline in Nikšić (−11.2% in heating days and −15% in degree days) also suggests that the central region of the country is not exempt from climatic shifts. Of particular interest is the case of Herceg Novi, where a slight increase in degree days was observed (+0.7%), despite a 9.2% decrease in the duration of the heating period. This may be the result of microclimatic variability, local conditions, or methodological differences in data processing. These findings suggest that the existing climatic parameters used in the design of heating and energy systems—many of which have not been updated in over 30 years—should be revised to reflect the current climate conditions. The continued use of outdated values leads to overestimated energy consumption projections, resulting in the oversizing of heating systems and fuel storage, thereby increasing construction and operational costs. This analysis provides a basis for redefining design practices and adapting energy strategies to the realities of a changing climate. Obtained values of degree days are given in Table 1, Table 2 and Table 3:

Table 1. Obtained values of degree days

Town	Degree day (new values)	Degree day (old values)	Percent (%)
Bar	829	1167	-29
Cetinje	2638	2830	-7
Herceg Novi	1021	1013	+0,7
Kolašin	3222	3698	-13
Nikšić	2298	2717	-15
Podgorica	1194	1618	-27
Pljevlja	2988	3323	-10
Ulcinj	1141	1301	-12

Table 2. Obtained values of number of heating days

Town	Heating days (new values)	Heating (old values)	Percent (%)
Bar	98	124	-21
Cetinje	201	205	-2
Herceg Novi	109	120	-9,2
Kolašin	234	244	-4,1
Nikšić	175	197	-11,2
Podgorica	121	142	-14,8
Pljevlja	210	219	-4,1
Ulcinj	111	129	-14

Table 3. Obtained values of the outdoor design temperature

Town	Outdoor design temperature (new values)	Outdoor design temperature (old values)
Bar	-1	-2
Cetinje	-14	-13
Herceg Novi	-2	-1
Kolašin	-17	-20
Nikšić	-9	-12
Podgorica	-4	-5
Pljevlja	-19	-19
Ulcinj	-2	-4

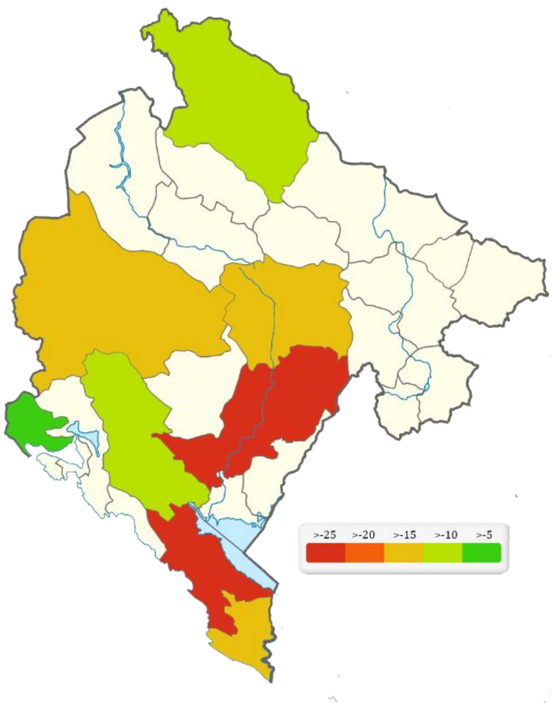

Figure 1. Percentage Change in Degree Days by Municipality

4. Case study

All calculations so far indicate that using the values from Prof. Dr. Branislav Todorović's book leads to errors in heat loss calculations and the required fuel for the heating season. Maximum heating requirements study was conducted using CYPETHERM software for a residential building in Ulcinj, comparing old and updated data. The results show a oversizing of the heating system due to outdated external temperature values.

CYPETHERM is a professional software developed by CYPE, used for HVAC design, including heat loss calculations and energy efficiency analysis, in compliance with standards such as ISO 13790 and EN 12831.

In the study, building envelope characteristics, insulation, and windows were kept identical in both cases to isolate the impact of different outdoor temperature assumptions. This ensures that differences in heat loss are due solely to environmental temperature variations, not construction differences.

A 3D model of the building was created for the analysis. The building is a residential structure with 8 apartments, an underground garage, ground floor, and four additional floors. The 3D model is presented in Figures 2 and 3:

Figure 2. Front view of the model of residential building used

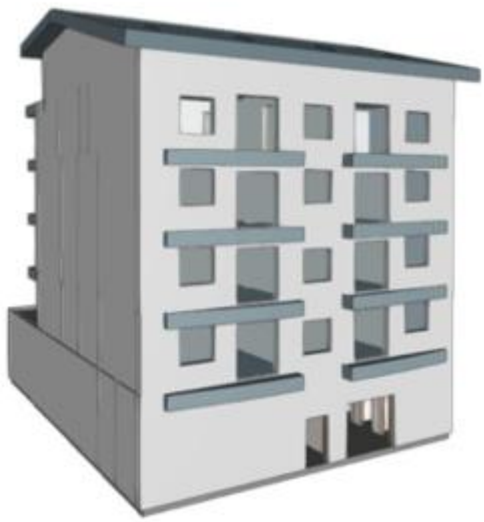

Figure 3. Back view of the model of residential building used

After performing the calculations for both scenarios, the results clearly demonstrated the impact of using updated climatic data. In the initial case, based on the older values, the total heat losses for the building were calculated to be **47,094 W.** However, when using the corrected and more accurate external temperature values, the heat losses were reduced to **43,235 W.** This comparison shows that relying on outdated data can lead to an overestimation of heating demand and, consequently, an oversized heating system.

To better understand the practical impact of using outdated versus updated climatic data, we calculated the difference in heating energy requirements between two scenarios. This results in a difference of 3,859 W, indicating an overestimation of heating needs in the first case.

This difference results in a lower initial investment—approximately €150 per kW—reducing the upfront cost by around €500 in this case.

Average energy consumption can be calculated using formula:

$$Q = \frac{HDD * 24 * Ueq * Aenv}{1000 * \eta}$$

HDD – heating degree days
U_{eq} - Equivalent heat transfer coefficient
A_{env} - Total building envelope area
η - Coefficient of Performance

For our comparison we will use both outdated and updated values of *HDD* to be able to compare values. All of the other values were kept identical. (Equivalent heat transfer coefficient is 0.71, Total building envelope area is 950 m^2, COP is 3 as we assume heat pumps are being used). After doing calculations, based on older values we got 7,025 kWh, while with updated values result was 6,161 kWh. The observed 13% difference in energy consumption suggests that the estimates provided by energy audits and certificates are not fully accurate, and that the most economically efficient energy-saving measures may vary as a result.

5. Conclusion

The conducted analysis clearly indicates a downward trend in both the number of heating days and degree days across most regions of Montenegro, confirming the impact of climate change on the country's heating energy demand. These climatic shifts, particularly evident in urban areas, emphasize the relevance of phenomena such as the Urban Heat Island effect and call for a reevaluation of traditional design parameters. The observed deviations between current climate data and outdated reference values, some of which have not been updated for over three decades, highlight the need to revise established standards for outdoor design temperatures and energy calculations. Updating these parameters is essential to ensure accurate energy planning, avoid system oversizing, and reduce unnecessary investment and operational costs. Moreover, such revisions would support the development of more sustainable and efficient heating systems adapted to Montenegro's evolving climate conditions. The findings presented in this paper serve as a foundation for further research and policy development aimed at improving the energy performance of buildings in response to current and future environmental challenges.

6. References

[1] **Todorović, B**. (2005). *Projektovanje postrojenja za centralno grejanje*. Mašinski fakultet univerziteta u Beogradu, Beograd, Serbia.
[2] *** Zavod za hidrometeorologiju i seizmologiju Crne Gore. (2015-2024). Godišnjak meteoroloških podataka za (2015-2024). godinu. Podgorica: Zavod za hidrometeorologiju i seizmologiju Crne Gore. Available on: https://www.meteo.co.me