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IMPACT OF CLIMATE CHANGE ON HEATING AND COOLING NEEDS IN CRIKVENICA AS A HEALTH TOURISM DESTINATION

Utjecaj klimatskih promjena na potrebe grijanja i hlađenja u Crikvenici kao odredištu medicinskog turizma

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Abstract: Crikvenica has had a long tradition of tourism in Croatia. In order to maintain tourism as the town's most lucrative activity, continuous investment in tourism and the auxiliary infrastructure is important - particularly medical tourism since it includes tourists with a need for special indoor and outdoor comfort. Climate changes are some of the most important reasons for infrastructure investment, since the great benefits of tourism in Crikvenica have always depended on its natural resources, mainly the pleasant climate. The influence of climate changes on internal thermal comfort during the period 1902-2016, analysed on the basis of seven derived temperature parameters, can be seen in the statistically significant trends in later start dates and earlier end dates for household heating, a decline in the energy needed for heating and an increase in the energy needed for cooling. On the basis of three temperature thresholds for four temperature parameters, heating/cooling energy consumption in poorly and highly insulated buildings is discussed, and the possibility of saving energy with the use of proper insulation is explained. In order to show the intensity of recent climate changes, seven temperature parameters' probability distributions for the period 1981-2010 are compared with the relevant distributions in the referent period 1961-1990. This comparison is made to improve the awareness of climate change risk and to help in strategic planning within the tourism industry in Crikvenica, with the intention of remaining competitive on the tourism market.

***Keywords*:** heating season start and end dates, heating and cooling degree-days, trends, probabilities, Crikvenica (Croatia)

Sažetak: Crikvenica ima dugu tradiciju u hrvatskom turizmu. U cilju održanja turizma kao najunosnije gradske aktivnosti potrebno je kontinuirano ulagati u turizam i popratnu infrastrukturu - osobito u medicinski turizam jer on uključuje turiste s posebnim potrebama u pogledu toplinskog komfora unutarnjeg i vanjskog prostora. Klimatske promjene su jedan od najvažnijih razloga za infrastrukturno ulaganje jer je oduvijek velika dobit od turizma ovisila o prirodnim izvorima, uglavnom o ugodnoj klimi. Utjecaj klimatskih promjena na toplinsku ugodnost unutarnjeg prostora u razdoblju 1902-2016., analiziran pomoću sedam izvedenih temperaturnih parametara, može se vidjeti na temelju statistički signifikantnih trendova kasnijeg početka i ranijeg završetka grijanja zgrada, opadanja energije potrebne za grijanje i porasta energije potrebne za hlađenje. Na temelju po tri temperaturna praga za četiri temperaturna parametra, raspravljena je potrošnja energije za grijanje/hlađenje u slabo i dobro izoliranim zgradama i prikazana je mogućnost uštede energije uz primjenu prikladne izolacije zgrada. U cilju prikaza intenziteta recentnih klimatskih promjena, uspoređene su razdiobe vjerojatnosti pojavljivanja za sedam temperaturnih parametara u razdoblju 1981-2010. s odgovarajućim razdiobama u referentnom razdoblju 1961-1990. Te su usporedbe provedene kako bi se poboljšala svijest o rizicima s kojima su povezane klimatske promjene i kako bi se pomoglo strateškom planiranju u turističkoj industriji u Crikvenici, s namjerom održavanja konkurentnosti na turističkom tržištu.

Ključne riječi: početak i kraj sezone grijanja, stupanj-dani grijanja i hlađenje, trendovi, vjerojatnosti, Crikvenica (Hrvatska)

1. INTRODUCTION

The tradition of organised tourism in Crikvenica dates back about 125 years. As early as at the end of the 19th century excellent conditions for the development of health and convalescence tourism were recognised in the Crikvenica area (Figure 1). Crikvenica is situated in the northern part of the Croatian Adriatic. The first tourists were attracted by the benefits of natural factors: the mild Mediterranean climate and microclimate which is also affected by the high orography of the Dinaric Alps hinterland (Penzar et al., 2001; Zaninović et al., 2008), fresh air, clean sea, sunshine and Mediterranean vegetation. At that time a number of hotels and health institutions offering various medical services started to operate. Many other types of tourism have developed in Crikvenica since, and many new tourist facilities have been opened. New tourist facilities appear continually, while many old ones are still in use.

However, the climate is changing and tourism is recognised as a highly climate-sensitive sector. One recent analysis has already shown a reduction of climate tourism potential caused by conditions too hot for outdoor activities in summer afternoons in some places along the Croatian coast (Brosy et al., 2014). Therefore in order to adapt to climate changes, new strategies should be applied in tourism, and an interdisciplinary approach is expected to be necessary. Namely, in order to prepare a cost-benefit analysis for each specific type of tourism, climatologists should be consulted about the changed climate conditions in the relevant part of the year, energy specialists should calculate the cost of energy needed for indoor cooling or heating of hotels, whilst civil engineers should determine the appropriate way and costs of adaptation or construction of hotels in order to a facilitate a comfortable indoor microclimate. Within the framework of globally detected warming, care about the indoor microclimate based on planning of heating and cooling is very important, especially for health tourism. This type of tourism is still one of the most important in Crikvenica, with tourists who are very sensitive to extreme weather conditions. Many come to Crikvenica for medical rehabilitation when suffering from respiratory organ diseases (thalassotherapy), and they need even more comfortable indoor conditions (during extreme weather conditions) than the local healthy population.

Figure 1. Location of the Crikvenica meteorological station under study (www.freeworldmaps.net).

Slika 1. Položaj analizirane meteorološke postaje Crikvenica (www.freeworldmaps.net).

This article analyses climate changes in Crikvenica on the basis of changes of temperature parameters specially derived for purposes of determining heating and cooling needs. Some analyses for the Mediterranean area (Parry et al., 2007; Spinoni et al., 2015), as well as specifically for Croatia (Cvitan and Sokol Jurkovic, 2011; Cvitan and Sokol Jurkovic, 2016), have already pointed to the rise in air temperature, decreasing the need for heating and increasing the need for cooling. The aim of this article is to show the influence of good building insulation on heating and cooling needs in Crikvenica in the period 1902-2016. Therefore, additional parameters have been included, not available in the previous studies, and the influence of insulation in the most recent climate period 1981-2010 and in the referent period 1961-1990 has been compared. The discussion focuses on the advisability of investment in tourism infrastructure, and especially in building thermal insulation, which could help Crikvenica to retain tourism as a profitable activity in future. Namely, climate change projections show a statistically significant warming in the eastern Adriatic region in the twenty-first century. The largest temperature increase is projected (for A1B greenhouse gases concentration scenario (Nakićenović et al., 2000)) for the summer and early autumn, gradually rising from +2° C in the near future to +5.5° C towards the end of the twenty-first century (Branković et al., 2013).

2. DATA AND METHODS

The requirements for the heating and cooling of indoor space are analysed on the basis of seven derived air temperature parameters. Their definitions may differ slightly in different countries, and even the input data - type of temperature (daily mean, minimum, maximum etc.), as well as the quantity and values of temperature thresholds may vary.

This study has implemented temperature parameters determined on the basis of the mean daily air temperature ($\bar{t}$) or air temperature measured at 9 p.m. (t_{21}). These are the input data from the Meteorological and Hydrological Service of Croatia (DHMZ). The mean daily temperature ($\bar{t}$) is determined from temperatures t_7, t_{14} and t_{21} measured at DHMZ stations at 7 a.m., 2 p.m., and 9 p.m., using the following equation:

$$\bar{t} = 1/4(t_7 + t_{14} + 2t_{21}) \quad (1)$$

The degree-day method applied in this study is widely used to quantify the energy demand of buildings for heating and cooling. Basically, degree-days are defined as the differences between mean daily temperatures and a base temperature (threshold). The base temperature is the outdoor temperature below/above which a building is assumed to need heating/cooling. Therefore, energy requirements for heating and cooling become minimal around base temperatures. They can be the same or different for heating and cooling. The equations for the calculation of the daily values of a heating degree-day (HDD) and a cooling degree-day (CDD) are the following:

$$HDD_i = \max(T^* - \bar{t}_i, 0) \quad (2)$$

$$CDD_i = \max(\bar{t}_i - T^{**}, 0) \quad (3)$$

where T* and T** are the base temperatures (thresholds) for HDD and CDD respectively, and $\bar{t}_i$ is the mean daily temperature on day i. Summing up the daily values of HDD_i or CDD_i over a specified period, for example, a whole year or season, gives the annual or seasonal value of HDD or CDD.

In American standards simple equations such as (1) and (2) dominate, with the same base temperatures for HDD and CDD (T* = T** = 18.3 °C, which corresponds to 65 Fahrenheit) and with the mean daily temperature determined as the average between daily minimum and maximum temperature (ASHRAE, 2001):

$$\bar{t} = (t_{min} + t_{max})/2 \quad (4)$$

The ASHRAE method (with base temperatures of 18.3° C or 18° C) for both HDD and CDD or for one of these, is used in many locations all over the world, for instance, in Canada (Wibig, 2003), Ireland (Semmler et al., 2010), Spain (Valor et al., 2001), the Netherlands (Hekkenberg et al., 2009), Australia (Australian Government - Bureau of Meteorology), and Saudi Arabia (Indraganti and Boussaa, 2017). This method was also often used in comparison with heating or cooling energy demands in various parts of the world (Sivak, 2009).

Besides the ASHRAE definition of mean daily temperature in degree-day calculation (based on maximum and minimum temperature), some countries use other equations, depending, amongst other things, on the availability of sub-daily temperature data. One of these equations is the previously mentioned (1), which is in use in Croatia. In Slovenia, on the other hand, both equations (1) and (4) are in use (ARSO, 2017). Equations for mean daily temperature are not referred in all degree-day literature.

Besides the ASHRAE base temperature, there is a long list of different base temperatures used in the literature on degree-day methodology ((2) and (3)) (Antunes Azevedo et al., 2015). This is not surprising because base temperatures should take into account the specific geographical and climatic characteristics of the region, as well as the characteristics of building construction, thermal insulation, air leakage, solar gains, and type of activity the building is used for.

Sailor and Muñoz, (1997) used a base temperature of 18.3° C to calculate degree days in

Ohio, Luisiana, and Washington, and 21 °C for Florida, to achieve the best adjustment for the energy consumption data in each state. For Israel, Beenstock et al. (1999) defined HDD by taking the base temperature of 10 °C and CDD by the base temperature of 25 °C. Büyükalaca et al. (2001) have analysed variations of annual degree-days with regard to base temperature value in 78 provinces in Turkey by using five base temperatures for HDD (14, 16, 18, 20 and 22 °C) and six base temperatures for CDD (18, 20, 22, 24, 26 and 28 °C). For the Mediterranean region, in studies of climate changes, Cartalis et al. (2001) used the threshold values of 15.5 °C for HDD and 18 °C for CDD calculations, whilst Giannakokopoulos et al. (2009) used 15 °C for the calculation of HDD and 25 °C for the calculation of CDD.

Base temperatures (thresholds) for HDD (2) are often several degrees lower than the expected indoor temperature. Therefore, some authors introduced an additional threshold to the HDD calculation, one which represents the outdoor temperature at the start, end, and resumption of heating. Yildiz et al. (2007) called it 'set point' temperature and calculated the annual HDD for Turkey for the base temperatures of 18 °C and 20 °C, summing up daily HDD_i (2) values only for the days when the mean daily temperature $\bar{t}_i$ was below the chosen 'set point' temperature of 12 °C and 15 °C. In that case, days with the daily temperature $\bar{t}_i$ below the 'set point' temperature were treated as heating days throughout the year. EUROSTAT (2017), the Statistical Office of the European Union, has also defined the method for the calculation of heating degree days by taking into consideration two thresholds; i.e., the outdoor temperature and room temperature. The recommended equations for a daily HDD_i value were:

$$HDD_i = (18\ ^\circ C - \bar{t}_i) \times d \quad \text{if } \bar{t}_i \text{ is lower than or equal to } 15\ ^\circ C \text{ (heating threshold)} \tag{5}$$

$$HDD_i = 0 \quad \text{if } \bar{t}_i \text{ is greater than } 15\ ^\circ C, \tag{6}$$

where $\bar{t}_i$ is the mean outdoor temperature ((Tmin + Tmax) / 2) over a period of d day; calculations are to be executed on a daily basis (d=1); and the temperature of 18 °C is the chosen value for room (indoor) temperature. The identical method for the calculation of HDD is now in practice in a neighbouring country, Slovenia. The same HDD method ((5) and (6)), but with the other/and other choices for values for outdoor and indoor temperature is in use (both in literature and in practice) in countries geographically close to Croatia - Germany (VDI, 1991), Switzerland (Christenson et al., 2006), Austria (Austroclim, 2011), and Slovenia (ARSO, 2017), as well as in Croatia (Cvitan and Sokol Jurkovic, 2011; Cvitan and Sokol Jurkovic, 2016), but in Croatia with equation (1) for the daily mean temperature.

Apart from the approaches described above in HDD and CDD calculations ((2), (3), (5) and (6)), which use solely the mean daily temperature ($\bar{t}_i$) and measures based on whether $\bar{t}_i$ is above or below the base temperature, there are also approaches that use different equations, depending on the relationship between the base temperature and each of the three ($\bar{t}_i$, Tmin and Tmax) daily temperatures separately. Some of these approaches use a single base temperature for both HDD and CDD, for example, 14 °C for Greece in a paper by Matzarakis and Balafoutis (2004), or a different one for each, for instance, 15.5°C for HDD and 22°C for CDD for Europe (more than 4,000 stations) in a paper by Spinoni et al. (2015).

There are no general regulations about the equations and the threshold temperatures to be used in HDD and CDD calculations in Croatia. The temperature thresholds included in degree-day definitions are usually based on the relationship between daily temperature and domestic energy demand. However, such an analysis has yet to be performed in Croatia due to a lack of daily data on domestic energy demand. Therefore, the temperature thresholds used in European countries that have more experience in calculating HDD and CDD are also used in Croatia in this study (Cvitan and Sokol Jurković, 2016). The following subsection gives the definitions and explanations of derived temperature parameters analysed in this paper.

2.1 Definitions of derived parameters

Heating degree-day (HDD; °C) and number of heating days (HD)

The value of the HDD parameter is proportional to the energy required for heating, and HD represents the number of days when indoor heating is needed. In this study the whole heating season is analysed, with the first part taking place in the period January-April and the second in the period October-December of the same year. The following equation is used to calculate a heating degree-day:

$$\begin{aligned} &HDD = \sum_{i=1}^{n} m_i (T_{IN} - \bar{t}_i); \\ &m_i = 1 \ \ if \ \ \bar{t}_i < T_{OH.} \\ &m_i = 0 \ \ if \ \ \bar{t}_i \geq T_{OH.} \end{aligned} \tag{7}$$

where $\bar{t}_i$ (°C) is the mean daily outdoor temperature of a particular day (i) over a period of *n* days, T_{IN}(°C) is the desired indoor temperature, and T_{OH}(°C) is the outdoor temperature threshold. This study uses T_{IN}=20 °C and the following three temperature threshold values for outdoor air temperature T_{OH} = 10, 12, and 15° C. Low T_{OH} values are normally used for highly insulated buildings and high TOH values are normally used for poorly insulated buildings. Basically, in highly insulated buildings the need for heating only appears in colder weather, while in poorly insulated ones it appears in less cold weather as well. The choice of several T_{OH} values is better for the purposes of this paper, because it indirectly includes a greater variety of building insulations, as well as many different users and purposes of indoor space in Crikvenica (e.g. the local population, tourists, risk groups - the retired and the ill, children, etc.).

It is also worth bearing in mind that there are 212 days (n) days in the heating season under consideration (n=31(January)+ 28(February)+ 31(March)+ 30(April)+ 31(October)+ 30(November)+ 31(December)=212 days), and that a heating day is a day when the mean daily temperature is below T_{OH}. Therefore, all the days in the heating season should not be heating days, and moreover, the total number of heating days (HD) is generally lower than the number of days (n) in heating season.

Start (SD) and end (ED) dates for building heating system and duration of heating (DH)

Depending on the assessment of weather conditions in a particular year, the heating season start and end dates may differ from one year to another. In reality, these dates can appear even before or after the heating season as defined above. The following definitions of these dates reflect Croatian practice.

The SD is the date of the fourth day in a first series of days (after August) with the air temperature at 9 p.m. lower or equal to 12 °C. If such a day appears before 15 September, the SD for that year is taken to be 15 September.

The ED is the date of the third day in a last series of days (before 15 May) with the air temperature at 9 p.m. higher than 12 °C. If such a day appears after 15 May, the ED for that year is taken to be 15 May.

The DH for a particular year is defined as the sum of days between 1 January and ED and between SD and 31 December over the same year.

The start and end dates of the cooling season are not yet defined in Croatia. Namely, there are still many more regulations for heating than for cooling.

Cooling degree-day (CDD; °C) and number of cooling days (CD)

The value of the CDD parameter is proportional to the energy required for cooling, and CD represents the number of days when indoor cooling is needed. In this study the whole cooling season is analysed, i.e. the period June-September. The following equation is used to calculate a cooling degree-day CDD:

$$\begin{aligned} &CDD = \sum_{i=1}^{n} m_i (\bar{t}_i - T_{OC}); \\ &m_i = 1 \ \ if \ \ \bar{t}_i > T_{OC.} \\ &m_i = 0 \ \ if \ \ \bar{t}_i \leq T_{OC} \end{aligned} \tag{8}$$

where $\bar{t}_i$ (°C) is the mean outdoor daily temperature of a particular day over a period of *n* days, and T_{OC}(°C) is the outdoor temperature threshold. A cooling day is a day when the mean daily temperature $\overline{t}_i$ is above T_{OC}. This study uses the following three temperature threshold values for outdoor air temperature T_{OH} = 18, 21, and 23 °C. Low T_{OC} values are normally used for poorly insulated buildings and high T_{OC} values are normally used for highly insulated buildings. Basically, in poorly insulated buildings the need for cooling is already present in less warm weather, while in highly insulated ones it only appears in warmer weather. In addition to the applied T_{OH} value, the applied T_{OC} value also depends on the type of use and users of the indoor space.

The degree-day method assumes a linear relationship between energy demand and the degrees below (above) the heating (cooling) threshold (Cox et al., 2015). According to the formulas (7) and (8), high/low values of HDD and CDD parameters point to the high/low demand for heating and cooling energy. However, because of somewhat different formulas for HDD (two temperature thresholds: T_{OH} and T_{IN}) and for CDD (one threshold: T_{OC}), the values of these two parameters are not comparable. It is important to note that the desired indoor temperature (T_{IN}) is usually defined for the heating season, while in the cooling season it is only recommended that the indoor temperature be no more than about 5 °C lower than the outdoor temperature on days when cooling is needed.

2.2 Statistical methods

Temporal variations of all seven described parameters (HDD, HD, SD, ED, DH, CDD, and CD) during the period 1902-2016 are expressed as deviations from the related mean values in the period 1961-1990 (the referent period for the "present" climate). The deviations can be treated as deviations from normal values since, according to the World Meteorological Organization Technical Regulations, data gathered over the 30-year period from 1961 to 1990 are used to define the latest global norms (WMO, 2016). Tendencies of increases and decreases of the seven parameter values over a 115-year period are shown by related fitted linear trends. Statistical significances of trends were tested using the nonparametric Mann-Kendall rank test, with the significance level of 0.05 (Mitchell et al., 1966).

A detailed insight into the different occurrences of specific values over the two 30-year climate periods is also provided for all parameters. For that purpose a comparison is made between the period 1981-2010 (the recent climate period) and the referent climate period 1961-1990 (also called the control period). Empirical relative cumulative distributions are shown for all seven parameters in both periods. Additionally, seasonal cycles of the monthly means of four parameters have also been analysed for these two periods.

Differences between the 1961-1990 and 1981-2010 frequency distributions and seasonal cycles are checked for statistical significance (Wilks, 2006). Frequency distributions in two thirty-year periods of seven parameters (30 samples; 15 pairs) were first tested for normality using the Shapiro-Wilk W test. Among the thirty samples, only four from the 1981-2010 period were not normally distributed. Differences between distributions of approximately normally distributed pairs are tested using the F-test (test for comparison between variances) and T-test (test for comparison between means). Differences between frequency distributions of four pairs, each with only the 1981-2010 sample not normally distributed, are checked for statistical significance using the Mann-Whitney Test for independent samples - an alternative non-parametric version of the T-test for two independent populations. Statistical significances of differences between seasonal cycles in 1961-1990 and 1981-2010 are tested by means of the Wilcoxon Signed-Rank Test for Paired Samples.

3. RESULTS

Heating degree-day

The results for seasonal HDDs show decreasing trends for all three temperature thresholds T_{OH} in Crikvenica during the period 1902-2016 (Figure 2). During the period 1902-2010 the decrease ranges from -179.2 °C/100 years (T_{OH}=15 °C) to -213.9 °C/100 years (T_{OH}=12 °C). In a period which is only six years longer (1902-2016), the corresponding trend magnitudes are 23-31% greater (Table 1). Both decreases are statistically significant and undoubtedly financially convenient since they are connected with the seasonal decrease of heating energy demand, which is (over a century) as high as the average amount of heating energy demand for one whole month (e.g. November in the recent period) (Figure 3).

In comparison with the referent period, the mean seasonal HDD in the period 1981-2010 is around 5% lower (Table 1), with lower mean HDD contributions for almost all months during the heating season (Figure 3). The differences between the seasonal cycles of mean monthly heating degree-days from the two periods for the two higher considered T_{OH} values are statistically significant (Table 2).

Cumulative distributions of seasonal HDD depend significantly on the threshold T_{OH} in both 30-year periods, indicating that building insulation (related to the chosen threshold values) essentially determines heating energy consumption. The greatest HDD values for the lowest threshold coincide with the lowest values for the highest T_{OH} threshold in both periods. These are the values of 1900 °C -1950 °C in the control period, and the values of 1750 °C - 1850 °C in the recent period. This means that the best insulated buildings needed as much energy in the coldest conditions as the buildings with the poorest insulation in the least cold conditions.

Seasonal HDD cumulative frequencies for the recent period (Figure 3, bottom left) are in the lower-value interval compared to the referent period (Figure 3, top left). That is accordance with the globally and locally detected climate change, i.e., warming. In normal (interval 25-75 percentile) and less cold conditions (interval 0-25 percentile) HDD values fall within the broader range, while in colder conditions (interval 75-100 percentile) they are less dispersed in the recent than in the referent period. The lower HDD dispersion in cold conditions in the recent than in the referent period reflects the negative trend of the number of cold days and nights (cold temperature indices), detected all over Croatia, which also show warming (MZOIP, 2014). A statistically significant difference between seasonal HDD frequency distributions in the two periods is detected only in the case of T_{OH}=12 °C (Table 2).

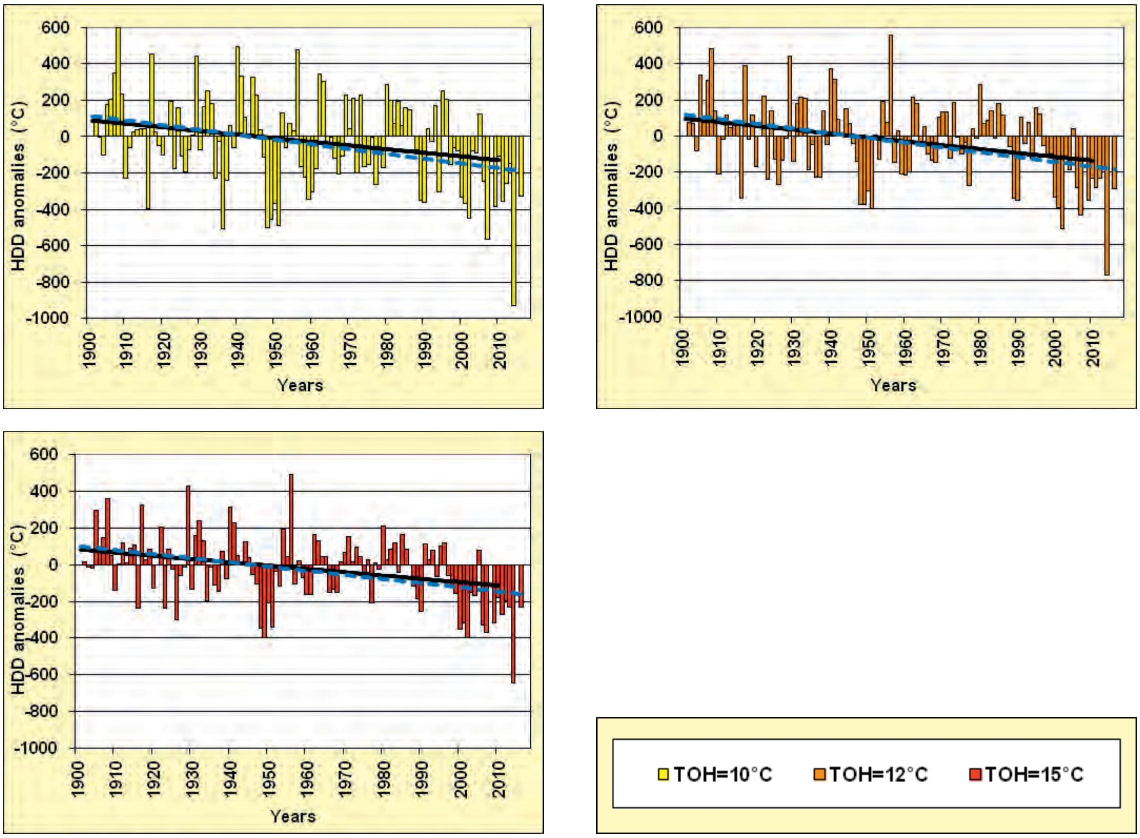

Figure 2. Anomalies of seasonal heating degree-days (HDD) for three temperature threshold values T_{OH} in the period 1902-2016, relative to 1961-1990 mean HDDs, and linear trends for 1902-2010 (solid line) and 1902-2016 (dotted line) periods.

Slika 2. Anomalije sezonskog stupanj-dana grijanja (HDD) za tri vrijednosti temperaturnog praga T_{OH} u razdoblju 1902-2016., relativno u odnosu na pripadni srednji HDD iz razdoblja 1961-1990., i linearni trendovi za razdoblja 1902-2010. (puna linija) i 1902-2016 (crtkana linija).

Table 1. Mean value and trend of seasonal heating degree-days (HDD) for three temperature threshold values T_{OH} in two periods each.

Tablica 1. Srednja vrijednost i trend sezonskog stupanj-dana grijanja (HDD) za tri vrijednosti temperaturnog praga T_{OH} u po dva razdoblja.

HDD	Mean (°C)		Trend (°C/100 years)	
	1961–1990	1981–2010	1902–2010	1902–2016
T_{OH}=10°C	1585.1	1499.1	-200.3	-262.6
T_{OH}=12°C	1897.6	1791.6	-213.8	-262.8
T_{OH}=15°C	2156.9	2065.0	-179.2	-224.8

* All trends are statistically significant according to the Mann-Kendall test (level 0.05).

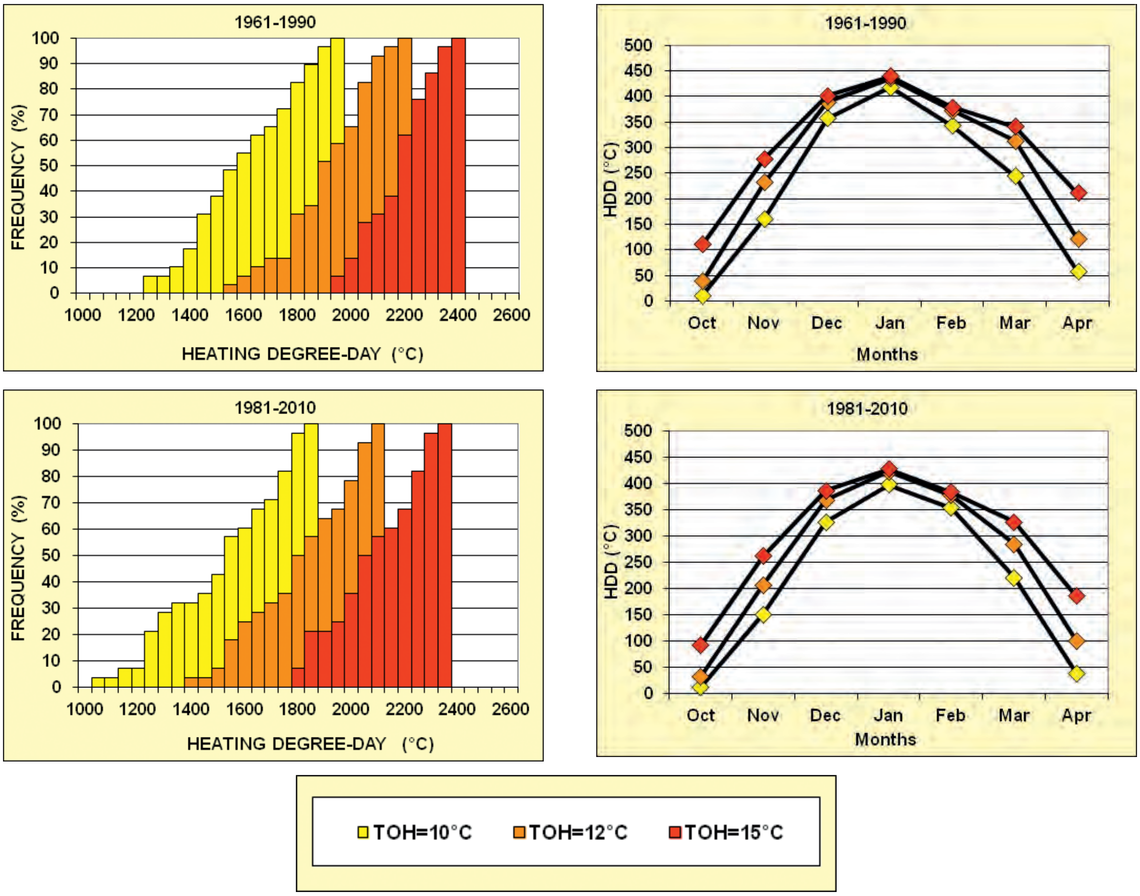

Figure 3. Cumulative relative frequency distributions of seasonal heating degree-days (left) and seasonal cycles of mean monthly heating degree-days (HDD) (right) for three temperature threshold values T_{OH} in two periods: 1961-1990 and 1981-2010.

Slika 3. Razdiobe kumulativnih relativnih učestalosti sezonskih stupanj-dana grijanja (lijevo) i sezonski hodovi srednjih mjesečnih stupanj-dana grijanja (HDD) (desno) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja 1961-1990. i 1981-2010.

Table 2. Statistically significant (S) and non-significant (NS) differences between a) frequency distributions of seasonal heating degree-days and b) seasonal cycles of mean monthly heating degree-days (HDD) for three temperature threshold values T_{OH} in two periods: 1961-1990 and 1981-2010. (The asterisk (*) symbol indicates that the differences between the frequency distributions in the two periods are tested by a nonparametric test)

Tablica 2. Statistički značajne razlike (S) i razlike koje nisu značajne (NS) između a) razdioba učestalosti sezonskog stupanj-dana grijanja i b) sezonskih hodova srednjih mjesečnih stupanj-dana grijanja (HDD) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja: 1961-1990. i 1981-2010. (Zvjezdica (*) označava da je testiranje razlika između razdioba učestalosti u dva razdoblja provedeno neparametarskim testom.)

T_{OH} (°C)	**HDD distribution**	**HDD cycle**
10	NS	NS
12	S	S
15	NS*	S

Number of heating days

During the analysed 115-year period the number of seasonal heating days has decreased gradually (Figure 4). The magnitude of the secular trend is the largest when T_{OH} is smallest, and it is the smallest for the largest T_{OH}. Depending on the temperature threshold value T_{OH}, the magnitude of the secular decreasing trend (Table 3) amounts to between 4 and 10% (in the period 1902-2010) and between 5 and 13% (in the period 1902-2016) of the mean seasonal number of heating days in the referent period. The trends in both periods are statistically significant.

In the recent period a smaller average frequency of seasonal heating days has been detected than in the referent period (Table 3), with a larger decrease in the average frequency of monthly heating days in November, March and April than in the other four months (Figure 5, right panels). Seasonal cycles of mean monthly number of heating days from the two periods differ more between themselves in cases of T_{OH} values of 12 °C and 15 °C (also statistically significant) than in the case of T_{OH}=10 °C (statistically non-significant) (Table 4).

In the recent and referent 30-year periods the HD distributions are more dependent on the threshold T_{OH} than the HDD distributions shown in Figure 3. Namely, in contrast to HDD, the HD distributions for the lowest and highest T_{OH} do not overlap (Figure 5, left panels).

In the recent period more seasons with very few heating days have been noted than in the referent period, and even some of the less cold seasons (interval 0-25 percentile) with fewer heating days than ever in the referent period have been found for all three T_{OH} values (Figure 5). Additionally, for T_{OH} of 12 °C and 15 °C, the coldest seasons (interval 75-100 percentile) with HD equalling the highest figures recorded in the referent period (166-175 days for T_{OH} of 12 °C; 201-215 days for T_{OH} of 15 °C) never appeared in the recent period. Only in the case of HD frequency distributions for T_{OH} of 12 °C and 15 °C have statistically significant differences been detected between the two periods (Table 4).

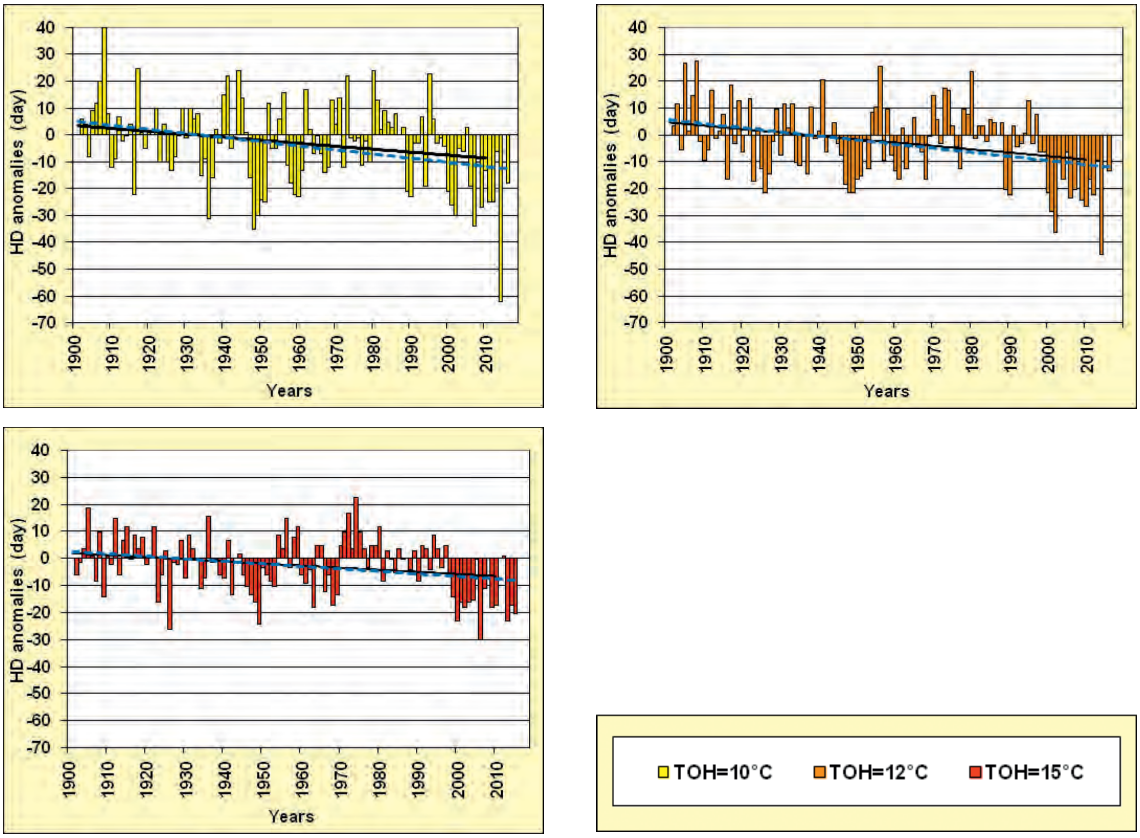

Figure 4. Anomalies in the seasonal number of heating days (HD) for three temperature threshold values T_{OH} in the period 1902-2016, relative to 1961-1990 mean HDs, and linear trends for 1902-2010 (solid line) and 1902-2016 (dotted line) periods.

Slika 4. Anomalije sezonskog broja dana grijanja (HD) za tri vrijednosti temperaturnog praga T_{OH} u razdoblju 1902-2016., relativno u odnosu na pripadni srednji HD iz razdoblja 1961-1990., i linearni trendovi za razdoblja 1902-2010. (puna linija) i 1902-2016 (crtkana linija).

Table 3. Mean value and trend of seasonal number of heating days (HD) for three temperature threshold values T_{OH} in two periods each.

Tablica 3. Srednja vrijednost i trend sezonskog broja dana grijanja (HD) za tri vrijednosti temperaturnog praga T_{OH} u po dva razdoblja.

HD	**Mean (day)**		**Trend (day/100 years)**	
	1961–1990	**1981–2010**	**1902–2010**	**1902–2016**
T_{OH}=10°C	116.1	109.7	-11.1	-15.3
T_{OH}=12°C	150.5	141.9	-12.5	-15.2
T_{OH}=15°C	189.3	182.6	-7.7	-9.3

* All trends are statistically significant according to the Mann-Kendall test (level 0.05).

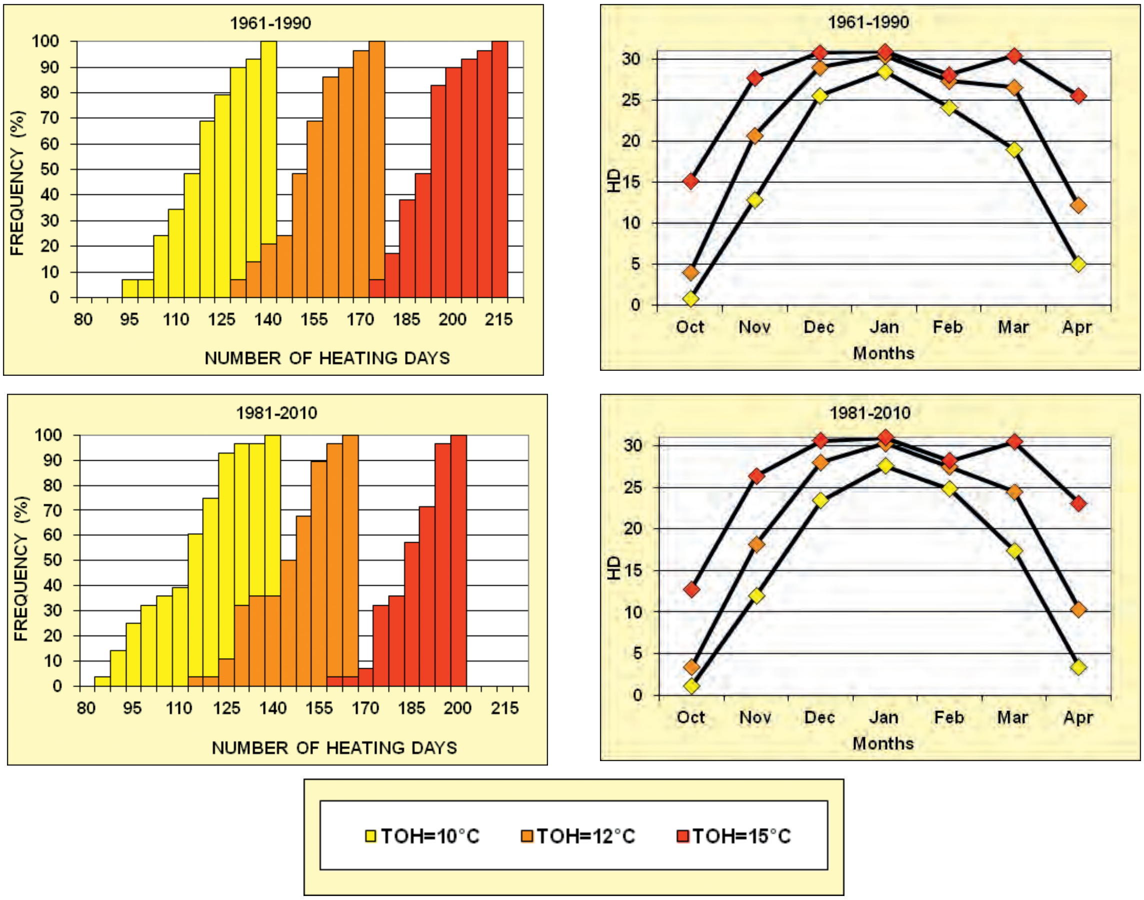

Figure 5. Cumulative relative frequency distributions of the seasonal number of heating days (left) and seasonal cycles of the mean monthly number of heating days (HD) (right) for three temperature threshold values T_{OH} in two periods: 1961-1990 and 1981-2010.

Slika 5. Razdiobe kumulativnih relativnih učestalosti sezonskih brojeva dana grijanja (lijevo) i sezonski hodovi srednjih mjesečnih brojeva dana grijanja (HD) (desno) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja 1961-1990. i 1981-2010.

Table 4. Statistically significant (S) and non-significant (NS) differences between a) frequency distributions of the seasonal number of heating days and b) seasonal cycles of the mean monthly number of heating days (HD) for three temperature threshold values T_{OH} in two periods: 1961-1990 and 1981-2010.

Tablica 4. Statistički značajne razlike (S) i razlike koje nisu značajne (NS) između a) razdioba učestalosti sezonskog broja dana grijanja i b) sezonskih hodova srednjih mjesečnih brojeva dana grijanja (HD) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja: 1961-1990. i 1981-2010.

T_{OH} (°C)	HDD distribution	HDD cycle
10	NS	NS
12	S	S
15	S	S

Start and end dates for building heating systems and duration of heating

In the both analysed periods, 109 and 115 years long, building heating systems start dates (SD) shifted towards later dates by about 9 days/100 years. End dates (ED) shifted towards earlier dates by about -8 days/100 years in the period 1902-2010 and about -10 days/100 years in the period 1902-2016. Therefore the duration of the heating season (DH) shows a decreasing trend of about -15 days/100 years in the shorter period, and of about -18 days/100 years in the six-year-longer period (Figure 6 and Table 5). Trends for all three parameters are statistically significant in both the 109- and the 115-year period (Table 5).

Distributions of heating start dates do not differ much in the two analysed thirty-year long periods (Figure 7) and the differences between them are not statistically significant either (Table 6). The mean SD is 2 November in both periods (Table 5). However, a somewhat increased date range can be seen in the recent compared to the referent period (about two days longer at both sides of the range). From the most frequent start dates, with the cumulative frequency of 25-75%, the earliest start dates (interval 0-25 percentile) are more dissipated than the latest dates (interval 75-100 percentile) in both periods. As this means that in both periods heating sometimes started much earlier than usual, an unfavourable local feature is reflected both from an organisational and financial point of view. However, start dates much earlier than usual were very rare.

At first sight, distributions of heating end dates are considerably different in the two analysed periods (Figure 7). A statistical analysis has confirmed their differences to be statistically significant (Table 6). The mean ED is 30 April in the referent period, while it is 22 April in the recent period (Table 5). Compared with the referent period, the recent period saw more heating end dates appearing much earlier. Therefore, for instance, the probability that heating would be needed after 1 May was 50% in the referent, but only 10% in the recent period.

The mean duration of the heating was not much shorter in the recent period than in the referent period (Table 5). Both periods, and especially the referent period, include a longer interval for 75-100 percentiles than for 0-25 percentiles (Figure 7). This means that the energy savings caused by the shortest DH were significantly lower than the energy expenditure caused by the longest DH (in both cases compared with average values). From a statistical point of view, the differences between DH distributions in the periods 1961-1990 and 1981-2010 are not significant (Table 6).

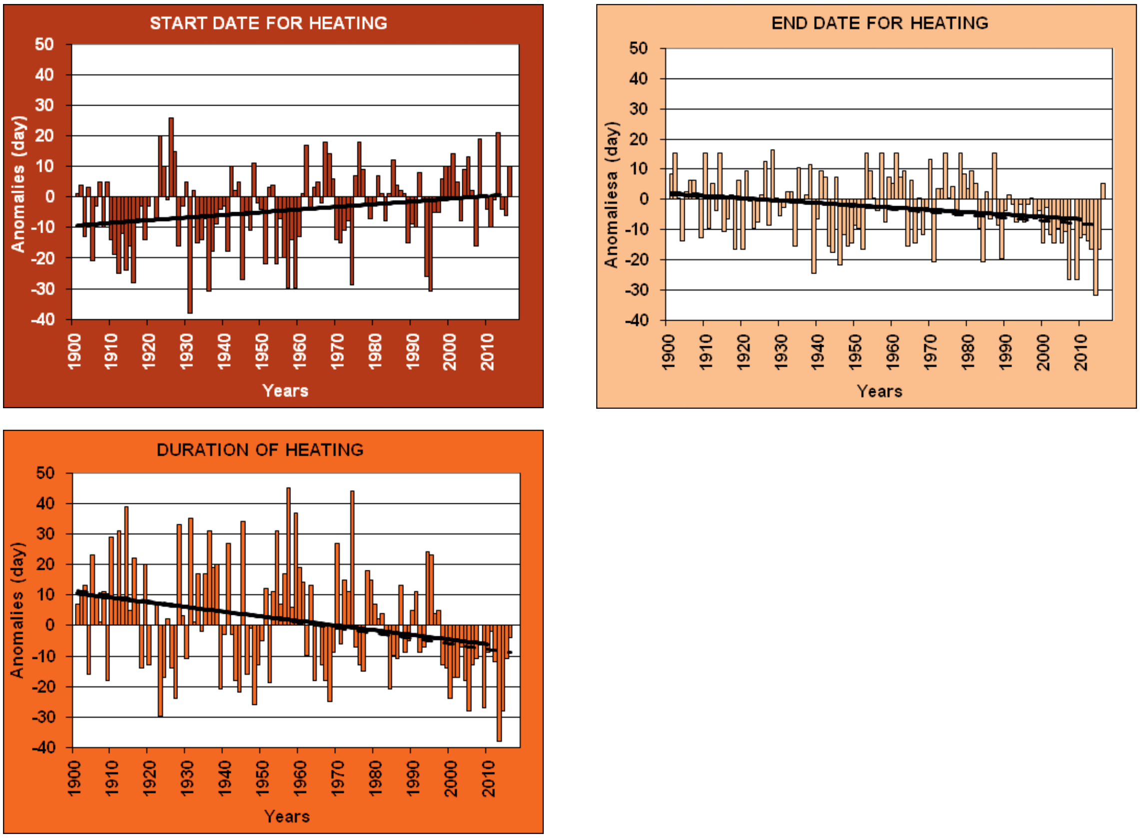

Figure 6. Anomalies of start (SD) and end dates (ED) for building heating systems and duration of heating (DH) in the period 1902-2016, relative to 1961-1990 mean SD, ED and DH, as well as related linear trends for the 1902-2010 (solid line) and 1902-2016 (dotted line) periods.

Slika 6. Anomalije datuma početka (SD) i datuma kraja (ED) grijanja zgrada, te trajanja grijanja (DH),u razdoblju 1902-2016. , relativno u odnosu na pripadne srednje SD, ED i DH iz razdoblja 1961-1990., kao i linearni trendovi za razdoblja 1902-2010. (puna linija) i 1902-2016 (crtkana linija).

Table 5. Mean date/day and trend of start (SD) and end dates (ED) for building heating systems and duration of heating (DH) in two periods each.

Tablica 5. Srednji datum/broj dana i trend početka (SD) i kraja (ED) grijanja zgrada, te trajanja grijanja (DH) u po dva razdoblja

HD	**Mean (date or day)**		**Trend (day/100 years)**	
	1961–1990	**1981–2010**	**1902–2010**	**1902–2016**
SD (date)	2nd November	2nd November	8.8	9.1
ED (date)	30th April	22nd April	-7.6	-9.5
DH (day)	179.9	173.8	-15.2	-17.6

* All trends are statistically significant according to the Mann-Kendall test (level 0.05).

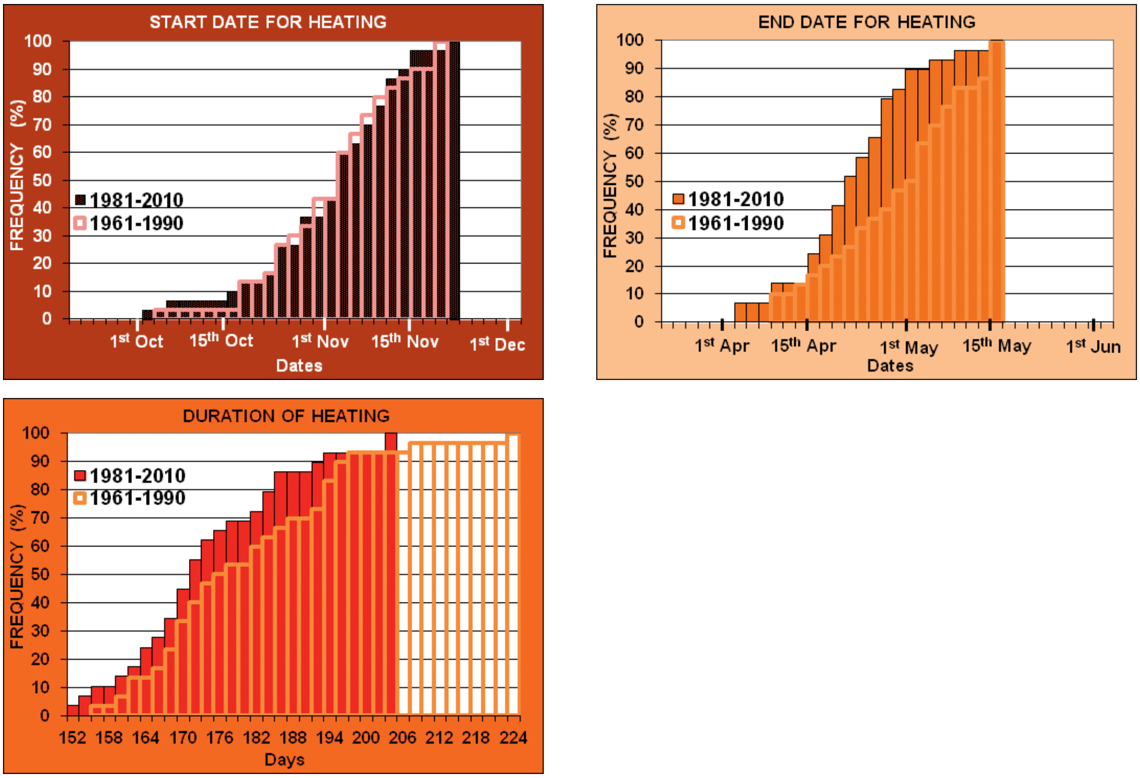

Figure 7. Cumulative relative frequency distributions of start (SD) and end dates (ED) for building heating systems and duration of heating (DH) in two periods: 1961-1990 and 1981-2010.

Slika 7. Razdiobe kumulativnih relativnih učestalosti datuma početka (SD) i datuma kraja grijanja (ED), te trajanja grijanja (DH) u dva razdoblja 1961-1990. i 1981-2010.

Table 6. Statistically significant (S) and non-significant (NS) differences between frequency distributions of start (SD) and end dates (ED) for building heating systems and duration of heating (DH) in two periods: 1961-1990 and 1981-2010. (The asterisk (*) symbol indicates that the differences between the frequency distributions in the two periods are tested by a nonparametric test.)

Tablica 6. Statistički značajne razlike (S) i razlike koje nisu značajne (NS) između razdioba učestalosti datuma početka (SD) i datuma kraja grijanja (ED), te trajanja grijanja (DH) u dva razdoblja: 1961-1990. i 1981-2010. (Zvjezdica (*) označava da je testiranje razlika između razdioba učestalosti u dva razdoblja provedeno neparametarskim testom.)

Parameter	Distribution
SD	NS
ED	S
DH	NS*

Cooling degree-day

During the periods 1902-2010 and 1902-2016 the seasonal cooling degree-day increased gradually, with growth almost twice as fast in the case of poorly insulated buildings (134 °C/100 years; 162 °C/100 years) compared with highly insulated ones (73 °C/100 years; 88°C/100 years) (Figure 8, Table 7). However, in comparison with mean seasonal CDD values in the period 1961-1990, the magnitudes of secular trends represent an increase in related mean CDD from 28% (1902-2010) to 35% (1902-2016) in the case of poor insulation, and from 96% (1902-2010) to 116% (1902-2016) in the case of high insulation (Table 7). The increasing CDD trends are statistically significant in both the 109- and the 115-year period. They indicate the financially unfavourable fact of an increasing need for cooling energy.

The mean seasonal CDD in the period 1981-2010 is 27% (T_{OC} = 18 °C) -84% (T_{OC} = 23 °C) higher than in the referent period (Table 7). The differences in the mean monthly CDD between the two periods are bigger during the three summer months (June, July, August) than over May and September (Figure 9, right panels). The differences between the seasonal cycles of mean monthly cooling degree-days in the two thirty-year periods are statistically significant for all three T_{OC} values (Table 8).

The lowest seasonal CDD values are considered the same for all thresholds in both 30-year periods, but their frequency is much lower in the recent period than in the referent period. In contrast, the highest CDD values (which are not very frequent in either period) are between 1.5 (for T_{OC} = 18 °C) and 2.5 (for T_{OC} = 23 °C) times larger in the warmer, recent period than in the colder, referent period (Figure 9). Such evident differences between seasonal CDD frequency distributions in the two periods have also been confirmed to be statistically significant (Table 8). Because the overall positive trend in annual air temperatures in Croatia is mainly caused by the significant positive summer trends (MZOIP, 2014), the CDD parameter shows, even more clearly than the HDD parameter, the warming effected by climate change.

The cumulative distributions of seasonal CDD show considerable differences for the three chosen threshold values (T_{OC}), especially in the referent period 1961-1990 (Figure 9, left). In that period the CDD distribution for the lowest chosen T_{OC} does not overlap with distributions for the other two chosen T_{OC} values. This indicates that the amount of energy needed for cooling was considerably greater in the case of poorly insulated buildings than the better insulated ones. In cases of identical warmth, four times more energy was necessary for cooling poorly insulated buildings (CDD=600 °C) compared with the highest chosen insulation (CDD=150 °C).

In the warmest cases of the period 1981-2010, the best insulated buildings would have enabled the consumption of less than half the amount of cooling energy (CDD=360 °C) than when using the poorest insulation (CDD=930 °C). Therefore, better insulated buildings could have enabled even greater energy savings in the recent than in the referent period.

Number of cooling days

An increasing trend in the seasonal number of cooling days has been detected for all three temperature threshold values T_{OC} in the period 1902-2010, as well as in the period 1902-2016 (Figure 10). As opposed to CDD trends, CD trends are highest (19 days/100 years and 22 days/100 years) for the largest chosen T_{OC} threshold and lowest (8 days/100 years and 10 days/100 years) for the lowest T_{OC} threshold (Table 9). Trend magnitudes range from 7% (1902-2010) and 9% (1902-2016) for T_{OC}=18 °C to 48% (1902-2010) and 56% (1902-2016) for T_{OC}=23 °C, of the related mean CD in the referent period.

Similarly to the mean seasonal CDD, mean seasonal CD is also greater in the period 1981-2010 than in the referent period (Table 9), and also with the largest differences in mean monthly CD frequencies between the two periods over the three summer months (Figure 11). Seasonal CD is 8% (T_{OC} = 18°C) - 42% (T_{OC} = 23 °C) greater in 1981-2010 than in 1961-1990. The differences between seasonal cycles of mean monthly number of cooling days in the two periods are statistically significant for all three chosen T_{OC} values (Table 10).

The empirical cumulative distribution in the referent period is more dependent on the T_{OC}

temperature threshold value than that in the recent period (Figure 11). In other words, in better insulated houses (compared to poorly insulated houses) cooling was needed less often during the referent than during the recent period. This point to the reduced effectiveness of the analysed thermal insulations in the recent period, which is warmer than referent period. However, the effectiveness is still evident. Namely, in both periods it is evident that in the warmest conditions the need for cooling appeared more frequently in poorly (T_{OC}=18 °C) insulated buildings (up to 130 days in the referent and up to 150 days in the recent period) than in highly (T_{OC}=23 °C) insulated ones (up to 60 days in the referent and up to 90 days in the recent period); i.e., in around 70 days more in the referent and in around 60 days more in the recent period.

For the warmest conditions, great differences in the number of CDs between the referent and the recent period have been detected; i.e., between around 15% (T_{OC}=18 °C) and 50% (T_{OC}=23 °C) more days with the need for cooling under the warmest conditions are found in the recent than in the earlier period (Figure 11). Differences between CD frequency distributions in two thirty year periods are statistically significant for all T_{OC} values (Table 10).

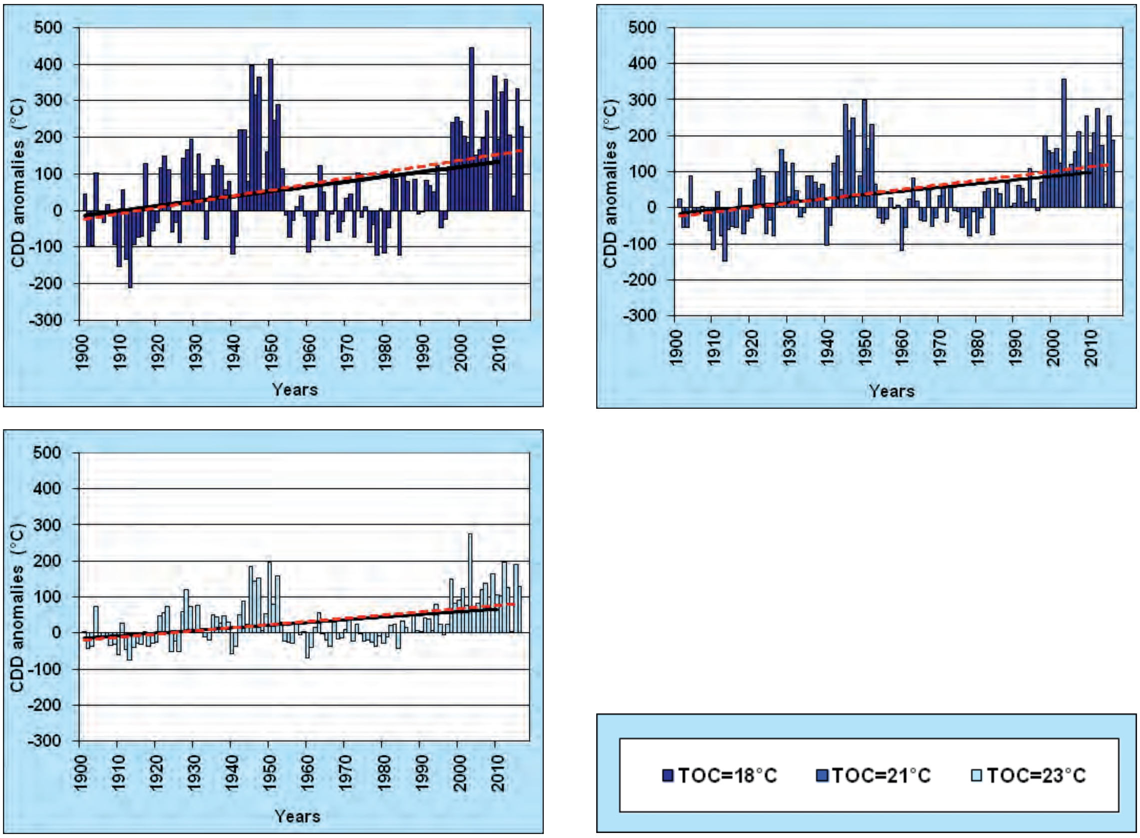

Figure 8 Anomalies of seasonal cooling degree-days (CDD) for three temperature threshold values T_{OC} in the period 1902-2016, relative to 1961-1990 mean CDDs, and linear trends for 1902-2010 (solid line) and 1902-2016 (dotted line) periods.

Slika 8. Anomalije sezonskog stupanj-dana hlađenja (CDD) za tri vrijednosti temperaturnog praga T_{OC} u razdoblju 1902-2016., relativno u odnosu na pripadni srednji CDD iz razdoblja 1961-1990., i linearni trendovi za razdoblja 1902-2010. (puna linija) i 1902-2016 (crtkana linija).

Table 7. Mean value and trend of seasonal cooling degree-days (CDD) for three temperature threshold values T_{OC} in two periods each.

Tablica 7. Srednja vrijednost i trend sezonskog stupanj-dana hlađenja (CDD) za tri vrijednosti temperaturnog praga T_{OC} u po dva razdoblja.

CDD	**Mean (°C)**		**Trend (°C/100 years)**	
	1961–1990	**1981–2010**	**1902–2010**	**1902–2016**
T_{OC}=18°C	469.0	596.5	133.6	162.4
T_{OC}=21°C	186.3	281.5	103.7	125.5
T_{OC}=23°C	75.8	139.7	73.1	87.9

* All trends are statistically significant according to the Mann-Kendall test (level 0.05).

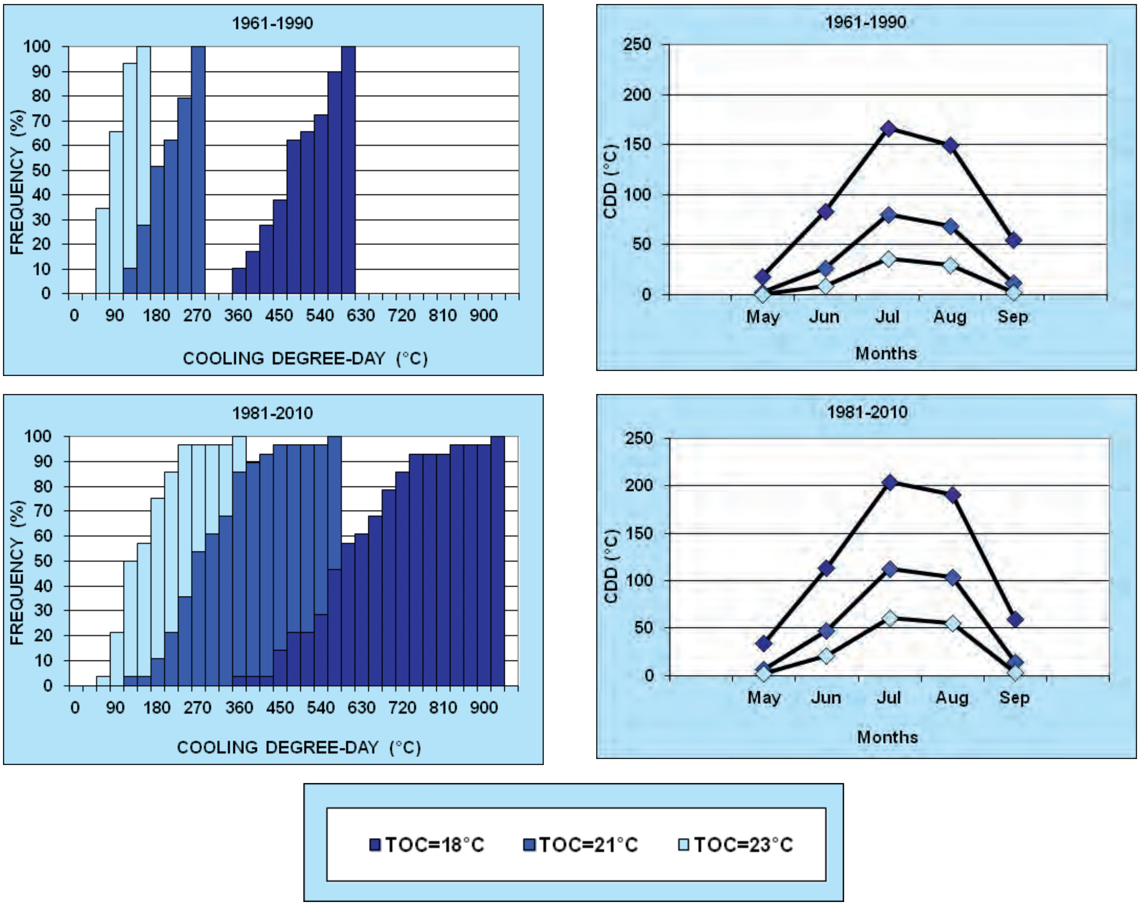

Figure 9. Cumulative relative frequency distributions of seasonal cooling degree-days (left) and seasonal cycles of mean monthly cooling degree-days (CDD) (right) for three temperature threshold values T_{OC} in two periods: 1961-1990 and 1981-2010.

Slika 9. Razdiobe kumulativnih relativnih učestalosti sezonskih stupanj-dana hlađenja (lijevo) i sezonski hodovi srednjih mjesečnih stupanj-dana hlađenja (HDD) (desno) za tri vrijednosti temperaturnog praga T_{OC} u dva razdoblja 1961-1990. i 1981-2010.

Table 8. Statistically significant (S) and non-significant (NS) differences between a) frequency distributions of seasonal cooling degree-days and b) seasonal cycles of mean monthly cooling degree-days (CDDs) for three temperature threshold values T_{OC} in two periods: 1961-1990 and 1981-2010. (The asterisk (*) symbol indicates that the differences between the frequency distributions in the two periods are tested by a nonparametric test.)

Tablica 8. Statistički značajne razlike (S) i razlike koje nisu značajne (NS) između a) razdioba učestalosti sezonskog stupanj-dana hlađenja i b) sezonskih hodova srednjih mjesečnih stupanj-dana hlađenja (CDD) za tri vrijednosti temperaturnog praga T_{OC} u dva razdoblja: 1961-1990. i 1981-2010. (Zvjezdica (*) označava da je testiranje razlika između razdioba učestalosti u dva razdoblja provedeno neparametarskim testom.)

T_{OC} (°C)	**CDD distribution**	**CDD cycle**
18	S	S
21	S	S
23	S*	S

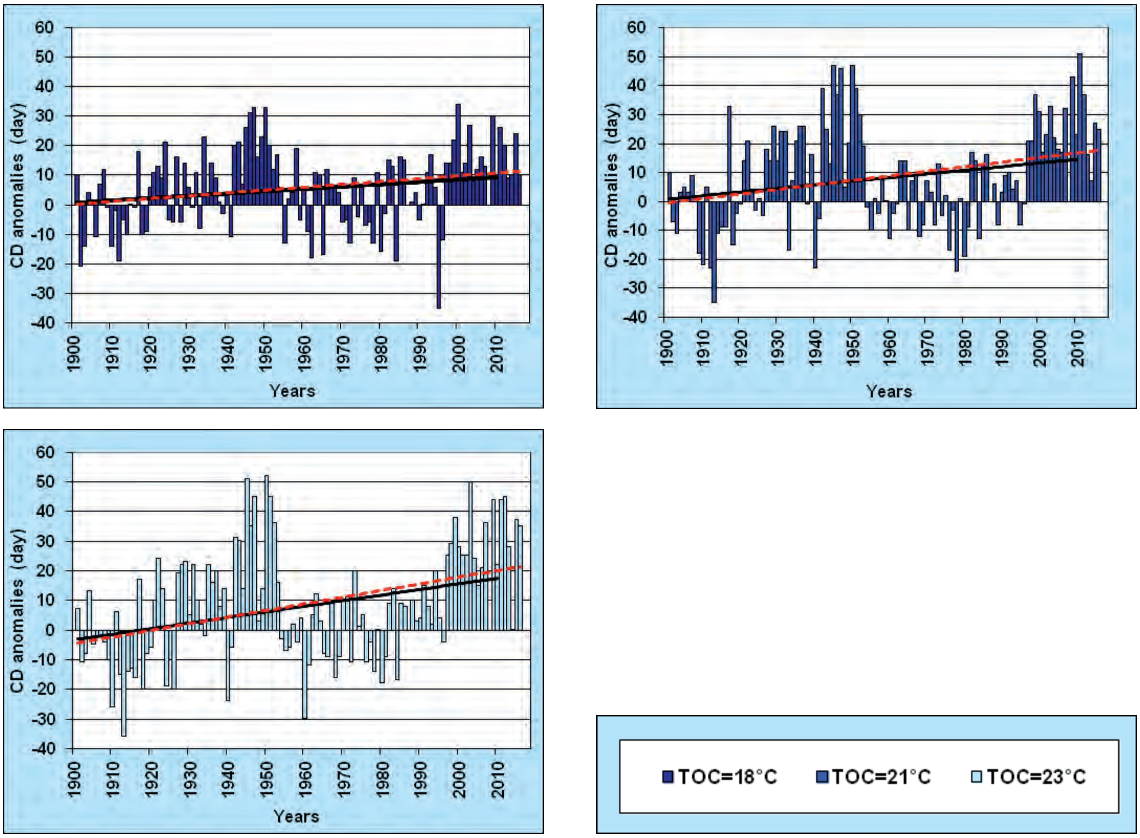

Figure 10. Anomalies of the seasonal number of cooling days (CD) for three temperature threshold values T_{OC} in period 1902-2016, relative to 1961-1990 mean CDs, and linear trends for 1902-2010 (solid line) and 1902-2016 (dotted line) periods.

Slika 10. Anomalije sezonskog broja dana hlađenja (CD) za tri vrijednosti temperaturnog praga T_{OH} u razdoblju 1902-2016., relativno u odnosu na pripadni srednji CD iz razdoblja 1961-1990., i linearni trendovi za razdoblja 1902-2010. (puna linija) i 1902-2016 (crtkana linija).

Table 9. Mean value and trend of seasonal cooling degree-days (CD) for three temperature threshold values T_{OC} in two periods each.

Tablica 9. Srednja vrijednost i trend sezonskog stupanj-dana hlađenja (CD) za tri vrijednosti temperaturnog praga T_{OC} u po dva razdoblja.

CD	**Mean (°C)**		**Trend (°C/100 years)**	
	1961–1990	**1981–2010**	**1902–2010**	**1902–2016**
T_{OC}=18°C	114.0	122.9	7.9	9.7
T_{OC}=21°C	69.9	84.2	12.5	15.7
T_{OC}=23°C	39.8	56.4	18.9	22.4

* All trends are statistically significant according to the Mann-Kendall test (level 0.05).

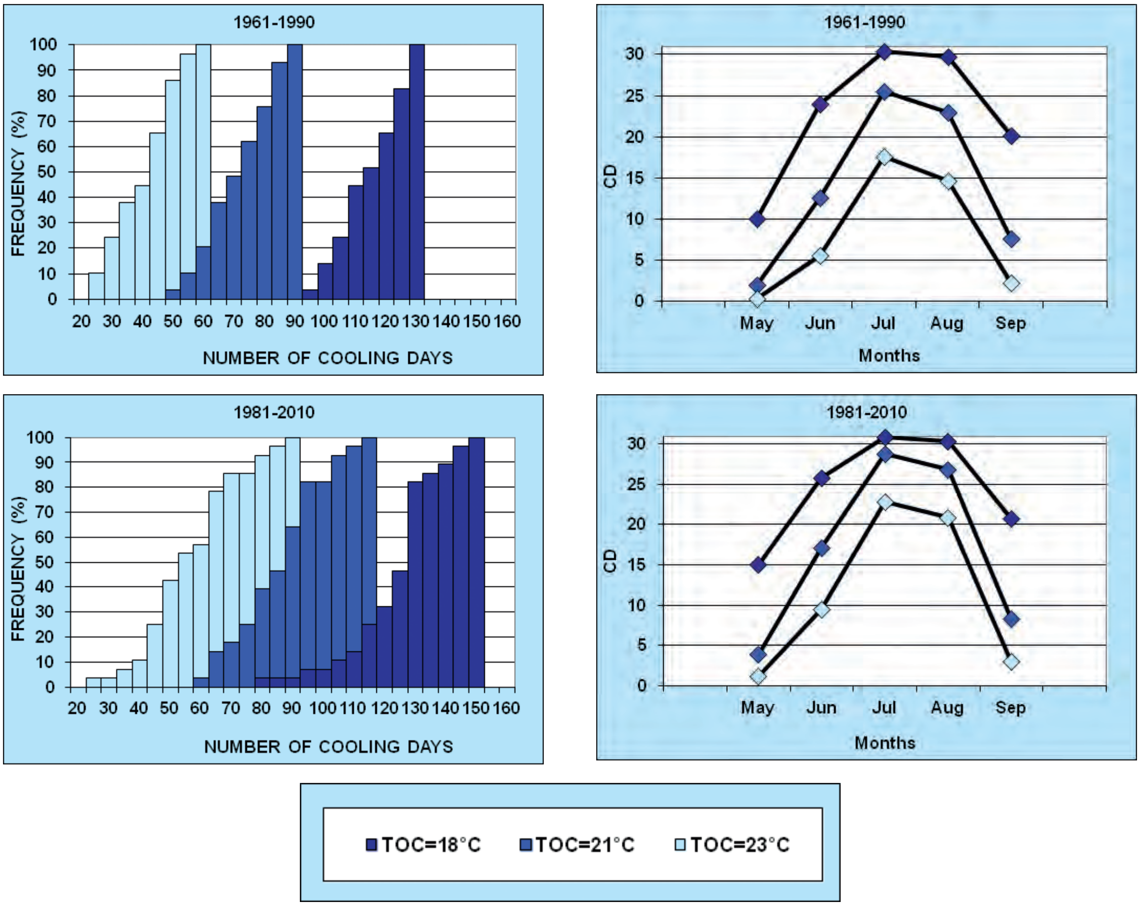

Figure 11. Cumulative relative frequency distributions of the seasonal number of cooling days (left) and seasonal cycles of the mean monthly number of cooling days (CD) (right) for three temperature threshold T_{OC} values in two periods: 1961-1990 and 1981-2010.

Slika 11. Razdiobe kumulativnih relativnih učestalosti sezonskih brojeva dana hlađenja (lijevo) i sezonski hodovi srednjih mjesečnih brojeva dana hlađenja (HD) (desno) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja 1961-1990. i 1981-2010.

Table 10. Statistically significant (S) and non-significant (NS) differences between a) frequency distributions of the seasonal number of cooling days and b) seasonal cycles of mean monthly number of cooling days (CD) for three temperature threshold values T_{OH} in two periods: 1961-1990 and 1981-2010. (The asterisk (*) symbol indicates that the differences between the frequency distributions in the two periods are tested by a non-parametric test.)

Tablica 10. Statistički značajne razlike (S) i razlike koje nisu značajne (NS) između a) razdioba učestalosti sezonskog broja dana hlađenja i b) sezonskih hodova srednjih mjesečnih brojeva dana hlađenja (CD) za tri vrijednosti temperaturnog praga T_{OH} u dva razdoblja: 1961-1990. i 1981-2010. (Zvjezdica (*) označava da je testiranje razlika između razdioba učestalosti u dva razdoblja provedeno neparametarskim testom.)

T_{OC} (°C)	**CDD distribution**	**CDD cycle**
18	S*	S
21	S	S
23	S	S

4. CONCLUSIONS

Tourism is just one of many human activities which need to prepare and adapt to climate changes. The significance of climate changes for the commercial prospects of tourism is discussed in terms of needs for investment in tourism infrastructure for heating and cooling. This is why the degree-day method has been applied, since it can be explained clearly and provides simple and understandable expressions for use by stakeholders in different fields - tourism, energy, architecture etc.

The application of three temperature threshold values for both heating and cooling degree-days have provided an insight into the influence of building thermal insulation on the energy required for heating and cooling. On the basis of mean values and trends, a possibility for energy savings with better insulation was detected over the period 1902-2016. Additionally, a comparison of seven derived temperature parameters was performed for the recent climate period 1981-2010 and the past period 1961-1990. For the period 1902-2016, statistically significant trends have been detected in later start dates (SD) and earlier end dates (ED) for household heating, as well as a statistically significant reduction in the duration of heating (DH). Decreases in heating degree days (HDD) and the number of heating days (HD), which indicates a decline in the energy needed for heating, were also statistically significant over the 115-year period. On the other hand, statistically significant increases in cooling degree days (CDD) and the number of cooling days (CD), which indicates an increase in the energy needed for cooling, have also been detected. The effect of building insulation on energy savings, shown by means of a comparison of the HDD and HD/CDD and CD calculated for three values of temperature thresholds T_{OH}/T_{OC} each, has shown that in the earlier colder referent period (1961-1990) the insulation effect was greater than in the recent warmer period (1981-2010). However, although the consequences of global warming are apparent, the use of adequate insulation could still keep heating and cooling energy consumption at much lower levels. For the considered thresholds, it was found that the buildings with the best insulation needed as much heating energy in the coldest conditions as the buildings with the poorest insulation in the least cold conditions, and also that in the warmest cases of the period 1981-2010, the best insulated buildings would have enabled the consumption of less than half the amount of cooling energy than when using the poorest insulation.

Based on the above results, a climatological basis for the determination of the relationship between long-term weather and (tourism) energy demand could be established. Understanding this local relationship could help in the cost-benefit analysis of renovation measures to be taken in old Crikvenica tourist facilities and the application of appropriate insulation standards in new ones. It is an important and necessary step before considering the impact of future climate scenarios on tourism in Crikvenica, which is planned to be the subject of further research.

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