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Thermal Actions And Climate Changes According To New Eurocodes

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Abstract

prEN 1991-1-5 provides operational rules for the determining thermal actions on buildings, bridges, and some industrial structures for the 2nd generation of Eurocodes. The revised document contains several modifications concerning the presently valid Eurocode EN 1991-1-5. A new presentation of models for thermal actions for buildings and bridges is provided. Basic rules on dealing with the effects of climate changes are also given. Selected aspects of probabilistic modelling of temperature extremes and interaction of temperature with other climatic loads are further discussed. Statistical analysis of long-term records indicates that a lognormal distribution might provide the best probabilistic model. In contrast, the popular Gumbel distribution seems conservative for both maxima and minima. Minima are generally associated with more considerable variability and seem to be significantly affected by climate warming. Open issues include the specification of partial factors and combination factors for the interaction of climatic actions and modelling of the effects of climate change.

Keywords: shade air temperature, solar radiation, thermal action, climate change, interactions of climatic actions.

1. Introduction

The new Eurocode prEN 1991-1-5, developed within the 2nd generation of Eurocodes, gives principles and application rules for thermal actions on buildings, bridges, and other structures. In comparison with the presently valid, in all CEN Member States nationally implemented EN 1991-1-5, the following main changes have been made in prEN 1991-1-5:

- A new presentation of temperatures for buildings (e.g., inner and outer temperatures merged in one table);
- A new approach for consideration of uncertainties related to the initial bridge temperature T_0 of a structural member at the relevant stage of its restraint (completion) considering its range ΔT_0, important for the design of bearings and expansion joints;
- An improved presentation (in the form of figures and tables) and update for the evaluation of the vertical components of temperature differences with non-linear effects on bridge decks;
- Principles for changes in the temperature of structural members due to the paving of hot asphalt on bridge decks;
- Introduction of a climate change term to consider climate change effects for thermal actions.

prEN 1991-1-5 has recently passed the enquiry phase of its development, after which 81 comments sent by the CEN Member States were considered. The document prEN 1991-1-5 is prepared for the Formal Vote phase and, after an expected positive vote, for publication and national implementation.

The definition of thermal actions on structures can be described considering the loading chain illustrated in Fig. 1, which comprises six links: climate characteristics of the region, the characteristics of construction works, the properties of atmosphere and terrain, the mechanism of temperature development, and design criteria (CEN/SC1.T6. 2021).

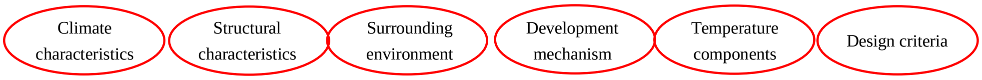

Fig. 1. The thermal loading chain.

2. Basic temperature components

Daily and seasonal changes in shade air temperature, solar radiation, and re-radiation result in variations of the temperature fields within individual members of a structure. Four basic components of the temperature distribution within an individual structural member are illustrated in Fig. 2, where ΔT_N denotes a uniform temperature component, ΔT_{MZ} a linearly varying difference temperature component about the *z-z* axis, ΔT_{MY} a linearly varying temperature difference component about the *y-y* axis and ΔT_E a non-linear temperature difference component.

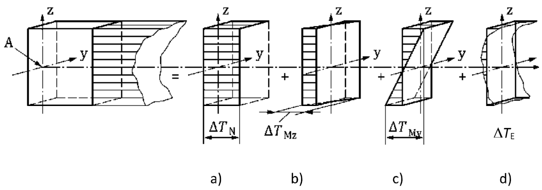

Fig. 2. Illustration of components of a temperature profile (with the centroid in A).

3. Thermal actions on buildings

Improved guidance for the determination of thermal actions on buildings is provided. Thermal actions on buildings due to environmental and operational temperatures are to be considered in the design of buildings where the ultimate or serviceability limit states may be exceeded due to thermal movements or stresses generated due to restraint.

Thermal effects on structures or their parts can be influenced by, e.g., the application of different materials with different thermal expansion coefficients, heat transfer characteristics, effects of orientation to solar radiation, colour and roughness of the surface, and shading from adjacent buildings. The location of the building and the structural detailing can also affect the determination of thermal actions. Commonly, recommendations on the length of dilatations of structural parts are given in the National Annexes of Eurocodes, e.g., for long buildings or industrial halls based on statistical evaluation of temperature measurements.

To determine the uniform temperature component ΔT_N, the initial temperature component when a structural member is restrained is introduced in the standard (information on uncertainties due to temperature contraction or expansion ranges is given in Section 8 for bridges).

The values of the inner and outer environment T_{in} and T_{out} for rooms with controlled temperature are based on data for regions between latitudes 45°N and 55°N. The temperatures from the outer environment on structural members depend on the colour of their surface (light-coloured or dark surfaces) and orientation to the sun (e.g., to North, South, and horizontally). Supplementary notes with recommended temperature ranges were added for rooms without the temperature control.

For the parts of buildings below the level of the surrounding ground, temperatures for underground parts are recommended. The National Annex can specify the values of temperatures for depth below the ground level and differentiating summer/winter seasons. In some cases, the relevant authority may determine project-specific values or, where not specified, agreed upon by the relevant parties for a specific project.

Supplementary guidance for determining temperature profiles in structures using the thermal transmission theory is given in Annex C.

The Technical committee CEN/TC 250 has decided that all parts of Eurocode EN 1991 focused on climate actions should include basic rules on dealing with the effects of climate change on construction works (in prEN 1991-1-5, particularly given in Section 8 for bridges).

4. Thermal actions on bridges

The classification of three main types of bridge decks remains unchanged in prEN 1991-1-5. The bridge deck (type No. 2) for composite bridges is presently better defined. The composite deck is assumed to be set up from a concrete deck compositely connected with steel members fully exposed below the concrete deck. For other types of materials of bridges, the National Annex can specify values of the uniform and difference temperature components. Supplementary rules for thermal actions on timber bridges are given in EN 1995-2.

The guidance for determining the uniform and difference temperature components in prEN 1991-1-5 remains, in principle, similar to in presently valid EN 1991-1-5.

The correlation between maximum (minimum) shade air temperatures and maximum (minimum) effective bridge temperature was analysed in several UK research reports and given in the Background document (König, 1999). Similar results were obtained within Czech national research project (Markova, 2012) where the relationship between long-term monitored shade air temperatures and bridge temperatures was analysed for three prestressed concrete bridges and one composite bridge.

Instead of the diagram given in current EN 1991-1-5, the relationship for calculating the uniform temperature component from shade air temperature for three types of bridge decks is newly provided. The relationship is based on the daily temperature range of 10 °C which is assumed to be appropriate for most European countries and which could be modified for other daily ranges; further information is given in (König et al., 1999).

For determination of the vertical difference temperature component, two alternative approaches are provided for national selection. It should be noted that it is not recommended to combine both alternative approaches, e.g., with respect to a specific length of the bridge span.

The procedure for considering the simultaneity of the uniform and difference temperature components remains unchanged; the values of reduction factors (ω_N, ω_M) are recommended for Approach 1, and a similar procedure is recommended for Approach 2.

Based on new measurements of several bridges, a significant amendment of the simplified model for the vertical difference temperature component has been proposed for composite bridges; see Fig. 3 for an example of a monitored Spanish railway bridge (Cornejo, 2010).

A new temperature profile for the steel part of the bridge superstructure (instead of concrete part) with a considerable increase in temperature (see Fig. 4) is recommended.

Fig. 3. Elevation view of the monitored viaduct “Arroyo las Piedras” and its cross-section (Cornejo, 2010).

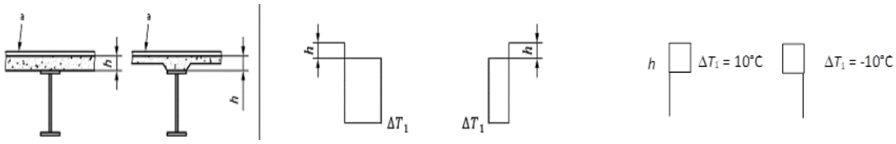

Fig. 4. A new temperature profile for composite bridges (on the left side) is given for heating, ΔT_1= 18°C, and for cooling, ΔT_1= -10°C of steel part of bridge superstructure, instead of currently valid models ΔT_1= 10°C and ΔT_1= -10°C (on the right side) for concrete part.

The initial bridge temperature T_0 should be considered as the temperature of a structural member at the relevant stage of its restraint (completion). In the absence of site-specific data, the initial bridge temperature T_0 can be given by the mean value of minimum/maximum shade air temperature ($T_{\min}$ and $T_{\max}$) or specified in the National annex. In presently valid EN 1991-1-5, T_0 = 10 °C is recommended.

The effects of the contraction over the range from $T_{0,\text{sup}}$ down to $T_{N,\min}$, and the expansion over the range from $T_{0,\text{inf}}$ up to $T_{N,\max}$ should be newly considered in prEN 1991-1-5. The upper and lower bound values of the initial bridge temperature ($T_{0,\text{sup}}$ and $T_{0,\text{inf}}$) should be used considering newly ΔT_0 as a range of the initial bridge temperature (see Fig. 5). The value of ΔT_0 is a Nationally Determined Parameter.

Thermal effects on bridge decks arising during the paving of hot asphalt layers in transient design situations are newly introduced in prEN 1991-1-5. Hot asphalt paving is a transient design situation of short duration, which should be in future transferred to prEN 1991-1-6, which is focused on actions during execution.

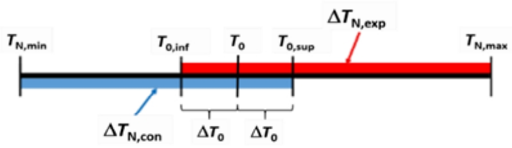

Fig. 5. Characteristic value of the maximum contraction and expansion ranges of the uniform bridge temperature component.

5. Consideration of climate changes in Eurocodes

Temperatures have been increasing over several previous decades and this trend is expected to continue towards the end of this century. Climate changes are to be considered in prEN 1991-1-5, and operational rules are expected to be given in its National Annex.

Several factors influence the magnitude of resulting temperatures and their effects on structures, including structural materials and their thermal properties, colour and type of surface, the geometry of the structure, its exposition to sun, shading by surrounding objects and vegetation, air humidity, the geographical and geomorphological position of the site, etc. It is also necessary to consider the accuracy of measurements (selected cross-sections, instrumentation), period, and evaluation procedure. Daily temperatures (instantaneous part) and seasonal temperatures (long-term part) influence the thermal action effects on the structure.

According to the CEN/SC1.T4 Report on climate change, the winter mean temperature is expected to rise more in Northern Europe than in Central Europe or the Mediterranean. In contrast, summer warming will likely be less intense in Northern Europe. The trends in temperature can be summarized as follows:

- The number of cold days in most parts of Europe has decreased since the mid-20th century.
- Hot days and heat waves are becoming more frequent.
- Most places in Europe will likely experience more hot and fewer cold extremes as global temperature increases.
- The magnitude of hot extremes is expected to increase faster and more severely than mean temperatures over large parts of Europe. Observed variations of temperature extremes are already much more significant than variations of mean temperature values.

The increase in frequency and magnitude of heat waves due to climate changes impacts temperature-sensitive structures, mainly those with a longer design life, such as bridges or monumental buildings. Increasing temperature demands should be considered in the design of these types of structures.

The anticipated increase of shade air temperature due to climate changes will magnify the uniform component of the thermal action, resulting in volume changes for unrestrained structures (including elongations of bridges) and an increase of internal forces for restrained structures (e.g., for frame or arch bridges). EN 1991-1-5 gives the relationship between the shade air temperature and the uniform temperature component which could also be influenced by changing temperature trends.

The expected increase of solar radiation will mainly amplify the temperature difference component, which affects temperature profiles in structures, leading to additional stresses, e.g., continuous multi-span bridges or joints of structures made of different materials. Climate change influences the design values of climatic and environmental actions leading, to an increase in the mean value and the coefficient of variation due to uncertain development of the effects (aleatory uncertainty) and the limited knowledge and modelling of those effects (epistemic uncertainty). For further discussion, see (Orcesi et al., 2022) and the references therein.

Climate change influences the probabilistic distribution of the extreme values of climatic actions. In addition, uncertainties exist regarding how climate change will influence the effects of actions on materials, structural components, and construction systems.

There might be needs for:

- Changing the material composition of structures and their structural robustness to adapt to the expected changes in operating conditions and
- An increase in maintenance to achieve the planned working life of structures or construction products.

To cover climate change's influence on thermal actions, the climate change factor is newly introduced in Eurocodes dealing with climate actions. Climate change factors can be derived by analysing a long series of high-resolution climate projections in moving time windows. The detailed procedure is expected to be given in the National Annex and can be summarised in the following steps based on the CEN/SC1.T6 Report:

- Collection of high-resolution climate projections of the investigated climate variables for the observation period (to be compared with recorded data for the same period) and for the future.
- Extraction of annual maxima considering periods t of fixed length shifted by, e.g., ten years each other of past observations.

- Extreme value analysis in each period to derive characteristic values of the investigated climate variables.

Currently, the analytical models for determining climatic actions in Eurocodes are based on the characteristic values of climatic actions and some conversion or influence factors to consider specific types, characteristics, and locations of buildings or civil engineering works. It should be noted that uncertainties connected with possible impacts of climate change are not considered in the present generation of Eurocodes.

It appears that the effects of climate change could reduce structural reliability over time more significantly than expected in stationary climate conditions, which is due to the degradation effects of resistance only. Consequently, the required target reliability is not reached for the design working life of the construction. To maintain the required reliability level, climatic actions would need some adaptation to consider the effect of climate change.

The effects of climate change in EN 1991-1-5 are proposed to be considered using the climate change term ΔT_{cc} greater than or equal to 0, applied to the shade air temperatures. When the approach based on the climate change term is used, minimum values for the climate change terms $\Delta T_{\mathrm{cc,max}}$ and $\Delta T_{\mathrm{cc,min}}$ can be recommended in the National Annex.

$$T'_{\mathrm{Max},k} = T_{\mathrm{Max},k} + \max(\,\Delta T_{\mathrm{Max,cc}}) \quad (1)$$

$$T'_{\mathrm{Min},k} = T_{\mathrm{Min},k} + \min(\,\Delta T_{\mathrm{Min,cc}}) \quad (2)$$

It should be noted that implementing the climate change term ΔT_{cc} may need to be accompanied by adjustment of the partial factor for climatic load as the design values can be more sensitive to uncertainties (increasing due to predicting climate change effects) than the characteristic values. However, unlike the characteristic values based solely on the shade air temperatures or ground snow loads, the design values also account for significant uncertainties in time-invariant components of the climatic load effects. Thus, the relative influence of uncertainties due to climate change may be small.

6. Analysis of meteorological data and statistical models

The network of meteorological stations has been extended during the decades, e.g., in the Czech Republic, the number of stations has increased from 5 in 1848 to more than 200 after 1961, and in 2020, Germany has approximately 180, Sweden has 285 and Finland has 891.

Common to all climatic data is the need to choose the relevant Extreme Value model. This shall be consistent with the statistical model describing the corresponding parent variable and able to describe the available data well. Maps containing the characteristic values of the shade air temperatures are given in the National Annexes of Member countries to Eurocode EN 1991-1-5. These maps have been produced at a national level using meteorological data from the meteorological service of the Member States. Thus, two problems arise. The first one is related to homogeneity, as the same procedure is not necessarily used in the different Member States to calculate the design values, and underlying datasets can also be heterogeneous. The second one is related to continuity, as values on the two sides of a border can be different due to the different datasets from which they are generated. Both aspects have to be considered when using existing data in new analyses.

The confidence in the statistical evaluation of data depends on the observation duration. For statistical analysis of these parameters, observation data for not less than 25 years should be applied (König, 1999). However, different values of shade air temperature can be obtained by measuring in the location of the site, dependent on specific local climatic conditions, e.g., frost pockets, where the difference can be more than 5°C. The extreme value probabilistic distributions may be applied for modelling the extremes of shade air temperature.

The uniform bridge temperature component may be specified based on shade air temperatures and expressions in Section 8 of prEN 1991-1-5. The extreme value probabilistic distribution may be applied to model the uniform temperature component. The uniform temperature component can be based on the three-day maxima of shade air temperature for concrete bridges and one-day maxima for steel and composite bridges as given in (König, 1999).

It should be noted that the skewness of the uniform and difference bridge temperature components determined from experimental bridge measurements (PMC JCSS, 2015) is considerably lower (between 0.2 and 0.6) than the skewness of the Gumbel distribution, which is recommended in some Parts of Eurocode EN 1991 for climate actions, as is further discussed in the following section.

7. Development of National maps

For the development of National maps of isotherms or ranges of temperatures given in tables for individual regions in the National Annexes to Eurocodes, the extreme value of maximum/minimum shade air temperature with an annual probability of being exceeded of 0.02 (equivalent to a mean return period of 50 years), based on the maximum hourly mean values recorded is needed. The procedure for determining thermal actions on structures for other reference periods or probabilities of exceedance (e.g., for transient design situations or temporary bridges) is given in Annex A.

The shade air temperature is the basis for specifying the uniform temperature component in EN 1991-1-5. For the development of maps, it is necessary to select a suitable, however sufficient number of stations where data should be statistically evaluated and inconsistencies corrected. It is possible to provide characteristic values of temperatures for individual regions of the country (e.g., the Czech Republic) or to give some relationship for consideration of different altitude (Austria, Italy). Some countries provide tables (Germany). The Czech Republic has developed maps of minimum and maximum shade air temperatures (4 regions are distinguished from 32°C to 40°C, and -28°C to - 36°C, with a range of 2°C), which are based on 37 stations and 60 years of measurements, assuming the Gumbel distribution.

Fig. 6 illustrates available maps of maximum isotherms for the relevant European countries given in the background document to prEN 1991-1-5 (Markova J. 2024). Several inconsistencies on the borders of CEN Member States are illustrated in violet. Some countries developed interactive maps that are somewhat difficult to transfer to Fig. 6 without background numerical data (Bulgaria, Bosnia and Hercegovina).

Many existing National maps were produced about twenty years ago, if not more. Therefore, they do not incorporate the more recent measurements, which are more accurate than older ones but also closer to the current situation, given a possible non-stationary behaviour arising from climate change.

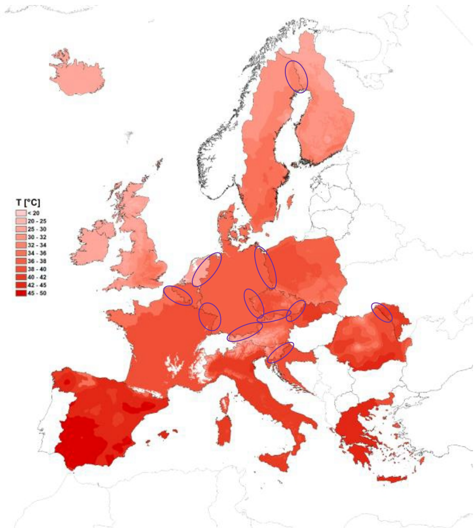

Fig. 6. Illustration of the European map of maximum isotherms of the available National Annexes of CEN Member States.

Tables 1 and 2 provide examples of comparisons of maximum and minimum shade air temperatures in selected CEN Member States. Some countries directly apply a range of characteristic values, while others have developed maps of minimum and maximum isotherms.

Table 1. Comparison of temperature differences in selected countries.

Country	A[1]	BE	CZ[2]	DK	GE	NL	SK[2]
T_{min}	-16 - kh	-21	-28 - (-36)	-31	-24	-25	-28 - (-30)
T_{max}	39 - kh	38	32 - 40	36	37	30	40

[1)] Austria recommends formulae where k = 0.006 and h = height above the sea level
[2)] The Czech Republic and Slovakia have available maps with isotherms and apply relationship 6.1, EN 1991-1-5

Table 2 illustrates the characteristic values of shade air temperature in the Czech Republic's borders with Austria. Negative values indicate more significant differences between shade air temperatures and uniform temperatures. Comparative analysis of shade air temperatures on the borders of selected CEN Member States revealed considerable differences in some cases, mainly in the case of minimum temperatures up to 13°C, and less differences in summer temperatures, about 8°C.

Table 2. Characteristic values of shade air temperatures on the Austrian-Czech border.

Alt. in m	CZ - $T_{max,}$	A - T_{max}	Δ T_{max}	CZ - $T_{min,}$	A - T_{min}	Δ T_{min}
600–900	38 - 36	35.4 - 33.6	2.6 - 2.4	-32-(-34)	-19.6 - (-21.4)	-12.4 - (-12.6)
470-500	40 - 38	36.2 - 36	3.8 - 2	-30-(-32)	-18.8 - (-19)	-11.2 - (-13)
400-500	38 - 36	36.6 - 36	1.4 - 0	-28-(-30)	-18.4 - (-19)	-9.6 - (-11)
200-250	40 - 38	37.8 - 37.5	2.2 - 0.5	-28-(-30)	-17.2 - (-17.5)	-10.8 - (-12.5)

The differences mentioned above for extreme temperatures are also observed in the Czech Republic. Table 3 and Table 4 provide the statistical characteristics of annual maxima and minima of the shade air temperature from several meteorological stations, respectively. The stations are located mainly in the lowlands in populated areas in a similar temperature climate (the same zone for maxima according to EN 1991-1-5 and three zones for minima). Available records span 60 years, from 1961 to 2021. Considering a range of probabilistic distributions, 98% fractiles are also determined and critically compared with the characteristic values, $T_{max,k}$ and $T_{min,k}$, provided in the Czech National maps in EN 1991-1-5.

Table 3. Statistical characteristics, 98% fractiles for different probabilistic distributions, and characteristic values according to the National map in CSN EN 1991-1-5 for maximum shade air temperatures at selected stations in the Czech Republic [in °C].

Station	Altitude [m]	m [1)]	V	w	$T_{N,0.98}$ [2)]	$T_{LN,0.98}$	$T_{Gum,0.98}$	$T_{Wei,0.98}$	$T_{max,k}$	$T_{Wei,0.98}$ / $T_{max,k}$
Borkovice	419	33.2	0.060	0.43	37.3	37.5	38.4	37.8		0.97
Doksany	158	34.6	0.066	0.26	39.4	39.6	40.6	39.3		1.01
Nadějkov	616	31.3	0.066	0.23	35.6	35.8	36.6	36.5		0.94
Prague – Ruzyně	364	33.1	0.058	0.32	37.0	37.2	38.0	37.6	39	0.96
Tábor	410	33.5	0.057	0.18	37.5	37.6	38.5	37.4		0.96
Temelín	500	33.3	0.057	0.30	37.2	37.4	38.2	38.4		0.98
Vráž	433	34.1	0.056	0.38	38.1	38.2	39.0	39.2		1.01
Representative value	-	-	0.060	0.30	37.4	37.6	38.5	38.0	39	0.98

[1)] m – sample mean, V – sample coefficient of variation, ω – sample skewness. [2)] N – normal, LN – lognormal, Gum – Gumbel, and Wei – Weibull distribution.

Table 4. Statistical characteristics, 98% fractiles for different probabilistic distributions, and characteristic values according to the National map in EN 1991-1-5 for minimum shade air temperatures at selected stations in the Czech Republic [in °C].

Station	m	V	w	$T_{N,0.98}$	$T_{LN,0.98}$	$T_{Gum,0.98}$	$T_{Wei,0.98}$	$T_{min,k}$	$T_{Wei,0.98}$ / $T_{min,k}$
Borkovice	-20.9	0.22	0.79	-30.6	-32.3	-33.2	-29.2	-35	0.83
Doksany	-17.3	0.25	0.02	-26.2	-27.8	-28.5	-26.3	-33	0.80
Nadějkov	-15.7	0.21	0.58	-22.5	-23.5	-24.2	-21.7	-33	0.66
Prague – Ruzyně	-16.6	0.23	0.18	-24.5	-25.9	-26.6	-25.3	-31	0.82
Tábor	-18.9	0.23	0.45	-27.6	-29.1	-29.9	-26.5	-35	0.76
Temelín	-17.5	0.23	0.81	-25.8	-27.2	-27.9	-25.0	-35	0.71
Vráž	-18.8	0.22	0.59	-27.5	-28.9	-29.7	-27.3	-33	0.83
Representative value	-	0.23	-	-	-	-	-	-	0.77

For the samples under investigation, the following conclusions are drawn:

- Regarding maxima:
  - The 98% fractiles of a Weibull distribution well correspond to the $T_{max,k}$-values.
  - The lognormal distribution might provide the best model as its skewness is mostly closest to sample skewness coefficients. The difference between $T_{LN,0.98}$- and $T_{Wei,0.98}$- values is slight.
  - A commonly used Gumbel distribution with a fixed skewness of 1.12 provides slightly conservative estimates compared to the Weibull distribution.
  - As a first approximation, the coefficient of variation of 6% and coefficient of skewness of 0.3 might be considered for locations in a similar temperature climate.
- Minima:
  - The $T_{min,k}$-values seem conservative; for instance, the 98% fractiles of the Weibull distribution are, on average, by 23% lower.

- Also, for minima, the lognormal distribution might provide the best model for most stations but further research is needed to provide a general recommendation. The Gumbel distribution is again somewhat conservative.
- The statistical characteristics of minima are more location-dependent than those of maxima. Minima has a more considerable variability, characterized by a coefficient of variation of 23%.

Fig. 7 displays the histograms and fitted normal distributions of the annual minima and maxima of the shade air temperature in Doksany. It appears that a normal distribution can also be considered for this station. It is emphasized that the results presented in Table 3, Table 4, and Fig. 7 are based on the assumption of stationary conditions.

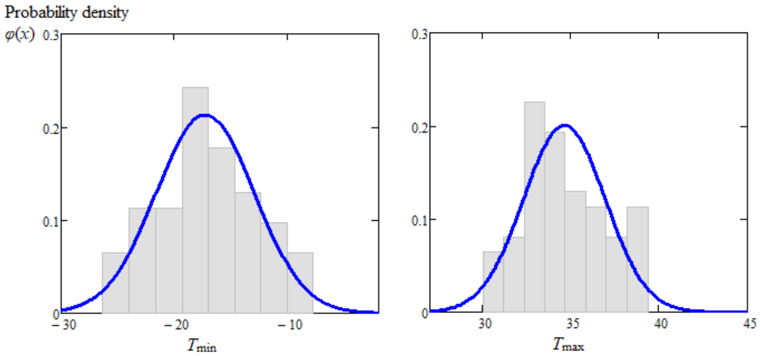

Fig. 7. Histograms and fitted normal distributions of annual minima (left) and annual maxima (right) of shade air temperature in Doksany.

In particular, the differences between the 98% fractiles obtained from measurements and $T_{min,k}$-values should be further investigated. The difference might be caused by warming. The time trend in Fig. 8 reveals a clear trend that will be analysed in future research.

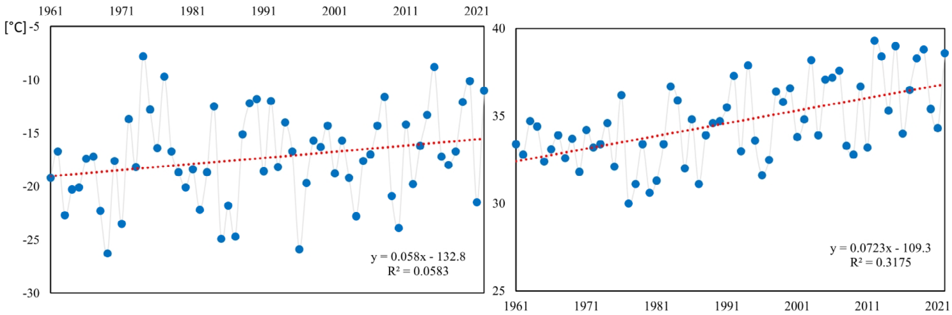

Fig. 8. Trends of annual minima (left) and annual maxima (right) of shade air temperature in Doksany (period 1961-2021).

8. Analysis of interdependence between temperatures, wind, and snow

Analysis of dependence among the different climatic variables could be used in updating climate models and calibration of combination factors ψ. There are no standardized procedures for a mutual combination of different climatic actions.

The recently published Background report (CEN/SC1.T6, 2021) includes selected studies with examples of statistical analysis of long-term measurements of temperatures, wind velocity, snow water equivalent (SWE), precipitation, and atmospheric icing in Norway, the Czech Republic, and Germany. Data series of daily maximum wind velocity (10-minute average) and maximum temperature have been analysed for the several locations in Norway and Germany for the period 1990-2019.

Fig. 9 illustrates the interdependence of 10-minute wind velocity (v_{wind}) and temperature (T) for locations in Bremen and Munich. The investigated variables were asymptotically independent, and a weak correlation was revealed. Wind velocity extremes appear to be generally concentrated in a temperature range of around 10°C.

High wind velocities (p = 0.999) occur with high probability for $T > 0°C$, and $F(T>0 \,|F_{wind}(v_{wind}) > 0.999)$ is equal to 0.999 and 0.98 for Bremen and Munich respectively. This outcome was also observed in Denmark and incorporated in the DK National Annex to EN 1990.

However, the temperature range associated with high wind velocity depends on the climatic zone and the altitude, as it is observed for Germany, and the possibility of combined presence of snow cannot be excluded.

The analyses have also been extended to temperature and snow at Oslo and Bergen, where the interdependence of snow water equivalent (SWE) and minimum temperature (T_{min}) is illustrated (see Fig. 10).

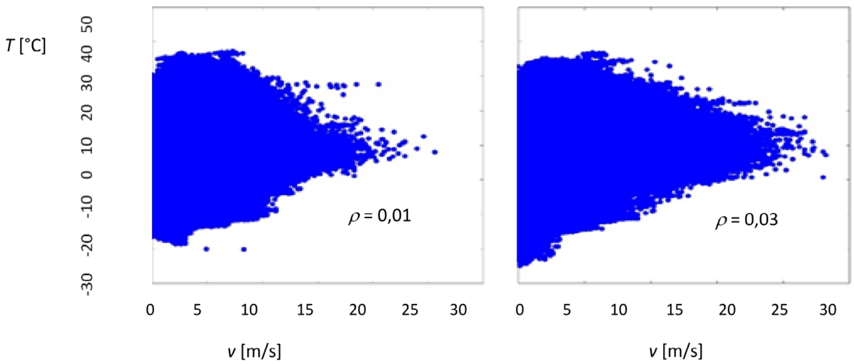

Fig. 9. Interdependence of 10-minute wind velocity (v_{wind}) and temperature (T) in two analysed locations - Bremen (left) and Munich (right) (CEN/SC1.T6, 2021).

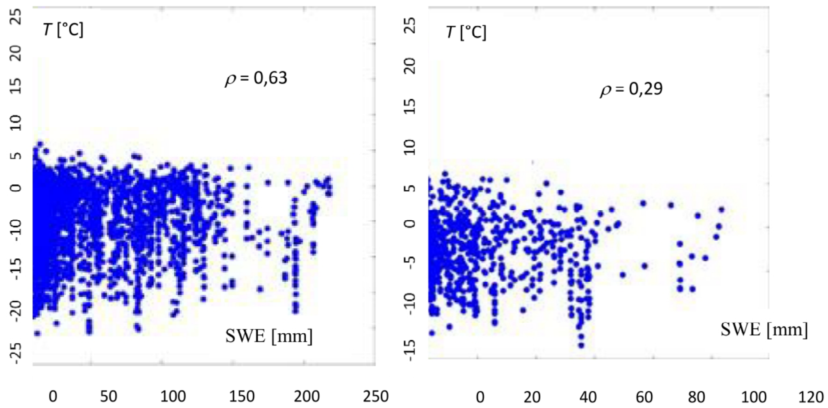

Fig. 10. Interdependence of daily minimum temperature and snow water equivalent SWE [mm] at Oslo and Bergen (CEN/SC1.T6, 2021).

This different outcome of interdependence could be influenced by the different climatic zone of Bergen (zone Temperate oceanic climate, without dry season, warm summer) with respect to Oslo (zone Cold climate, without dry season, warm summer). Bergen is characterized by a shorter snow season, and the highest snow loads generally in January/February, when minimum temperatures also occur. Further information on the interactions of climatic loads can be found in (Markova, 2021; Markova et al., 2022, Thiis, 2022).

9. Conclusions

prEN 1991-1-5 provides new operational rules for the determination of thermal actions on buildings, bridges, and some industrial structures such as chimneys, silos, and cooling towers. Compared to presently valid Eurocode EN 1991-1-5, currently better explained and more user-friendly provisions are given. An improved presentation (in figures and tables) and update for the vertical components of temperature differences with non-linear effects on bridge decks is given.

Supplementary guidance is given for uncertainties related to a structural member's initial bridge temperature T_0 at the relevant stage of its restraint (completion) using its range ΔT_0, which is especially important for the design of bearings and expansion joints. Principles for changes in the temperature of structural members due to the paving of hot asphalt on bridge decks are also provided. The climate change term is newly introduced to consider climate change effects on thermal actions.

However, some issues still need to be solved, including the specification of values of partial factors and combination factors for the interaction of climatic actions. Suitable consideration of climatic models and their combinations clearly impacts the reliability level of buildings or bridges and also the economics of design.

Despite some Nationally Determined Parameters being removed during the development of the new prEN1991-1-5, alternative procedures for specification temperature difference component still remain due to long-term tradition in their application in various European countries. Also, the cross-border differences in characteristic values challenge future developments. Statistical analysis of long-term records for selected seven stations in the Czech Republic indicates that a lognormal distribution might provide the best model for analysed maxima samples; a popular Gumbel distribution seems conservative for both maxima and minima. Minima are generally associated with more considerable variability and seem to be significantly affected by climate warming.

It became very clear from current Technical reports and background materials that the science of global climate changes is still not sufficiently developed to identify substantial methods for quantifying extreme values (with given return periods) for neither temperature, wind, rain, snow, nor any combination of these, to be valid for forecasting the developing climate in Europe.

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