Comparison of the predicted insulation of clothing in Toruń and Koniczynka in the years 1998–2012*

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Abstract: *Comparison of the predicted insulation of clothing in Toruń and Koniczynka in the years 1998–2012*. This paper compares the predicted insulation of clothing (*Iclp*) in Toruń and Koniczynka, presented using a scale of evaluation of thermal environment proposed by B. Krawczyk (2000). The annual mean value of predicted insulation of clothing in urban areas of Toruń was equal to 1.0 clo, which was 0.1 less than in the agricultural area of Koniczynka. The influence of atmospheric circulation on the *Iclp* index was also analysed. The study used the circulation types as classified by Niedźwiedź (1981) in the Catalogue of atmospheric circulation for the Bydgoszcz--Toruń region (Przybylak and Maszewski 2009, 2013). The frequency of occurrence of individual circulation types was examined along with their influence on the predicted insulation of clothing in different seasons of the year and in an annual course. During the year, the highest mean value of *Iclp* (1.4 clo in Koniczynka) corresponded to cyclonic situations with northerly advection, whereas the lowest value (0.8 clo in Toruń and Koniczynka) was observed for the anticyclonic wedge.

Key words: biometeorological conditions, predicted insulation of clothing, atmospheric circulation, Toruń, Koniczynka

INTRODUCTION

Clothing provides the most basic protection from unfavourable influence of weather. In changeable climate conditions the equilibrium between the amount of heat received and lost by the human body can be maintained thanks to thermoregulatory reactions, but also thanks to adequately chosen clothes (cf. Krawczyk 1993, Yan and Oliver 1996). A great number of problems with adaptation to unstable weather conditions results from the use of unsuitable clothing. The index of predicted insulation of clothing (*Iclp*) enables the determination of thermal insulation properties of clothing (in clo units) required to strike the thermal balance of the body in given meteorological conditions (Kuchcik et al. 2013). Nowadays, clothing can be optimally adapted to the conditions of any environment and physical activity in order to provide man with thermal comfort.

The observations were conducted in Toruń, a city situated in the Toruń valley, and its suburban area in the village of Koniczynka, situated in the Chełmno Lakeland. The area, according to the regional division proposed by Romer (1949), falls into the climate category of the Land of Great Valleys, whereas

in the agricultural and climatic classification of Gumiński (1948) it belongs to the 7th central district. Woś (1996) drew attention to the area's climatic peculiarity by identifying a separate Chełmno--Toruń climate region there. The lowland part of Poland, where the analysed stations are situated, has a 'weak stimulating bioclimate' (Kozłowska-Szczęsna et al. 1997). It is an area with the smallest number of thermally uncomfortable days as compared with the rest of Poland.

The climatic conditions of the Chełmno Lakeland, and of Toruń and Koniczynka (Central Poland) in particular, have been the subject of a number of studies. A detailed list of these works can be found, for example, in the publications of Kejna et al. (2004), Kejna (2006) or Wójcik and Marciniak (2006). As far as bioclimatic studies of the area are concerned, the article of Araźny et al.

(2007) is a useful reference, providing an analysis of the cooling power of air.

The purpose of this paper is to compare the predicted insulation of clothing in Toruń and at Koniczynka in the years 1998–2012. Additionally, the influence of atmospheric circulation on the values of *Iclp* in the analysed area is addressed.

MATERIAL AND METHODS

The study applies to the station of the Institute of Meteorology and Water Management in Toruń Wrzosy and to the station of the Integrated Monitoring of the Natural Environment at Koniczynka, and concerns the period of 1998–2012. The two stations have distinct features. The meteorological station in Toruń Wrzosy (Fig. 1) is situated in right part of the Toruń valley (φ = 53°02'N, λ = 18°35'E, h = 69 m a.s.l.), some 5 km from the river Vistula. The station at Koniczynka (Fig. 2) is situated in the

FIGURE 1. The station of the Institute of Meteorology and Water Management in the Toruń district of Wrzosy (photo by A. Araźny)

FIGURE 2. The base station of the Integrated Monitoring of the Natural Environment at Koniczynka near Toruń (photo by M. Kejna)

Chełmno Lakeland (φ = 53°07'N, λ = = 18°42'E, h = 84 m a.s.l.), north of Toruń on the young glacial flat moraine plain formed during the last glaciation and has been extensively cultivated (Wójcik and Marciniak 1996).

In order to calculate the *Iclp* index fixed-time values (12:00 UTC) of air temperature and wind speed were used. To determine the wind conditions and to calculate the *Iclp* in Toruń and at Koniczynka, the wind speed at the level of measurement (the anemometer height) was reduced to a height of 1.2 m a.g.l. (i.e. the level of a human torso) using Milewski's formula (1960).

The predicted insulation of clothing (*Iclp*) was determined on the basis of the values of air temperature and wind speed using the following formula (Błażejczyk 2004):

$$Iclp = 0.082 \cdot [91.4 - (1.8 \cdot T + 32)] / (0.01724 \cdot M) - 1 / (0.61 + 1.9 \cdot v^{0.5})$$

where:
t – air temperature (°C),
v – wind speed (m·s^{-1}),
M – metabolism (W·m^{-2}).

For the calculation of *Iclp*, the value of metabolism was assumed at 135 W·m^{-2} which corresponds to moderate physical activity (such as walking at 4 km·h^{-1}). Then the predicted insulation of clothing was determined (in clo) using Bioklima 2.6 software package (Błażejczyk 2013).

On the basis of the value of *Iclp* the thermal environments of Toruń and Koniczynka were evaluated using the scale proposed by Krawczyk (2000): very warm (<0.30 clo), warm (0.31– –0.80 clo), neutral (0.81–1.20 clo), cool (1.21–2.00 clo), cold (2.01–3.00 clo), very cold (3.01–4.00 clo), arctic cold (>4.00 clo). The thermal insulation properties of selected seasonal clothing are shown in Table 1.

TABLE 1. Basic thermal insulation of clothing ensembles (*Icl*) to be used outdoor (Krawczyk 1993)

Type	Clothing description	Icl	
		clo	K·m²·W⁻¹
1	Summer clothing		
1.1	Very light		
	a) shorts	0.1	0.016
	b) shorts, T-shirt	0.3	0.045
1.2	Light		
	a) long trousers, T-shirt	0.5	0.078
	b) robe with short sleeves	0.5	0.078
	c) light working clothing	0.6	0.093
	d) light military uniform	0.7	0.108
	e) light sport's wear	0.9	0.140
1.3	Oridinary		
	a) wool men's suit	1.0	0.155
	b) wool women's suit	1.0	0.155
	c) typical working clothing	1.0	0.155
2	Transient season's clothing		
	a) men's suit shirt, coat	1.5	0.232
	b) women's suit, blouse, coat	1.5	0.232
	c) typical working clothing, coat	1.5	0.232
	d) warm working clothing	1.5	0.232
	e) similar to type 2a. 2b + hat, scarf, gloves	2.5	0.388
3	Winter clothing		
3.1	Light	3.0	0.465
	similar to type 1.3 + warm coat, cap, sharf, gloves		
3.2	Oridinary	3.5	0.542
	similar to type 3.1 × warm underwear, boots		
3.3	Arctic	>4.0	>0.620
	thermoinsulative underwear, polar (sweter), heavy coat, cap, gloves, boots		

The study also presents the influence of atmospheric circulation on the predicted insulation of clothing, using the circulation types identified by Niedźwiedź (1981) in the Catalogue of atmospheric circulation for the Bydgoszcz-Toruń region (Przybylak and Maszewski 2009, 2013). For the classification, the type of barometric centre was defined (a – anticyclone, c – cyclone) as well as the direction of advection using the 8-point wind rose. Also, the following situations were identified: the anticyclonic centre (Ca), the anticyclonic wedge (Ka), the cyclonic centre (Cc) and the cyclonic trough (Bc), whereas any other situations were marked with an 'X'. In this paper, the frequency of occurrence of individual circulations types was analysed along with their influence on *Iclp* in seasonal, annual and multi-annual courses.

RESULTS AND DISCUSSION

General meteorological conditions

Changes in air temperature have a significant influence on the physical well-being of people staying outdoors for a long time (Kozłowska-Szczęsna et al. 1997). The mean annual air temperature at 12:00 UTC in Toruń in the years 1998–2012 was 12.0°C and was 0.2°C higher than the one determined for Koniczynka (Table 2). The lowest mean monthly temperature in the reference

The movement of air is essential in the process of heat exchange between a human body and the environment. A high wind at low temperatures, or a hardly noticeable breeze at high temperatures may both disturb the heat balance of a human body (Kuchcik et al. 2013). The mean annual wind speed at a level of the human torso (1.2 m) at 12:00 UTC in Toruń was 2.3 m·s^{-1} (Table 3). At Koniczynka, which is a village in a flat and open moraine plain, the mean wind speed was 0.6 m·s^{-1} higher than

TABLE 2. Mean (T_m), the highest (T_h) and the lowest (T_l) values of air temperature (°C) at 12:00 UTC in Toruń and at Koniczynka in the years 1998–2012

Para-meter	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Toruń													
T_m	0.2	1.6	6.3	13.5	18.3	20.8	23.1	22.6	18.4	12.0	5.7	1.1	12.0
T_h	12.2	13.7	20.2	30.2	30.9	33.7	35.8	34.3	30.4	24.0	15.6	12.4	35.8
T_l	−19.7	−14.3	−3.3	0.8	6.4	10.6	12.0	12.0	8.1	0.3	−9.7	−12.5	−19.7
Koniczynka													
T_m	−0.1	1.1	5.8	13.2	18.0	20.4	22.8	22.5	18.2	11.8	5.3	0.5	11.8
T_h	10.4	11.8	19.8	30.1	29.8	34.2	35.2	33.8	30.7	23.3	15.4	11.0	35.2
T_l	−20.7	−13.5	−4.9	0.6	6.5	9.8	11.8	12.4	7.8	−0.5	−10.6	−13.2	−20.7

period occurred in January (−0.1°C at Koniczynka and 0.2°C in Toruń), whereas the highest one was recorded in July (23.1°C in Toruń and 22.8°C at Koniczynka). The range of midday (at 12:00 UTC) air temperatures in both places was similar (approx. 56°C): from −19.7 to 35.8°C in Toruń and from −20.7 to 35.2°C at Koniczynka (Table 2).

its counterpart in Toruń. The greatest monthly mean values of the wind speed were observed from January to April. High speed winds, particularly if gusty, provide unfavourable mechanical stimuli for man. Throughout the year maximum values of wind speed at Koniczynka are a few m·s^{-1} higher than in Toruń (Table 3).

TABLE 3. Mean (V_m) and the highest (V_h) values of wind speed (m·s^{-1}) at 1.2 m a.g.l. at 12:00 UTC in Toruń and at Koniczynka in the years 1998–2012

Para-meter	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Toruń													
V_m	2.3	2.4	2.5	2.5	2.3	2.3	2.2	2.2	2.2	2.3	2.1	2.1	2.3
V_h	5.9	5.9	6.5	5.9	5.2	5.9	4.6	5.2	5.2	5.2	7.9	5.2	7.9
Koniczynka													
V_m	3.1	3.2	3.4	3.0	2.7	2.8	2.7	2.7	2.7	2.8	2.7	2.8	2.9
V_h	11.6	11.6	10.3	9.6	8.3	8.3	8.3	10.9	8.3	8.2	11.1	10.3	11.6

Predicted insulation of clothing

The predicted insulation index (*Iclp*) was used to evaluate the bioclimates of Toruń and Koniczynka from the point of view of demand for suitable clothing that would provide man with thermal comfort. The annual mean value of *Iclp* in Toruń was 1.0 clo, which was 0.1 clo lower than at Koniczynka (Table 4). In both analysed sites mean values indicate a neutral thermal environment. In spring, summer and autumn, seasonal mean values of *Iclp* are the same in both sites (1.0, 0.4 and 1.0 clo, respectively). In winter, however, the thermal insulation index of clothing should be higher at Koniczynka (1.8 clo) than in Toruń (1.7 clo). *Iclp* demonstrates considerable variability in annual courses of both day-by-day (Fig. 3) and year-by--year values (Fig. 4). In Poland the longest multi-annual changes of *Iclp* was calculated in Kraków (Błażejczyk et al. 2003).

TABLE 4. Mean (*Iclpm*), the highest (*Iclph*) and the lowest (*Iclpl*) values of the predicted insulation of clothing (clo) at a moderate physical activity (*M* =135 W·m^{-2}) at 12:00 UTC for Toruń and Koniczynka in the years 1998–2012

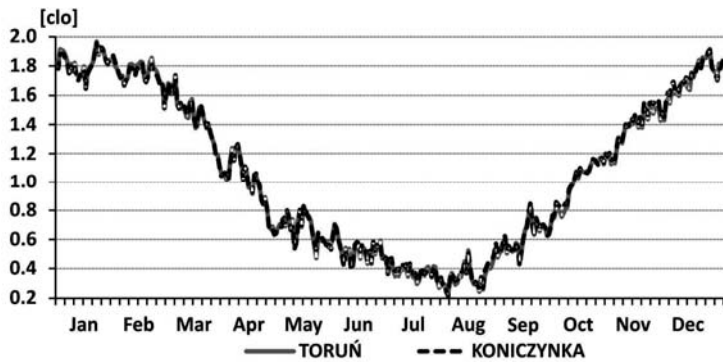| Para-meter	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Toruń													
$Iclp_m$	1.8	1.7	1.4	0.9	0.6	0.5	0.3	0.4	0.6	1.0	1.4	1.7	1.0
$Iclp_h$	3.0	2.6	2.0	1.8	1.4	1.2	1.1	1.1	1.3	1.8	2.3	2.7	3.0
$Iclp_l$	1.1	0.9	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.8	1.0	0.0
Koniczynka													
$Iclp_m$	1.8	1.7	1.5	1.0	0.7	0.5	0.4	0.4	0.6	1.1	1.4	1.7	1.1
$Iclp_h$	3.1	2.6	2.2	1.9	1.5	1.2	1.1	1.1	1.3	1.9	2.5	2.7	3.1
$Iclp_l$	1.0	0.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.7	0.9	0.0

FIGURE 3. Annual course of the *Iclp* index (clo) at a moderate physical activity for Toruń and Koniczynka in the years 1998–2012, according to the values at 12:00 UTC
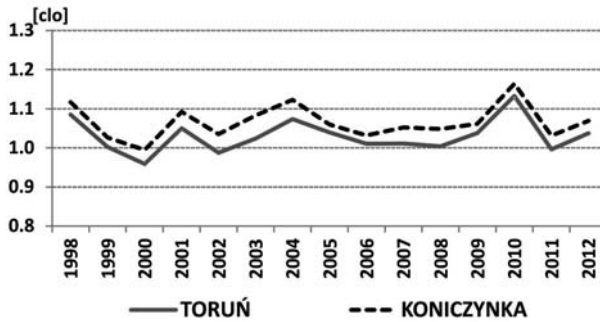

FIGURE 4. Year-by-year course of mean values of the *Iclp* index (clo) at a moderate physical activity for Toruń and Koniczynka in the years 1998–2012

In the period 1901–2000 was observed important trends –0.11 clo per 100 years for *Iclp*.

Throughout the year, in Toruń and at Koniczynka, the optimal outfits required for man in motion – considering its thermal insulation properties – ranged from summer to winter clothing (Table 4, Fig. 3). In the analysed sites, light and very light clothing (<1.0 clo) should be worn for about 180 days in the warm half of the year (i.e. from April to October in Toruń, and from April to September at Koniczynka). For about 80 days, from June to August only light summer clothes (<0.5 clo) should be usually worn. In March and October, the summer clothing should be supplemented with accessories that increase its heat insulating properties (1.0–1.5 clo). On the annual basis, this kind of clothing is used in the analysed sites for about 88 days. Transitional season clothing (1.5–2.5 clo) is necessary to maintain the heat balance for approximately 94 days in Toruń and 102 days at Koniczynka, whereas light winter clothing should be worn from November until February.

One should remember, however, that in order to provide a man standing outdoors with a similar thermal comfort clothing should have twice as high insulation properties as for a man moving. This results from the fact that heat generated by metabolism when standing still decreases from approx. 135 to 70 W·m^{-2}, which is almost 100% less as compared with the heat produced by the body of a walking man.

In winter season, e.g. in January, "cool" and "cold" thermal environment conditions clearly prevailed (Fig. 5),

making up 70% (Koniczynka) to 72% (Toruń) and 27% (Toruń) to 29% (Koniczynka) cases within the study area, respectively. In summer months, such as July, the most frequent thermal conditions observed for a man walking at 4 km·h^{-1} outdoors were either "warm" or "very warm". These made up about 90% of all cases (Fig. 5).

Table 5 contains the differences in the frequency of occurrence of thermal environment in the different classes of *Iclp* between Toruń and Koniczynka in the analysed period. It was found that in

FIGURE 5. Annual course of the frequency of occurrence (%) of different thermal environment classes for the predicted insulation index of clothing (clo) at a moderate physical activity in Toruń in the years 1998–2012

TABLE 5. Annual course of the difference in the frequency of occurrence (%) of different thermal environmental classes (very warm, warm etc.) for the *Iclp* (clo) at a moderate physical activity, between Toruń and Koniczynka in the years 1998–2012

Thermal feeling	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Very warm	.	.	.	0.2	−1.1	0.7	4.7	−0.2	−0.7	0.0	.	.
Warm	.	.	0.0	2.2	5.4	3.1	−2.4	2.8	6.7	0.9	−0.4	.
Neutral	0.0	1.2	3.4	1.3	−2.4	−2.7	−2.4	−2.6	−4.9	4.3	1.6	0.4
Cool	1.9	4.0	−1.3	−3.8	−1.9	−1.1	.	.	−1.1	−5.2	−1.6	4.5
Cold	−1.9	−5.2	−2.2	.	.	.	.	.	.	.	0.4	−4.9
Very cold	0.0	.	.	.	.	.	.	.	.	.	.	.

all categories of thermal conditions conducive to the cooling of the human body were more frequent at Koniczynka than in the urban area of Toruń.

The influence of atmospheric circulation on the predicted insulation of clothing

Specific types of atmospheric circulation and correlated advections of air masses with different physical properties determine the values of weather elements which affect the amount of heat ex-

change between the human body and its environment (Krawczyk 1993). Stable anticyclonic weather is the least biologically active, whereas cyclonic situations provide particularly powerful stimuli (Błażejczyk 2004, Kozłowska-Szczęsna et al. 2004).

The frequency of atmospheric circulation types demonstrates a variability in annual, seasonal and multi-annual courses (Fig. 6). On average, in the years 1998–2012, cyclonic types prevailed in the analysed area, making up 50.2% of
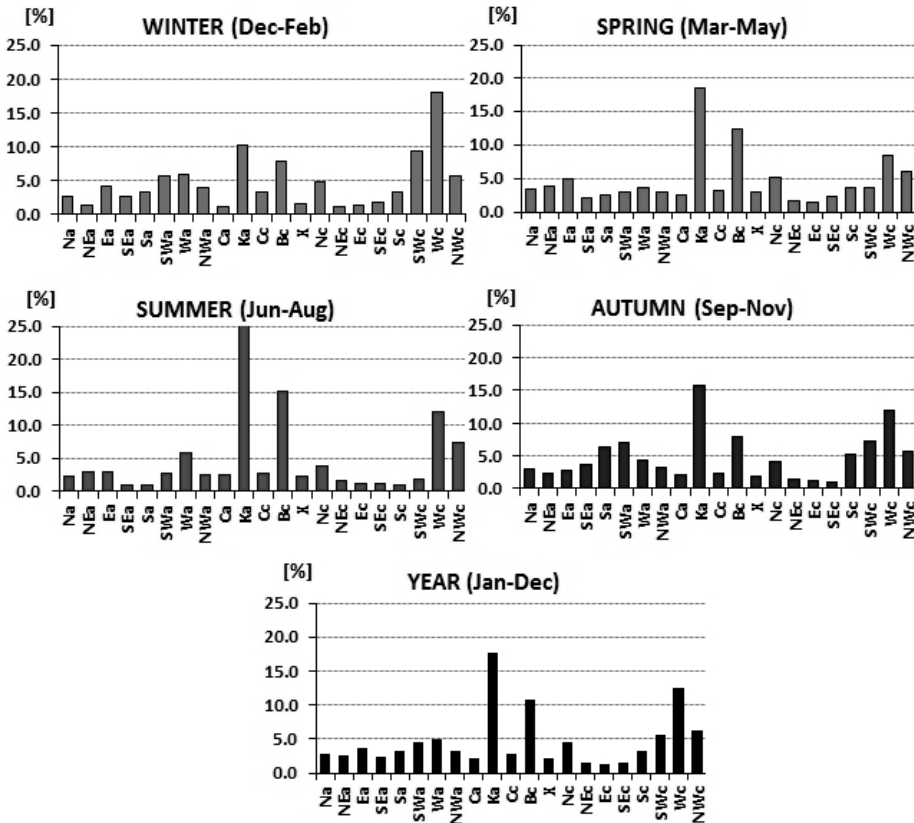
FIGURE 6. Average frequency of atmospheric circulation types according to the classification of Niedźwiedź in the Bydgoszcz-Toruń region in individual seasons and in the whole year in the years 1998–2012

observed situations. On the other hand, anticyclonic types constituted 47.5% of all cases. The rest of the days were determined as an "X" type.

In an annual course, the direction of advection changes, just as the frequency of occurrence of individual circulation types. In the analysed period, the Ka circulation type revealed the greatest frequency (17.6%), along with Wc and Bc situations: 12.6 and 10.8% of the days, respectively (Fig. 6). The anticyclonic wedge was most frequent in summer (25.6%) and the least frequent in winter (10.3%), when the advection of air masses with westerly cyclonic types prevails, with the dominant Wc type (17.9%). Circulation types Ka, Bc and Wc occur more than a half of all summer days.

The advection of air masses from different directions when cyclonic or anticyclonic situations occur considerably affects the predicted insulation properties of clothing for the given area. The average demand for heat insulation of clothing of a man performing a moderate physical activity in the case of the cyclonic macro-type was 0.1 and 0.2 clo higher (at Koniczynka and in Toruń, respectively) than with an anticyclonic macro type (observed differences 0.1 and 0.2 clo are statistically significant at the level of 0.05).

The relationship between the predicted insulation of clothing and the atmospheric circulation in Toruń and at Koniczynka is similar in all seasons of the year, except for winter. In spring, summer and autumn, a better-than-average thermal insulation of clothing (about 0.3–0.4 clo) is necessary in the case of

cyclonic synoptic situations with the inflow of air masses from the north-eastern sector. In winter, extra layers of clothing are also required in the case of anticyclonic synoptic situations with air masses inflowing from the north-east (Fig. 7). In individual seasons, less insulating clothes can be worn when air masses flow from the S-W sector (the type of the barometric system is not important). Throughout the year, the highest mean value of *Iclp* occurred with Nc situations (1.4 clo at Koniczynka), whereas the lowest value was recorded for Ka type (0.8 clo in both stations) – Figure 7.

The highest values of *Iclp* around midday were recorded with different synoptic situations in individual seasons of the year, however some of them were more conducive to the occurrence of anomalies (e.g. Ea, NEa, Sea, Ec or Nc) than the other. The highest value of *Iclp* (at a moderate physical activity $M = 135$ W·m^{-2}) around midday in Toruń was observed on 22 January 2006 with Ea situation (3.1 clo at Koniczynka and 3.0 clo in Toruń).

CONCLUSIONS

As a result of the meteorological conditions prevailing in Poland the value of the predicted insulation index for clothing ranges from about 0.5 clo in the summer months to about 1.5–2.0 clo in winter (e.g. Krawczyk 1993, Kuchcik et al. 2013). Similar values at midday hours were confirmed in Toruń and at Koniczynka. The mean annual value of the *Iclp* index at a moderate physical activity was 1.0 clo in the urban area of Toruń. In the open farmland of
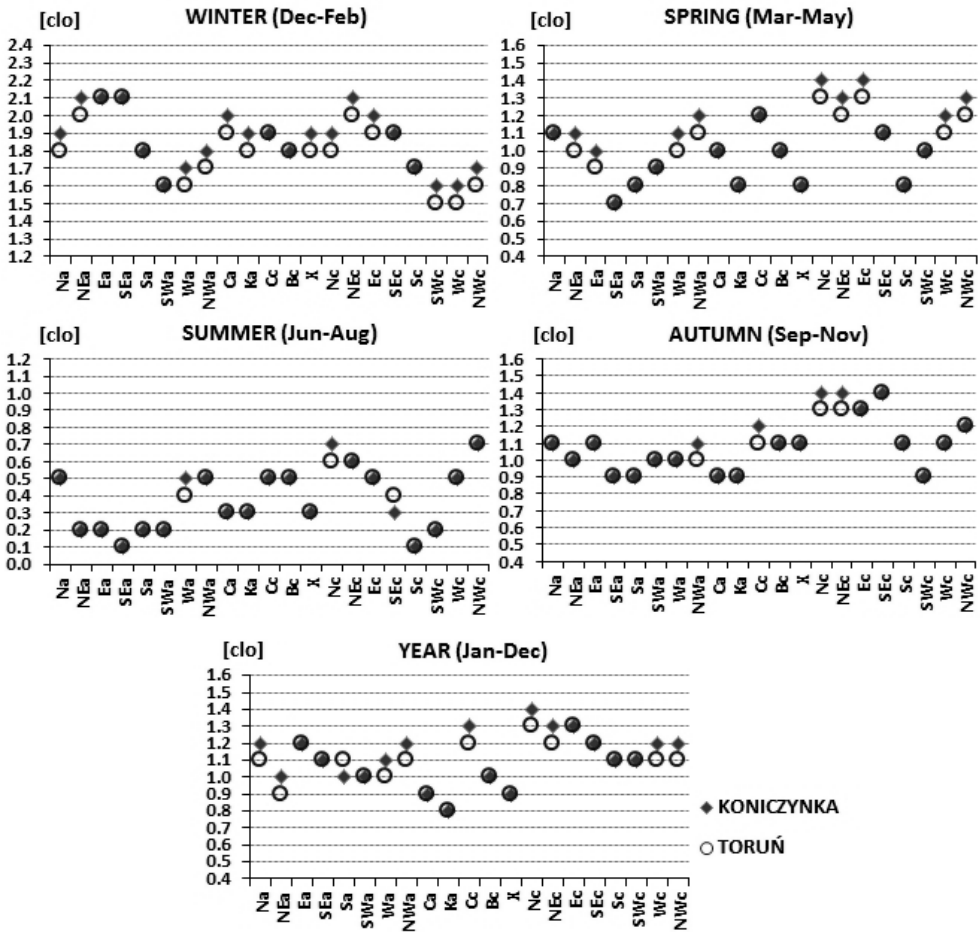
FIGURE 7. Mean values of the *Iclp* index (in clo) for different atmospheric circulation types in Toruń and at Koniczynka at a moderate physical activity in individual seasons and in the whole year in the years 1998–2012

Koniczynka the required thermal insulation index of clothing should be a little higher (by 0.1 clo). The difference is due to the winter weather conditions which involve a 0.1 clo higher value of the *Iclp* index of clothing at Koniczynka, as compared with Toruń. In the period from spring to autumn, the values of *Iclp* are similar in both stations. On av-erage, during the whole year extra lay-ers of clothing are most often required in the case of cyclonic synoptic situations with northerly and easterly advection of air masses. Summing up, the prevailing thermal sensation across the studied area is "cool". Standard summer clothing or transitional season clothing is recom-mended throughout most of the year.

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Streszczenie: *Porównanie przewidywanej termoizolacyjności odzieży w Toruniu i Koniczynce w latach 1988–2012*. Celem pracy jest porównanie przewidywanej termoizolacyjności odzieży (*Iclp*) w Toruniu i Koniczynce. Opracowanie wykonano dla Stacji IMGW Toruń Wrzosy oraz dla Stacji Zintegrowanego Monitoringu Środowiska Przyrodniczego w Koniczynce dla okresu 1998–2012. Każda z badanych stacji charakteryzuje się indywidualnymi cechami. Przewidywaną termoizolacyjności odzieży przedstawiono według skali oceny środowiska termicznego zaproponowanej przez B. Krawczyk (2000). Zbadano również wpływ cyrkulacji atmosferycznej na wskaźnik *Iclp*. W badaniach wykorzystano typy cyrkulacji wg klasyfikacji T. Niedźwiedzia (1981) z Katalogu cyrkulacji atmosferycznej dla Regionu Bydgosko-Toruńskiego (Przybylak i Maszewski 2009, 2013). Przeanalizowano częstość występowania poszczególnych typów cyrkulacji oraz ich wpływ na przewidywaną termoizolacyjność odzieży w poszczególnych porach roku i przebiegu rocznym.

Słowa kluczowe: warunki biometeorologiczne, przewidywana termoizolacyjność odzieży, cyrkulacja atmosferyczna, Toruń, Koniczynka

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