Thermal impact of weather on the humans*

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Content

- Motivation
- Models [human body and clothing, environment (weather), metabolic activity (19 transparencies)]
- Data (weather, human (5 transparencies))
- Results (about 25 transparencies)
- Conclusions

Why humans and weather?

- Since I was educated as biometeorologist and this field was still „open” for me.
- So, this work is my hobby, pliancy to stringency.

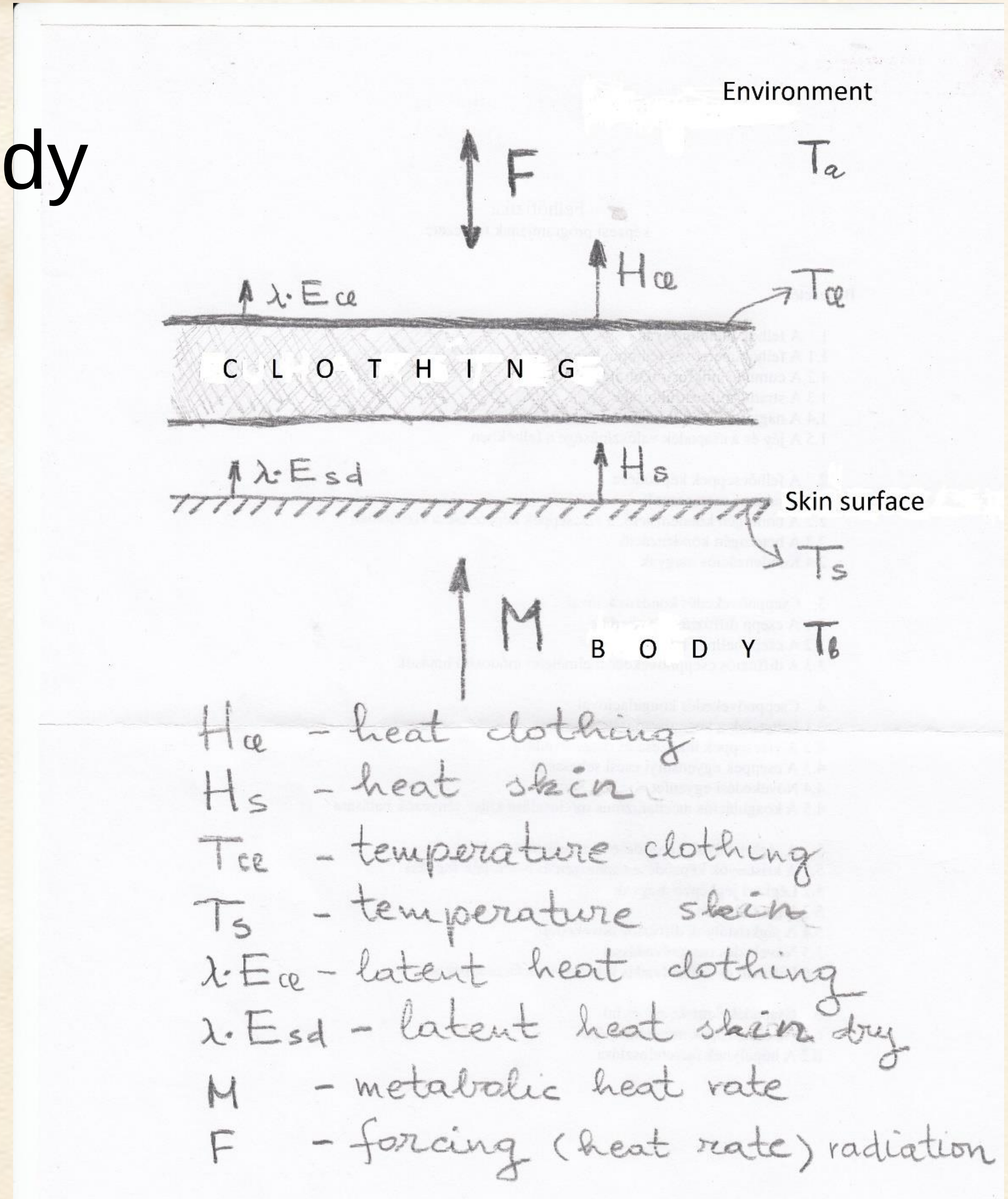
Humans in outdoor conditions

- In outdoor environment, humans are mostly walking. So, human body is impacted by both environmental (E) and metabolic heat (M) forcing. These two effects are „balanced” by changing of the clothing.
- Our goal is to present the main equations of a human body-clothing energy balance model to characterise humans’ heat forcing in terms of clothing.

Human body-clothing model – main suppositions

- Two-layer model: layer 1: human body and the skin surface (T_s=34 °C); layer 2: clothing. Air layer between skin surface and clothing is not taken into account, that is, clothing sticks strongly to the skin surface.
- Our basic supposition: human is in the movement, but it doesn't sweat during the movement (sweating is consequence of the unbalanced heat exchange!).

2-layer clothing-body model



The model schematically

Some state variables, flux densities and parameters

- T_b = body temperature, ~ 37 °C,
- T_S = skin temperature, ~ 34 °C,
- T_{cl} = clothing temperature [°C],
- T_a = air temperature [°C],

- λE_r = latent heat flux of respiration via trap (not denoted) [Wm^{-2}]
- r_{cl} = heat resistance of clothing [sm^{-1}]. It is usually expressed in [Clo].

  1 [Clo] = 186.7 sm^{-1}.

Main equations

- $$r_{cl} = \rho c_p \cdot \frac{T_S - T_a}{M - (\lambda E_{sd} + \lambda E_r) - W} - r_{Hr} \cdot \left(\frac{R_{ni}}{M - (\lambda E_{sd} + \lambda E_r) - W} + 1 \right). \quad (1)$$

r_{cl} is a „resistance” (let you see its resistance dimension [sm^{-1}]) expressing either

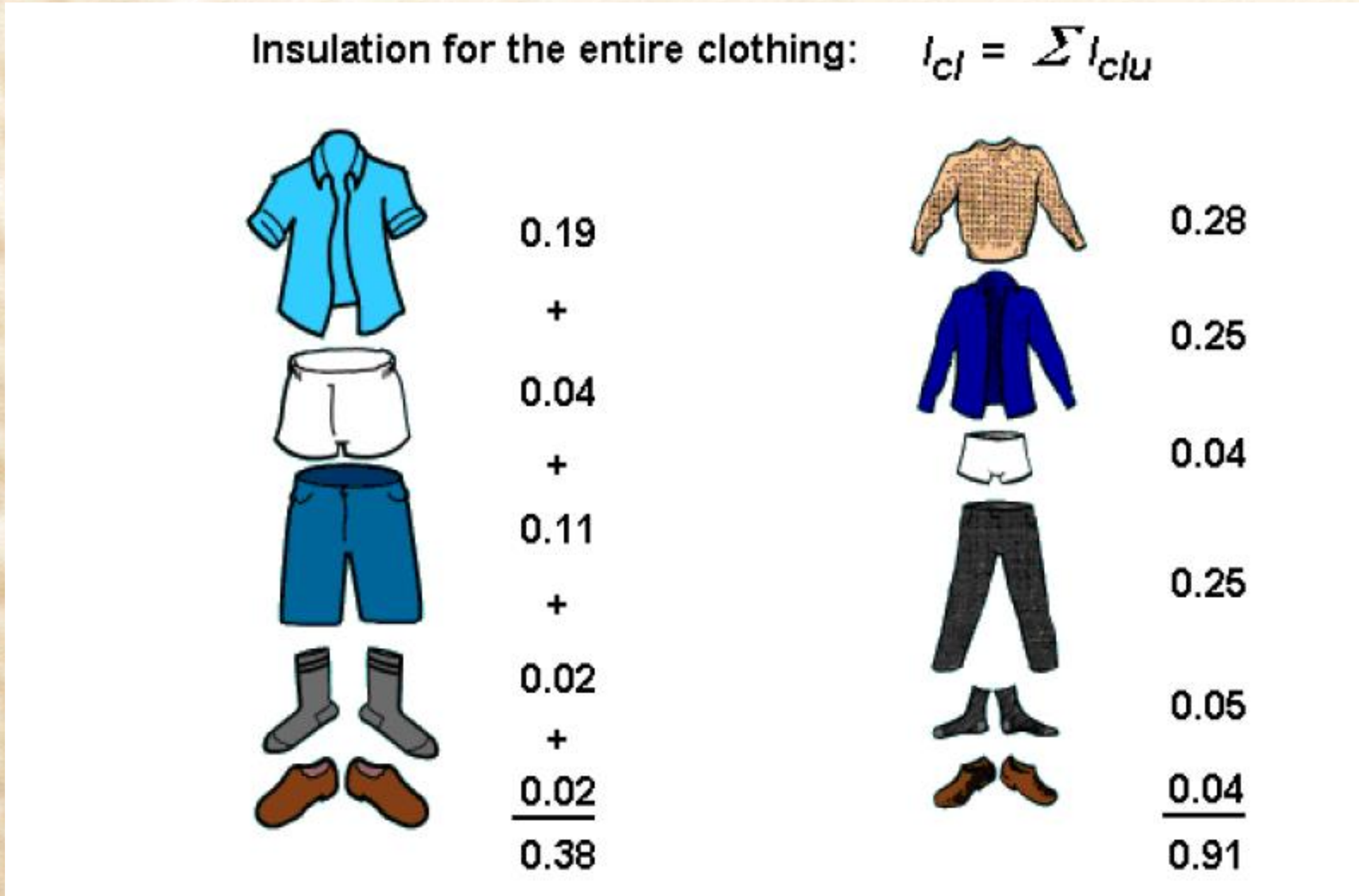
- warming effect in cold weather/climate or
- cooling effect in warm weather/climate

which is needed for reaching heat balance of the human body-clothing system.

Negative r_{cl}

- So far only postive r_{cl} values are used and considered in the scientific literature.
- I do not know the reason why it is so, I presume because there is no such clothing in the day to day life which can refrigerate in warm conditions.

Clothing – [Clo]-values



Main equations

- $T_o = T_S - (r_{Hr} + r_{cl}) \cdot \frac{M - (\lambda E_{sd} + \lambda E_r) - W}{\rho cp}$. (2)

- $T_o = T_a + \frac{R_{ni}}{\rho c_p} \cdot r_{Hr}$. (3)

Net isothermal radiation R_{ni}

$$R_{ni} = S \cdot (1 - \alpha_{cl}) + \varepsilon_a \sigma {T_a}^4 - \varepsilon_{cl} \sigma {T_a}^4$$

S = global radiation, α_{cl} = clothing's or skin's albedo, ε_a = atmospheric emissivity and ε_{cl} = clothing's or skin's emissivity.

In the model, α_{cl} = 0.25-0.27 and ε_{cl} = 1 (the values are taken from literarure). S and ε_a have to be parameterized!

α_{skin}?

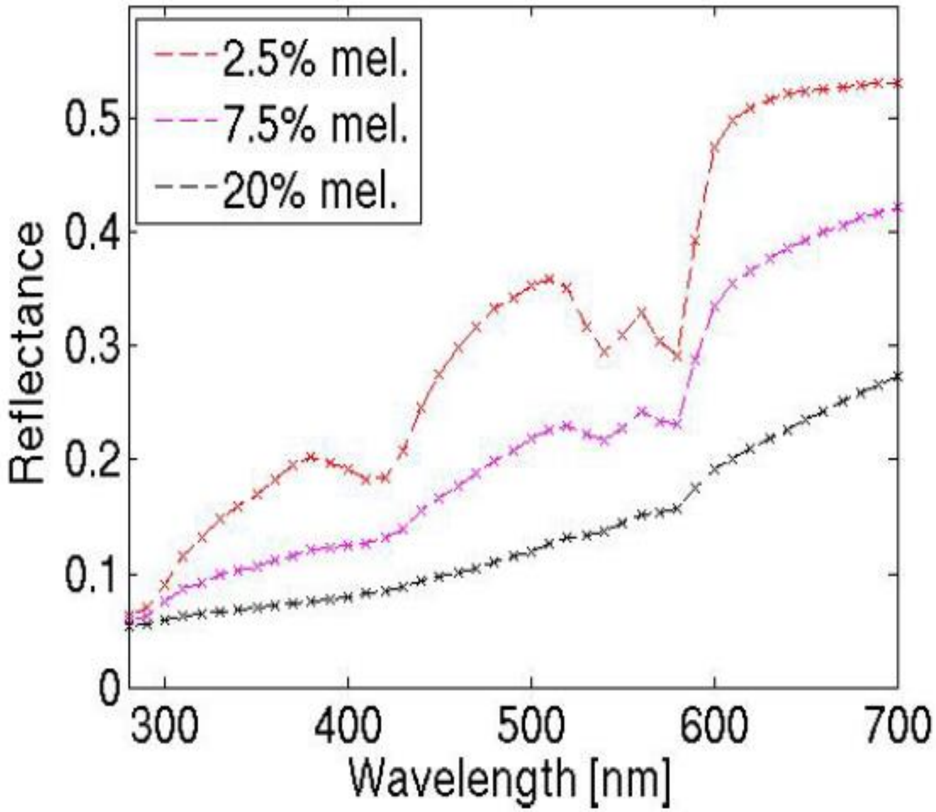


Figure 2. *Skin reflectance in the wavelength regions of UVB (280-320 nm), UVA (320-400 nm) and visible (400-700 nm) for three different concentrations of melanosomes in the epidermis corresponding to skin types II, III and IV, respectively.*

Parameterization of S

- S is parameterized as function of relative sunshine duration (n/N) (Mihailović and Ács, 1985).

- Both hourly [$MJ \cdot m^{-2} \cdot h^{-1}$] and daily [$MJ \cdot m^{-2} \cdot day^{-1}$] values are considered.

- $S = Q_0[\alpha + (1 - \alpha) \cdot \frac{n}{N}]$,

Q_0 values

$$Q'_0 = \sum_{i=1}^{m} Q_{0i} \tag{4}$$

I. TÁBLÁZAT

A számított Q_0 mennyiség óra ($MJ\ m^{-2}$ óra^{-1}) *és napi* ($MJ\ m^{-2}$ nap^{-1}) *értékeinek havi átlaga az 1966–1970 évi periódusra Újvidéken*

Óraköz	J	F	M	A	M	J	J	A	S	O	N	D
4–5					0,523	0,155	0,243					
5–6				0,398	0,440	0,502	0,444	0,410				
6–7			0,586	0,733	0,917	0,996	0,854	0,762	1,139	0,448		
7–8		0,452	0,862	1,197	1,516	1,566	1,520	1,290	0,913	0,586	0,389	0,293
8–9	0,498	0,892	1,390	1,796	2,089	2,114	2,052	1,851	1,453	1,030	0,682	0,829
9–10	0,938	1,331	1,859	2,299	2,621	2,562	2,537	2,299	1,985	1,486	1,080	1,047
10–11	1,340	1,712	2,206	2,625	2,960	2,872	2,876	2,613	2,282	1,813	1,415	1,369
11–12	1,503	1,909	2,366	2,780	3,140	3,128	3,086	2,759	2,433	1,976	1,545	1,344
12–13	1,390	1,897	2,395	2,801	3,107	3,148	3,040	2,759	2,395	1,959	1,541	1,285
13–14	1,344	1,746	2,165	2,587	2,960	2,952	2,914	2,608	2,160	1,792	1,357	1,114
14–15	0,925	1,310	1,817	2,269	2,554	2,625	2,562	2,290	1,846	1,398	0,992	0,821
15–16	0,507	0,846	1,302	1,758	2,131	2,240	2,144	1,905	1,352	0,913	0,578	0,348
16–17	0,167	0,373	0,754	1,214	1,553	1,637	1,562	1,256	0,795	0,452	0,205	0,318
17–18			0,440	0,649	0,946	1,047	0,959	0,670	0,385	0,243		
18–19				0,134	0,377	0,523	0,440	0,209				
19–20					0,126	0,268	0,255					
Nap	8,612	12,468	18,141	23,241	27,959	28,336	27,486	23,681	19,138	14,097	9,785	8,767

α values

Látható fokozatos csökkenésük szeptembertől decemberig, majd hirtelen ug-

II. TÁBLÁZAT (α)

A számított mennyiség óra- és napi értékeinek több éves havi átlaga az 1966–1970. évi periódusra Újvidéken

Óraköz	J	F	M	A	M	J	J	A	S	O	N	D
4–5					0,07	0,37	0,12					
5–6				0,22	0,39	0,47	0,47	0,35				
6–7			0,32	0,46	0,36	0,39	0,59	0,45	0,17	0,11		
7–8		0,35	0,38	0,39	0,36	0,36	0,34	0,38	0,43	0,35	0,18	0,04
8–9	0,39	0,39	0,38	0,34	0,37	0,34	0,35	0,37	0,44	0,36	0,29	0,17
9–10	0,42	0,42	0,39	0,35	0,35	0,32	0,31	0,40	0,42	0,39	0,31	0,28
10–11	0,43	0,39	0,40	0,35	0,32	0,34	0,34	0,37	0,40	0,38	0,30	0,30
11–12	0,42	0,40	0,35	0,34	0,31	0,35	0,35	0,38	0,38	0,41	0,30	0,35
12–13	0,47	0,41	0,35	0,34	0,32	0,37	0,34	0,37	0,35	0,41	0,31	0,37
13–14	0,39	0,39	0,35	0,33	0,31	0,34	0,29	0,33	0,39	0,38	0,30	0,35
14–15	0,41	0,37	0,32	0,34	0,33	0,37	0,31	0,45	0,43	0,35	0,32	0,30
15–16	0,38	0,36	0,32	0,30	0,33	0,32	0,28	0,31	0,40	0,38	0,29	0,35
16–17	0,25	0,33	0,31	0,37	0,30	0,35	0,34	0,37	0,44	0,38	0,22	0,05
17–18			0,18	0,37	0,38	0,34	0,43	0,33	0,34	0,10		
18–19				0,45	0,39	0,42	0,40	0,38				
19–20					0,15	0,22	0,17					
Súlyozott napi átlag	0,42	0,39	0,35	0,34	0,33	0,35	0,34	0,37	0,39	0,37	0,30	0,29

III. TÁBLÁZAT

A konvergencia-együttható értékei havonként az 1966–1970 évi periódusban

	1966	1967	1968	1969	1970		1966	1967	1968	1969	1970
Jan.	0,456	0,235	0,335	0,212	0,281	Júl.	0,100	0,250	0,120	0,250	0,080

Parameterization of ε_a

- ε_a depends on climate type! For Köppen's Cfb climate type the following formula is valid:

- $$\epsilon_a = \left[0{,}319 + 0{,}379 \cdot \left(\frac{e}{T_a}\right)^{\left(\frac{1}{7}\right)}\right] \cdot \left(1 - N^{1{,}7}\right) + 0{,}93 \cdot N^{1{,}7}$$

e is vapor pressure [Pa], T_a is air temperature [K], N is cloudiness (0 for cloudless and 1 for completely overcast conditions).

Parameterization of r_{Hr}

- $\frac{1}{r_{Hr}} = \frac{1}{r_{Ha}} + \frac{1}{r_R} \quad \rightarrow \quad r_{Hr} = \frac{r_{Ha} \cdot r_R}{r_{Ha} + r_R};$

where

$$r_{Ha} = 7{,}4 \cdot 41 \cdot \sqrt{\frac{D}{U_{1,5}}}, \quad \frac{1}{r_R} = \frac{4\varepsilon_{cl}\sigma {T_a}^3}{\rho c_p}.$$

D is diameter of that cylindrical body by which human body is approached. Dimension of r_{Ha}, r_R and r_{Hr} is [sm^{-1}].

Parameterization of M

- M is parameterized for walking human since this movement formation is most frequent in the outdoor environment! Walking's speed is assumed to be 1.1 ms^{-1} (4 $km \cdot h^{-1}$). Metabolic rate (M [Wm^{-2}]) during walking can be expressed as

- $\mathrm{M} = M_b + M_w$

where M_b is the basal metabolic rate and M_w is the metabolic rate referring to walking.

Parameterization of M_b

- M_b can be measured or parameterized! It depends strongly on age, gender, body mass and body length. In this model, Frankenfield et al.'s (2005) parameterization is used!

- Male: $M_b = 9{,}99 \cdot M_b[kg] + 6{,}25 \cdot L_b[cm]$
  $-4{,}92 \cdot age[year] + 5,$
- Female: $M_b = 9{,}99 \cdot M_b[kg] + 6{,}25 \cdot L_b[cm]$
  $-4{,}92 \cdot age[year] - 161.$

Parameterization of M_b

- M_b is given in [kcal·day^{-1}]! To express it in [Wm^{-2}], human body's surface (A) has also to be calculated.

- This is done according to Dubois and Dubois (1915) using body mass [kg] and body length [m] as inputs.

- $A[m^2] = 0{,}2 \cdot M_b[kg]^{0{,}425} \cdot L_b[m]^{0{,}725}$.

Parameterization of M_w

- M_w is parameterized according to Weyand et al. (2010)!

- $M_w = \frac{1.1 \cdot 3.80 \cdot L_b^{-0.95} \cdot M_b}{A}$.

Parameterization of W and $(\lambda E_{sd} + \lambda E_r)$

- W and $(\lambda E_{sd} + \lambda E_r)$ are usually expressed as function of M.

- In this model, W = 0,1·M and

  $(\lambda E_{sd} + \lambda E_r)$ = 0,08·M.

Data

- Model needs two data types: weather/climate and human data.
- Weather data:

Q_0, α (knowing month and hour interval),

n/N (observed in the given time interval),

N (observed in the given time interval),

T_a (taken from web sites or datasets),

e (taken from web sites or datasets),

U_{10} (taken from web sites or datasets; $U_{1.5}$ is calculated assuming logaritmic wind profile)

Source of weather data

- Relative sunshine duration, cloudiness: personal observations in the given time interval,
- All other state variables: web site of the Hungarian Meteorological Service:
- https://www.met.hu/idojaras/aktualis_idojaras/megfigyeles/homerseklet/

Source of human data

- Human data: age, gender, body mass and body length for each person separately. Note D is taken as constant (0.33 m).
- All these data are obtained from Department of Biological Anthropology at ELTE, personally from Annamária Zsákai.
- Some of these data were already published (Utczás et al., 2015; Zsákai et al., 2015) in anthropological investigations!

Systematization of human data

- Human data are organized according to the age: year 7, year 8, year 9, year 10, year 11, year 12, year 13, year 14, year 15, year 16, year 17, year 18, year 19, year interval 20-29, year interval 30-39, year interval 40-49, year interval 50-59, year interval 60-70.
- Each age class is represented only with four „extreme” humans (2 males and 2 females) who possess either the smallest/largest M_b or the smallest/largest L_b.

Human datasets

- So, we have two datasets and two extraordinarily added two persons: UTCI human and me!
- Human data set 1: Male and female humans possessing the smallest and the largest M_b with corresponding L_b for all age classes.
- Human dataset 2: Male and female humans possessing the smallest and the largest L_b with corresponding M_b for alle age classes.

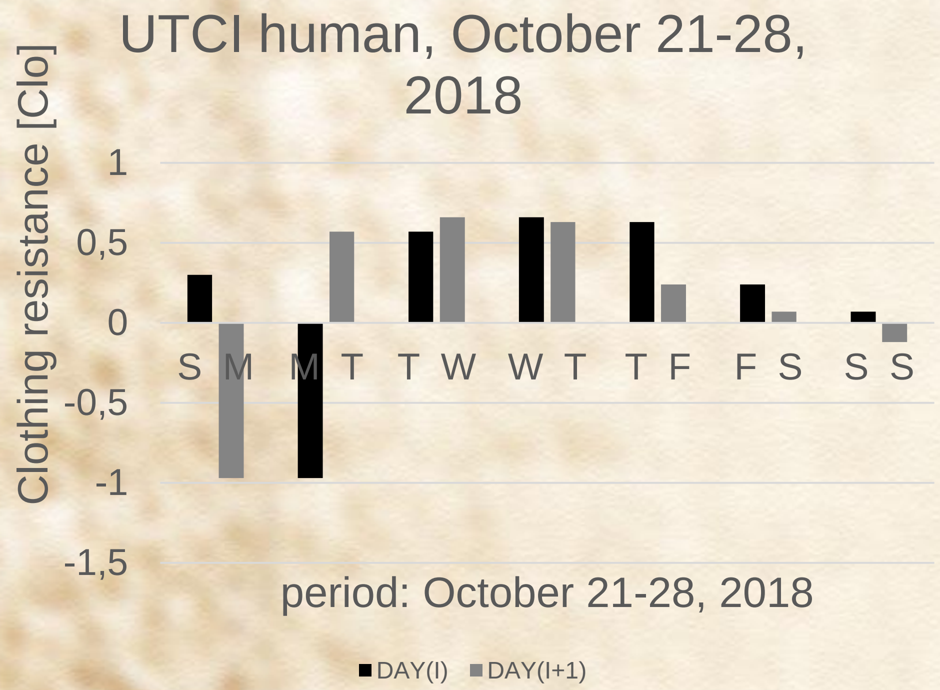
Results

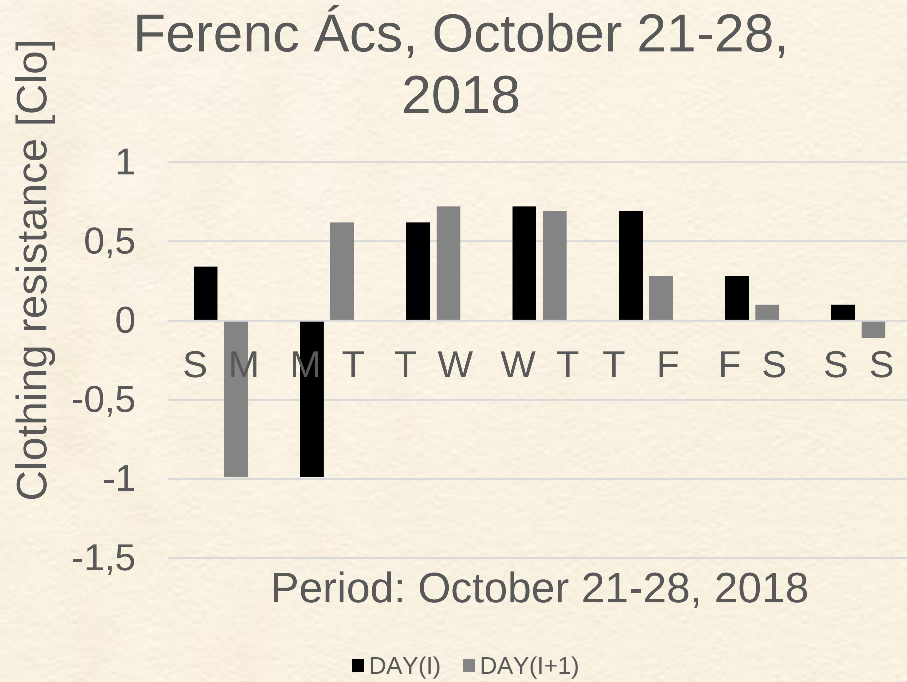
- Human thermal environment is analyzed in terms of r_{cl} and T_o considering both

- weather variations and
- interperson variations of humans.

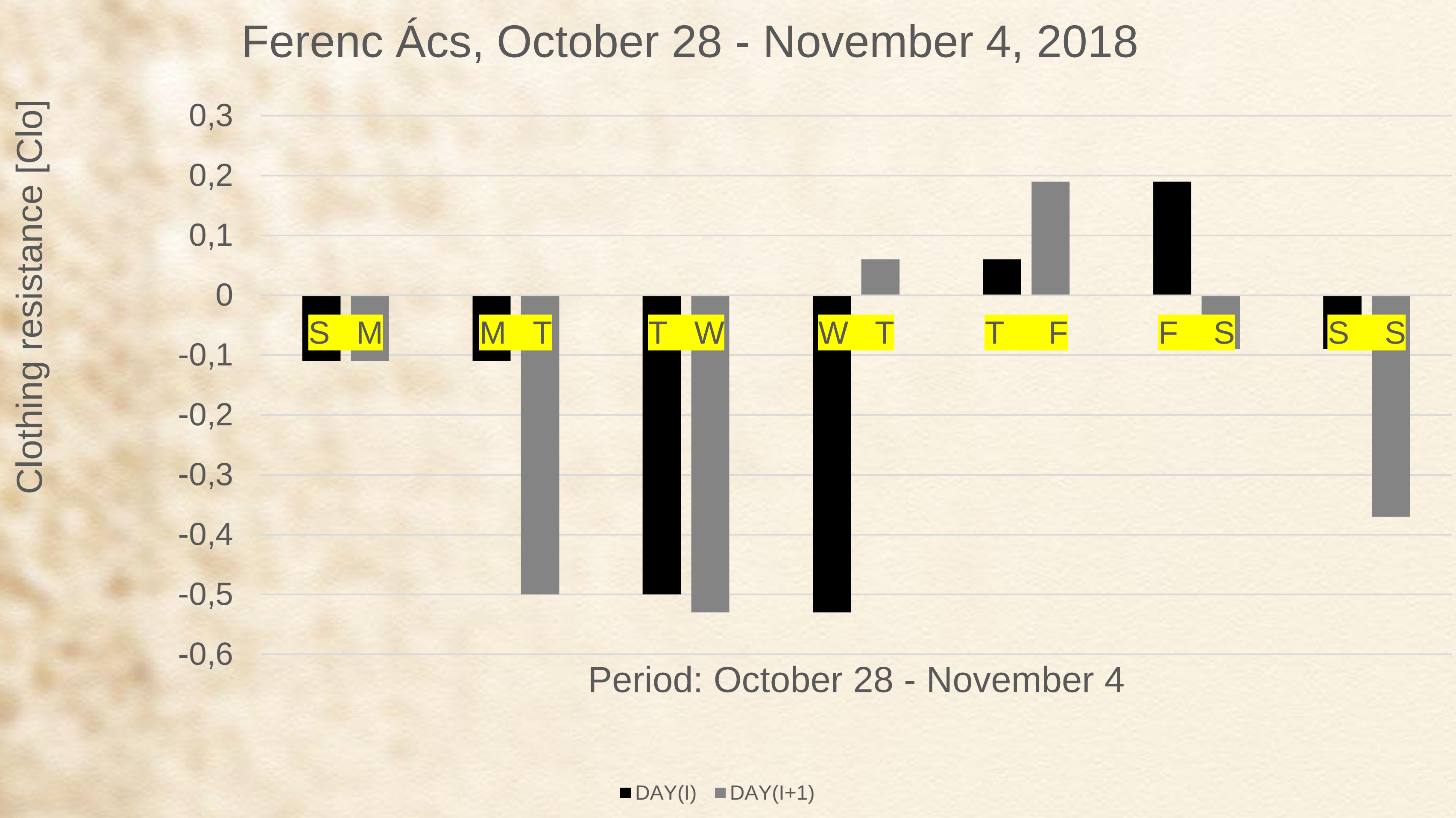
Weather variation effects

Weather variations – 8 days period: October 21-28, 2018

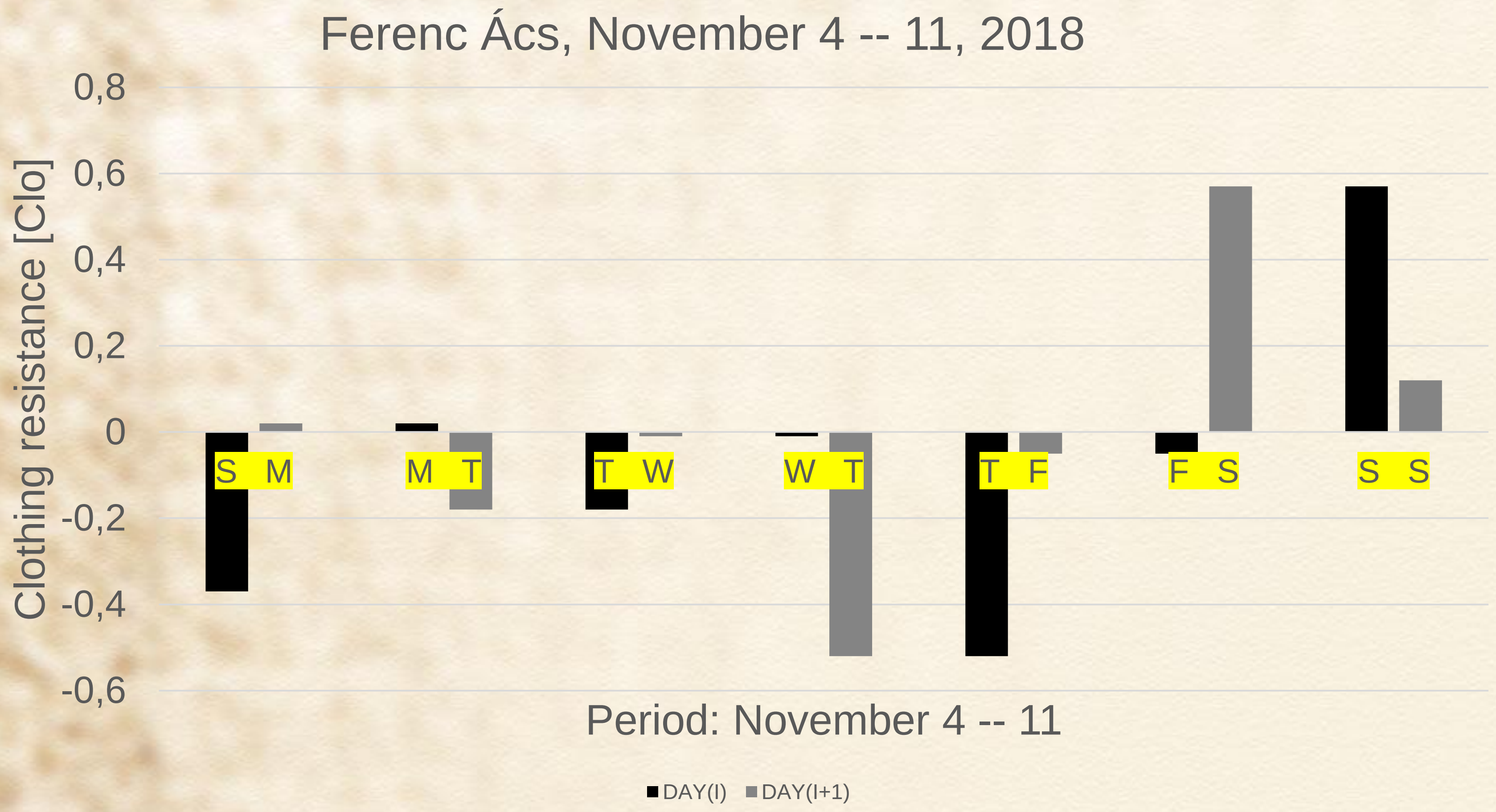




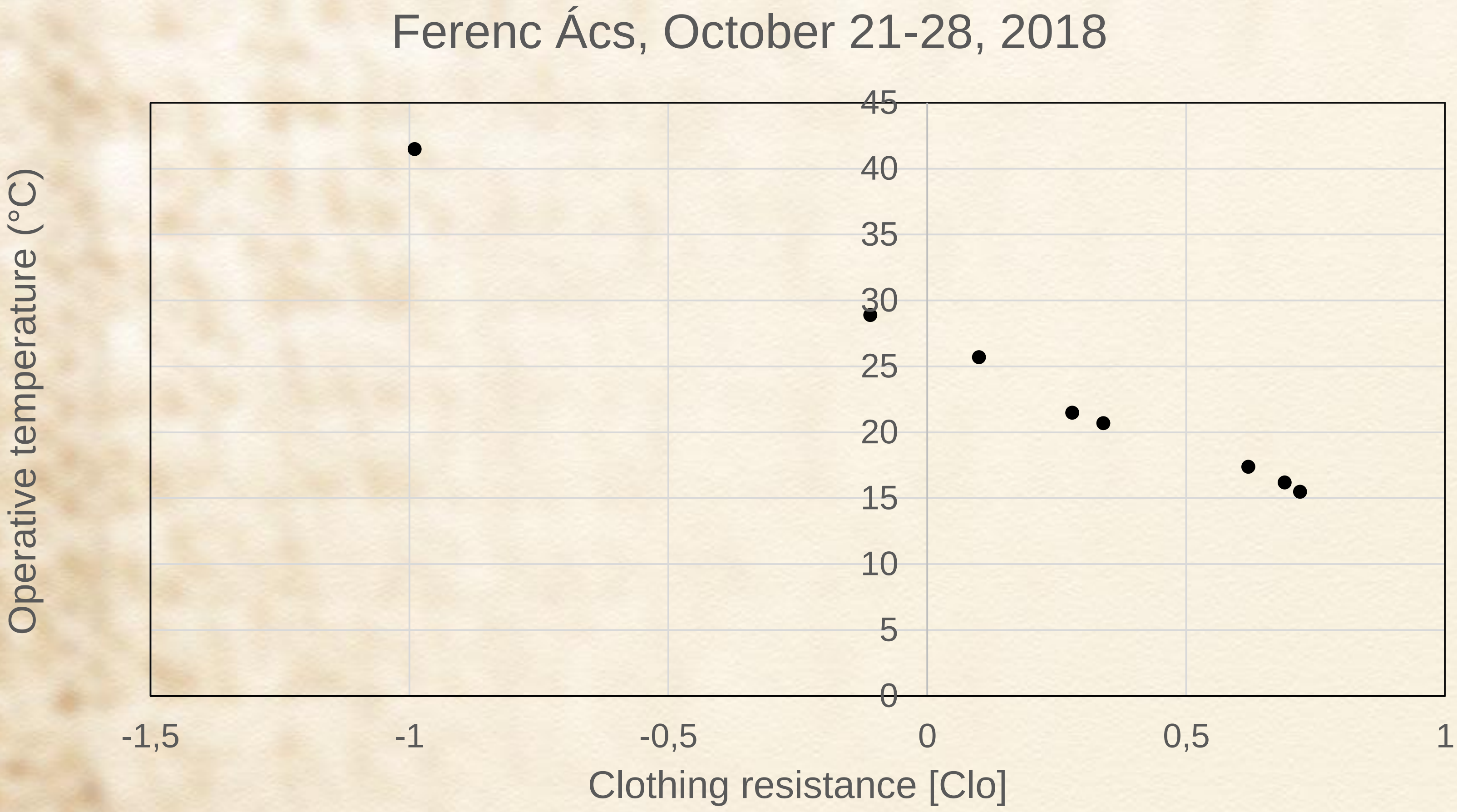
Weather variations – 8 days period: October 28 – November 4, 2018



Weather variations – 8 days period: November 4 – 11, 2018



r_{cl} – T_o relationship



Interperson human variation effects

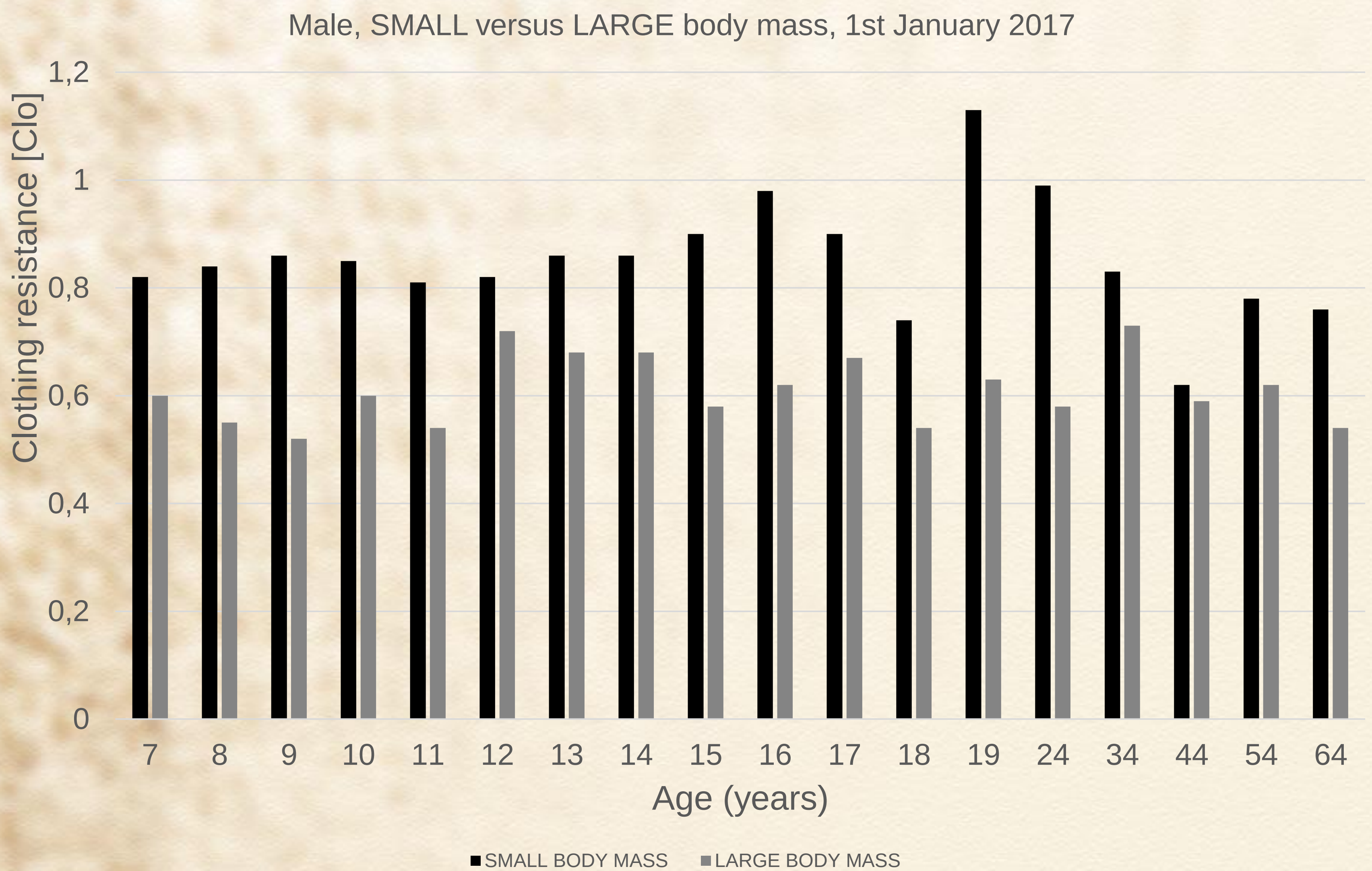
On 1st January 2017

wonderful fog!

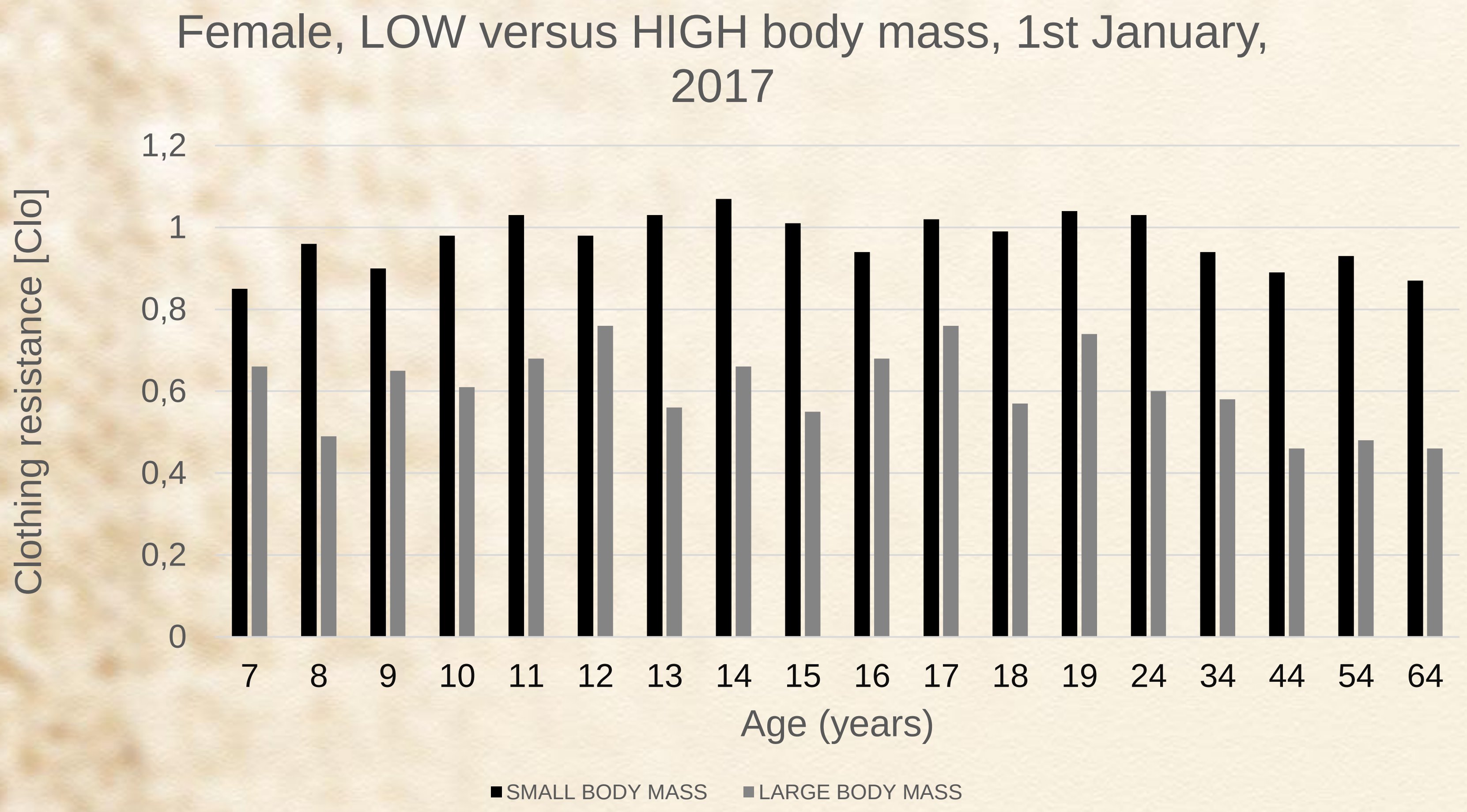
- time interval: 10.49 – 11.40

- Q_0=1,503 $MJm^{-2}h^{-1}$, α=0,42, n/N=0, N=1,
- T_a=-5,0 °C, r=100%, U_{10}=0,80 ms^{-1}.

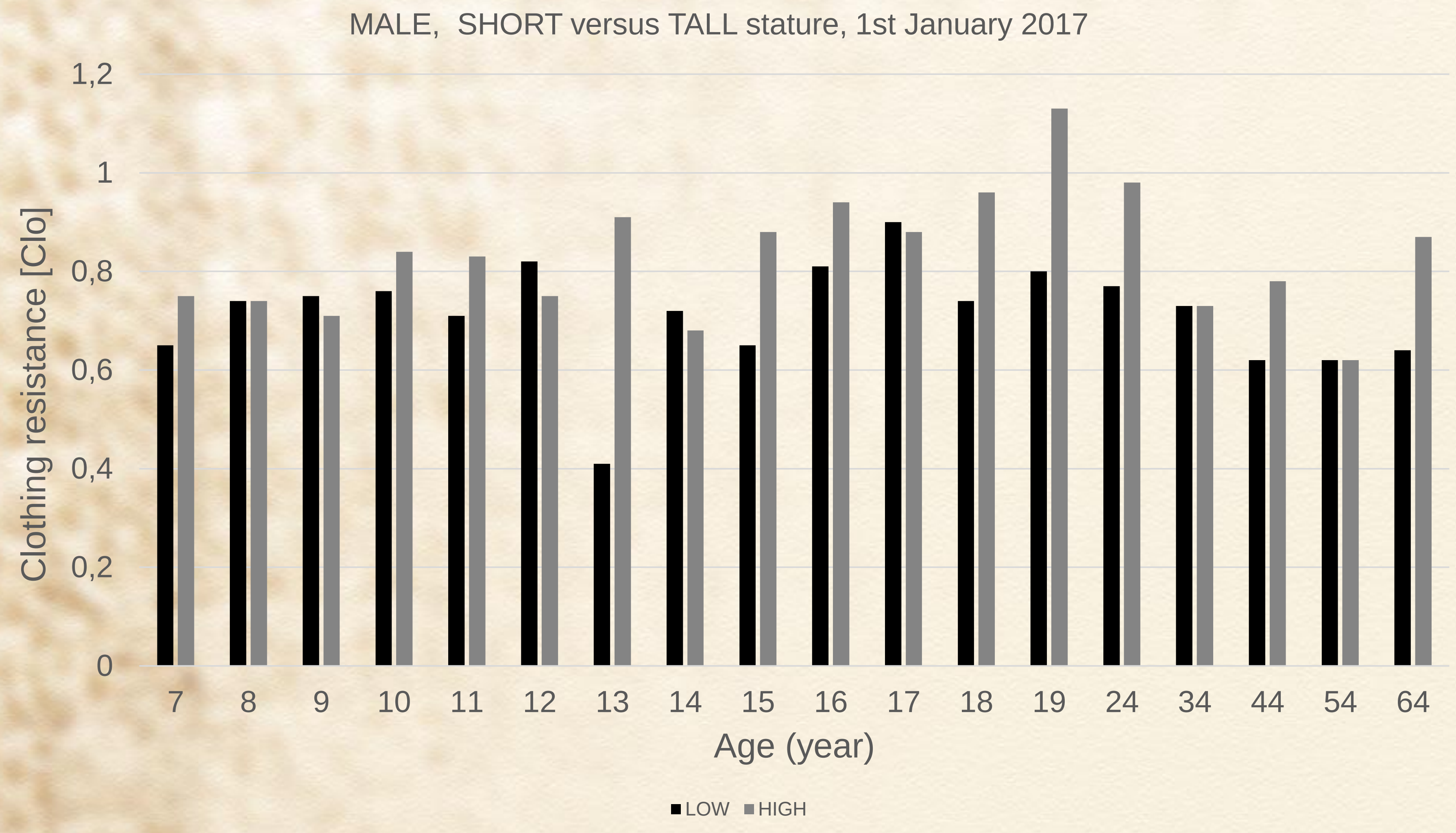
Male, on 1st January 2017



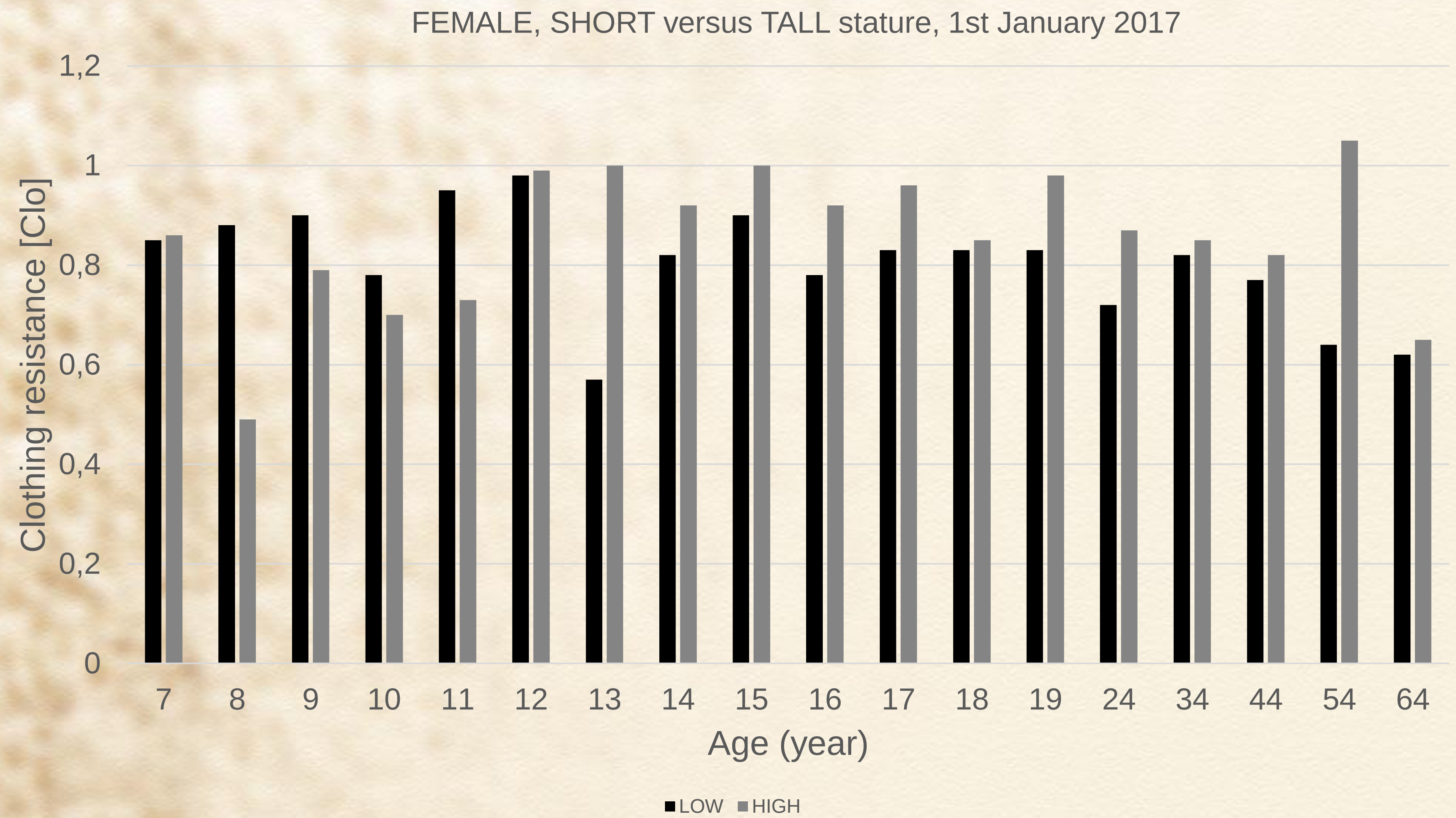
Female, on 1st January 2017



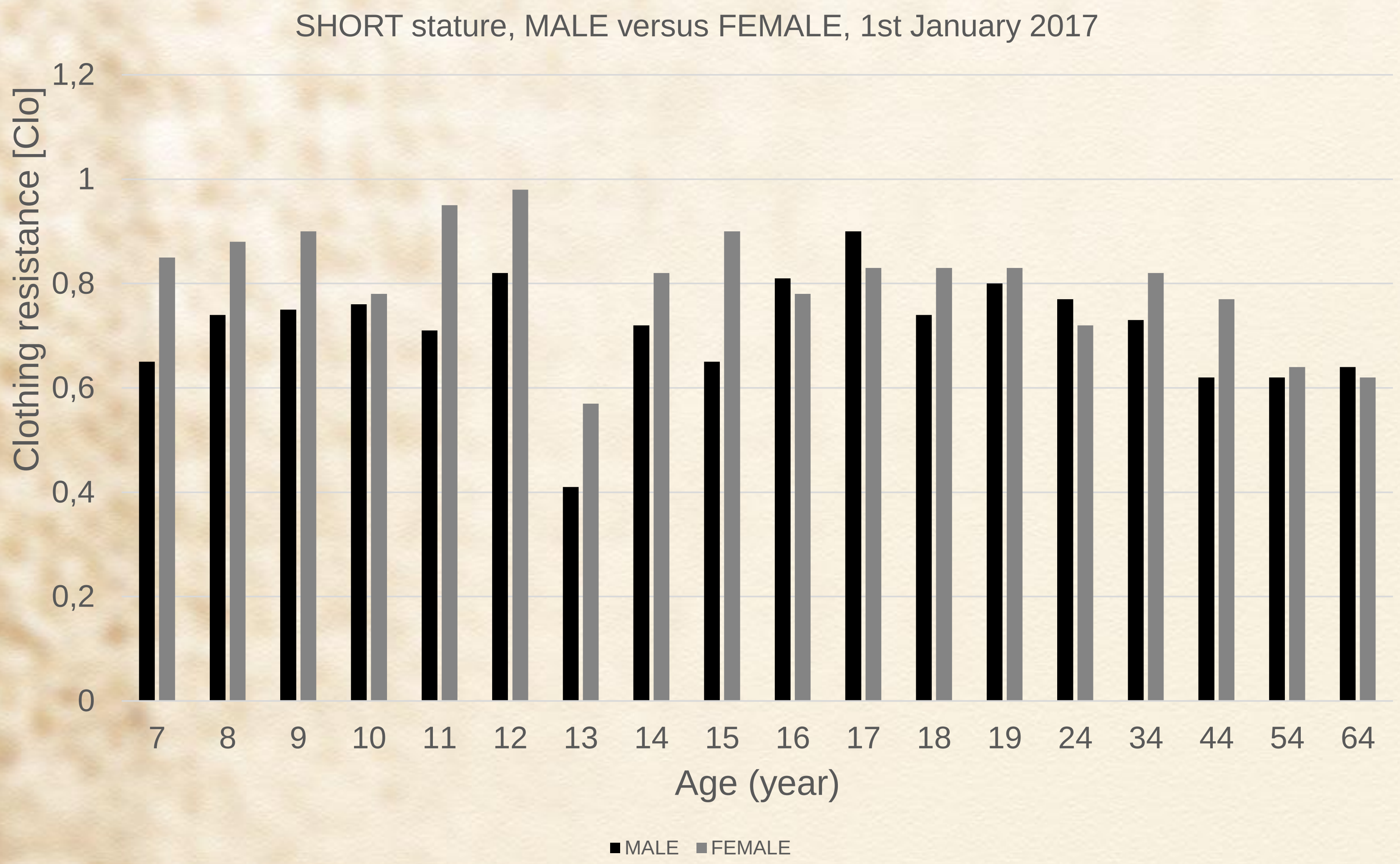
Male, on 1st January 2017



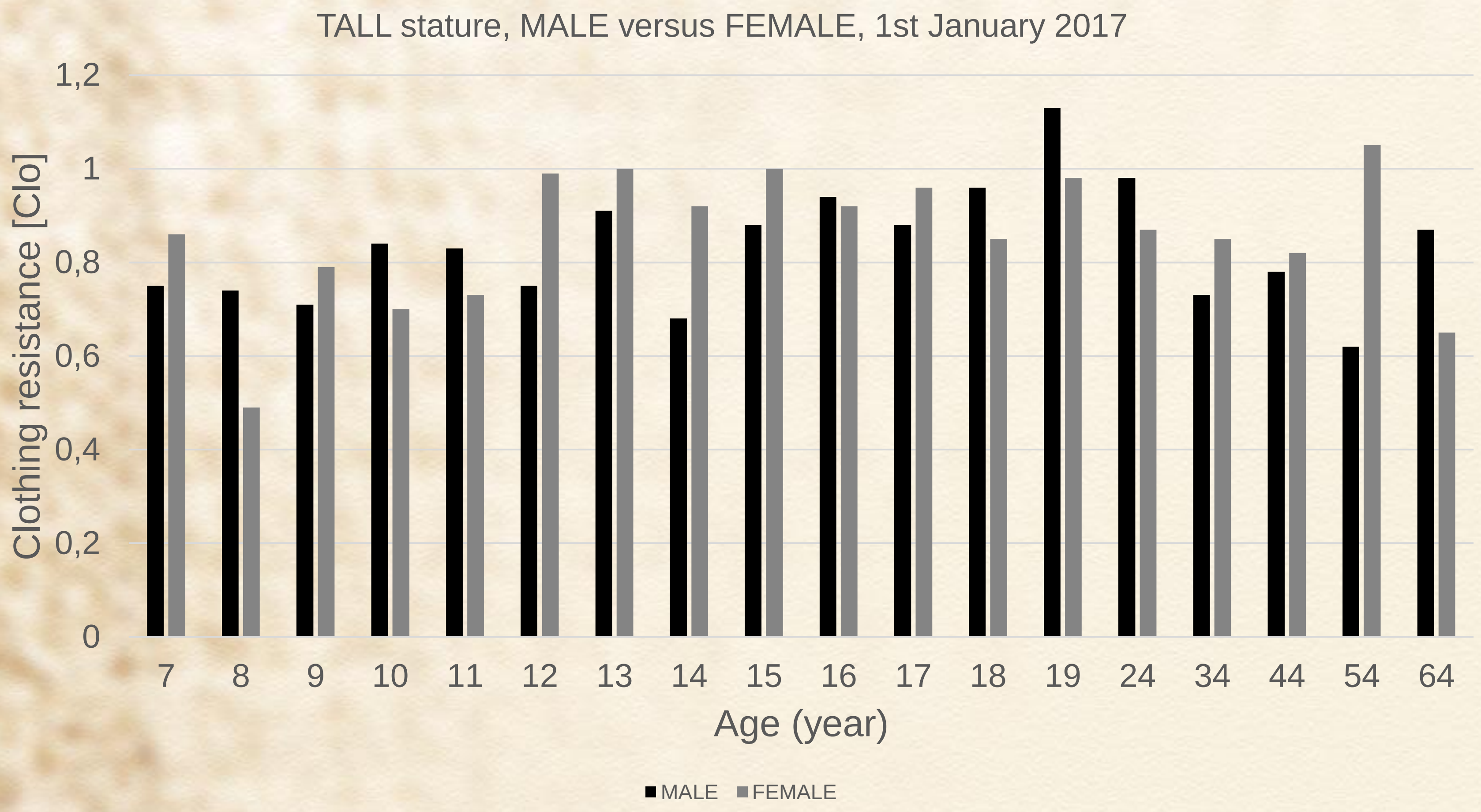
Female, 1st January 2017



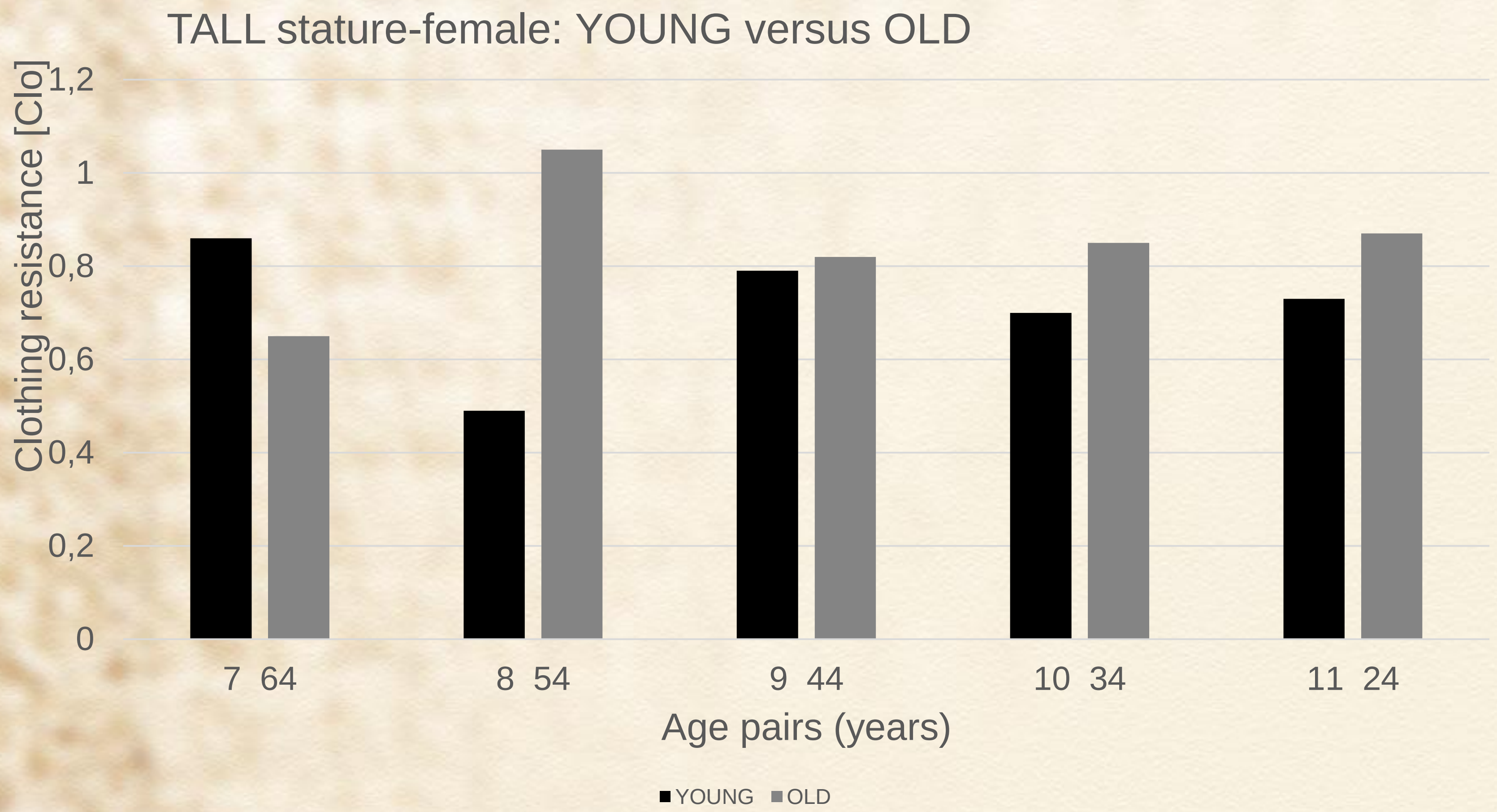
Short stature, on 1st January 2017



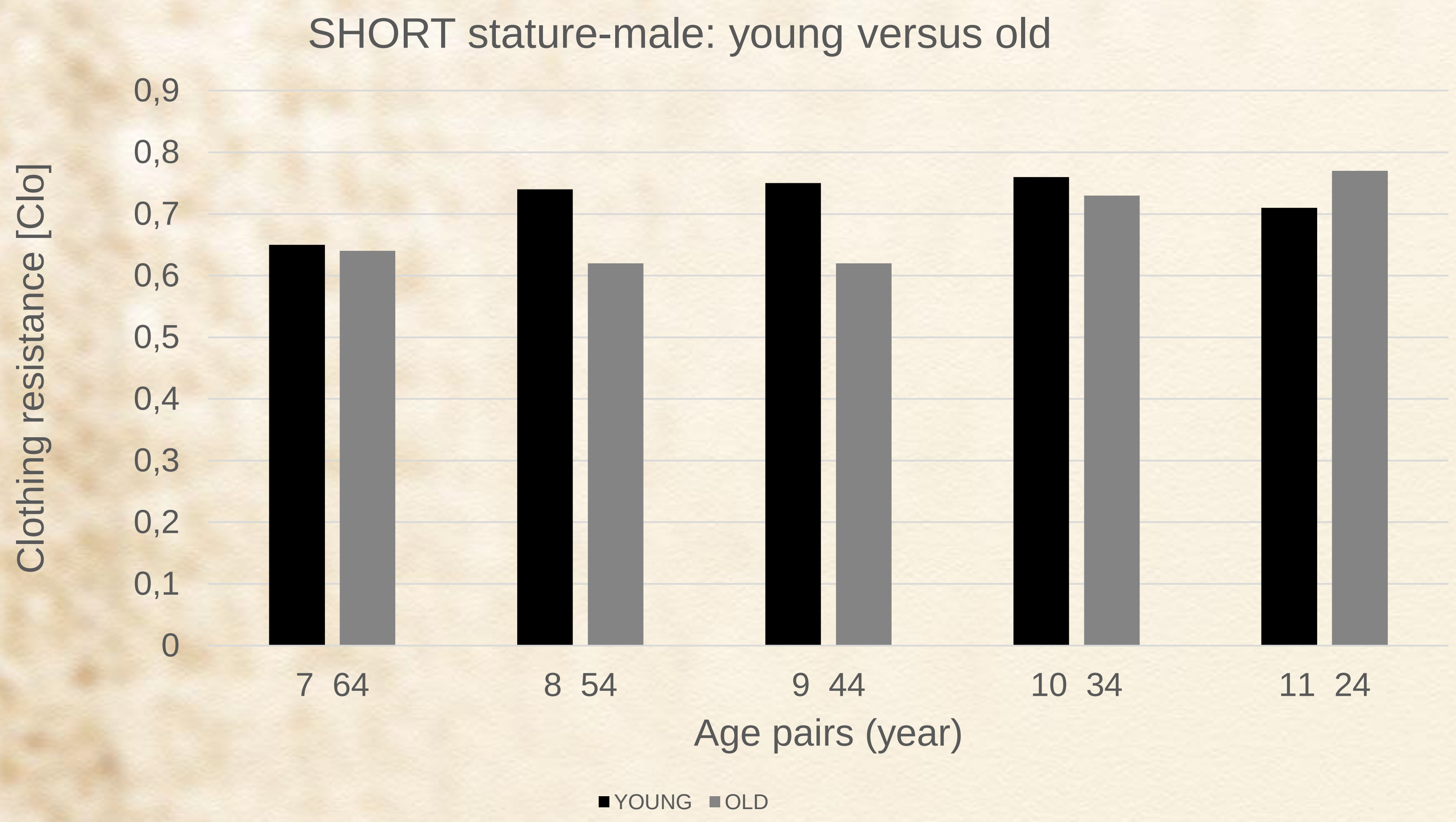
Great stature, on 1st January 2017



On 1st January 2017



On 1st January 2017

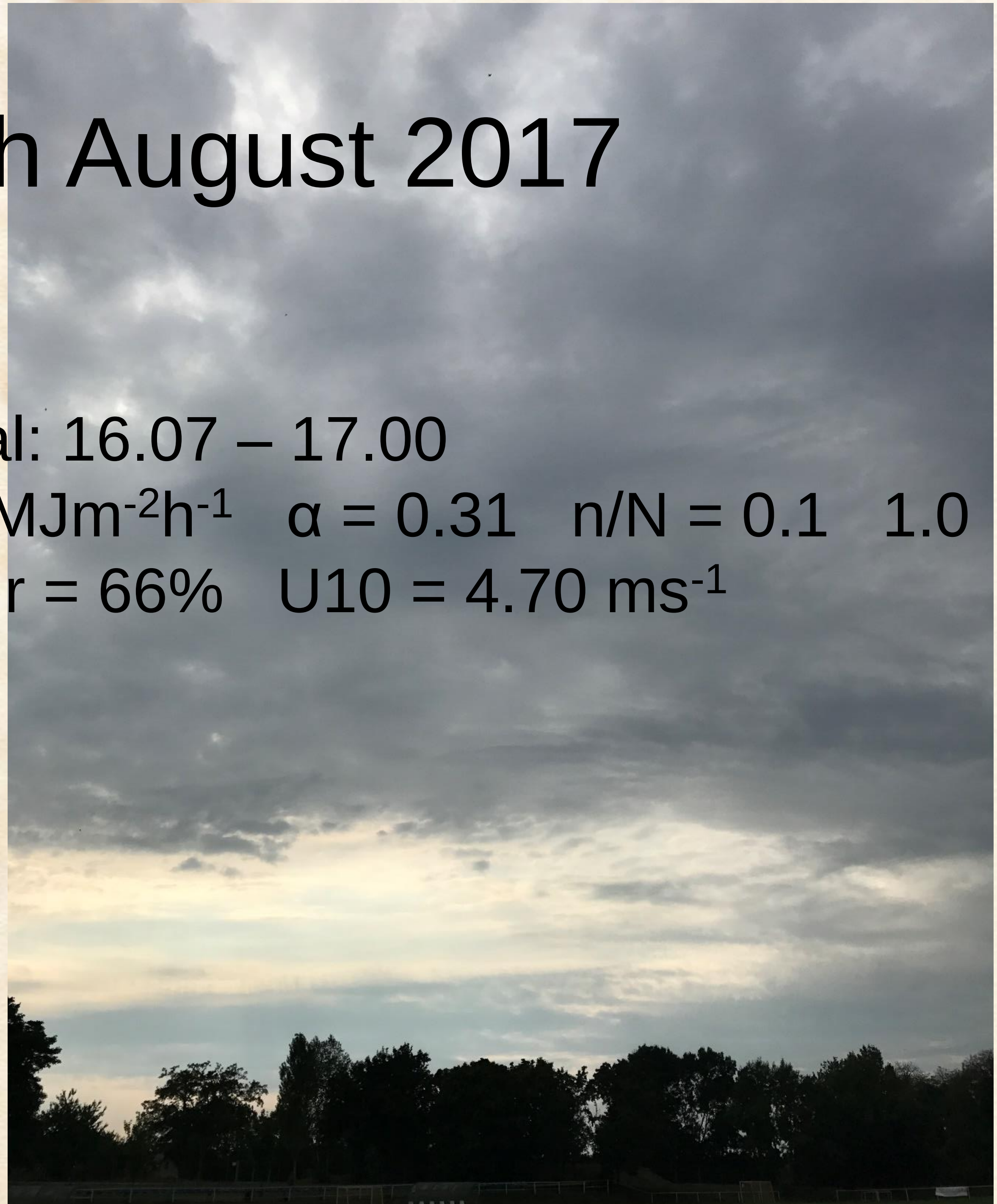


On 19th August 2017

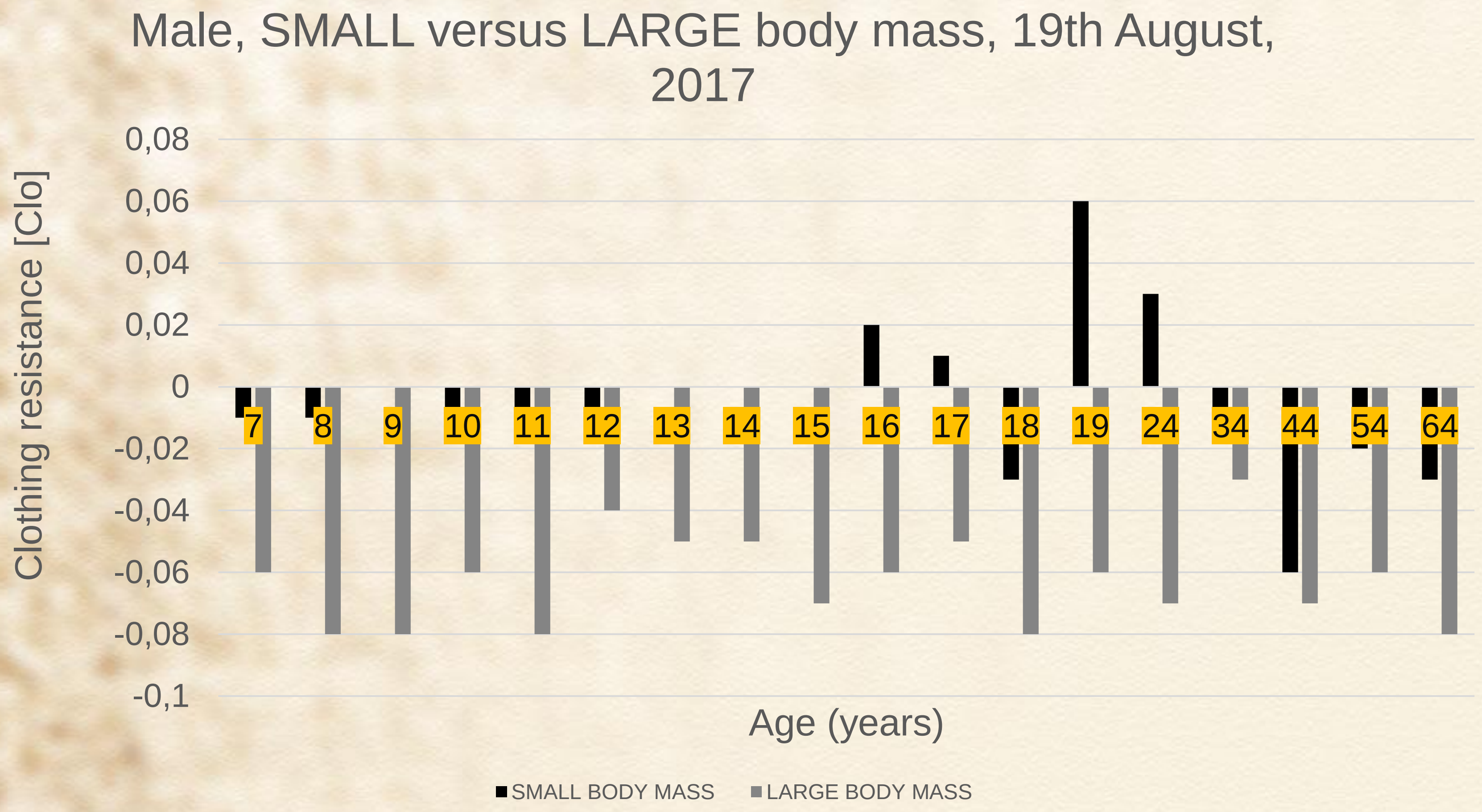
Time interval: 16.07 – 17.00

Q_o = 1.905 $MJm^{-2}h^{-1}$ α = 0.31   n/N = 0.1   1.0

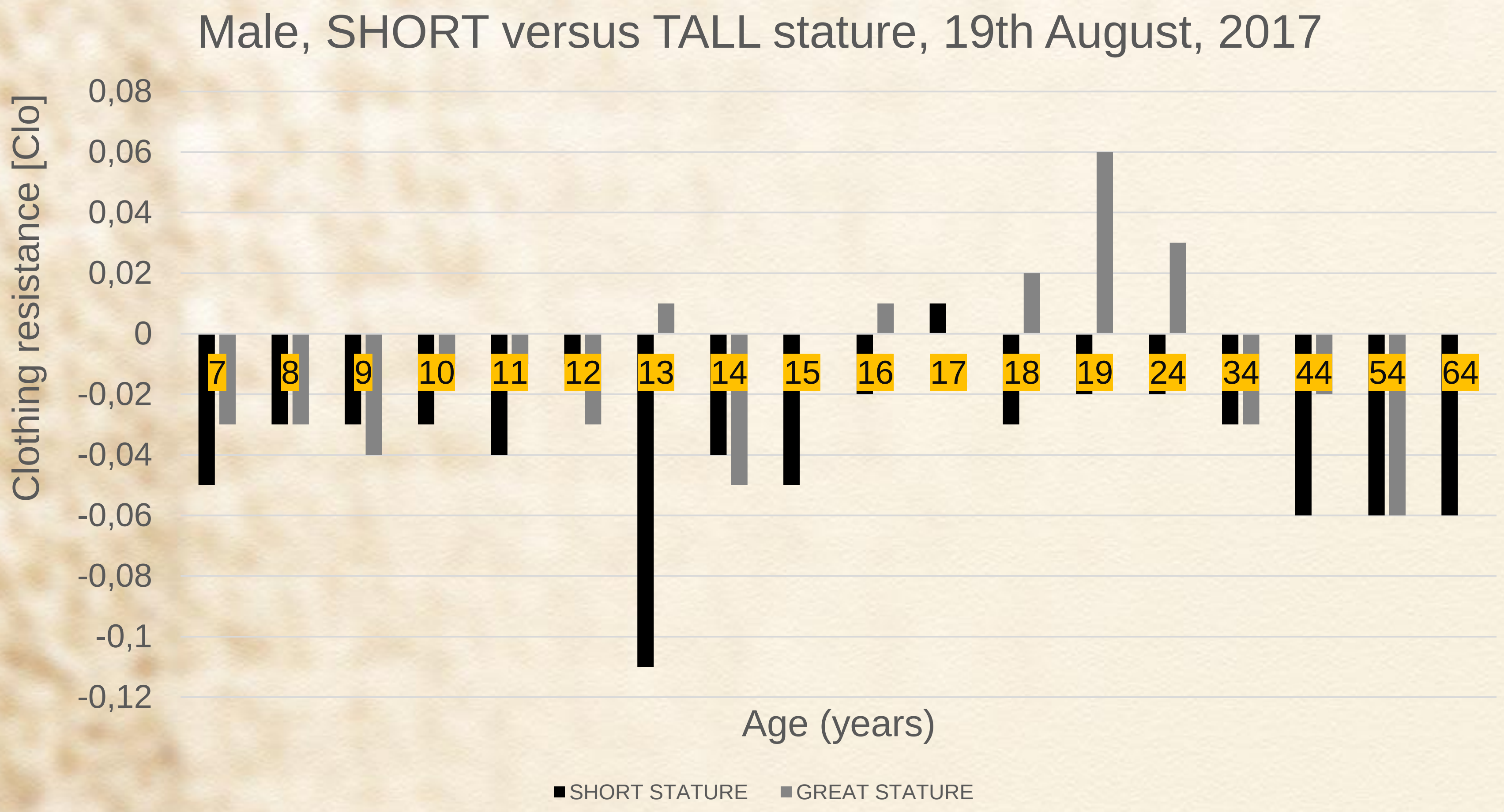
T_a = 23 °C   r = 66%   U10 = 4.70 ms^{-1}



Male, on 19th August 2017



Male, on 19th August 2017

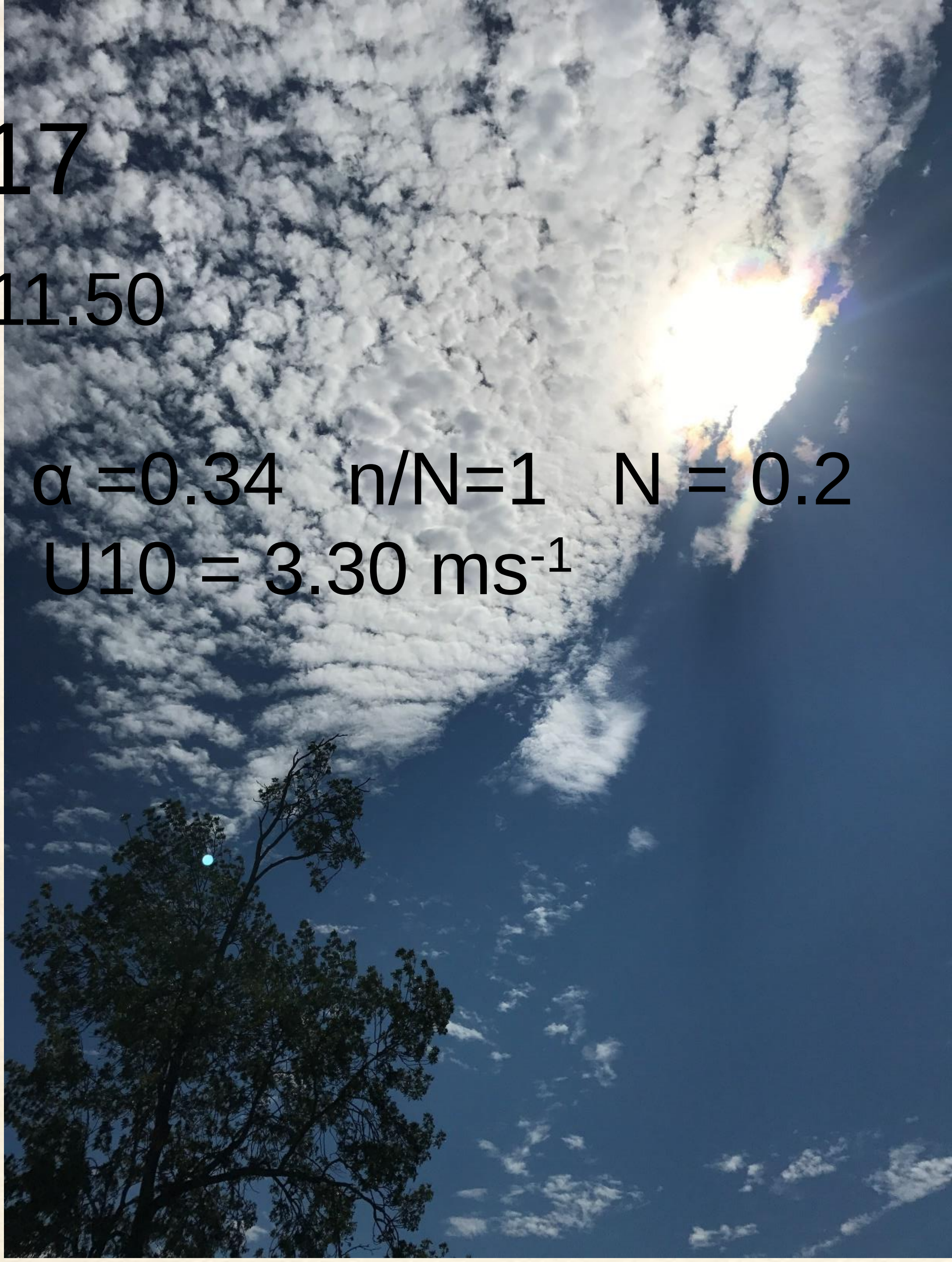


On 30th July 2017

time interval: 11.0 – 11.50

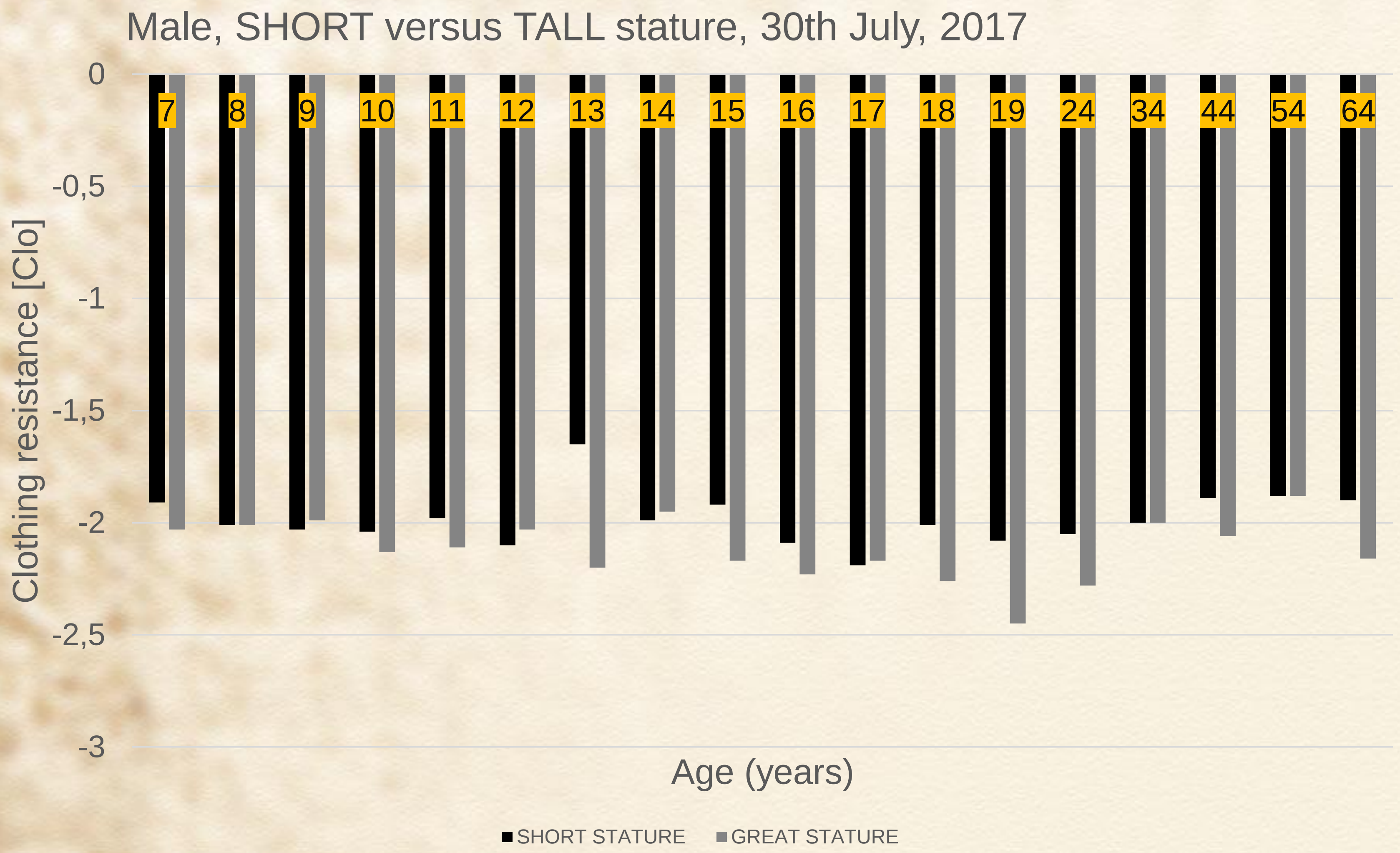
Q_o = 2.876 $MJm^{-2}h^{-1}$ α =0.34   n/N=1   N = 0.2

T_a = 30 °C   r = 40%   U10 = 3.30 ms^{-1}



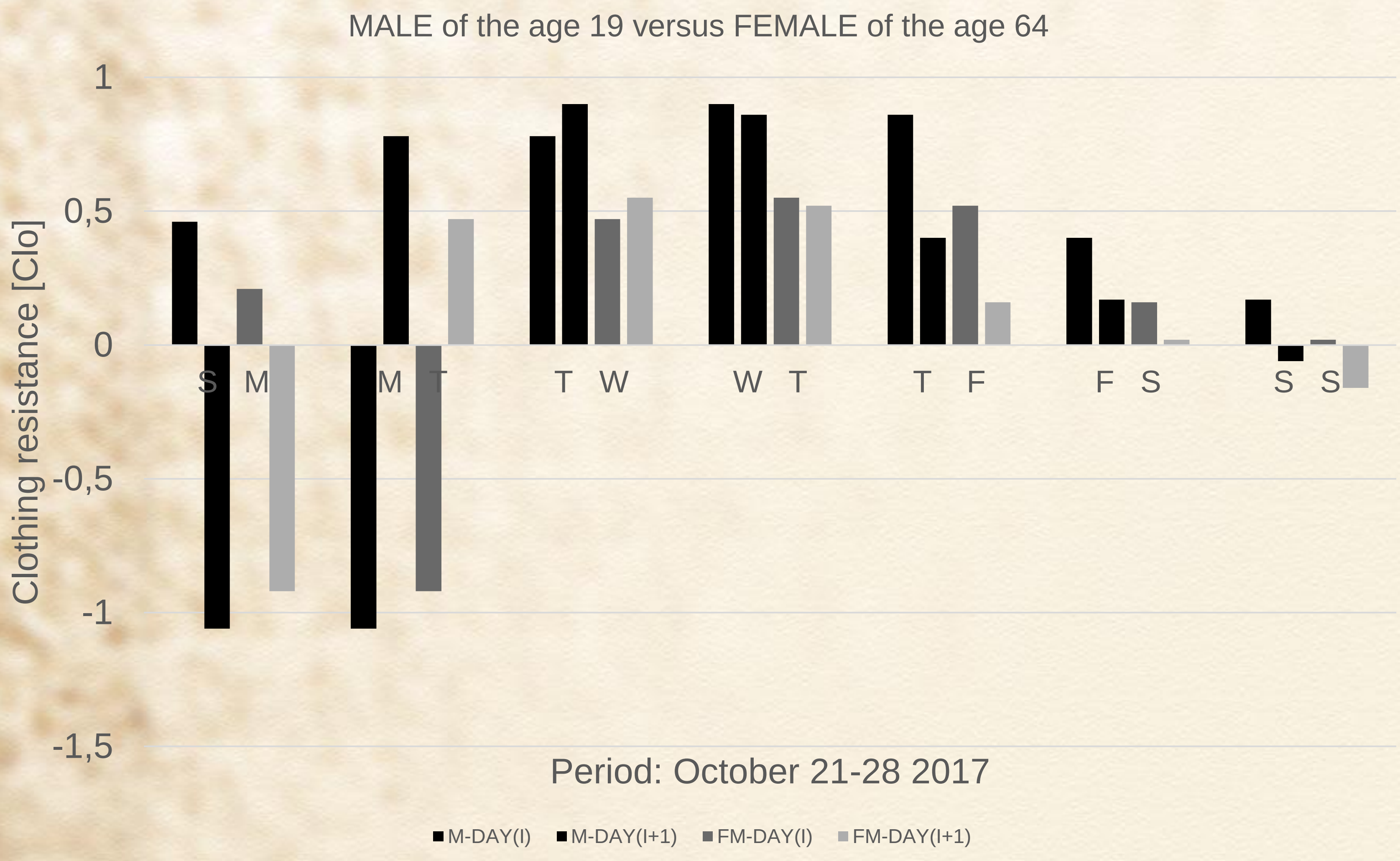
Male, on 30^{th} July 2017

Male, on 30th July 2017

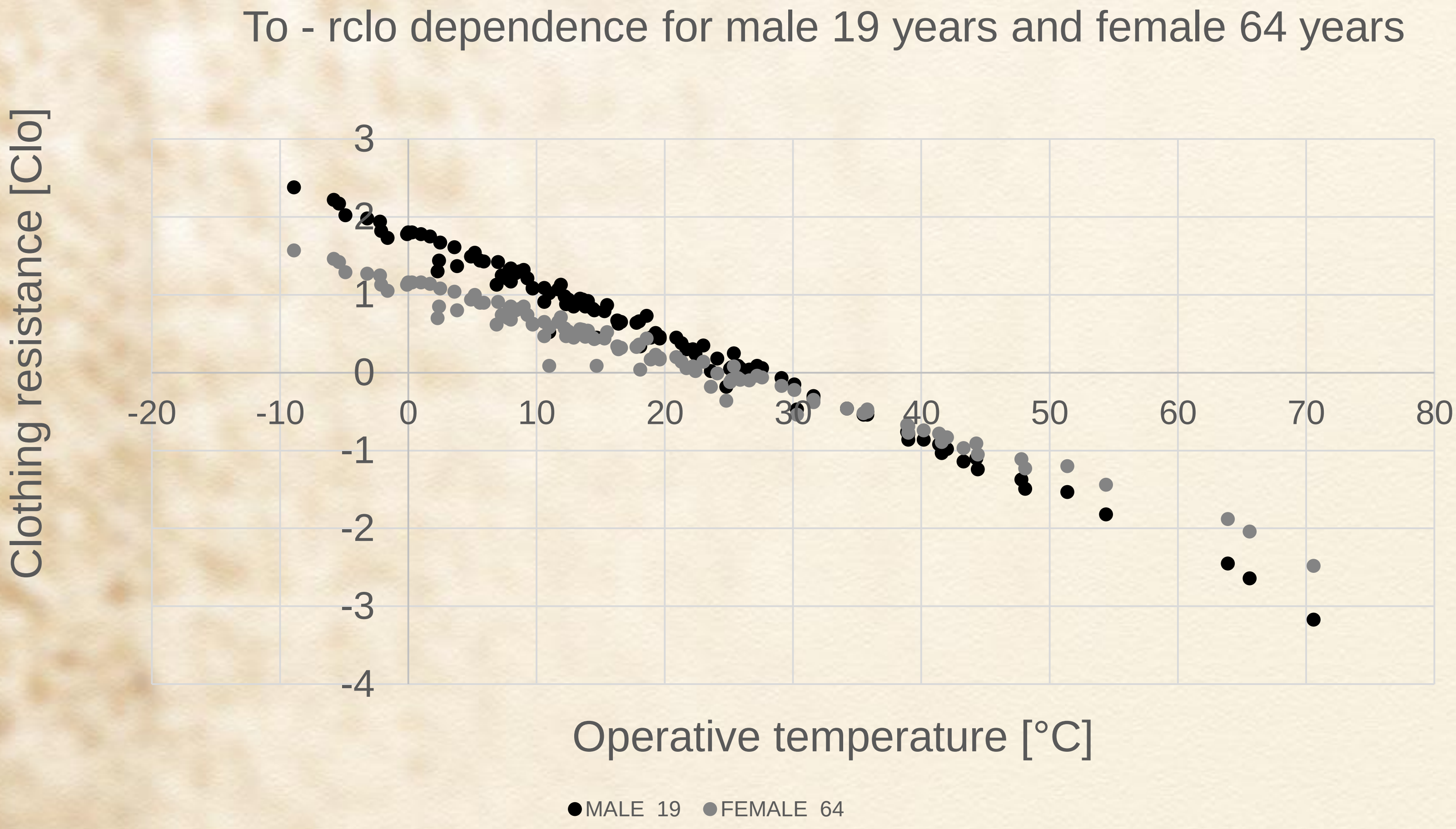


Comparison of weather and interperson human variation effects

Eight days: 21 – 28 October 2018
Two persons: male-19 – female-64



r_{clo} – T_o dependence for a 19 years male (57.1 kg, 195 cm) and a 64 years female (68 kg, 146 cm)



Conclusions

In this presentation, I focused on r_{cl}. r_{cl} expresses

- warming effect in the cold and
- cooling effect in the warm weather

which is needed for reaching heat balance of the human body-clothing system.

So far, r_{cl} is used only for characterizing cold climates! It is not used for characterizing warm weather or climate at all.

Conclusions

- r_{cl} seems to be suitable for characterizing thermal impact of weather variations (changes from warm to cold or from cold to warm) on the humans.
- r_{cl} depends not only on weather but also on metabolic rate! Consequently it varies from person to person, when the weather is the same.
- It seems to be that interperson variation is mostly determined by variations in body mass.

Conclusions

- In general, r_{cl} changes induced by weather changes are much greater than r_{cl} changes induced by interperson variations.
- Note that r_{cl} differences between persons of small and large body mass can reach 0.5 [Clo] which is not negligible at all.

Conclusions

- Lastly, our basic question, how shoud we be clothed today, will remain perpetually.

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