Implications of climate change on the manufacturing sector in Slovenia: with particular reference to summer heat

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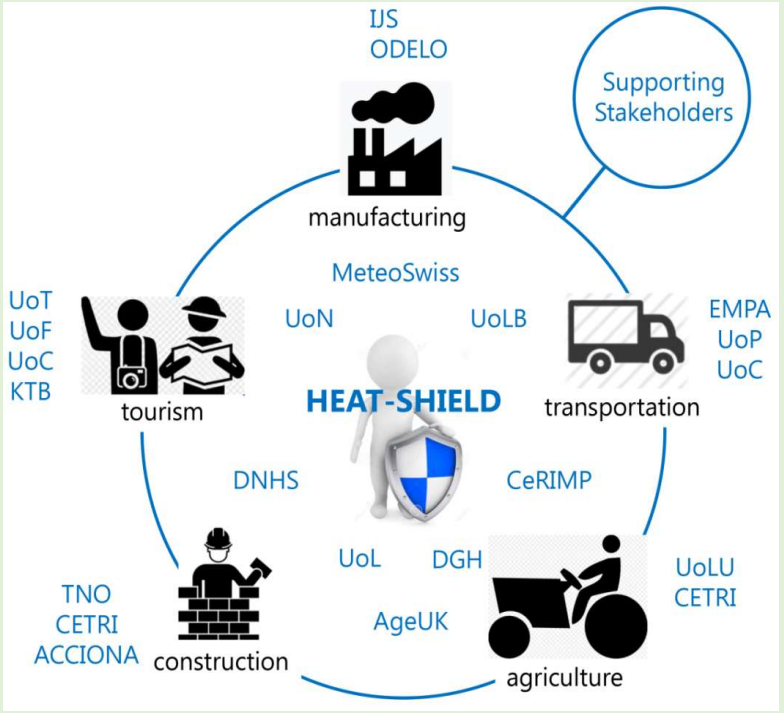
Occupational exposure to heat without sufficient protection

- increases the risk of heat-related illnesses and injuries
- and compromises economic productivity by reducing work efficiency

The European Commission has recently initiated a programme of research (**the HEAT-SHIELD project**) **to assess the effect of the present and projected changes in climate on workers** in five strategic industries (transport, construction, manufacturing, tourism, and agriculture) representing approximately 40% of the workforce in Europe.

HEAT SHIELD

https://www.heat-shield.eu/

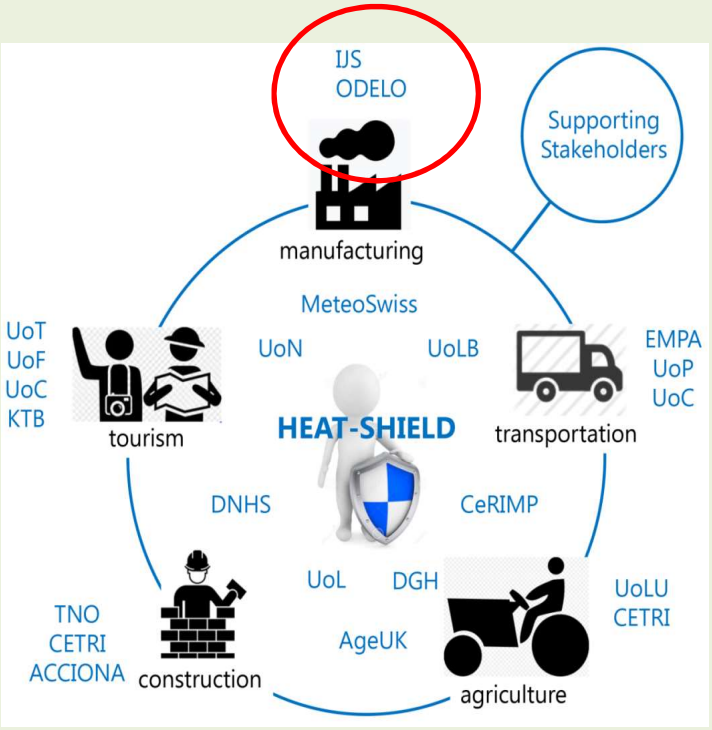


The purpose of the study was

- climatological analysis of summer heat in combination with the occupational heat stress, focussing on the local climate conditions in the region of the odelo d.o.o. manufacturing plant (Prebold, Slovenia)

- The study also surveyed the workers in the odelo d.o.o. manufacturing plant regarding on how the heat waves affected them during the summer heat waves of 2016

HEAT SHIELD



Specific Objective 1 Forecast weather patterns for various climate change scenarios

Specific Objective 2 Assess the effects of different weather patterns

Specific Objective 3 Define technical and biophysical solutions to promote worker health and prevent disease

Specific Objective 4 Formulate relevant guidelines

Specific Objective 5 Develop an online open access service and disseminate adaptation guidelines

Specific Objective 6 Assess the effectiveness of formulated strategies

Climatological analysis – past and current temperature conditions, trends and forecasts

VARIABLES: Summer mean and maximum air temperatures, Hot days, Heat stress index

Variable	Symbol	Description	Unit
Tmean	TmeanJJA	Summer mean temperature	°C
	trTmeanJJA	Summer trend of TmeanJJA	°C/decade
Tmax	TmaxJUL	Monthly (July) mean of daily maximum temperature	°C
	HD	Summer hot days (i.e. number of summer days with Tmax>=30°C)	days
	trTmaxJUL	Summer trend of TmaxJUL	°C/decade
	trHD	Summer trend of HD	days/decade
WBGT	WBGTmean	Summer mean WBGT-wet bulb globe temp.	°C
	WBGTx	Summer maximum WBGT	°C
	WBGTg27	Number of summer days with WBGT>27°C	days

Simplified Wet Bulb Globe Temperature

$$sWBGT = 0.567\,T + 0.393\,vp + 3.94$$

(Sherwood and Huber, 2010)

$$vp = \frac{RH}{100}\,6.105\,e^{\frac{17.27\,T}{237.7+T}}$$

T	air temperature (°C)
vp	vapor pressure (hPa)
RH	relative humidity

- The WBGT is the ISO standard for quantifying thermal comfort (ISO 7243, 2017)

- 26 °C is the upper WBGT at which physical labour can be conducted at full productivity (above that value = extreme heat stress risk)

Data archive: Slovenian Environment Agency (ARSO);
Ministry of the Environment and Spatial Planning

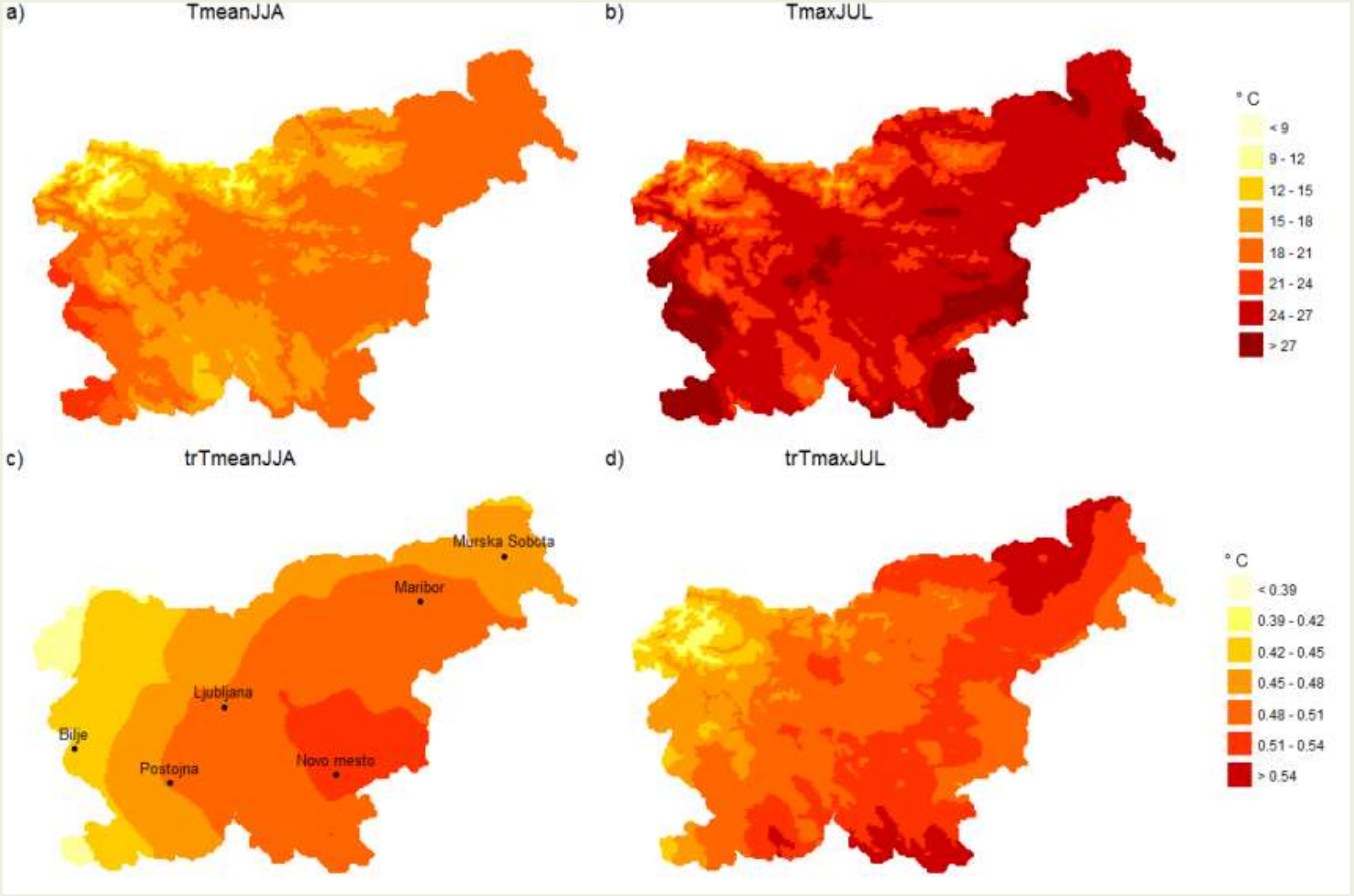
PAST CONDITIONS (1981-2010): Data from 60 weather stations were used to build a gridded map, based on the homogenized time series of **daily mean and maximum air temperatures, dew point temperatures**

The **51-year period (1961–2011) was used for calculating *LONG-TERM TRENDS***. This non-standard period was used since it was assigned in the project "Climate variability of Slovenia" of ARSO

FUTURE CONDITIONS (2070-2099): A set of 16 point stations were considered for the climate change projections, reference period 1981-2010
- RCM simulations from the EURO-CORDEX initiative were used to project future heat conditions in Slovenia (84 simulations (RCM-GCM chains spanning different combinations of RCMs and GCMs, covering three Representative Concentration Pathways -RCP2.6, RCP4.5, RCP8.5

Detailed Methods:
Pogačar T., Casanueva A., Kozjek K., Ciuha U., Mekjavič I.B., Kajfež-Bogataj L., Črepinšek Z. 2018. **The effect of hot days on occupational heat stress in the manufacturing industry: implications for workers' well-being and productivity**. *International Journal of Biometeorology*, 62:1251-1264

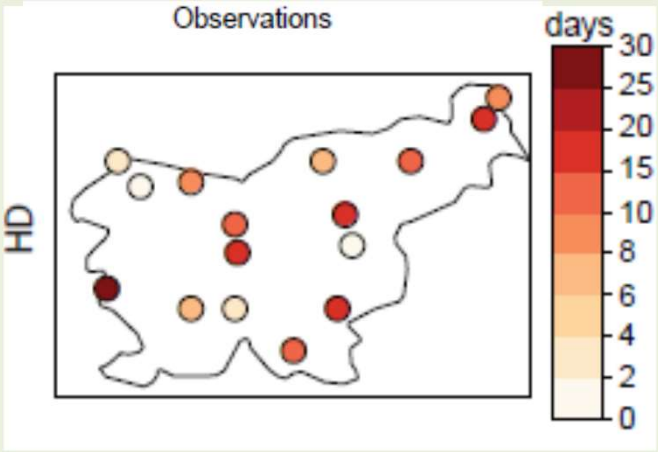
RESULTS



The spatial distribution of 30-year (1981-2010) mean summer temperature (a), 30-year (1981-2010) mean maximum temperature of the hottest month (July) (b), 51-year (1961-2011) long-term trend of mean summer temperature (c) and 51-year (1961-2011) long-term trend of mean maximum temperature of the hottest month (d)

- **Overall trends range from 0.4 to 0.6 °C per decade**

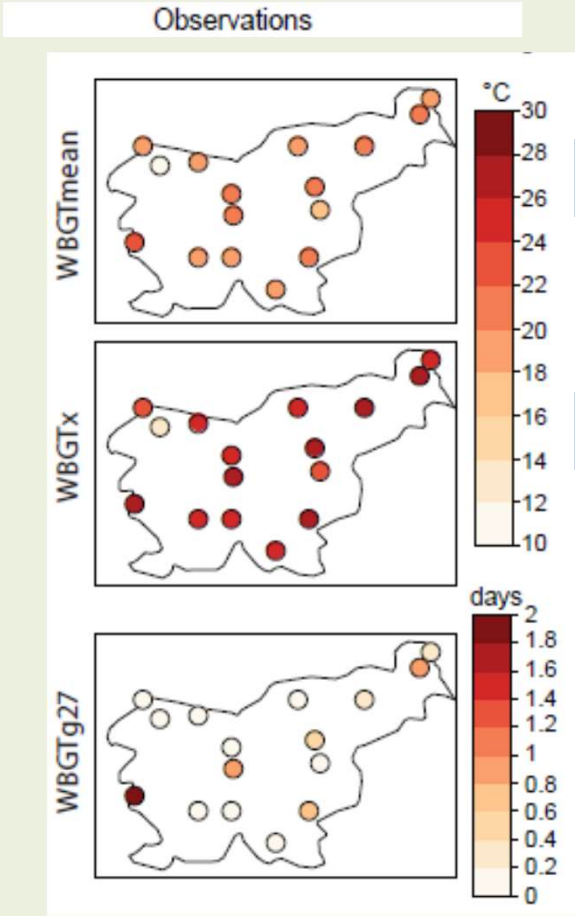
Number of hot days (T>30°C)



Period 1981-2010

The highest number of hot days was found in Bilje, on average 31 days/summer, values are much smaller elsewhere, trend was positive – overall more than 3 days/decade.

Heat stress index (WBGT)



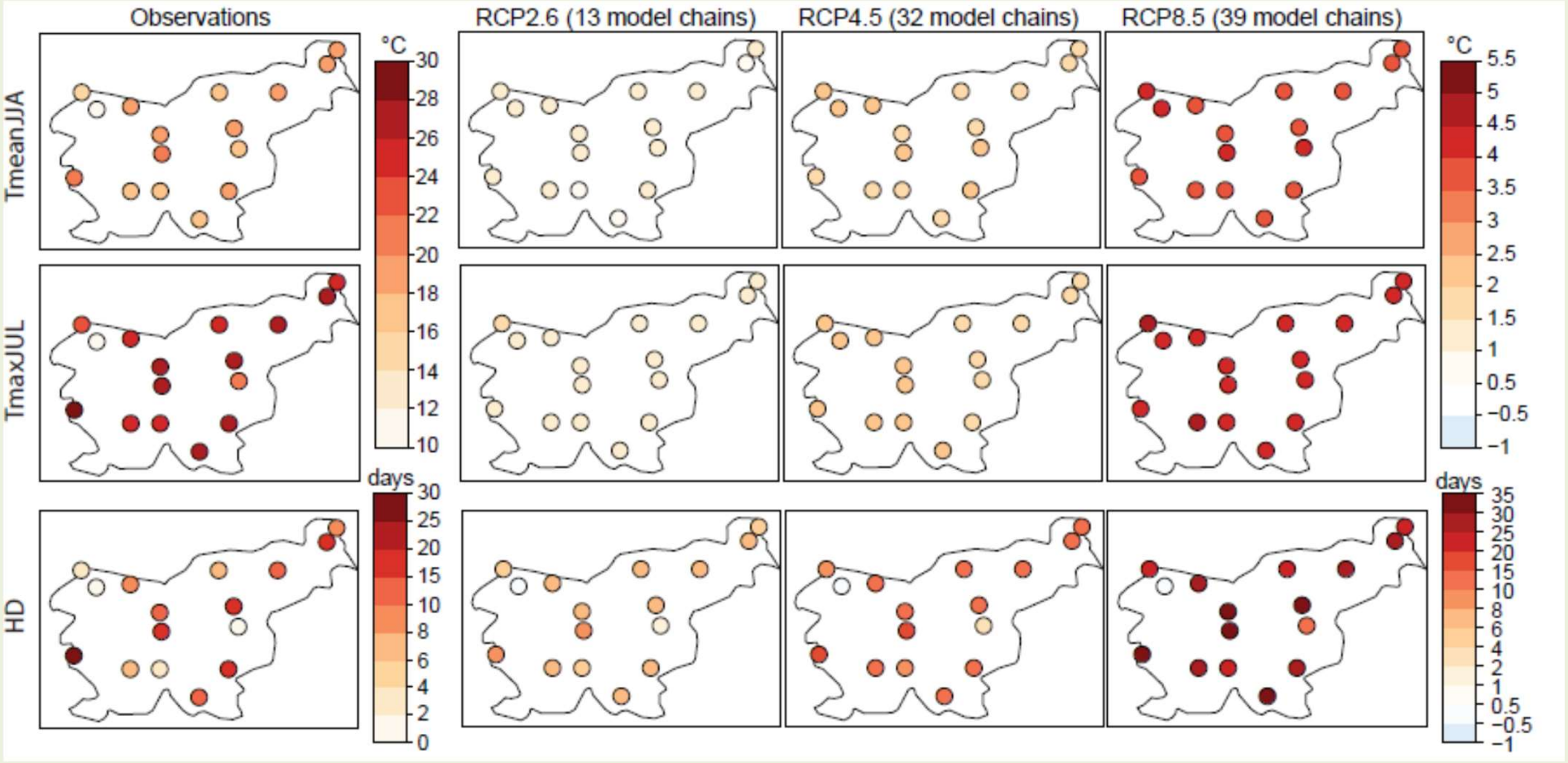
22 to 26°C

24 to 30°C

WBGTg27- number of summer days with WBGT>27°C - high heat stress risk

such days are rare in present climate (Bilje, 2 days/summer with sub-Mediterranean climate)

The 27°C WBGT threshold is associated with high heat stress risk for acclimatized workers doing moderate work (NIOSH, 2016)

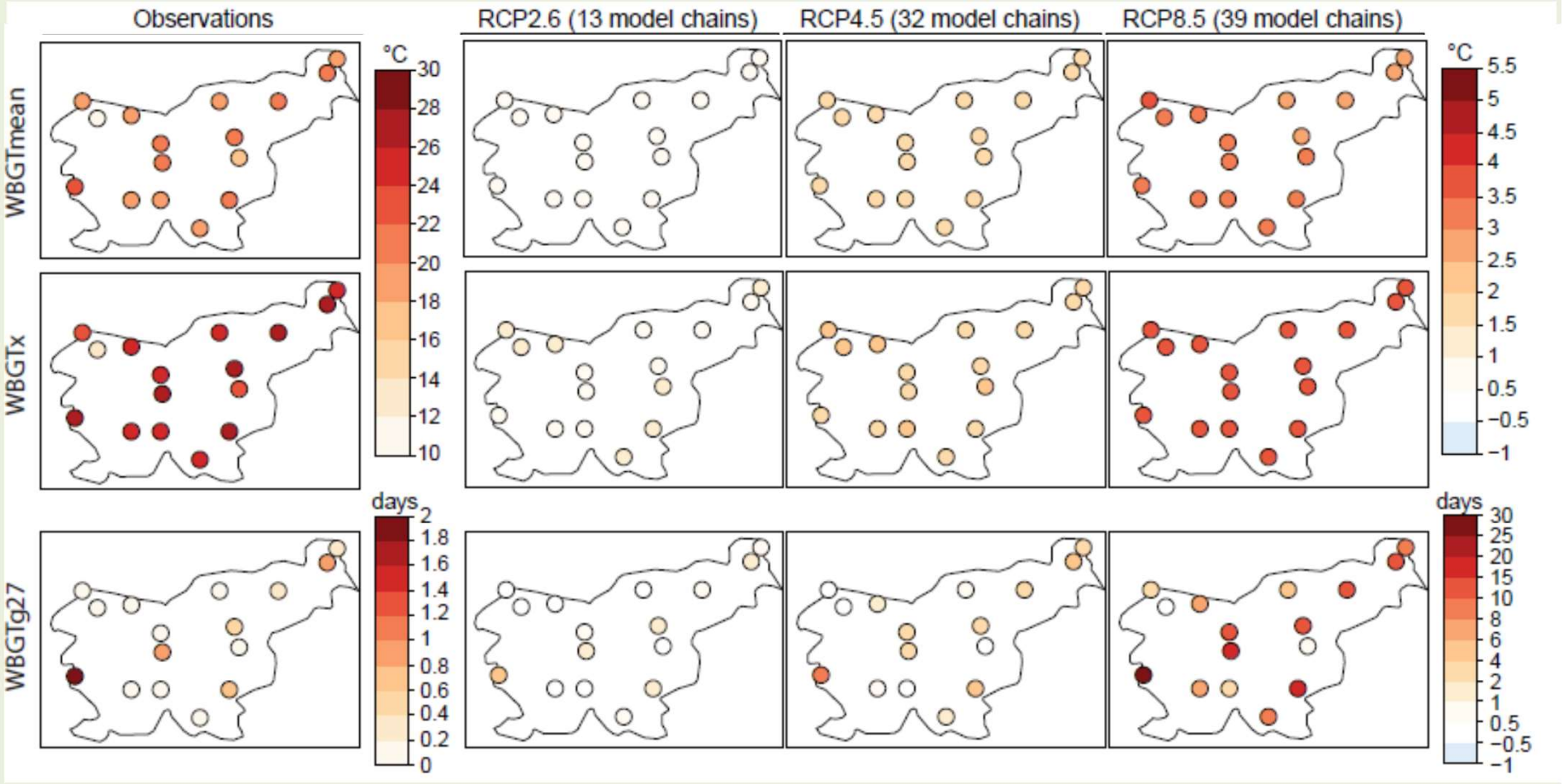


Predictions for the period 2070-2099 with respect to 1981-2010:

- **all indices are projected to increase**

Changes range

- in summer **temperatures from 1°C** (RCP2.6) **to 4.5 °C** (RCP8.5)
- in number of hot days (HD) 2-10 days per summer (RCP2.6) and up to 35 days (RCP8.6)



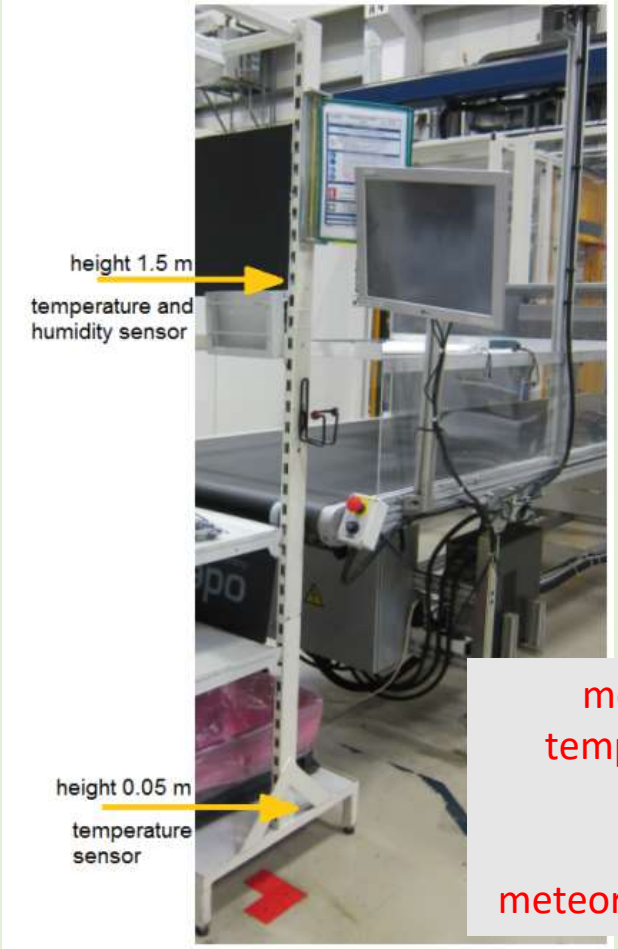
Predictions for the period 2070-2099 with respect to 1981-2010:

- WBGT- mean, WBGT- maximum – are projected to increase from 1 °C to 3.5°C, depending on the emission scenario
- The frequency of extreme heat stress (WBGT>27°C) is projected to increase up to 20 days in the central Slovenia and more than 30 days in sub-Mediterranean climate (western part)

Odelo d.o.o.; production of automotive rear lights using injection molding

Manufacturing hall - Slovenia

The survey was conducted on workers (n=400) in the odelo factory, Slovenia, in July-August 2016 – **about their perception of the temperature at the workplace during heat wave**

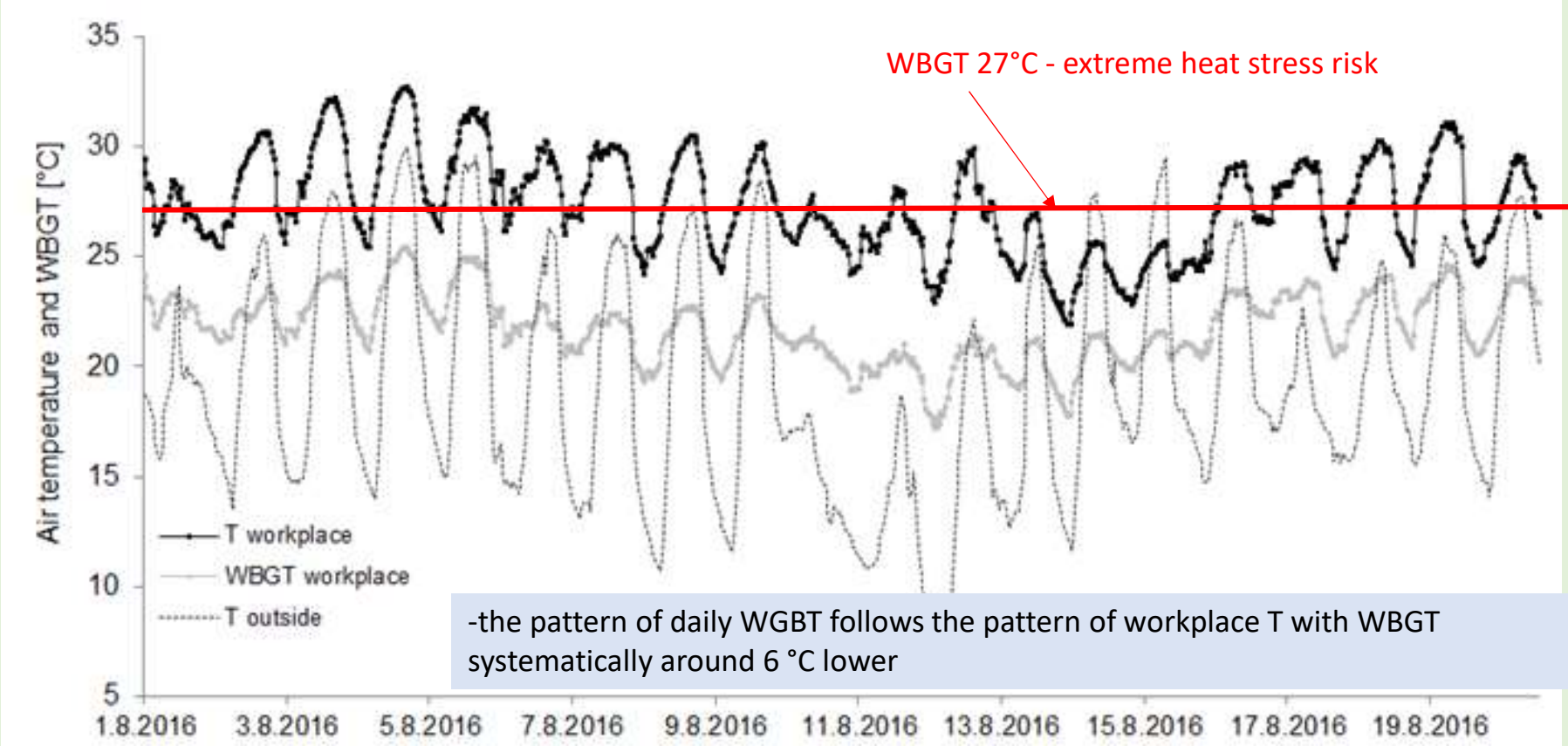


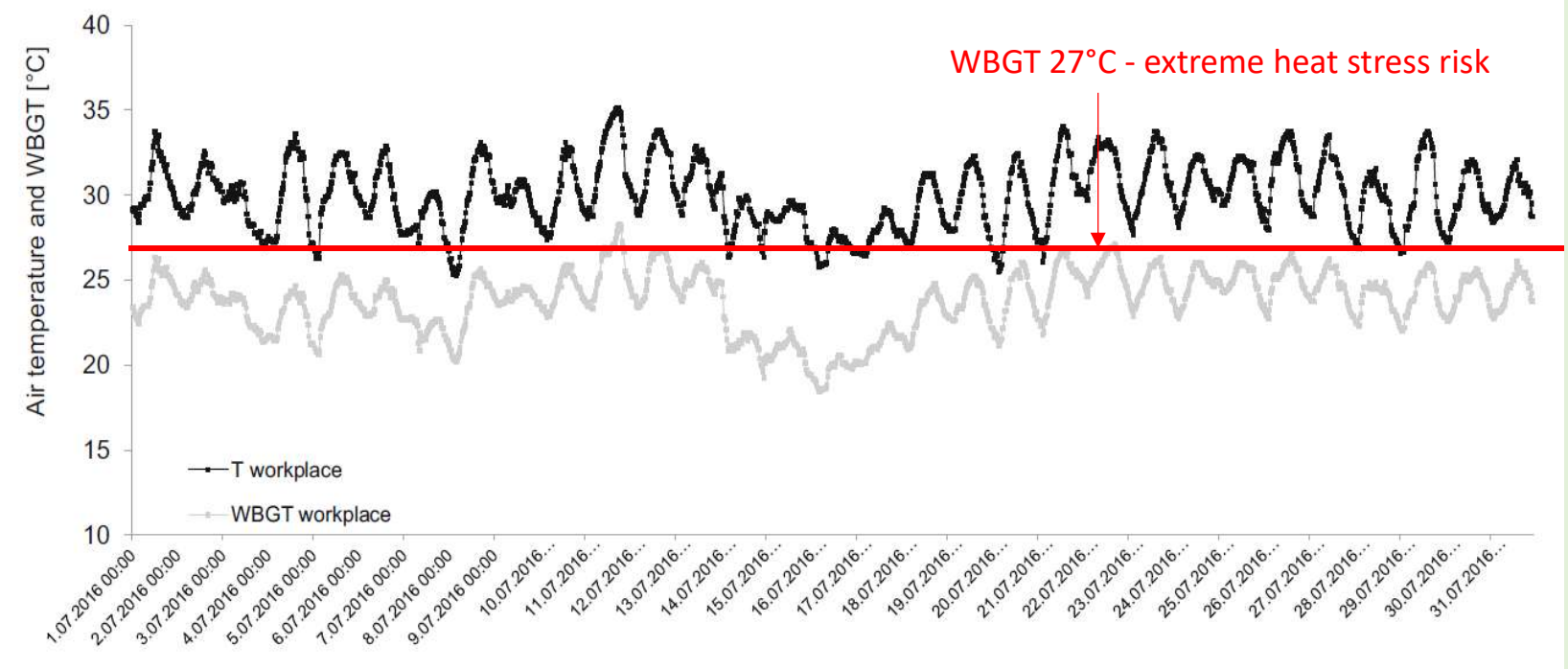
measurements of air temperature and relative humidity inside
+
meteorological station outside

Thermal (dis)comfort

Measurements of outside and indoor (1.5 m height) air temperatures, WBGT (every half hour) at the injection molding workplace in the odelo factory in August 2016, Slovenia

Correlation coefficient of the indoor T with the outside T was high -0.85; temperatures inside were higher and their variability was lower;
relative humidity was significantly lower inside the plant compared to the outside.

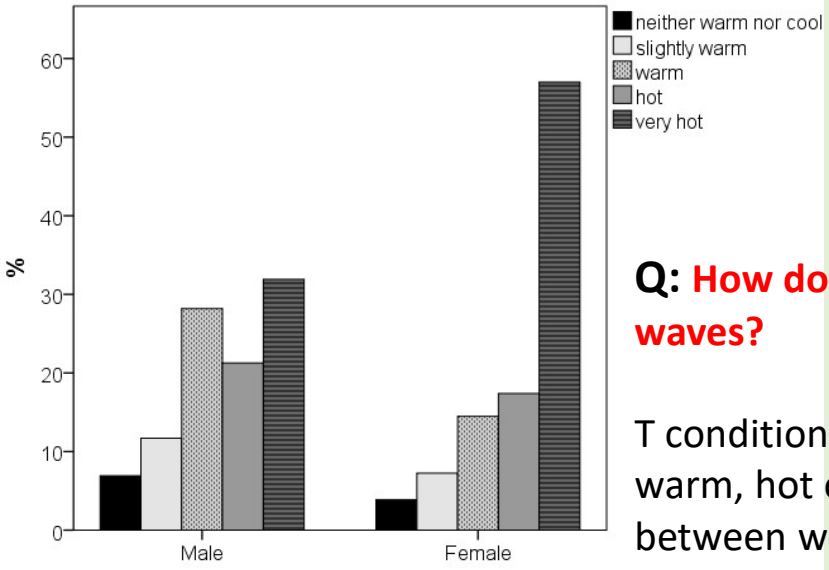




WBGT – mean 24.2°C (July 2016)

In the first half of July 2016 WGBT at the injection molding work place was between 20 and 25°C, in the second half of July values increased above 25°C - with maximum of 28.3°C on 12th of July

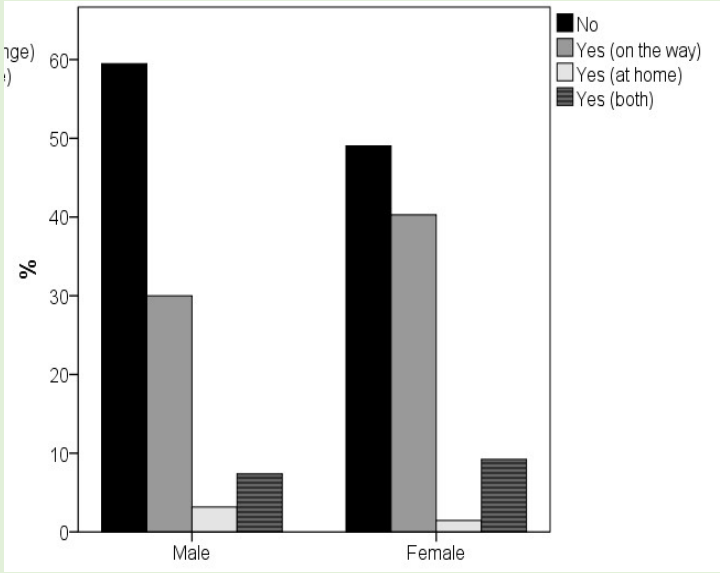
…some results of the survey among workers



- summer of **2016 was not very hot**, with only one heat wave, it can be considered representative of summer conditions in that location

Q: How do you perceive the workplace temperature during heat waves?

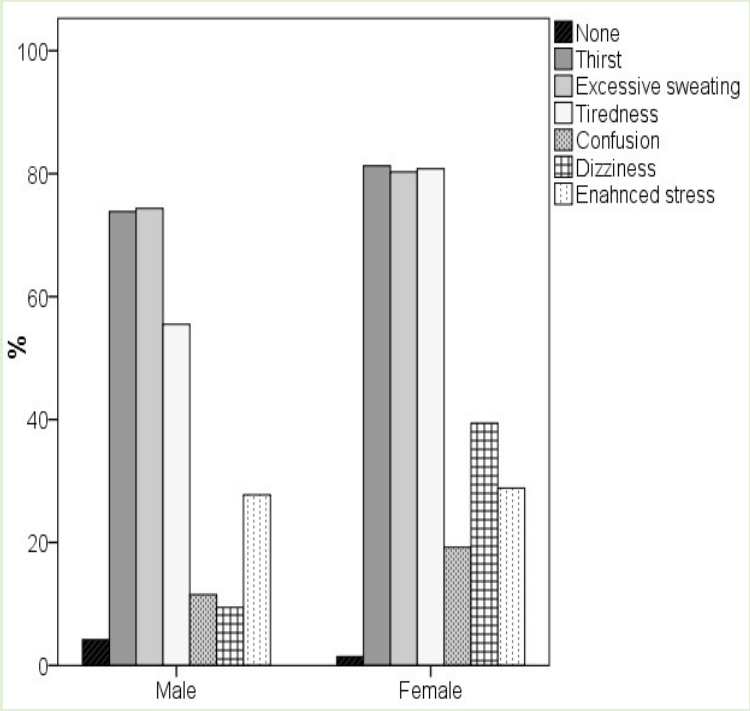
T conditions were suitable for less than 4%, for the majority it was warm, hot or very hot, there was a statistical significant difference between women and men regarding feeling working conditions as'very hot'- women had higher sensitivity to the hot conditions, as has already been published in other surveys.



Q: Is the situation regarding temperature during summer worse at home/on the way than at your workplace?

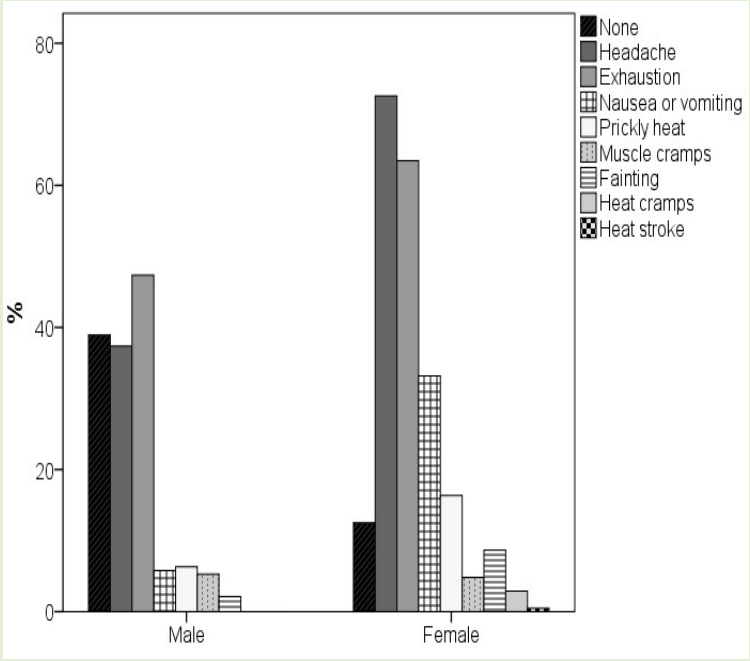
More than 50% of the workers reported having better climate conditions at home and on the way to work.

- we used the approach of **the Hothaps** (The High Occupational Temperature, Health, and Productivity Suppression) **Program** (Kjellstrom et al., 2011)



Q: Which of these heat stress symptoms do you face during work in summer?

Thirst and excessive sweting are the first signs of heat, reported by more than 70% of men and more than 80% of women.
Tiredness, confusion and dizziness are more commonly perceived by women.
Enhanced stress due to heat is experienced by around 30% of men and women.



Q: Have you ever been affected by any of these health problems at work during a heat wave?

Since becoming operational in 2005 there has only been one incident of heat stroke and 13 incidents of heat-induced problems that required hospitalisation.
Gender differences are evident: 39% of male workers did not report any health problems and only the 6% of female group reported the same.

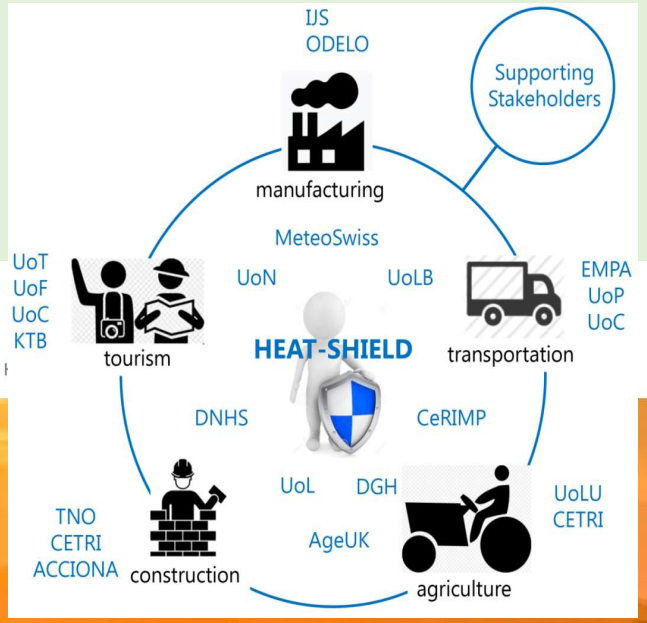
What did we find in our study - main conclusions:

- **Observed trends** (1961-2011) of summer mean and maximum air temperatures, number of hot days (Tmax>30°C) and heat stress indices **were positive**
- Climate change **projections showed an increase** up to 4.5 °C for mean summer **temperatures** and 35 days for **hot days** by the end of 21st century
- Summer **heat stress indices are projected to increase** from 1 to 3.5 °C; the frequency of extreme heat stress (WBGT>27°C) will increase – up to 20 days in the central Slovenia and by more than 30 days in Sub-mediterranean climate
- During hot days, **the working conditions in the manufacturing plant were near critical**, with mean WBGT index 20-25°C, exceeding critical values during heat waves
- Case study, odelo d.o.o. factory, summer 2016: **96% of workers perceived the working thermal conditions as unsuitable**

Employers should be aware that by reducing heat stress the company will be able to maintain the productivity on the planned level

Adaptation strategies should be planned to reduce the health impacts of heatwaves in the country also in other areas

For more information please visit
http://heat-shield.eu/



References:

- **ARSO (2017)** PPS project: Project reports and interactive portal on climate change in Slovenia, Slovenian Environment Agency. http://meteo.arso.gov.si/met/sl/climate/pss-project/Accessed October 3th, 2018

- **Heat Shield Project (2018):** The Horizon 2020 research project. https://www.heat-shield.eu/Accessed October 3th, 2018

- **ISO (2017)** Hot environments - Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index. ISO Standard 7243. Geneva: International Standards Organization

- **Kjellstrom T., Odland J.O., Nilsson M. (2011)** Progress in the Hothaps program assessing impacts and prevention of heat effects on working people in relation to local climate change. Asia Pacific Newslett Occup Heal Saf 18, 24-5

- **NIOSH (2016)** NIOSH criteria for a recommended standard: occupational exposure to heat and hot environments. By Jacklitsch B., Williams W.J., Musolin K., Coca A., Kim J.H., Turner N.. Cincinnati, OH, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication 2016-106

- **Pogačar T., Casanueva A., Kozjek K., Ciuha U., Mekjavič I.B., Kajfež-Bogataj L., Črepinšek Z. (2018)** The effect of hot days on occupational heat stress in the manufacturing industry: implications for workers' well-being and productivity. *International Journal of Biometeorology*, 62:1251-1264

- **Sherwood S.C., Huber M. (2010)** An adaptability limit to climate change due to heat stress. Proc Natl Acad Sci USA. doi: 10.1073/pnas.0913352107