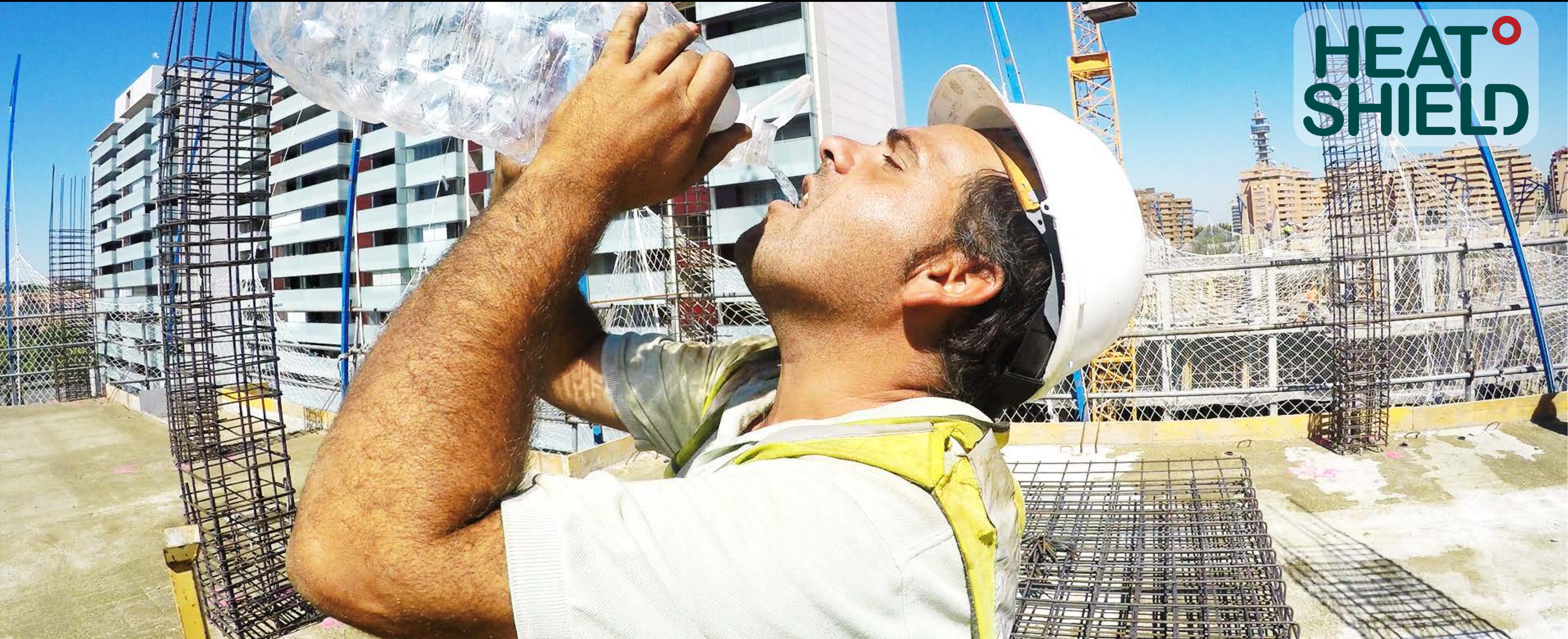
# IMPACTS OF OCCUPATIONAL HEAT STRAIN ON HEALTH & PRODUCTIVITY

Andreas D. Flouris
FAME Lab, University of Thessaly, Greece



HEAT SHIELD

# OUTLINE

- Vulnerable population groups
  - workers
  - elderly
  - people with chronic diseases

# LIMITED KNOWLEDGE

- **Mission**: to address the negative impacts of workplace heat stress on the health and productivity of workers in strategic European industries

HEAT SHIELD

European Commission | Horizon 2020 European Union funding for Research & Innovation

Funded by the EU Horizon 2020 research and innovation programme (no.668786)

# HEALTH & PRODUCTIVITY IMPACT OF OCCUPATIONAL HEAT



## Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis

Andreas D Flouris, Petros C Dinas, Leonidas G Ioannou, Lars Nybo, George Havenith, Glen P Kenny, Tord Kjellstrom

### Summary

**Background** Occupational heat strain (ie, the effect of environmental heat stress on the body) directly threatens workers' ability to live healthy and productive lives. We estimated the effects of occupational heat strain on workers' health and productivity outcomes.

**Methods** Following PRISMA guidelines for this systematic review and meta-analysis, we searched PubMed and Embase from database inception to Feb 5, 2018, for relevant studies in any labour environment and at any level of occupational heat strain. No restrictions on language, workers' health status, or study design were applied. Occupational heat strain was defined using international health and safety guidelines and standards. We excluded studies that calculated effects using simulations or statistical models instead of actual measurements, and any grey literature. Risk of bias, data extraction, and sensitivity analysis were performed by two independent investigators. Six random-effects meta-analyses estimated the prevalence of occupational heat strain, kidney disease or acute kidney injury, productivity loss, core temperature, change in urine specific gravity, and odds of occupational heat strain occurring during or at the end of a work shift in heat stress conditions. The review protocol is available on PROSPERO, registration number CRD42017083271.

**Findings** Of 958 reports identified through our systematic search, 111 studies done in 30 countries, including 447 million workers from more than 40 different occupations, were eligible for analysis. Our meta-analyses showed that individuals working a single work shift under heat stress (defined as wet-bulb globe temperature beyond 22·0 or 24·8°C depending on work intensity) were 4·01 times (95% CI 2·45–6·58; nine studies with 11 582 workers) more likely to experience occupational heat strain than an individual working in thermoneutral conditions, while their core temperature was increased by 0·7°C (0·4–1·0; 17 studies with 1090 workers) and their urine specific gravity was increased by 14·5% (0·0031, 0·0014–0·0048; 14 studies with 691 workers). During or at the end of a work shift under heat stress, 35% (31–39; 33 studies with 13 088 workers) of workers experienced occupational heat strain, while 30% (21–39; 11 studies with 8076 workers) reported productivity losses. Finally, 15% (11–19; ten studies with 21 721 workers) of individuals who typically or frequently worked under heat stress (minimum of 6 h per day, 5 days per week, for 2 months of the year) experienced kidney disease or acute kidney injury. Overall, this analysis include a variety of populations, exposures, and occupations to comply with a wider adoption of evidence synthesis, but resulted in large heterogeneity in our meta-analyses. Grading of Recommendations, Assessment, Development and Evaluation analysis revealed moderate confidence for most results and very low confidence in two cases (average core temperature and change in urine specific gravity) due to studies being funded by industry.

**Interpretation** Occupational heat strain has important health and productivity outcomes and should be recognised as a public health problem. Concerted international action is needed to mitigate its effects in light of climate change and the anticipated rise in heat stress.

**Funding** EU Horizon 2020 research and innovation programme.



*Lancet Planet Health* 2018; 2: e521–31

FAME Laboratory, Department of Exercise Science, University of Thessaly, Trikala, Greece (A D Flouris PhD, P C Dinas PhD, L G Ioannou MSc); Human and Environmental Physiological Research Unit, Faculty of Health Sciences, University of Ottawa, Ottowa, ON, Canada (A D Flouris, Prof G P Kenny PhD); Department of Nutrition, Exercise and Sports, August Krogh Building, University of Copenhagen, Copenhagen, Denmark (L G Ioannou, Prof L Nybo PhD); Centre for Technology Research and Innovation, Lemesos, Cyprus (L G Ioannou, Prof T Kjellstrom PhD); Environmental Ergonomics Research Centre, Loughborough Design School, Loughborough University, Loughborough, UK (Prof G Havenith PhD); and Clinical Epidemiology Program, Ottawa Hospital Research Institute, Ottawa, ON, Canada (Prof G P Kenny)

Correspondence to: Dr Andreas D Flouris, FAME Laboratory, Department of Exercise Science, University of Thessaly, Trikala 42100, Greece andreasflouris@gmail.com

### Introduction

Nearly a third of the world's population is regularly exposed to climate conditions that exceed human thermoregulatory capacity, leading to major increases in morbidity and mortality.[1–3] Even if aggressive mitigation measures were to be adopted, estimates suggest that half of the world's population will be exposed to such conditions by 2100,[1] and several studies[4–7] report that the resulting occupational heat strain will directly threaten workers' health, with corresponding negative effects on productivity, poverty, and socioeconomic inequality. Occupational heat strain refers to the physiological effect of environmental heat stress on the body and it has a major impact on the ability of workers to live healthy and productive lives; nearly 1 million work life-years are projected to be lost by 2030 due to occupational heat stroke fatalities, with 70 million work life-years lost because of reduced labour productivity.[8,9] Warning systems for extreme weather events have been piloted in some countries, but they are designed for the general





Flouris et al., 2018; Lancet Plan Health

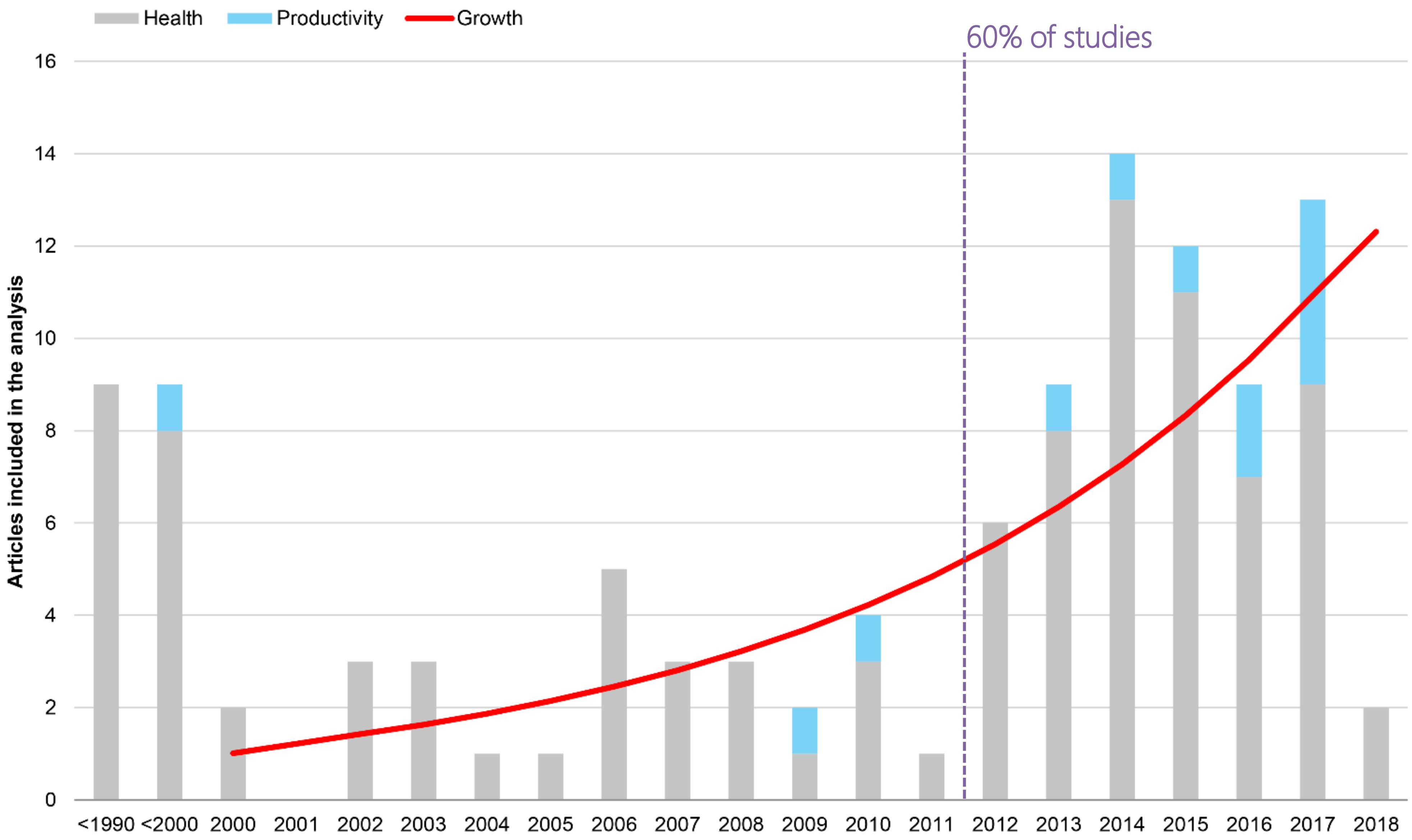
# HEALTH & PRODUCTIVITY IMPACT OF OCCUPATIONAL HEAT

- PRISMA guidelines
- PubMed and Embase (date of inception to **Feb 5, 2018**)
- No search limits
  - labour environment
  - language
  - workers' health status
  - study design
- Six random-effects meta-analyses estimated the impact of occupational heat strain on health and productivity outcomes
- Review protocol (CRD42017083271) available on PROSPERO



Flouris et al., 2018; Lancet Plan Health

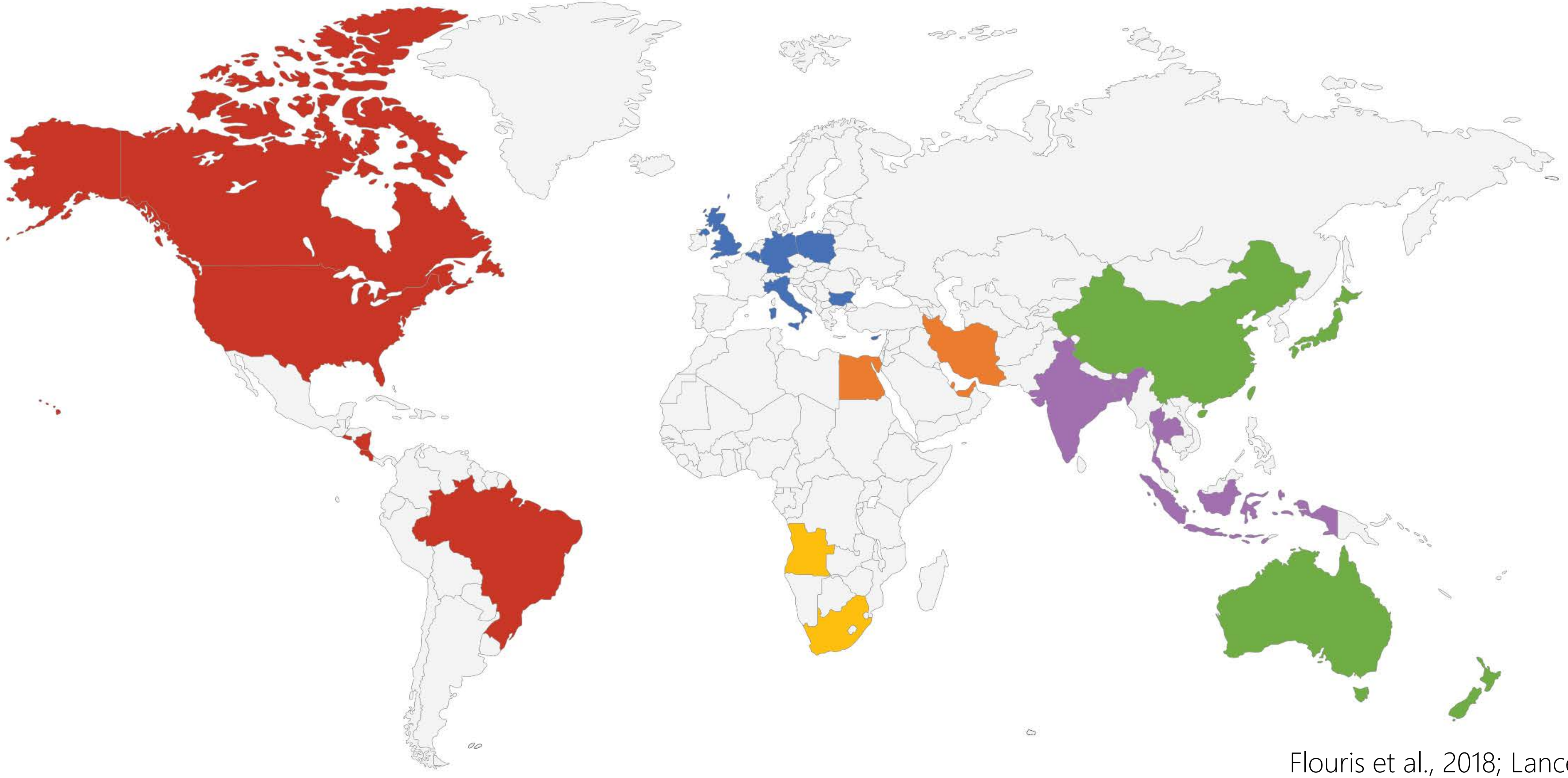
# HEALTH & PRODUCTIVITY IMPACT OF OCCUPATIONAL HEAT




Flouris et al., 2018; Lancet Plan Health

# HEALTH & PRODUCTIVITY IMPACT OF OCCUPATIONAL HEAT

- 111 studies from **30** countries that assessed **447 million** workers from **>40** different jobs



Flouris et al., 2018; Lancet Plan Health

# HEALTH IMPACT OF OCCUPATIONAL HEAT

- Those who frequently work in the heat experience
  - **4-fold** increase in the likelihood of having heat strain
  - **0.7°C** higher body temperature
  - **14.5%** increase in urine specific gravity
  - **15%** risk for kidney disease / acute kidney injury

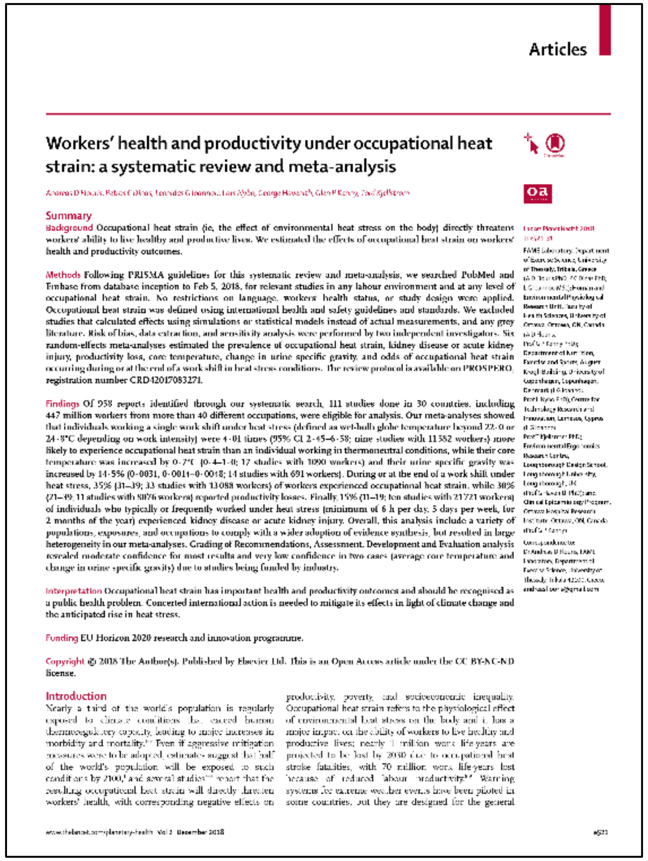


Flouris et al., 2018; Lancet Plan Health

# HEALTH IMPACT OF OCCUPATIONAL HEAT

- During or at the end of a single work shift under heat stress

  – **35%** of workers experience symptoms of occupational heat strain


Articles

**Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis**


Summary

Background Occupational heat strain (ie, the effect of environmental heat stress on the body) directly threatens workers' ability to live healthy and productive lives. We estimated the effects of occupational heat strain on workers' health and productivity outcomes.

Methods Following PRISMA guidelines for this systematic review and meta-analysis, we searched PubMed and Embase from database inception to Feb 5, 2018, for relevant studies in any labour environment and at any level of occupational heat strain. No restrictions on language, workers' health status, or study design were applied. Occupational heat strain was defined using international health and safety guidelines and standards. We excluded studies that calculated effects using simulations or statistical models instead of actual measurements, and any grey literature. Risk of bias, data extraction, and sensitivity analysis were performed by two independent investigators. Six random-effects meta-analyses estimated the prevalence of occupational heat strain, kidney disease or acute kidney injury, productivity loss, core temperature, change in urine specific gravity, and odds of occupational heat strain occurring during or at the end of a work shift in heat stress conditions. The review protocol is available on PROSPERO, registration number CRD42017083271.

Findings Of 958 reports identified through our systematic search, 111 studies done in 30 countries, including 447 million workers from more than 40 different occupations, were eligible for analysis. Our meta-analyses showed that individuals working a single work shift under heat stress (defined as wet-bulb globe temperature beyond 22·0 or 24·8°C depending on work intensity) were 4·01 times (95% CI 2·45–6·58; nine studies with 11582 workers) more likely to experience occupational heat strain than an individual working in thermoneutral conditions, while their core temperature was increased by 0·7°C (0·4–1·0; 17 studies with 1090 workers) and their urine specific gravity was increased by 14·5% (0·0031, 0·0011–0·0018; 14 studies with 691 workers). During or at the end of a work shift under heat stress, 35% (31–39; 33 studies with 13088 workers) of workers experienced occupational heat strain, while 30% (21–39; 11 studies with 8076 workers) reported productivity losses. Finally, 15% (11–19; ten studies with 21721 workers) of individuals who typically or frequently worked under heat stress (minimum of 6 h per day, 5 days per week, for 2 months of the year) experienced kidney disease or acute kidney injury. Overall, this analysis include a variety of populations, exposures, and occupations to comply with a wider adoption of evidence synthesis, but resulted in large heterogeneity in our meta-analyses. Grading of Recommendations, Assessment, Development and Evaluation analysis revealed moderate confidence for most results and very low confidence in two cases (average core temperature and change in urine specific gravity) due to studies being funded by industry.

Interpretation Occupational heat strain has important health and productivity outcomes and should be recognised as a public health problem. Concerted international action is needed to mitigate its effects in light of climate change and the anticipated rise in heat stress.


Funding EU Horizon 2020 research and innovation programme.



Introduction



Flouris et al., 2018; Lancet Plan Health

# FIELD STUDIES ACROSS EUROPE

**HEAT-SHIELD mission:** to address the negative impacts of workplace heat stress on the health and productivity of workers in strategic European industries

tourism

GREECE
CYPRUS

agriculture

CYPRUS
ITALY
GREECE
SLOVENIA

manufacturing

SLOVENIA
DENMARK

construction

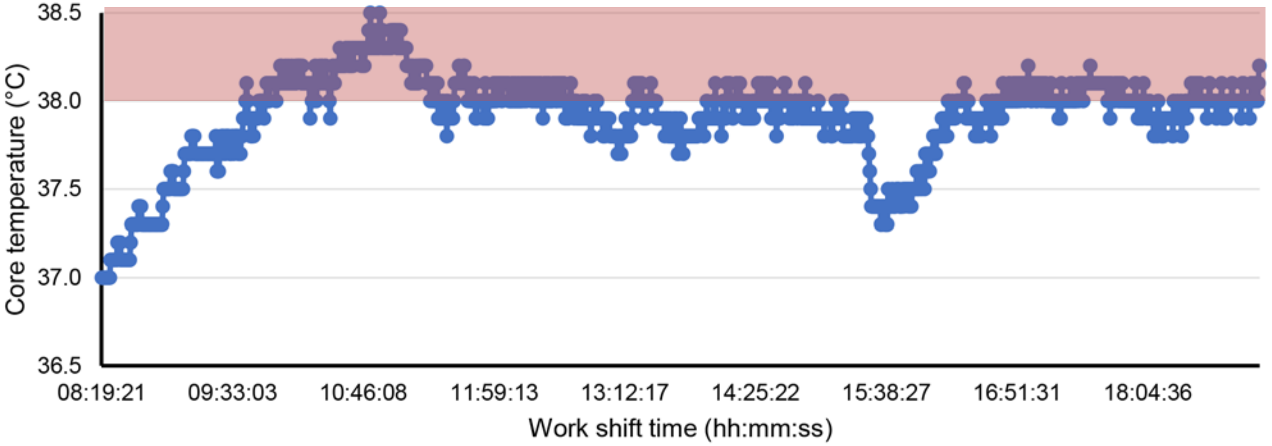
SPAIN
ITALY

transportation

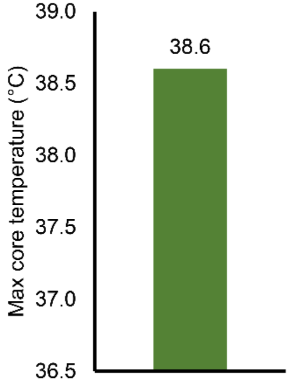
SWITZERLAND
PORTUGAL
GREECE

# HEAT IN THE WORKPLACE

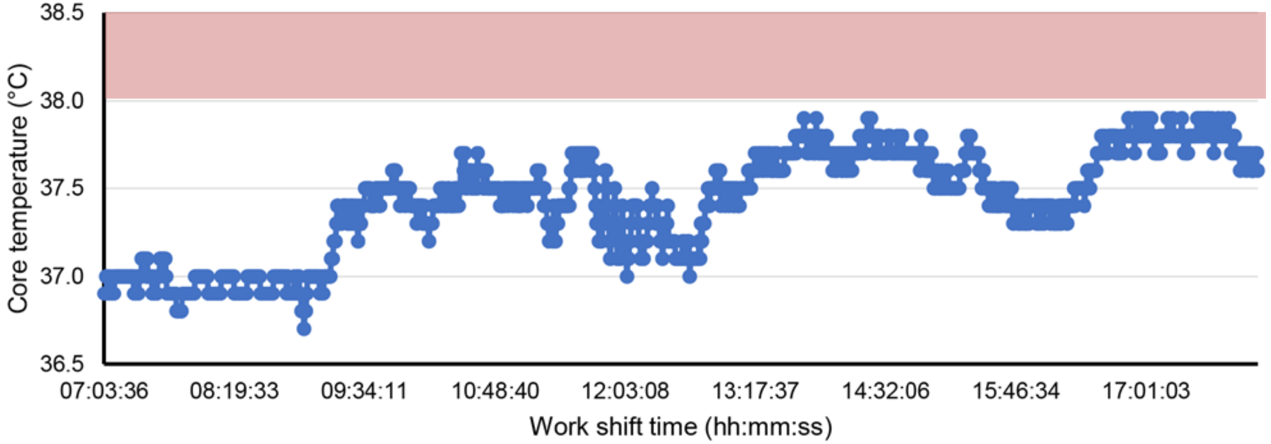
## Construction



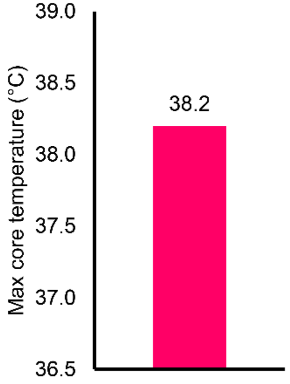

max core temp. recorded




## Agriculture



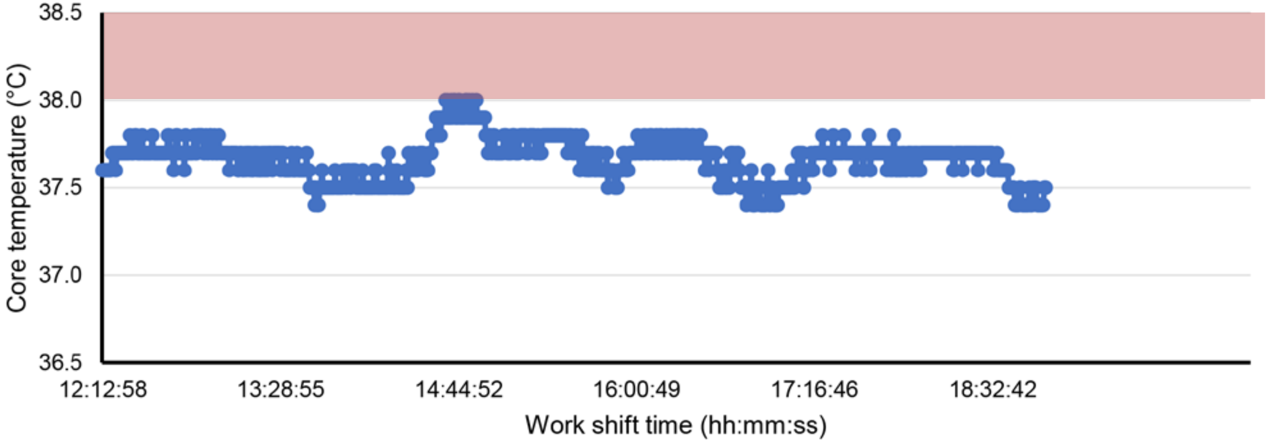

max core temp. recorded

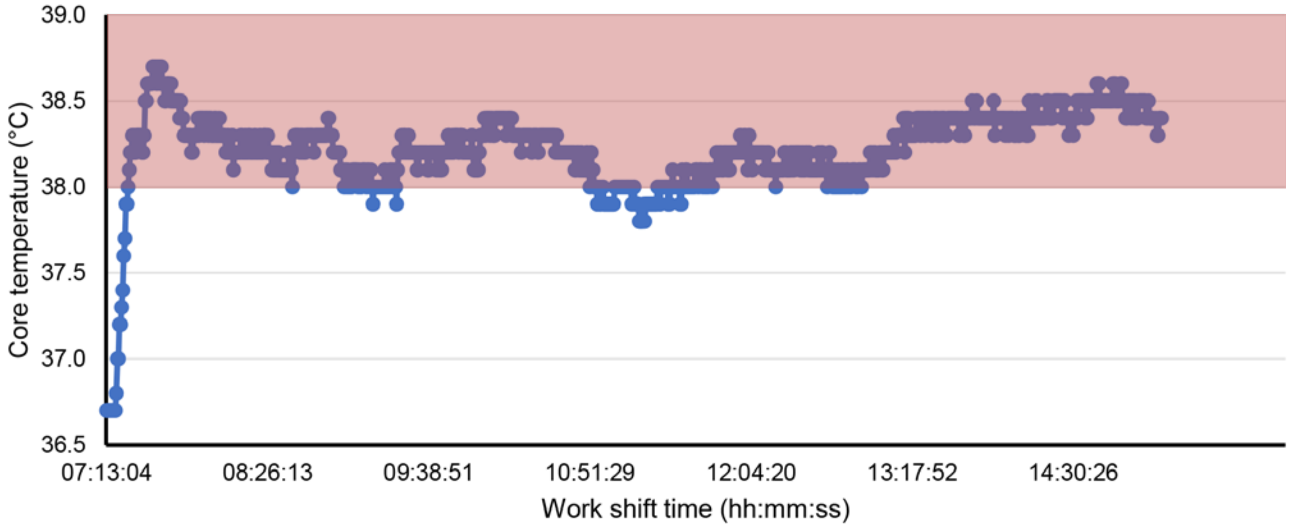



Flouris et al., Unpublished Data

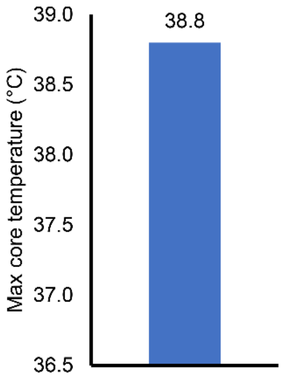
# HEAT IN THE WORKPLACE

Tourism




max core temp. recorded



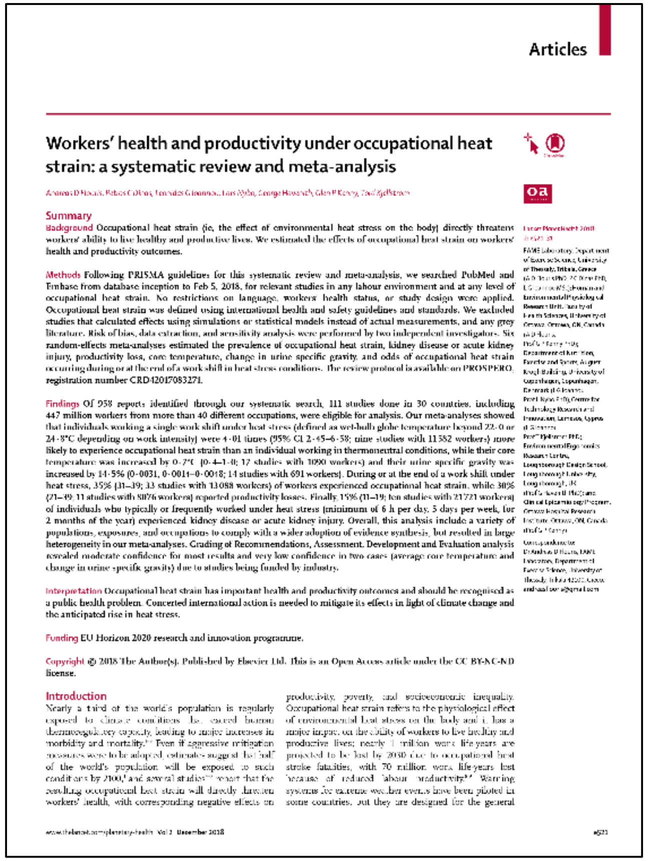



Flouris et al., Unpublished Data

# HEALTH IMPACT OF OCCUPATIONAL HEAT

- During or at the end of a single work shift under heat stress

  – **35%** of workers experience symptoms of occupational heat strain



Articles

## Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis

**Summary**

**Background** Occupational heat strain (ie, the effect of environmental heat stress on the body) directly threatens workers' ability to live healthy and productive lives. We estimated the effects of occupational heat strain on workers' health and productivity outcomes.

**Methods** Following PRISMA guidelines for this systematic review and meta-analysis, we searched PubMed and Embase from database inception to Feb 5, 2018, for relevant studies in any labour environment and at any level of occupational heat strain. No restrictions on language, workers' health status, or study design were applied. Occupational heat strain was defined using international health and safety guidelines and standards. We excluded studies that calculated effects using simulations or statistical models instead of actual measurements, and any grey literature. Risk of bias, data extraction, and sensitivity analysis were performed by two independent investigators. Six random-effects meta-analyses estimated the prevalence of occupational heat strain, kidney disease or acute kidney injury, productivity loss, core temperature, change in urine specific gravity, and odds of occupational heat strain occurring during or at the end of a work shift in heat stress conditions. The review protocol is available on PROSPERO, registration number CRD42017083271.

**Findings** Of 958 reports identified through our systematic search, 111 studies done in 30 countries, including 447 million workers from more than 40 different occupations, were eligible for analysis. Our meta-analyses showed that individuals working a single work shift under heat stress (defined as wet-bulb globe temperature beyond 22·0 or 24·8°C depending on work intensity) were 4·01 times (95% CI 2·45–6·58; nine studies with 11 582 workers) more likely to experience occupational heat strain than an individual working in thermoneutral conditions, while their core temperature was increased by 0·7°C (0·4–1·0; 17 studies with 1090 workers) and their urine specific gravity was increased by 14·5% (0·0031, 0·0011–0·0018; 14 studies with 691 workers). During or at the end of a work shift under heat stress, 35% (31–39; 33 studies with 13 088 workers) of workers experienced occupational heat strain, while 30% (21–39; 11 studies with 8076 workers) reported productivity losses. Finally, 15% (11–19; ten studies with 21 721 workers) of individuals who typically or frequently worked under heat stress (minimum of 6 h per day, 5 days per week, for 2 months of the year) experienced kidney disease or acute kidney injury. Overall, this analysis include a variety of populations, exposures, and occupations to comply with a wider adoption of evidence synthesis, but resulted in large heterogeneity in our meta-analyses. Grading of Recommendations, Assessment, Development and Evaluation analysis revealed moderate confidence for most results and very low confidence in two cases (average core temperature and change in urine specific gravity) due to studies being funded by industry.

**Interpretation** Occupational heat strain has important health and productivity outcomes and should be recognised as a public health problem. Concerted international action is needed to mitigate its effects in light of climate change and the anticipated rise in heat stress.

**Funding** EU Horizon 2020 research and innovation programme.

**Copyright** © 2018 The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY-NC-ND license.

**Introduction**

Nearly a third of the world's population is regularly exposed to climate conditions that exceed human thermoregulatory capacity, leading to major increases in morbidity and mortality. Even if aggressive mitigation ... productivity, poverty, and socioeconomic inequality. Occupational heat strain refers to the physiological effect of environmental heat stress on the body and it has a major impact on the ability of workers to live healthy and productive lives; nearly 1 million work life-years are ...

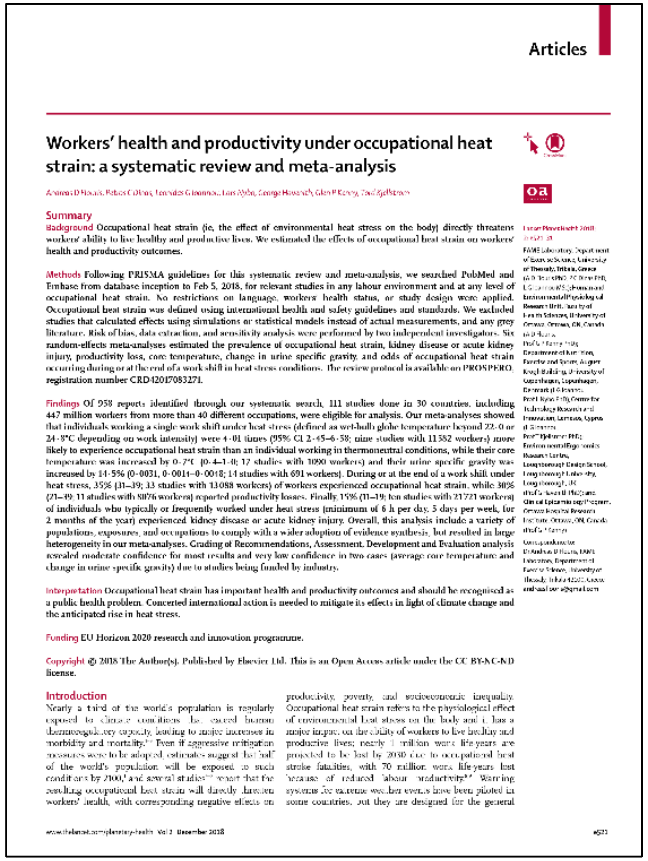


Flouris et al., 2018; Lancet Plan Health

# PRODUCTIVITY IMPACT OF OCCUPATIONAL HEAT

- During or at the end of a single work shift under heat stress

  – **30%** of workers report productivity losses



Articles

**Workers' health and productivity under occupational heat strain: a systematic review and meta-analysis**

**Summary**

**Background** Occupational heat strain (ie, the effect of environmental heat stress on the body) directly threatens workers' ability to live healthy and productive lives. We estimated the effects of occupational heat strain on workers' health and productivity outcomes.

**Methods** Following PRISMA guidelines for this systematic review and meta-analysis, we searched PubMed and Embase from database inception to Feb 5, 2018, for relevant studies in any labour environment and at any level of occupational heat strain. No restrictions on language, workers' health status, or study design were applied. Occupational heat strain was defined using international health and safety guidelines and standards. We excluded studies that calculated effects using simulations or statistical models instead of actual measurements, and any grey literature. Risk of bias, data extraction, and sensitivity analysis were performed by two independent investigators. Six random-effects meta-analyses estimated the prevalence of occupational heat strain, kidney disease or acute kidney injury, productivity loss, core temperature, change in urine specific gravity, and odds of occupational heat strain occurring during or at the end of a work shift in heat stress conditions. The review protocol is available on PROSPERO, registration number CRD42017083271.

**Findings** Of 958 reports identified through our systematic search, 111 studies done in 30 countries, including 447 million workers from more than 40 different occupations, were eligible for analysis. Our meta-analyses showed that individuals working a single work shift under heat stress (defined as wet-bulb globe temperature beyond 22·0 or 24·8°C depending on work intensity) were 4·01 times (95% CI 2·45–6·58; nine studies with 11 582 workers) more likely to experience occupational heat strain than an individual working in thermoneutral conditions, while their core temperature was increased by 0·7°C (0·4–1·0; 17 studies with 1090 workers) and their urine specific gravity was increased by 14·5% (0·0031, 0·0011–0·0018; 14 studies with 691 workers). During or at the end of a work shift under heat stress, 35% (31–39; 33 studies with 13 088 workers) of workers experienced occupational heat strain, while 30% (21–39; 11 studies with 8076 workers) reported productivity losses. Finally, 15% (11–19; ten studies with 21 721 workers) of individuals who typically or frequently worked under heat stress (minimum of 6 h per day, 5 days per week, for 2 months of the year) experienced kidney disease or acute kidney injury. Overall, this analysis include a variety of populations, exposures, and occupations to comply with a wider adoption of evidence synthesis, but resulted in large heterogeneity in our meta-analyses. Grading of Recommendations, Assessment, Development and Evaluation analysis revealed moderate confidence for most results and very low confidence in two cases (average core temperature and change in urine specific gravity) due to studies being funded by industry.

**Interpretation** Occupational heat strain has important health and productivity outcomes and should be recognised as a public health problem. Concerted international action is needed to mitigate its effects in light of climate change and the anticipated rise in heat stress.

**Funding** EU Horizon 2020 research and innovation programme.

**Copyright** © 2018 The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY-NC-ND license.

**Introduction**

Flouris et al., 2018; Lancet Plan Health

# PRECISE LABOUR LOSS QUANTIFICATION

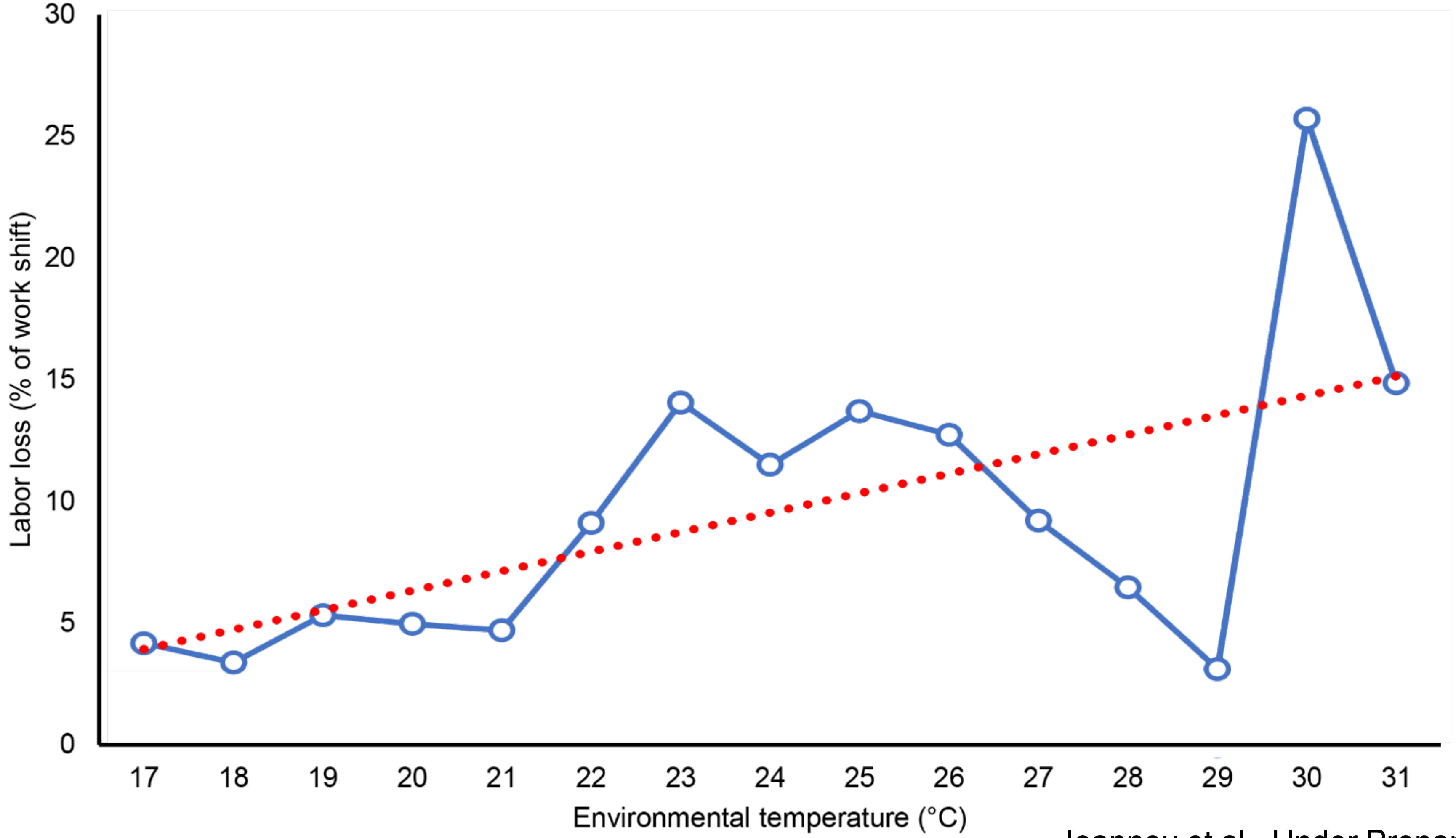
# IRREGULAR WORK BREAKS

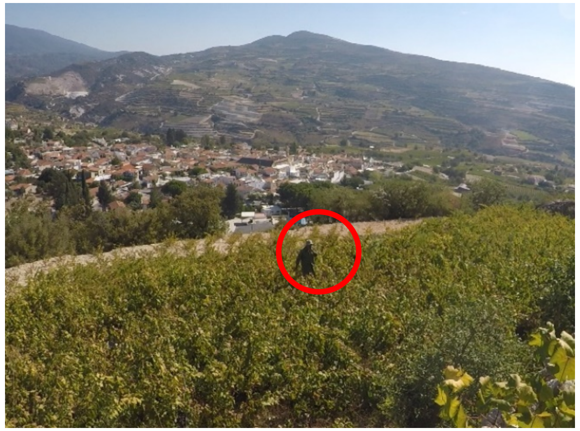
FAME LAB

# DO YOU THINK THE HEAT AFFECTS YOUR PRODUCTIVITY?

# DO YOU THINK THE HEAT AFFECTS YOUR PRODUCTIVITY?

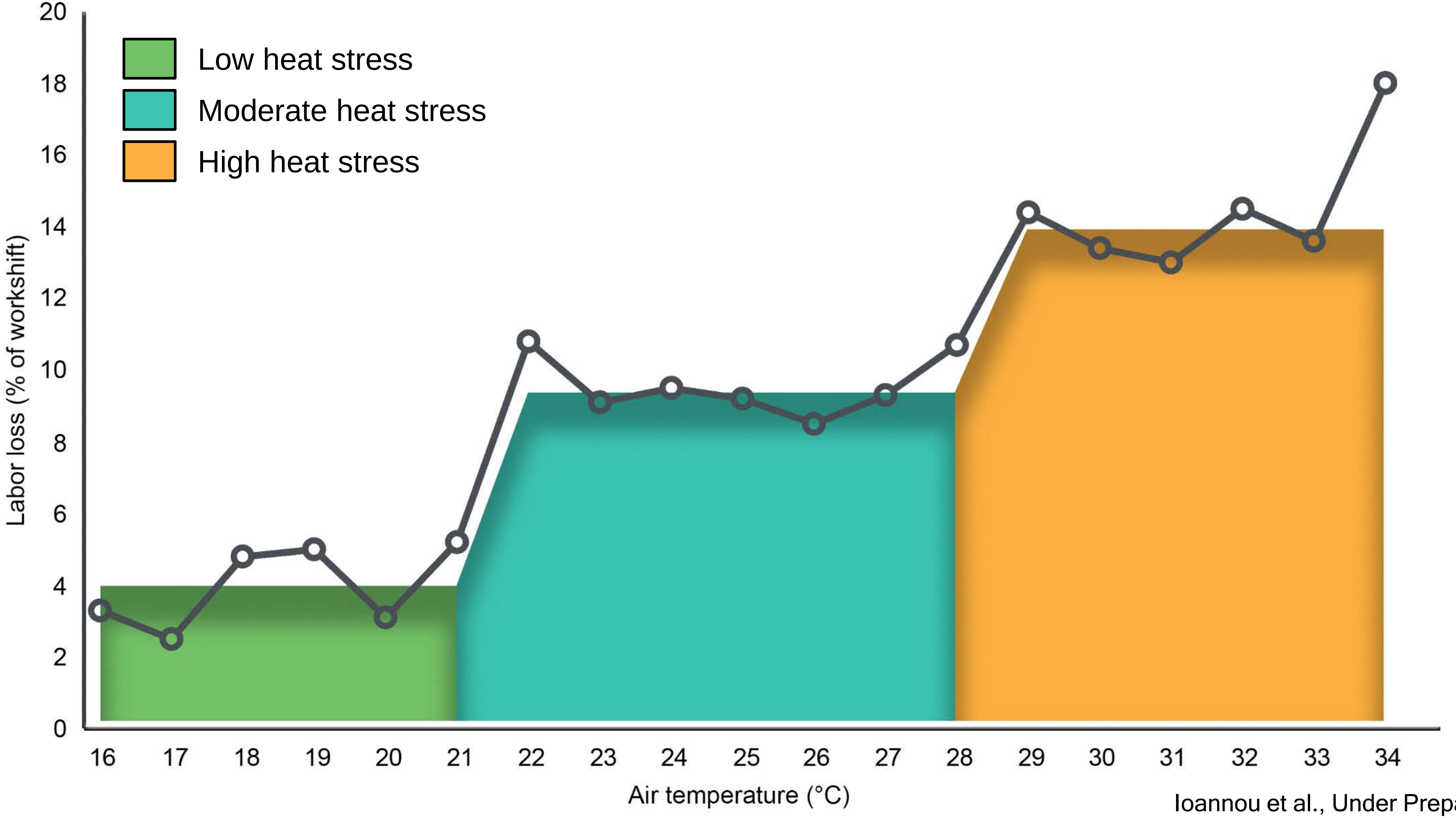
- Loss of **1%** of labour time for every 1°C increase in environmental temperature



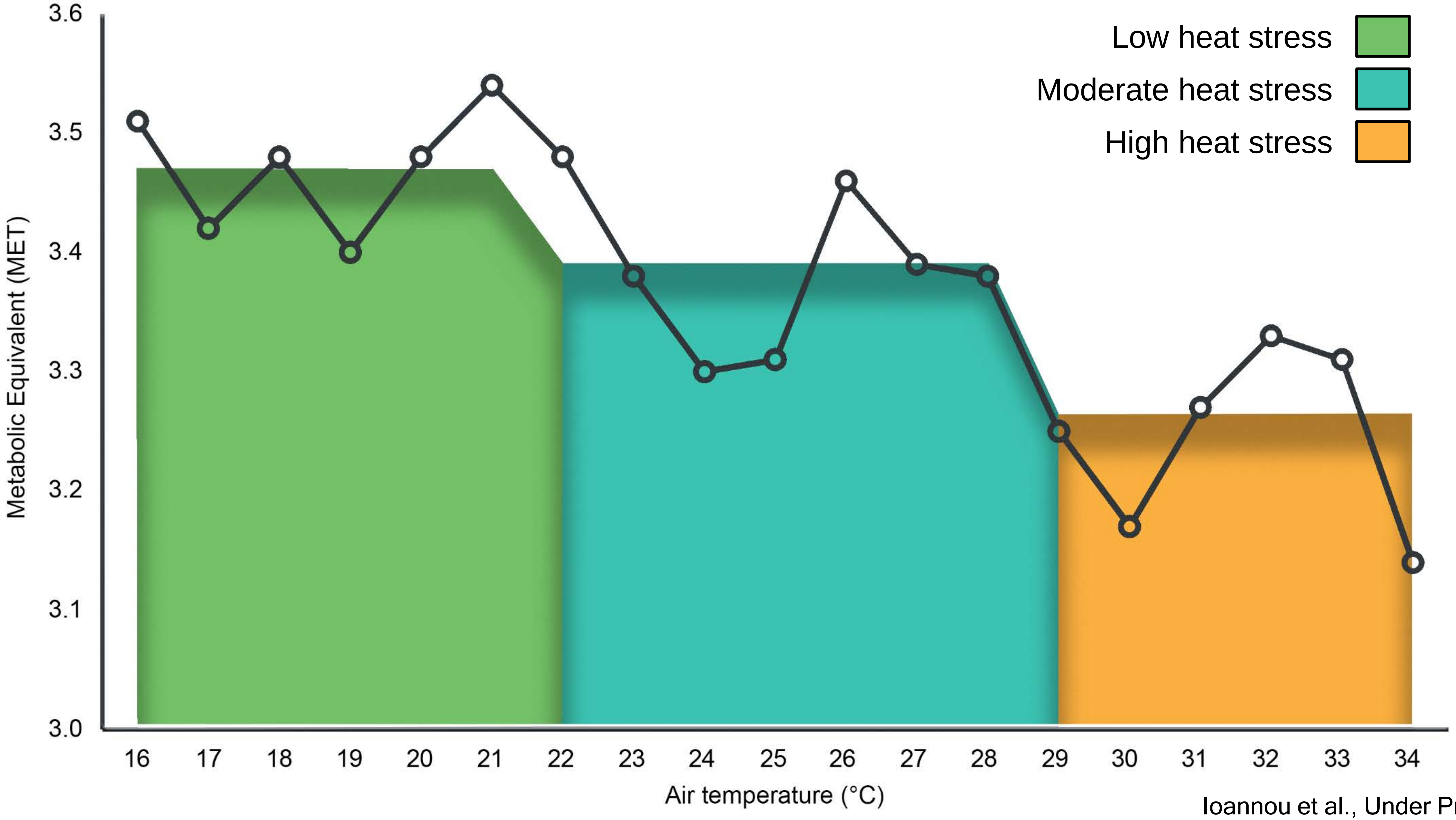
Ioannou et al., Under Preparation

# TEMPERATURE & LABOUR LOSS



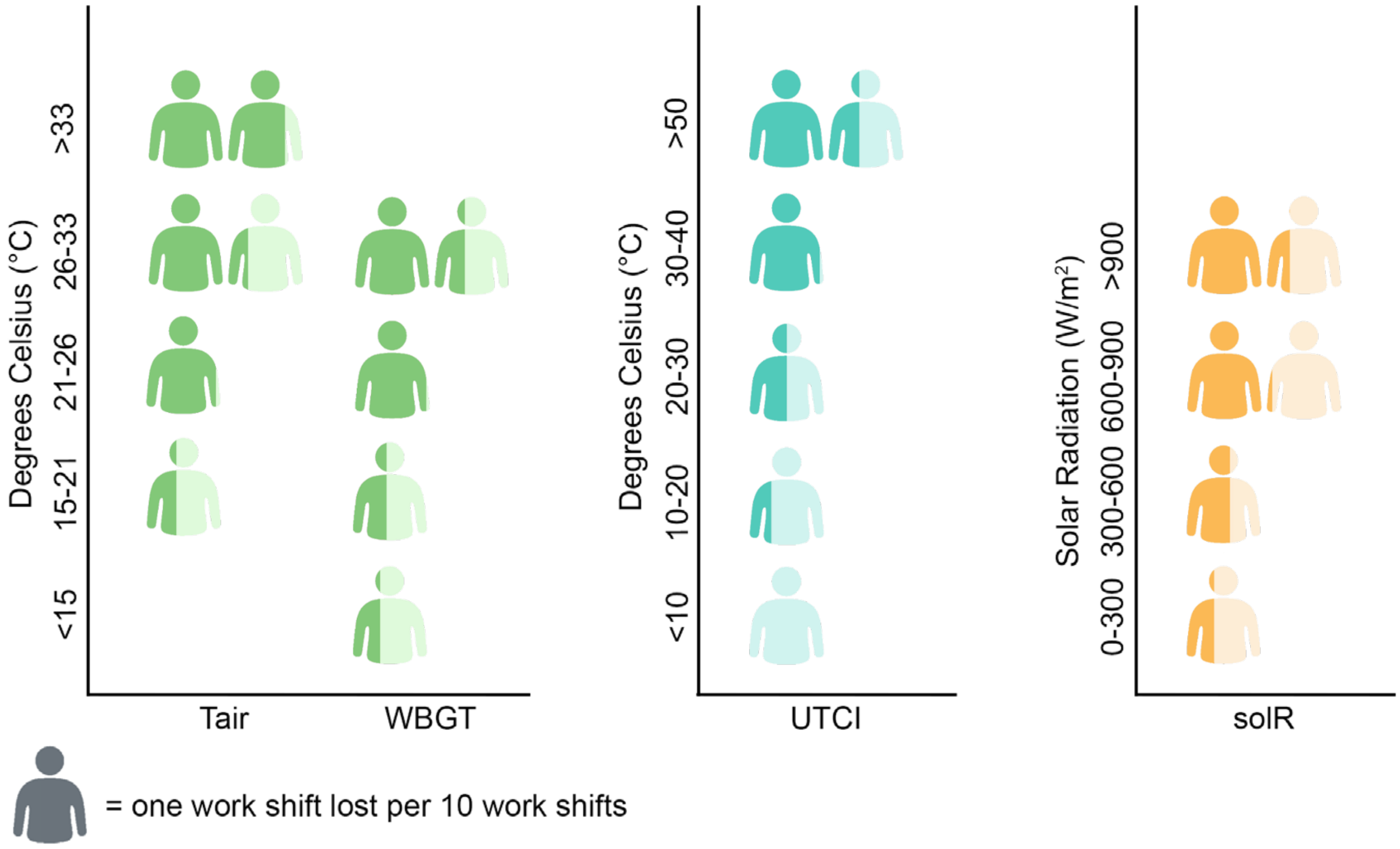

Ioannou et al., Under Preparation

# TEMPERATURE & WORK INTENSITY




Ioannou et al., Under Preparation

# HEAT STRESS & LABOUR LOSS

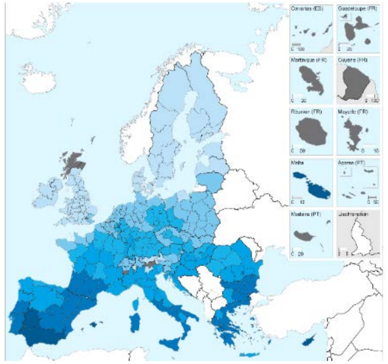



Ioannou et al., Under Preparation

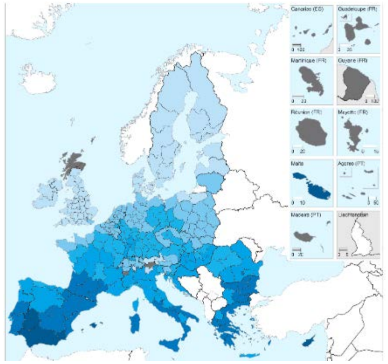
# VULNERABILITY MAPS FOR EUROPE AT NUTS2

- Percentage of gross value added lost across Europe

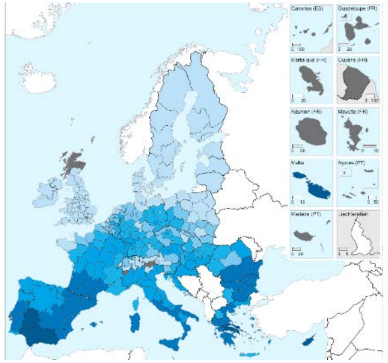
agriculture



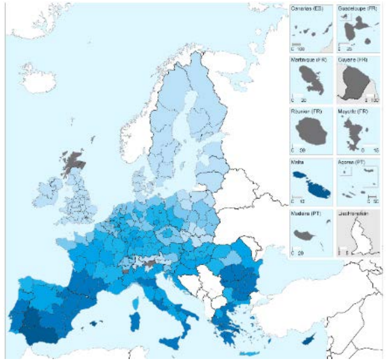
construction



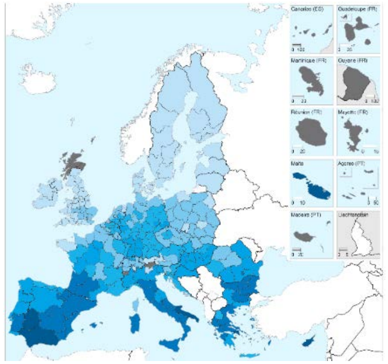
manufacturing

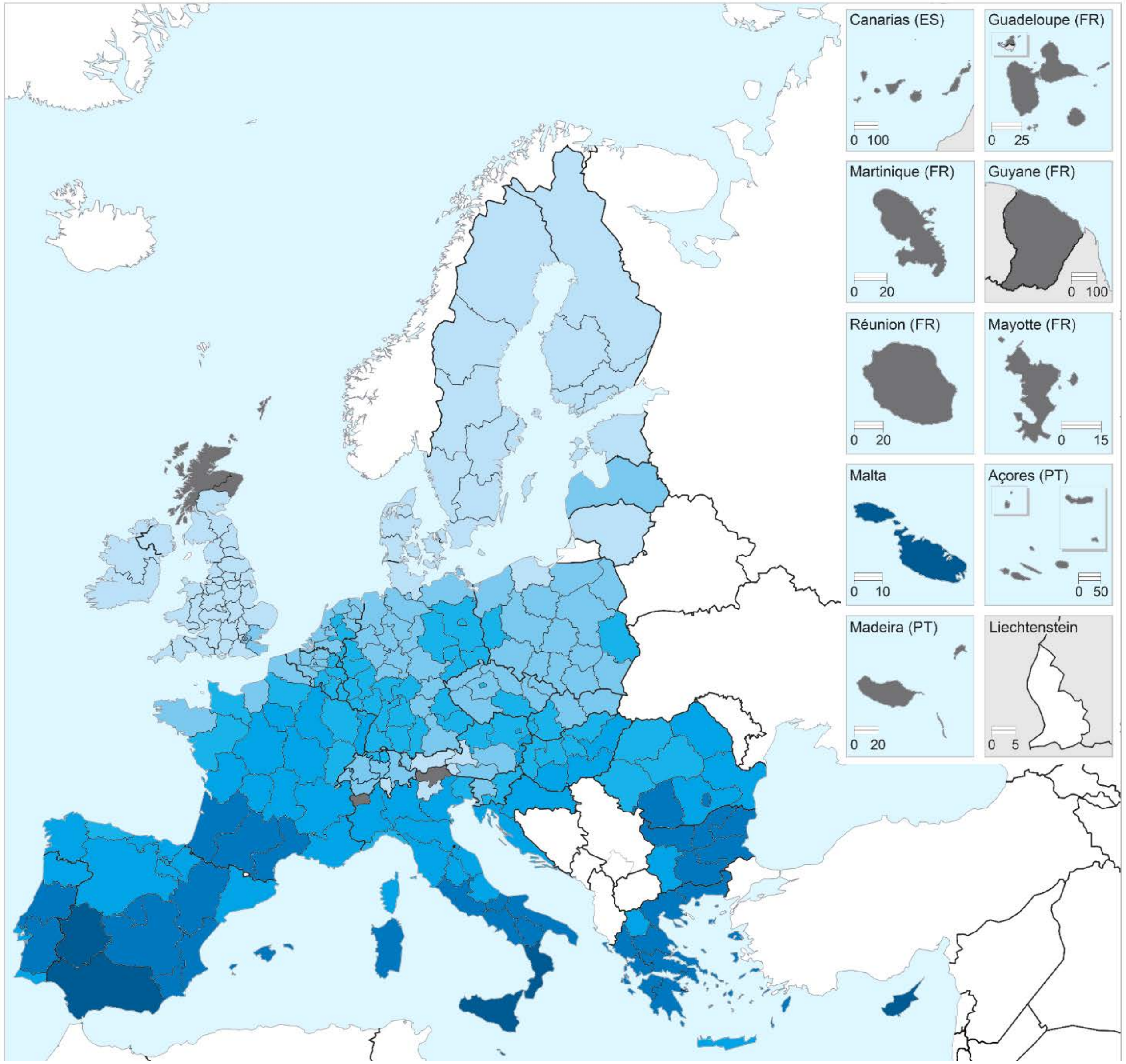


tourism



transportation






Flouris et al., Under Preparation

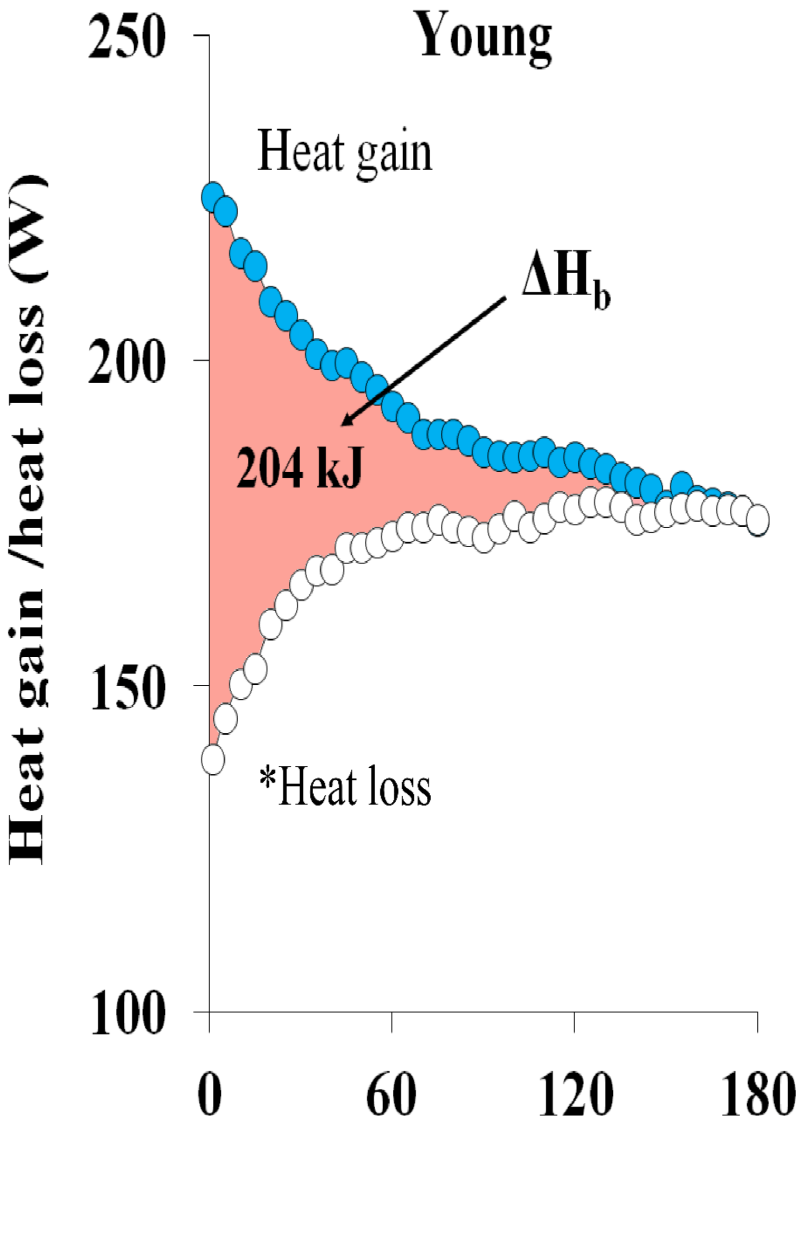
# HEAT - HEALTH - PRODUCTIVITY

- Workplace heat generates significant adverse effects
  - health risks
  - loss of productivity with substantial effects on the economy

# OUTLINE

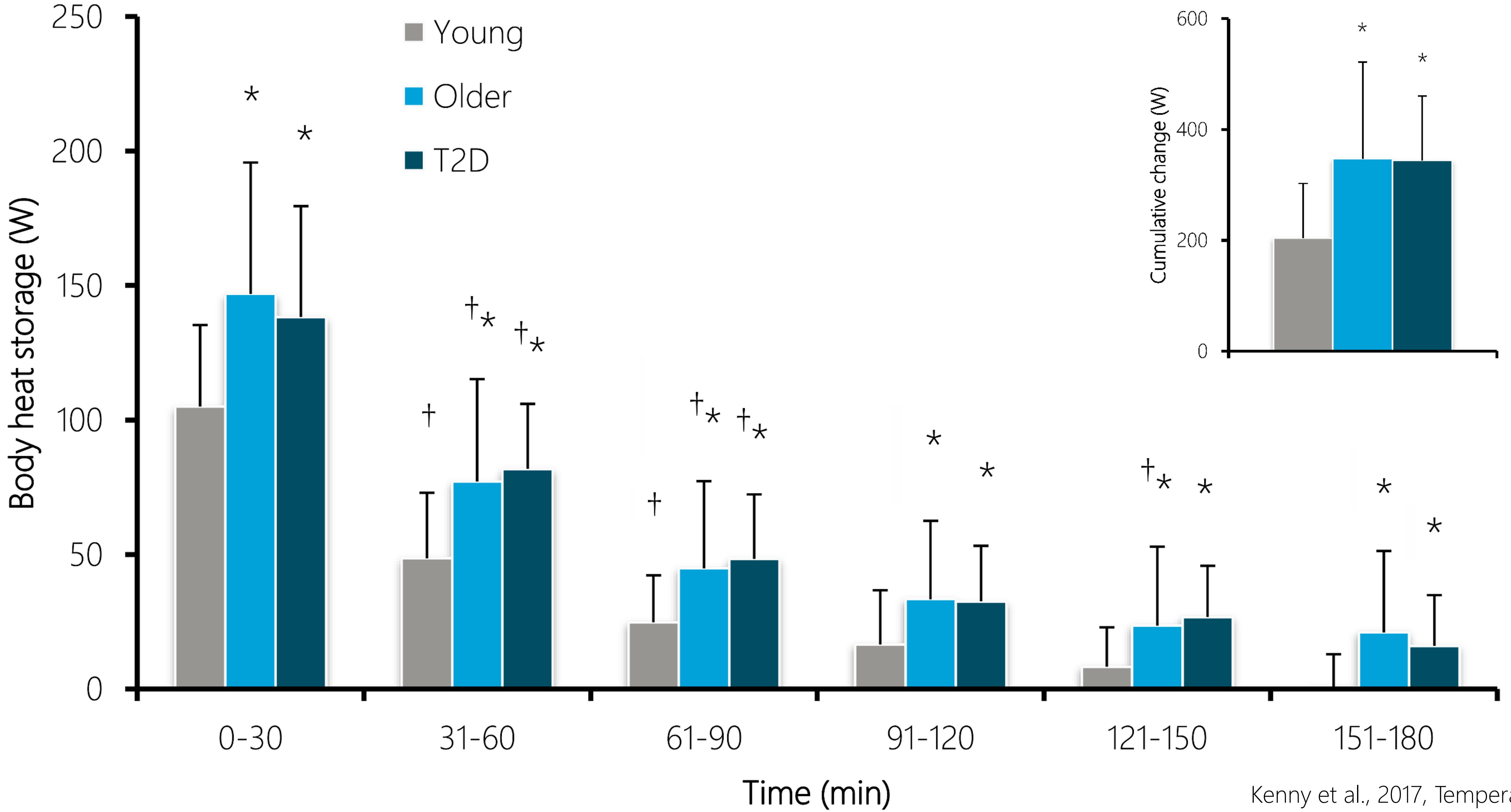
- Vulnerable population groups
  - workers
  - elderly
  - people with chronic diseases

# THERMOREGULATION – AGING – DIABETES



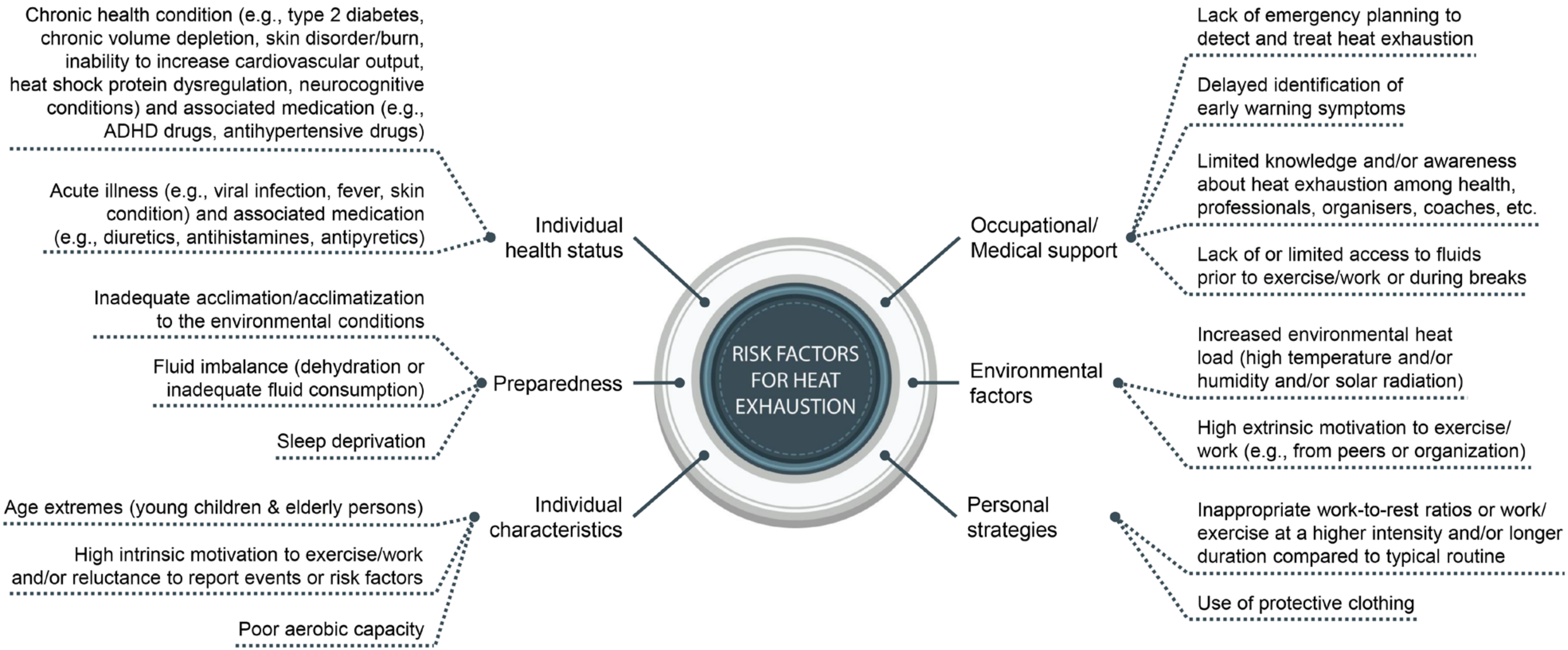

Kenny et al., 2017, Temperature

# THERMOREGULATION – AGING – DIABETES




Kenny et al., 2017, Temperature

# RISK FACTORS FOR HEAT SUSCEPTIBILITY



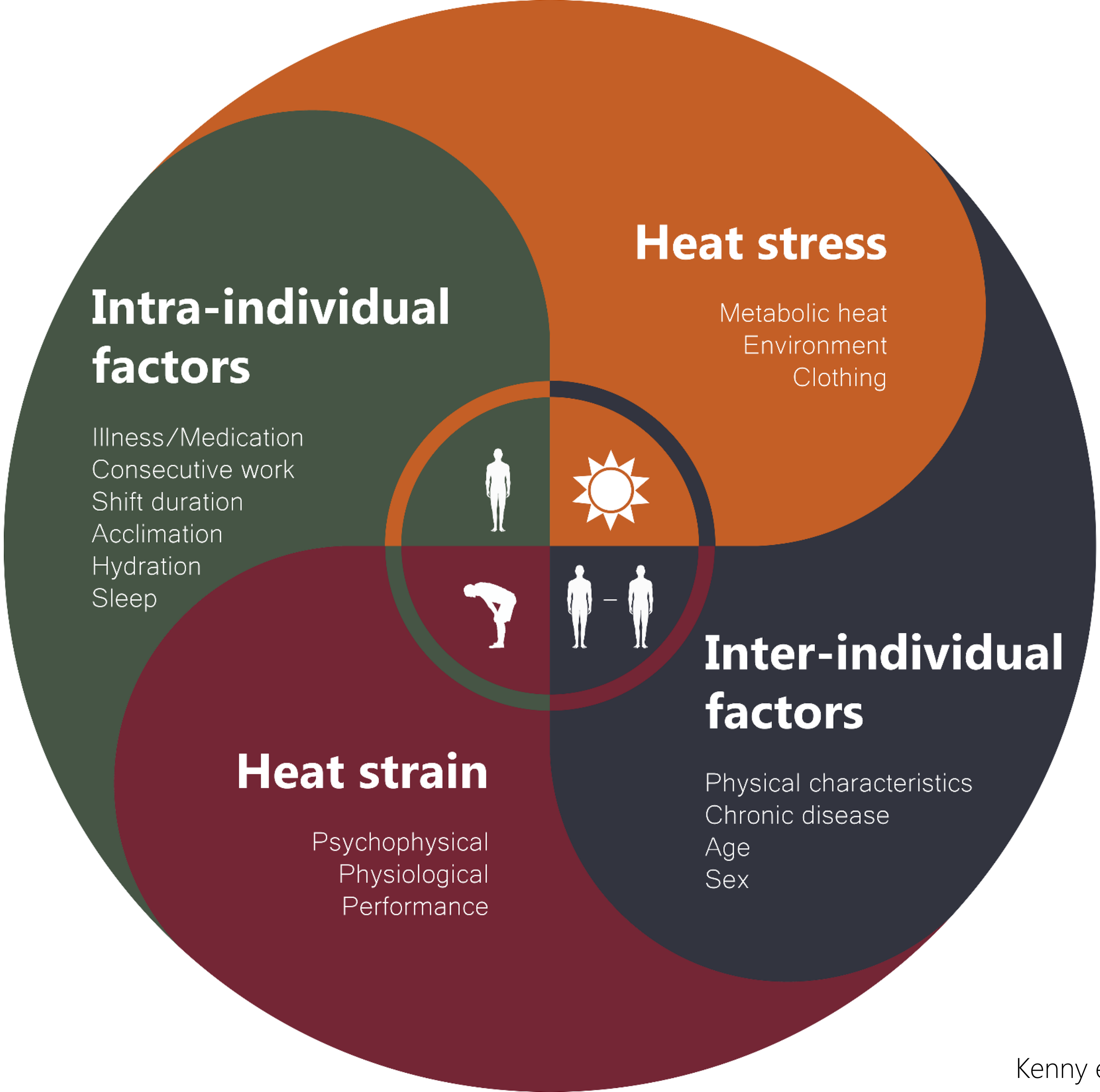

Kenny et al., 2018, Handb Clin Neurol

# SCREENING CRITERIA FOR HEAT STRAIN SUSCEPTIBILITY

- Individuals exercising/working in the heat who are 31-70 years old are at higher risk for heat strain when demonstrating two or more of the following (♂, ♀):
  - age
    - ≥53/56 years
  - body composition/morphology
    - BMI: ≥30/26 kg/m$^2$
    - adiposity: ≥29/35 %
    - body surface area: ≤2.0/1.7 m$^2$
  - aerobic fitness
    - $VO_2$peak: ≤48/41 ml$O_2$/kg FFM/min



Flouris et al., 2017, Temperature




Kenny et al., Under Review, Am J Ind Med

# IMPACTS OF OCCUPATIONAL HEAT STRAIN ON HEALTH & PRODUCTIVITY

Andreas D. Flouris

FAME Lab, University of Thessaly, Greece


Leonidas G. Ioannou,[1,2,3] Lydia Tsoutsoubi,[1,3] Paraskevi Gkiata,[1] Konstantinos Mantzios,[1] Maria Vliora,[1] Konstantinos Dallas,[1] Eleni Nintou,[1] Tânia Amorim,[1] Konstantina Poulianiti,[1] Giorgos Gkikas,[1] Gerasimos Agaliotis,[1] George Samoutis,[4] Lucka Kajfez Bogataj,[5] Marco Morabito,[6,7] Glen P. Kenny,[8] Igor Mekjavic,[9] George Havenith,[10] Chuansi Gao,[11] Tord Kjellstrom,[3] Lars Nybo[2]

[1]FAME Laboratory, School of Exercise Science, University of Thessaly, Greece
[2]Department of Nutrition, Exercise and Sports, August Krogh Building, University of Copenhagen, Denmark
[3]Centre for Technology Research and Innovation (CETRI), Limassol, Cyprus
[4]Medical School, University of Nicosia, Nicosia, Cyprus
[5]Biotehnical Faculty, University of Ljubljana, Slovenia
[6]Institute of Biometeorology, National Research Council, 50145 Florence, Italy
[7]Centre of Bioclimatology, University of Florence, 50121 Florence, Italy
[8]Human and Environmental Physiology Research Unit, School of Human Kinetics, University of Ottawa, Ottawa, ON, Canada
[9]Environmental Ergonomics Research Centre, Loughborough Design School, Loughborough University, Loughborough, United Kingdom
[10]Jozef Stefan Institute, Ljubljana, Slovenia
[10]Thermal Environment Laboratory, Department of Design Sciences, Faculty of Engineering, Lund University, Lund, Sweden