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OCCUPATIONAL AND SAFETY ISSUES OF WORKERS IN CENTRAL TOWER SOLAR ENERGY FACILITIES

PhD thesis in Sustainable Energy Systems,
supervised by Professor Almerindo Domingues Ferreira and Professor Manuel Carlos Gameiro da Silva,
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T H E S I S

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ABSTRACT

Due to the environmental problems arising from the use and exploitation of fossil fuels, countries are opting for developing technologies based on renewable sources as alternatives to satisfy the growing energy demand. Among the renewable energy technologies, in some countries, solar energy seems to be a promising solution to meet the energy supply due to its abundance and non-polluting character.

Based on solar energy industrial applications, the Concentrated Solar Power Systems (CSP) option is growing both in number of solar power plants and installed capacity, impacting also substantially in job generation. Among the CSP technologies that are dominating the market, are central receiver systems (CRS). CRS requires the use of heliostats to reflect solar radiation in its surfaces in order to concentrate it in a receiver. This process results in a considerable amount of concentrated solar radiation (visible light, infrared and ultraviolet radiation) inside and in the neighborhood of the installations.

Usually solar power plants are located in sunny environments due to requirements for power generation. Meanwhile, as the ozone layer damage has been exceeding its natural restoration, a growing level of UV radiation reaches the surface of the Earth where solar industry working force will be facing new risks.

Some previous studies have provided information about exposure to high levels of solar radiation, indicating that it may negatively influence the biological system. Working population performing activities outdoors and exposed to solar radiation may meet health impairments on skin, eyes and nervous system.

The excess of light due to both the reflection of the sunlight on the heliostats' surface and the brightness of the receiver is considered as a possible situation of risk for the eyes. The OSHA defined dehydration, heat exhaustion, heat stroke as consequences of exposures to heat. These impairments on health may also negatively impact the performance of the workers and, simultaneously, decrease their productivity.

This work aims to contribute with crucial information about the environmental conditions in solar energy facilities. In addition, the exposures to solar radiation in a case study, a CRS facility in an experimental solar facility in Mexico, are assessed. The research briefly outlines the relation between solar effects on eyes, skin and nervous system subjected to momentary and cumulative exposures. It also addresses the Methodology and safety doses. An assessment of eye, skin and level of heat stress on working population, based on solar radiation measurements was carried and results are presented and discussed. The main objective is to contribute with information directed to environmental scientists, standard developers and the solar industry. This way it will be possible to improve/develop procedures directed toward the occupational health and safety within solar energy industry.

Keywords: solar energy; risk analysis; concentrated solar power systems; occupational health and safety

RESUMO

Devido aos problemas ambientais decorrentes do uso e exploração de combustíveis fósseis, os países têm optado pelo desenvolvimento de tecnologias baseadas em fontes renováveis como alternativas para alcançar a crescente procura de energia. Entre as tecnologias de energia renovável, em alguns países, a energia solar parece ser uma solução promissora para garantir o fornecimento de energia devido à sua abundância e ao seu carácter não poluente.

Com base em aplicações industriais de energia solar, os sistemas de energia solar concentrada (CSP, siglas em inglês) estão a crescer em número de centrais de energia solar e em capacidade instalada, tendo um impacto substancial na criação de empregos. Entre as tecnologias CSP que dominam o mercado, está a tecnologia denominada, sistemas recetores centrais (siglas em inglês, CRS). O CRS requer o uso de helióstatos para refletir a radiação solar nas suas superfícies, de modo a concentrá-la num preceptor. Este processo resulta numa quantidade considerável de radiação solar concentrada (luz visível, infravermelho e ultravioleta) dentro e nas imediações das instalações.

Normalmente, as centrais de energia solar estão localizadas em ambientes ensolarados devido aos requisitos de geração de energia. Entretanto, como os danos da camada de ozono excedem a sua restauração natural, um nível crescente de radiação UV atinge a superfície da Terra onde o público trabalhador da indústria solar enfrentará novos riscos.

Alguns estudos anteriores forneceram informações sobre a exposição a altos níveis de radiação solar. Indicando que estes podem influenciar negativamente o sistema biológico. A população trabalhadora que realiza atividades ao ar livre, expostas tais quantidades elevadas de radiação solar, pode enfrentar deficiências de saúde na pele, nos olhos e no sistema nervoso.

O excesso de luz devido ao reflexo da luz do sol sobre a superfície dos helióstatos e o brilho do recetor são considerados possíveis situações de risco para o olho. A OSHA definiu a desidratação, a exaustão por calor, e a insolação como consequências das exposições ao calor. Estes efeitos nefastos na saúde também podem afetar negativamente o desempenho do trabalhador, diminuindo a sua produtividade.

Este trabalho tem como objetivo contribuir com informações sobre as condições do meio ambiente nas instalações de energia solar. Como exemplo de aplicação, as condições de exposição à radiação solar em um CRS são apresentadas e avaliadas num caso de estudo realizado numa instalação solar experimental no México. Neste trabalho descreve-se, brevemente, a relação de efeitos solares nos olhos, pele, e sistema nervoso quando submetidos a exposições momentâneas e cumulativas.

Apresenta-se a metodologia de estudo e as doses de segurança. É prevista uma avaliação do olho, pele e nível de estresse térmico na população trabalhadora, com base em medições de radiação solar. Os resultados serão apresentados e discutidos na seção final da análise do caso de estudo.

O presente trabalho tem como principal objetivo contribuir com informações dirigidas a cientistas ambientais, criadores de normas, e à indústria solar, para que se possam melhorar/desenvolver procedimentos direcionados para a saúde e segurança ocupacional no setor de energia solar.

Palavras-chave: energia solar; análise de riscos; sistemas de concentração solar; saúde e segurança ocupacional

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LIST OF ABBREVIATIONS

ACGIH= American Conference of Governmental Hygienists
AIHA= American Industrial Hygiene Association
ARPANSA= Australian Radiation Protection and Nuclear Safety Agency
BCC= Basal Cell Cancer
BLS=Bureau of Labor Statistics
CDC= Centers for Disease Control and Prevention
CEN= European Committee for Standardization
CM=Cutaneous Melanoma
CO_2= Carbon dioxide
CONACYT= Concejo Nacional de Ciencia y Tecnología
CPH= Experimental facility field of heliostats
CRS= Central receiver system
CSP= Concentrated solar power
DNA= Deoxyribonucleic acid
DT= Delayed tanning
EU- OSHA= European Occupational Safety and Health Agency
GHG= Greenhouse gas
ICNIRP= International Commission on Non-Ionizing Radiation Protection
INSHT = National institute of safety and health at work
IPD= Immediate pigment darkening
IR = Infrared radiation
IR-A= Infrared radiation type A
IR-B= Infrared radiation type B
IR-C= Infrared radiation type C
IRENA= International Renewable International Agency
ISO= International Standardization Organization
MED= Minimal Erythema Dose
MM= Melanoma
NREL= National Renewable Energy Laboratory
NIOSH= National Institute for Occupational Safety and Health
NIR= Non-Ionizing Radiation
NSTTF= National Solar Thermal Test Facility
OSHA =Occupational Safety and Health Administration
PET= Physiological Effective Temperature
PMV= Predicted Mean Vote
PPD= Persistent pigment darkening
PV= Photovoltaic
RALs = Recommended Alert Limits
RELs = Recommended Exposure Limits
ROS= Reactive oxygen species

SCC= Squamous Cell Cancer
SED= Standard Erythema Dose
SET= Standard Effective Temperature
Sim UVEx= Simulating UV Exposure
SPF= Sun protection factor
TLV's = Threshold Limit Values
TSF= The Solar Foundation
UNEP= United Nations Environment Programme
U.S. = adj. of United States
USD= currency of United States (dollar)
UTCI= Universal Thermal Climatic Index
UV = Ultraviolet radiation
UV-A= Ultraviolet radiation type A
UV-B= Ultraviolet radiation type B
UV-C= Ultraviolet radiation type C
UVI= Global Solar UV Index
VHF= Vertical Heliostat Field
VL= Visible light
WBGT= Wet- bulb globe temperature
WHO= World Health Organization
WMO= World Meteorological Organization
WT= Wet Bulb
DEW= Dew Point

LIST OF SYMBOLS

Skin

Δ_{λ}= measurement intervals

α = age dependent factor

β=biological amplification factor

$\mathbf{F_{es}} *$ = Corrected Skin exposure factor

$\mathbf{F_{es}}$= Skin exposure Factor

F_2= Cloud cover

F_3= Duration of the exposure

F_4= Ground reflectance

F_5=Clothing factor

F_6= Shade factor

H_{eff} = Effective exposure dose in J/cm^2

E_{eff}= effective irradiance in W/m^2 normalized to a monochromatic source 270nm

$E_{erythema}$ = Irradiance

E_{λ}= spectral irradiance from measurements in W/m^2

SCC_{risk} = Risk of squamous cell cancer

$S(\lambda)$= Relative spectral effectiveness (unitless)

UVI= UV index

$t_{erythema}$ = Duration of the exposure in seconds

t_{max} = Permissible UV exposure time in seconds

UV_{lunch}= The exposures during the lunch activity

UV_{occ}= The exposures during the work

UV_{recr}= The exposures during the recreational time

UV_{tot}= Cumulative UV exposure dose received

Eyes

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f= Focal length of the eye (m)

ρ= Reflection coefficient

β= Total beam divergence angle (mrad)

ττ= Transmittance coefficient

ω= Subtended angle from the source (mrad)

ω_{spot}= Subtended angle of the reflected image on a mirror as observed from a given distance (mrad)

A_{spot}= Area of the reflected image on a surface viewed by the observer (m^2)

A_p = Area of the pupil (m^2)

A_{equiv} = Equivalent area of the ***n*** heliostats (m^2)

A_{obs}= Area seen by the observer (m^2)

A'= Area of the reflecting surface (m^2)

b= Focal length (m)

C = Concentration ratio

D_h= Effective diameter of the mirror (m)

d_{spot}= Reflecting area of the mirror (m)

d_s = Source size (m)

d_p= Daylight adjusted pupil diameter (m)

$d_r$$\mathrm{d_r}$ = fω= Diameter of the image projected onto the retina (m)

E_{beam}= Beam irradiance (W/cm^2)

E_c= Irradiance in outside the cornea (W/cm^2)

E_{DNI}= Direct normal irradiance at the Earth´s surface (W/m^2)

E_{equiv}= Equivalent Irradiance of the ***n*** heliostats (W/cm^2)

$E_r$$\mathrm{E_r}$= Retinal irradiance ($W/cm^2$)

E_{ref}= Reflected irradiance (W/cm^2)

$E_{r,burn}$= Retinal burn threshold (W/cm^2)

$E_{r,flash}$= Potential after-image threshold (W/cm^2)

E'= Irradiance of the reflecting surface (W/cm^2)

r= Distance between the eye and the source (m)

r_{obs}= Location of the observer (m)

x = Distance (m)

X_{obs} = Distance between the observer and the tower (m)

Z_{obs}= The tower height minus the height of the observer (m)

Heat stress

T = Dry-bulb temperature (ºC)

T_g= Black –globe temperature (ºC)

T_{nw}=Natural wet-bulb (static) temperature (ºC)

T_a =Air temperature (ºC)

RH = Humidity (%)

M = Metabolic rate (W)

vp = Vapor pressure (hPa)

v = Wind speed (m/s)

$\mathrm{WBGT_{out}}$= Wet-bulb Globe Temperature with solar load (ºC)

$\mathrm{WBGT_{in}}$= Wet-bulb Globe Temperature without solar load (ºC)

$\mathrm{WBGT_{avg}}$= Wet-bulb Globe Temperature in mixed environments (ºC)

$\mathrm{WBGT_{p}}$= Wet-bulb Globe Temperature productivity (ºC)

W = rate of mechanical work (W m−2)

C = perceptible heat loss from skin by convection (W m−2)

R = perceptible heat loss from skin by radiation (W m−2)

Esk = rate of total evaporative heat loss from skin (W m−2)

Cres = rate of convective heat loss from respiration (W m−2)

Eres = rate of evaporative heat loss from respiration (W m−2)

Ssk = rate of heat storage in the skin (W m−2)

Sc = the rate of heat storage in the core (W m−2)

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1. INTRODUCTION

The sun is our primary energy source (Yunus, 2002). Energy is an important component in the improvement of life quality and economic development of a country (Sindhu, et al., 2016). There are concerns about achieving those goals by using technologies based on fossil fuels. In particular, the environmental matter is the release of considerable amounts of pollutants into the atmosphere (Wiser, et al., 2016), called greenhouse gas (GHG) emissions. Among the GHG, the strong increase in carbon dioxide (CO_2) is mainly contributing to the global warming issue (Comodi, et al., 2016).

The World Health Organization (WHO) revealed that the effects of climate disturbances will cost 320,000 lives per year by 2020 due to natural disasters, high temperatures and diseases (Mekhilef, et al., 2011). High levels of GHG emissions have encouraged countries to develop and implement strong measures to mitigate the global warming (Comodi, et al., 2016). As an example, the Ministry of Energy of Chile, aimed to regulate the CO_2 emissions by translating the levels of CO_2 emissions into pollution taxes. In reaction to this, companies opted for the development of clean energy technologies in order to achieve its energy demand (Parrado, et al., 2016).

Other countries are summed to the cause of GHG emissions decrements by following the Kyoto Protocol and Doha amendment (He Shawei, et al., 2017; Oncel, 2017). In addition, the Paris Agreement (2015) motivates the global parties to decrease the global warming levels (less than 2º C) compared with the levels in the pre-industrial era. The industrial era left a growing footprint that causes a big dilemma between those countries who can adapt to fast environmental changes while some others who cannot in a scale that money can't fix the problem (Oncel, 2017).

Besides the environmental issues, energy usage has become a crucial concern in the last decades because of rapid increase in energy demand, a request that will continue to grow in the future (Mekhilef, et al., 2011; Parrado, et al., 2016; He

Shawei, et al., 2017; Oncel, 2017). In this context, many countries are looking for a cost-effective way to meet their electricity demand while maintaining the GHG levels at a minimum. Renewable energy is a promising alternative solution to solve environmental problems, besides resolving the puzzle between energy demand and reduction of conventional fuels' consumption (Sindhu, et al., 2016; Mekhilef, et al., 2011; Parrado, et al., 2016; Ashouri, et al., 2015; Cortés, et al., 2015; Soria et al., 2016). Renewable energy provided approximately 19.3% of global final energy consumption and grew in capacity and production during 2015, and also in 2016. The power sector experienced the greatest increases in renewable energy capacity in 2016 (Renewables global status report, 2016).

Among the renewable energy technologies, solar power generation has attracted the attention all around the world. It is classified as a greatest promising option to be applied in industries due to its abundance, economical energy source costs and zero pollution (Sindhu, et al., 2016; Mekhilef, et al., 2011; Ashouri, et al., 2015; Reyes, et al., 2016; Zhen-Yu, et al., 2017; Jamel, et al., 2016). Also, as a consequence of the increment in oil prices (Jamel, et al., 2016), solar energy generation has increased in almost all the countries over the past years (Cortés, et al., 2015).

The United States is opting for avoiding combustion-based electricity technologies due to the environmental and public health benefits that solar energy brings to the public (Wiser, et al., 2016). In the European Union, solar technologies are playing a key role in the way to achieve the 20/20/20 targets (Reda, et al., 2015). Japan is the top solar energy producer per capita, followed by the United States, and China that is the top producer of solar energy according to its production-based approach (Cortés, et al., 2015). The solar energy industrial applications are divided into two main categories: the photovoltaic (PV) and the concentrated solar power (CSP) (also named concentrating solar power or concentrated solar thermal) (Mekhilef, et al., 2011; Zhen-Yu, et al., 2017).

In the study made by Zhen-Yu et al. 2017, is foreseen that CSP technology will contribute with 7% to the global electricity production by 2050. South Africa and

Brazil, in their attempt to achieve the GHG mitigation goals, found CSP plants as an attractive option (Soria, et al., 2016; Fluri, 2009). Brazil considered that this technology is the most mature and commercial at a worldwide level (Fluri, 2009). However, Parrado et al. 2016, added that the cost of CSP plants tends to decrease and will become more affordable in the future. In addition, large amounts of produced energy can be stored at high temperature at competitive cost in CSP plants. This fact is important for the future development of electricity markets because it increases the stability of the network (Reyes, et al., 2016; Meybodi and Beath, 2016).

The CSP technologies application began to raise their penetration on the global market since 1998 and, by the end of 2014, Spain and United States were leading in numbers. These countries accounted 52% and 38%, respectively, of the global installed capacity. China summed to leadership behavior in terms of planned installed capacity of CSP generation (Zhen-Yu, et al., 2017).

Moreover, beside the increment of the installed capacity and the number of power plants distributed around the world, there is also a substantial impact in the creation of new jobs (Oncel, 2017; IRENA, 2015). The U.S. Solar Foundation (TSF) affirms that solar industry employment has grown by 123.4% since late 2010. According to that institution, the number (for September 2016) of workers spending at least 50% of their time on solar-related work was 139 813 individuals (TSF, 2016).

Among the CSP technologies that are dominating the market are the parabolic trough and the central receiver systems (CRS) (Behar, et al., 2013; Gauché, et al., 2017). Basically, CRS uses multiple sun-tracking mirrors, called heliostats, concentrate the sunrays by reflecting them at one point, called receiver. The generated heat is used to produce steam from heating fluids. The steam drives a turbine connected to an electrical generator that produces electricity (Kalogirou, 2009; IEA, 2014). The CRS facilities are usually located in sunny places due to the production requirements and therefore these facilities require high solar exposure conditions (Zhen-Yu, et al., 2017; Franck, et al., 2010).

Franck et al. 2010, classified the solar light reflections from the receiver and the heliostats within CRS installations in some different human-interacting scenarios: the reflection directly to the sky (potential risk for airplane pilots), non-concentrated reflection from one single heliostat (potential risk for a person standing in front of the mirror), concentrated solar radiation from the heliostats field (potential risk for workers located in the solar tower) and the reflected solar radiation from the receiver (potential risks for people outside the heliostats field although in the nearby, e.g. car drivers passing in nearby roads, neighbors or pedestrians). Other scenarios were added by Ho et al. 2011, such as the diffuse radiation from the receiver, or the reflection from the mirrors when they are moving from the standby mode or when they are not orientated toward the receiver.

Also, a CRS facility, in order to take the highest advantage of solar energy, has to be submitted to regular cleaning and maintenance of heliostats surfaces, as those activities will allow the maximum reflectivity to achieve the highest productivity level. The cleaning activities can be rather accomplished by a cleaning system based on wet brushing (robot) or/ and by manual activities when it may be required (SENER, 2011; ECLIMP Termosolar, 2016; Kattke and Vant-Hull, 2012).

Hamilton, in 2011, classified some of the duties, among solar thermal facilities, as repetitive, physically demanding and sometimes developed under inclement weather conditions, especially those workers in charge of the control and operation of pump manifold systems and the ones in charge of the installation, maintenance, and reparation of the pipe systems.

Each type of renewable energy production process (construction, operation, and maintenance) has its own occupational hazards (Schulte, et al., 2016). The Occupational Safety and Health Administration (OSHA) supports that there are some hazards attempting to the health and safety (called green job hazards) of the workforce in the manufacture, installation, or maintenance operations, related to the solar energy industry (OSHA, n.d.; J. Hamilton, 2011).

Even though populations are adapted to their local climate (Kovats, 2008), the ozone layer loss has been exceeding its natural restoration due to climate change.

Therefore a growing level of UV radiation reaches the surface of the Earth which means that a growing population of workers in solar industry will be facing risks over short timescales (Ellwood, et al., 2014).

People working in the industry of solar energy must be aware that, like any other type of energy, the energy coming from the sun has the potential to interact with the surrounding bodies by transmitting its irradiance to them (Ipiña, et al., 2014). Even though living organisms are naturally exposed to the sun on a daily basis, biological systems have a spectral sensitivity to the ultraviolet (UV) interval. It is expected that any increase in the intensity of radiation produces significant chemical changes which could induce biologic effects. The biological effect is produced by a change that can be measured after the introduction of some stimuli.

Even though, it does not necessarily suggest the presence of health hazard those changes in the biological system could end in detectable impairments. The effects could impact at a physiological, biochemical or behavioral level in individuals. Prolonged human exposure to solar UV radiation may result in acute and chronic health effects on the skin, eye and nervous system (Kwan-Hoong, 2003). Carrasco (2003) described at least five types of damages to the eye and skin due to exposure to natural visible light.

If solar energy is not properly used, the outcomes will not be the ideal ones (Oncel, 2017). Therefore, analyzing the environmental conditions and addressing the safety at work of such a growing industry is important and relevant to the society.

1.1 Objectives and research questions

The overall purpose of this investigation is to provide safety elements for the development or/and improvement of procedures towards the occupational safety and health within central receiver solar power facilities.

Table 1.1. *Research questions and objectives to the corresponding chapter*

Research Question	Objective	Chapter
1. Is solar radiation a potential risk for individuals inside and/or near solar facilities?	1.1 Analysis of the relationship between solar irradiance and the work conditions in a solar energy installation.	2
	1.2 Identification of standards and establishment of a methodology and safety doses for the assessment of the potential risk situations identified	
2. Which are the risky scenarios of being exposed to concentrated solar radiation in central tower facilities?	2.1 Identification of the situations with potential risk, its possible impacts on health and the vulnerable population facing those situations of risks.	
3. Is the flux of solar irradiance exceeding the safety limits of exposure for skin?	3.1 Definition of the relationship between solar exposures and skin.	3
	3.2 Analysis of the irradiance to assess its impact on skin based on measured data.	
4. Is the flux of solar irradiance in a solar facility exceeding the safety limits of exposure in the eyes?	4.1 Definition of the relationship between the flux of irradiance coming from the sun that is reflected from the receiver and heliostats surfaces, and the eyes.	4
	4.2 Assessment of the glint and glare of reflected solar light from the receiver and heliostats surfaces based on simulations and measured data.	
5. What is the level of heat stress on workers within solar industry?	5.1 Definition of the relationship between solar exposures and heat stress levels.	5
	5.2 Analysis of the level of heat stress based on measured data.	

1.1.1 Risk analysis framework

The steps of the risk analysis start with the identification of possible risk situations, continue with the analysis of the results provided from simulation or measured data, followed by the suggestion of preventive measures and it ends in the definition of the monitoring process. In particular, this investigation is going through almost all of these steps except for the definition of a monitoring process.

1.1.2 Risk identification

The identification of possible risk situations in the workplace is based on extensive research about solar radiation and its potential impacts on human's health diagnosed in previous studies. The identification of risks is the first step to achieve in risk analysis, which is a very important step because at this point all the situations that can be considered of potential risk at work have to be found. To consider a situation as a potential risk, it is needed to take into account the complexity of the process and all the involved variables. Besides, the literature review and workers' interviews will be used to gather information about how individuals may be exposed to hazardous situations (OSHAb, n.d.). Risk identification will be based on the process about identifications of physical hazards of the OSHA; centering the identification of risks due to solar radiation and heat exposures.

1.1.3 Risk evaluation

Risk evaluation starts by prioritizing the situations that present an unacceptable level of risk according to the level of severe consequences. It means that the situation with a higher degree in severity of consequences will have priority in the analysis. A description of methods for the evaluation, maximum permissible limits of exposure and safety dose for those situations identified and related to solar radiation and hot weather conditions is made.

1.1.4 Risk estimation

The total solar energy incident on Earth is divided in two parts classified as direct or diffuse. The part of the global solar energy that reaches the Earth´s surface, without being scattered or absorbed, is called direct solar radiation. The remaining part is called diffuse radiation. Direct radiation is coming in a straight path and diffuse radiation is coming from all directions. The radiation that reaches the Earth surface can be measured and is called Irradiance. The irradiance represents the amount of energy incident on the area of a surface, per period of time, with units

W/m². When some flux of irradiance hits the area of a surface, some part of it is reflected and some part is absorbed; if there is any remaining part, it is transmitted (Yunus, 2002).

When the human body is exposed to solar irradiance, it will experience heat. The form of radiation emitted by the bodies due to its temperature is called thermal radiation and all the bodies at a temperature above zero emit it. Temperature is the measure of the intensity of energy transitions of molecules, atoms, and electrons of substance from those activities, the electromagnetic radiation emitted as a result is thermal radiation (Yunus, 2002; Kwan-Hoong, 2003; Givoni 1976 cited by Hodder and Parsons, 2006). A good descriptor of the influence of hot environmental conditions (amount of heat experienced by a worker) is the Wet bulb globe temperature (WBGT), which is a representative measure of a combination of different environmental factors that represent the level of heat exposure (ISO 7243).

The risk estimation has been performed by the acquisition of real data and simulations. The measured indicators were the irradiance and the WBGT temperature.

1.1.4.1 Equipment

Different parameters of radiation are needed for the design, sizing, performance, evaluation, and research of solar energy applications. Some of them are the total solar radiation, direct (beam) radiation, diffuse radiation, and sunshine duration.

There exist basically two types of instruments to measure solar radiation. The first one is the pyranometer that is used to measure the total radiation (direct plus diffuse) within its hemispherical field of view (Kalogirou, 2009). The other instrument is called pyrheliometer and is mainly used to measure direct solar irradiance. Direct or beam radiation is the portion of solar radiation that reaches the surface of Earth from the sun without any scattering. The level of radiation is calculated by this instrument on direct solar radiation, taking into account all heat losses (Iqbal, 1983). This sensor consists of a copper thermopile with 9 mm diameter; the measurements can be easily made with a digital voltmeter. This instrument allows tracking the sun at its diurnal motion.

In order to evaluate the level of heat experienced by a worker when the humidity is combined with temperature, air movement, and radiant heat WBGT meters are used to record data. In the present work Extech HD32.2[1], HT30 and HT200[2] were used. The HD32.2 is an instrument made for the analysis of WBGT index in the presence or in absence of solar radiation. The instrument is provided with three inputs for probes with SICRAM module; the SICRAM module interface between the instrument and sensor connected and communicate the sensor parameters and calibration data to the instrument. The measurements of the WBGT index, using the HT30, consider the effects of temperature, humidity, and direct or radiant sunlight. The Black Globe Temperature monitors the effects of direct solar radiation on an exposed surface. The HT200, a Heat Stress WBGT Meter, allows accurate measurements of WBGT, Black Globe Temperature, the percentage of humidity and the air temperature. Also, a BL30[3] climate data logger is used to record the air temperature and relative humidity of the environmental conditions.

1.1.4.2 Software

The National Renewable Energy Laboratory (NREL) provides on its website the SolTrace software tool developed to model concentrating solar power (CSP) systems and analyze their optical performance within the entire system. This tool utilizes Monte Carlo ray-tracing methodology and the user can select a number of rays to be traced. Such software can be used to model the flux of radiation in lineal concentration and punctual concentration collectors and it also allows to model optical geometries as a stage-series including shape, contour, and optical quality. Besides the NREL website, Wendelin and Dobos (2013) provide information about how to define each state during the simulation process in their technical report entitled "SolTrace: A Ray-Tracing Code for Complex Solar Optical Systems".

[1] https://www.ghm-group.de/fileadmin/GhmProduct/PDF/Datenblatt/en/ghm_HD32_2_WBGT_en_datasheet.pdf
[2] http://www.extech.com/ht30/
http://www.extech.com/display/?id=14522
[3] https://uk.trotec.com/products/measuring-devices/climate/climate-data-loggers/bl30-climate-data-logger/

1.1.5 Protective measures recommendations

Protective measures will differ depending upon the occupational exposure results to the working environmental conditions. The use of sunscreens, hats, eye protectors, clothing, and sun-shading structures are practical protective measures to reduce sunlight exposure (ICNIRP, 2004).

Recommendations about protection and preventive measures against solar radiation occupational exposures are specified according to the results obtained. Also, it is specified strategies to maintain under control the level of heat experienced by a worker.

1.2 Contribution

This investigation aims to contribute with crucial information about solar radiation exposures and its effects on skin, eyes and nervous system within solar power facilities using CSP technology. The work developed enhances the occupational and safety at work on thermal facilities by:

- Providing information about the usage of equipment and tools, methods of evaluation, maximum limits of exposure and safety doses for the improvement of solar working conditions;
- Demonstrating that there exist potential risk situations for human health due to the evaluation of solar radiation exposures based on real measured data in a solar facility location;
- Providing recommendations for the development of solar working tasks under safety conditions.

The outcome of the present investigation will contribute with some guidelines points directed to solar energy enterprises, policy-makers and environmental scientists about occupational safety and health in the way of minimizing natural hazards and health care costs on solar working population.

The originated articles on published, submitted, under review or under development are presented by the corresponding chapter in **Table 1.2**

Table 1.2. *Articles published, submitted and/ or in preparation by corresponding chapter*

Article	**Corresponding Chapter**
Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2016. Occupational exposures to solar radiation in concentrated solar power systems: A general framework in central receiver systems. Renewable and Sustainable Energy Reviews, Vol. 65, pp. 387-401. http://doi.org/10.1016/j.rser.2016.06.038	Chapter 2
Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2017. Cumulative and momentary skin exposures to solar radiation in central receiver solar systems. Energy. doi.org/10.1016/j.energy.2017.02.170	Chapter 3
Samaniego, D. R., Ferreira, A. D., and Da Silva M. G. Review of glint and glare assessments in central receiver systems: a case of study based on measured data of direct solar radiation (Submitted).	Chapter 4
Samaniego, D. R., Ferreira, A. D., and Da Silva M. G. Assessment of the level of heat stress in a solar power facility based on measured data (Manuscript in final preparation).	Chapter 5

Other related involvements:

- Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2015. Risk assessment in a CRS. 14th International Conference on Sustainable Energy Technologies (SET 2015), Nottingham, UK. ISBN: 9780853583134, vol. I.
- Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2016. Proposal of guideline elements dedicated to central tower solar energy facilities (original version in Spanish). 5º Symposium of Conacyt in Europe. Strasburg, France.
- Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2016. Proposal of guideline elements dedicated to central tower solar energy facilities. 2016 MIT Portugal Annual Conference. Braga, Portugal.

1.3 Investigation outline

In the next sections of this thesis, six chapters including the introductory chapter, outlines:

In **Chapter 2,** a review and description of the occupational exposures to solar radiation related to a solar facility are provided, following by a detailed description of the components of solar radiation classified by its wavelength within the solar spectrum. It is also presented a timeline of the previous studies in solar thermal facilities and related green jobs hazards. Finally, are addressed the different guidelines that might provide some relevant points to improve the occupational safety and health within solar industry.

In **Chapter 3,** the health impairments on the skin of individuals subjected to momentary and accumulative solar exposures are presented. It includes also the presentation of methods of evaluation, maximum limits of exposure, safety doses, and the usage of the ultraviolet index. Additionally, the evaluation of solar irradiance based on measured data is carried out in one of the solar technologies within the energy market. Finally, the results obtained from the analysis of the case study are presented and discussed.

Chapter 4 presents the temporary and permanent ocular health impairments due to momentary and accumulative solar exposures. Also, the method of evaluation, maximum limits of exposure and safety doses are provided. The chapter continues with the evaluation of solar irradiance based on measured data of a case study which is presented and discussed.

Chapter 5 presents an assessment of the level of heat stress due to hot weather conditions, being presented the results of a measuring campaign carried out in one of the solar technologies within the energy market. The chapter includes the description of the relationship between solar energy, health effects, climate change and productivity, followed by the assessment method and safety limits, ending with the presentation and the discussion of results of the measurement of the level of heat stress in a solar plant.

Chapter 6 provides the final conclusions of the investigation and enables recommendations for ocular, skin and heat exposures of workers in the presence of solar radiation in a solar facility.

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2. OCCUPATIONAL EXPOSURES TO SOLAR RADIATION IN CONCENTRATED SOLAR POWER SYSTEMS: A GENERAL FRAMEWORK IN CENTRAL RECEIVER SYSTEMS.

The content of this chapter is presented in:

Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2016. Occupational exposures to solar radiation in concentrated solar power systems: A general framework in central receiver systems. Renewable and Sustainable Energy Reviews, Vol. 65, pp. 387-401. http://doi.org/10.1016/j.rser.2016.06.038

2.1 Introduction

The radiation, coming from the sun, is used as a renewable energy source in solar thermal power plants for the production of electricity. Like any other form of energy, the solar radiation has the potential to interact with biological systems (Knave B, 2001; Kwan-Hoong, 2003).

According to National Renewable Laboratory (NERL) solar thermal power plants have increased their number and capacity, there is an increased number of environments where the high levels of solar radiation represent potential risks to human health. This study has the main objective of analyzing the environmental conditions in solar facilities using central receiver technology in order to provide information that may improve the occupational health and safety in those locations.

2.2 Solar Radiation and CSP technology

The solar radiation passing through the atmosphere is composed by three types of non-ionizing radiation (NIR), namely ultraviolet (UV), visible light (VL), and infrared (IR) radiation, and all of them are classified by its wavelength within the solar spectrum [**Figure 2.1**].

Nearly half of the solar radiation can be perceived through the eyes and the rest of it cannot be perceived by any of the human senses unless the source has a high intensity so it can be perceived by feeling heat. The radiant heat (thermal radiation), known as infrared radiation, is emitted by all objects with temperature above zero. IR -radiation conform almost half of the solar radiation, and it is subdivided in IR-A, IR-B and the IR-C through the solar spectrum. Besides IR radiation in the solar spectrum, the VL is the part of it that can be perceived with the eyes. The UV is a form of optical radiation of shorter wavelengths and photons (particles of radiation) more energetic than VL; subdivided into UV-A, UV-B and UV-C. Solar radiation classification differs somehow depending on the involved discipline [**Figure 2.2**]. For example, in the area of environmental and dermatological photo-biology, UV radiation is usually defined as UV-A from 400 to 320nm, UV-B from 320 to 290nm and UV-C from 290 to 200 nm (Knave B, 2001; Kwan-Hoong, 2003; Brauer, 2006; Carrasco, 2003; Hodder and Parsons, 2007; Yunus, 2002).

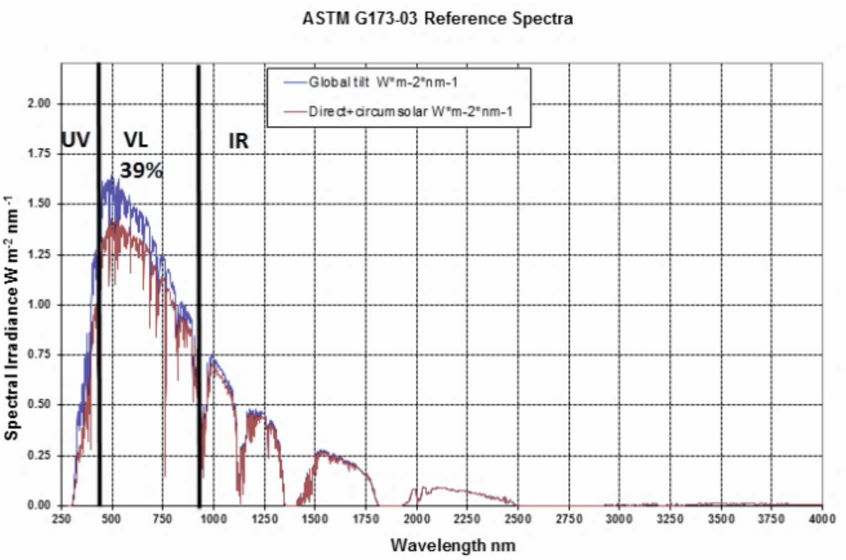

Figure 2.1. *Solar spectrum based on ASTMG173-03[4]. Own elaboration.*

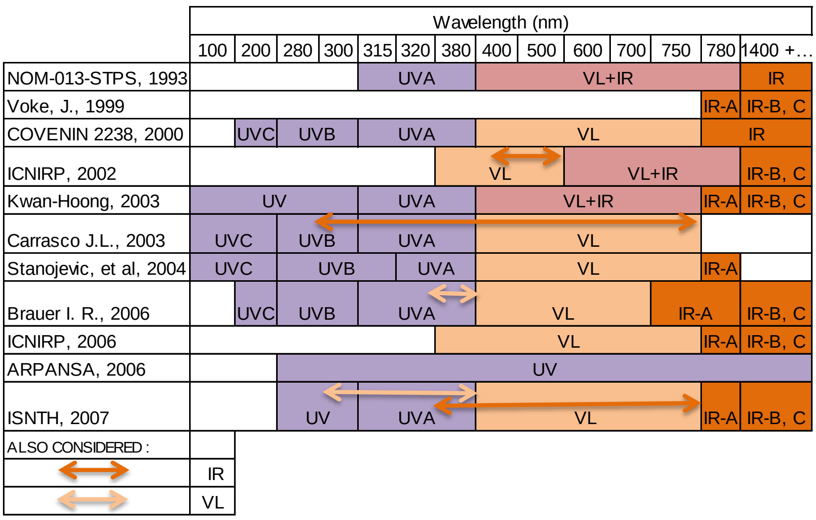

Figure 2.2. *Wavelength classifications. Literature adaptation.[5]*

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[4] ASTMG173-03 represents the standard terrestrial solar spectral irradiance distribution developed by American Society for Testing and Materials (ASTM).

[5] Kwan-Hoong, Ng., 2003; Brauer I. R., 2006; Carrasco J.L., 2003; Stanojević, M. R., et al. 2004; Voke, J., 1999; Segura, B. D., and Calvo, M. J. R., 2007; ICNIRP 2002; ACGIH 1993; CEN 2004; COVENIN 2238: 2000; ARPANSA 2006.

Brauer (2006) considers the part of UV that falls in the range between 200 and the 315 nm a concern in order to ensure human health and safety, while Kwan-Hoong (2003) believes that the biggest risks to the public are the ones coming from visible light and ultraviolet radiation or, in other words, natural light exposures. Natural light is present in solar thermal power plants in a daily basis, and, due to the countries´ motivation of using renewable energy sources for electricity production instead of fossil fuels, the risk of exposure of the workers to solar radiation is expected to have a significant increase.

One of the several types of solar thermal technology is based on the concept of the concentration of sunrays, known as the concentrated solar power (CSP) system. It uses the solar radiation as a renewable source for the electricity production through a thermodynamic cycle (Hamilton, 2011; IRENA, 2013).

In 2013, Behar et al. recognized that, among all the CSP technologies available in the late years, the one that uses central receiver system (CRS) is the type of technology moving to the forefront, giving it a chance to become the technology of choice.

Basically, these systems concentrate the sunrays on the receiver by reflecting the sunlight through heliostats' surfaces (mirrors) (Kalogirou, 2009). The receiver absorbs the concentrated solar energy and transfers it to a circulating fluid. The heated fluid is pumped into storage tanks and passed across a heat-exchanger, where steam is produced. This steam is used in a turbine connected to a generator in order to produce electricity (Hamilton, 2011; IRENA, 2013; Kalogirou, 2004). The heliostat's surface is designed to focus the beams on the receiver where the reflected light will be scattered on a level that increases proportionally to the distance between the heliostat and the focal point.

These reflections can be classified in different human-interacting situations according to Franck et al. (2010): the reflection aimed at the sky (potential risk for pilots), non-concentrated reflection from one single heliostat (potential risk for a person standing in front of the mirror), concentrated solar radiation from the heliostats field (potential risk for the workers located in the solar tower), and solar field and beyond (potential risks for people outside the heliostats field although nearby, i.e. roads, neighbors and pedestrians) (González, et al., 2015). Other scenarios can be also added according to Ho et al. (2011), e.g., the diffuse radiation from the receiver, the reflection from the mirrors when they are moving from the standby mode or stowed position and when they are not oriented towards the receiver.

In order to take full advantage of solar energy, the CRS has to be submitted to regular heliostats cleaning and maintenance because those activities will allow the maximum reflectivity from the heliostats surface to achieve the desired productivity levels (SENER, 2011; ECLIMP, 2014). The cleaning activities can be rather accomplished by a cleaning system based on wet brushing (robot) (SENER, 2011) or/ and by manual activities when it might be required (Kattke and Vant-Hull, 2012). Special cleaning care is required in cases with the presence of some environmental agents, such as chemical compounds attached to the heliostat surface, dust, smog and/or air contaminants.

On the other hand, Hamilton (2011) provided information about solar jobs and classified some of the duties as repetitive, physically demanding, and sometimes developed under inclement weather conditions. The situation is more evident especially for those workers in charge of the control and operation of pump manifold systems and also the ones in charge of the installation, maintenance, and reparation of the pipe systems.

The CRS facilities are usually located in sunny environments with a high solar ultraviolet index (Franck, et al., 2010) and solar radiation has a potential impact in biological systems (Knave B, 2001; Kwan-Hoong, 2003). Locations with these characteristics may represent an indirect drawback because working places under that kind of environmental conditions seem to allow possible scenarios of potential risks for human health. Therefore, it may be necessary to analyze the environmental conditions in order to ensure the occupational health and safety in future facilities.

2.3 Health impacts

The sun, considered as the principal source of visible light, ultraviolet and infrared radiation, has the potential to transmit its irradiance (energy coming from a source) to the surrounding bodies. When a body surface is exposed to such incident irradiance, scatters a part of it and absorbs the other portion in the form of photons. The absorbed fraction induces cellular reactions causing alterations (effects) directly or indirectly in the biological system, which is susceptible to produce physiological, biochemical or behavioral changes, resulting, from that process, skin impacts (erythema and burns) and several types of damage to the eyes (Kwan-Hoong, 2003; Brauer, 2006; Carrasco, 2003; Stanojević, et al., 2004).

According to Toet et al. (2013), some of those effects can be classified as reversible when the effect is physiologically healed with time, even though those situations can lead to secondary effects. In the opposite way, long-term hazards that cannot be healed with time because the occurred alteration is a permanent damage. Toet et al. (2013) classify those long-term hazards as irreversible effects. Usually, long-term hazards are related to UV chronic exposures, where skin cancer and skin aging (photo-aging) are the main examples (Polefka, et al., 2012). According to Knave (2001) and Brauer (2006), the relationship between the dose (determined by the duration of the exposure and the amount of radiation) and the response to human skin carcinogenesis hasn't been clearly established yet. The individuals with fair skin and those individuals with burns history, especially if these burns were produced in a young skin, are more likely to develop skin cancer, compared to those with occupations requiring extensive outdoor work and those who live in sunny regions.

In Cuba, Fernández et al. (2014) conducted a study aiming to identify different occupational factors associated with skin cancer. The study reaffirmed that skin cancer has a direct relation with heat, sunlight and non-ionizing radiations, in combination with some chemicals and other factors such as people with fair skin, old age people, the location of the exposure, and the biological characteristics of the individual.

When a surface of a body is exposed to solar radiation, a temperature rise is noticed. In fact, when the incident irradiance reaches the body surface, an increment on the body's temperature is produced, where an interchange of thermal radiation (present in the IR, VL, and a portion of UV radiation) occurs. The initial physiological response of the human body starts with the action of sweating. If the heat persists, it leads into abundant sweating susceptible to induce dehydration and the rise of the deep-body temperature, ending the process in a whole system collapse. The collapse is caused by the absence of thermal equilibrium or heat balance between the body and the environment (Yunus, 2002; Parsons, 2009).

The OSHA (Occupational Safety and Health Administration) defined two health effects in consequence of exposures to hot environments, namely heat stroke and heat exhaustion (OSHAa, n.d.). According to Parsons (2009), there are also behavioral disorders that can negatively influence the performance capacity of the workers due to the discomfort and psychological stress, produced by a hormonal imbalance, which leads to a considerable decrease of their productivity.

However, all biological changes depend on a multitude of different factors such as radiation dose, intensity of the source, time and duration of exposure, power of the radiant beam, characteristics of the source emission, environmental conditions (clouds, air pollution, air humidity, etc.), type of work activities, biological conditions of the body (e.g. the type of skin), and the capacity of absorption of different tissues. It also depends on the wavelength because in the electromagnetic spectrum of solar radiation some wavelengths are more energetic than others. It may be also hard to know whether people are sufficiently sensitive to react physiologically to subtle changes in the spectral content of radiation (Kwan-Hoong, 2003; Brauer, 2006; Hodder and Parsons, 2007; Stanojević, et al., 2004; Polefka, et al., 2012).

With the previous health impacts information, the classification of the effects in human health seems to be a complex topic. Therefore, hazards are summarized in

APPENDIX "A", in order to identify the potential health effects, biological system affected-area, wavelength, primary, secondary and/ or side-effects.

2.4 CRS assessments of environmental conditions: previous studies

Several studies investigated the impact of solar radiation reflections of visual sources at solar thermal power plants.

Saur and Dobrash in 1969 published the study about visual inspection of sun reflections from metal surfaces in order to calculate the duration of afterimage disability in automobile drivers. The results showed the need of curvature in mirrors surfaces and matte surfaces in the receiver for the reduction of the glint and glare.

Years later in 1977, Young, developed a research emphasizing on hazards associated with reflecting concentrated solar energy from the receiver in the experimental installations of Sandia National Laboratories in Albuquerque, New Mexico. In the same year and same installations, Brumleve carried on an investigation about eye hazards associated with concentrated reflected light of single and multiple coincident heliostat beams. The results showed that the irradiance of a single heliostat exceeds the safety limits within a short focal distance (up to 40 m), even though, the safe limits for retina damage were never exceeded in heliostats with focal lengths of more than 270 m.

Almost four decades later Ho et al. (2009) presented a compilation of previous assessments about glint and glare effects and optical risks in the different CSP technologies. The study provides the metrics used to determine safe retinal irradiance exposures in order to avoid the permanent eye damage. In addition the authors suggested additional quantitative metrics that could be used for glint and glare analysis in concentrating solar thermal power plants with eye hazards prevention purposes.

One year later, Franck et al. (2010) analyzed potential risks for skin and eyes due to exposure to the brightness of the reflected sunlight from the heliostats and the receiver. The authors explored the operation and design features of a central tower installation (facility with 1,600 heliostats approximately) in Israel. Through analyzing the potential effects on human health and the safety metrics for the evaluation, the authors conclude with some recommendation for eyes and skin.

In 2011, Ho evaluated potential glint and glare hazards during short-term exposures from the concentrating solar collector's field at the National Solar Thermal Test Facility (NSTTF). The study basically evaluated the potential for permanent eye injury (retinal burn) and temporary visual impairment (after-image) using Digital photographs of the glare to quantify the irradiance flux in each pixel. The results revealed a strong glare could be observed from the surface of the heliostat over 1700 m (> 1 mile) away when the heliostats were placed in a standby mode; with an aim point ~30 m to the east of the top of the tower. After viewing the glare source directly, a temporary after-image effect was experienced.

In the same year, Ho, in collaboration with Ghanbari and Diver proposed an analytical model for the evaluation of the specular reflections in point- focus collectors and line-focus collectors, and diffuse reflections (receiver surface). The Metrics proposed aimed to contribute with the assessment of permanent eye damage and temporary after-image effects by calculating the irradiances from various concentrating solar collector systems (e.g., heliostats, dishes, troughs, receivers).

Toet et al., in 2013, provided the reversible and irreversible effects of visible light on human eyes and defined the requirements for effective optical measures, but the study didn't take place on a solar facility.

After a year, Ho et al. (2014; 2015), evaluated the glare in the solar power plant Ivanpah located in the United States, due to the existence of reports submitted by pilots and air traffic controllers about the glare originated from the facility. The fact drove to the evaluation and quantification of the flux of irradiance in the facility in order to identify the potential ocular impacts of the glare source at distance ranging from 2-32 km. The assessment was based on the quantification of the irradiance in photographs processed using the PHLUX method. The results showed the intense glare caused by the heliostats' surfaces in standby mode could cause an after-image effect (up to a distance of 10 km). In the case of the receiver's surface, the glare had a low potential to cause the same effect.

Samaniego et al. (2012; 2015) evaluated the eye hazards due to solar radiation exposure in a CRS experimental facility in Mexico. Basically, the levels of the solar radiation flux were simulated with the NREL software ¨SOLTRACE ¨[6]. The actions of looking directly at the surface of the heliostats, and looking directly the receiver's surface were estimated with the metrics proposed by Ho et al. (2011). The data were compared with the maximum permissible limits showed in previous studies. The results showed that permanent damage (e.g., retinal injuries) and momentary vision loss (after-image effect) could occur. In the situation when a person looks directly at a single heliostat' surface, the reflected irradiance has enough potential to cause damage to the retina in a range of 300 meters.

In 2015, González, et al., focused on the evaluation of glare that produces permanent eye damage and temporary flash blindness by adding a new step in order to adapt the methodology provided by previous analyses performed by other authors. The study was carried on the "Vertical Heliostat Field" (VHF) located in the region of Madrid. The results showed that values for temporary blindness suggested the need for preventive measures in order to avoid solar reflections from bright surfaces.

2.5 Green job´s hazards

The European Occupational Safety and Health Agency (EU-OSHA) provides a full description of possible future insides in green jobs (Ellwood, et al., 2014). The Bureau of Labor Statistics (BLS) (2010) defines the term "green job" as those jobs in which workers' duties involve making their establishment's production processes using natural resources. According to the OSHA in the United States of America

[6] http://www.nrel.gov/csp/soltrace.html

(USA) the green job´s hazards, in solar energy workers industry, are mostly related to dehydration, heat stroke, heat exhaustion and, in extreme cases, may cause death (OSHAa, n.d.).

In 2014, Xiang et al., provided information about outdoor and indoor workers. From 43 reviewed studies, 44% of all of them were dealing with outdoor environments, 23% of all of them were carried out in America and only 7% in Europe. The results showed that in 90% of the cases, the individuals who work in outdoors presented discomfort due to the heat strain sensation; even though it is classified as no pathological effect, it can affect the physical and mental well-being of a person and should be considered a potential health hazard as well (Xiang, et al., 2014; Wolska, A., 2013; ICNIRP; 2002).

The Solar Foundation (2013) conducted a research based on the definition of "solar worker" (employee who spends at least 50% of all his work time supporting solar-related activities). It was found that 90.7% (almost 130,000 workers) of those who are called as solar workers actually spend 100% of their time supporting solar activities.

The EU-OSHA, in order to inform policy-makers, governments, trade unions, and green industry employers, has defined different risk scenarios that might be present in the future renewable technologies appliances in Europe. The final report, which is the result of 26 interviews, summarizes nine technologies involving the occupational health and safety as (Ellwood, et al., 2014):

- Wind energy,
- Green construction and building retrofitting,
- Bio-energy,
- Waste management and recycling,
- Green transport, green manufacturing,
- Robotics and automation,
- Batteries and energy storage,
- Domestic and small-scale renewable energy

- Energy transmission and distribution

Even though the solar energy production at industrial scale wasn't discussed, the fast development of new technologies for green energy production may surely impact in jobs growth (Ellwood, et al., 2014).

In the annual solar jobs census in the United States of America, it was estimated 93,502 workers in the solar industry in the year of 2010; a number that lately increased 53% in 2013. In November of 2014, the number increased 21.8% (173,807 solar workers) within 12 months, what means an increment of 86% since they started to make the solar jobs census in 2010. The projected number of solar workers for the year 2015 is around 210,060 workers (TSF, 2014; 2015) [**Table 2.1**].

Table 2.1. *Number of solar workers by sector. Reproduced from TSF, 2015.*

	2010	**2011**	**2012**	**2013**	**2014**	**Projected 2015**
Installation	43,934	48,656	57,177	69,658	97,031	118,942
Manufacturing	24,916	37,941	29,742	29,851	32,490	37,194
Sales & Distribution	11,744	13,000	16,005	19,771	20,185	25,480
Project Developers	no category	no category	7,988	12,169	15,112	18,004
All other	12,908	5,548	8,105	11,248	8,969	10,440
Total	93,502	105,145	119,016	142,698	173,807	210,060

It is also projected in **Figure 2.3**, the number of workers by working area in solar industry: installation, manufacturing, sales and distribution, project developers, among others, where the area of installation is on the top of the priorities list (TSF, 2015). The workers in the installation sector, who spend at least 50% of their time on solar-related activities, are projected as 118,942 workers for late 2015.

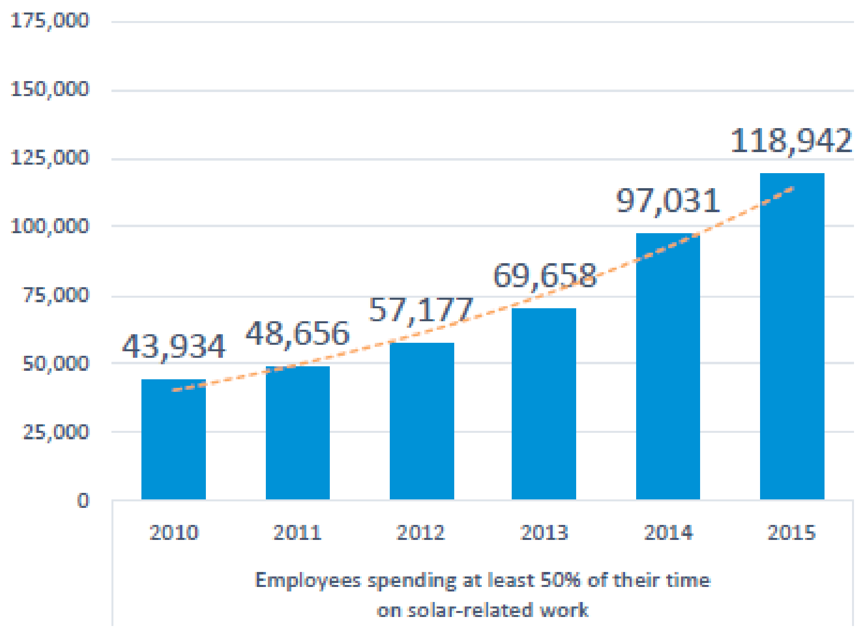

Figure 2.3. *Solar installation employment growth, 2010-2015 projection. Taken from TSF, 2015.*

Jobs related to solar power will increase in number as a consequence of the solar power industry growth, but those projections can be affected by the global competition, renewable energy targets, regulatory policies and other factors, such as economic stability (TSF, 2014). E.g., Spain, once defined as the pioneer of renewables by International Renewable International Agency (IRENA), in 2014, had increased the number of concentrated solar power jobs until 2011 in spite of the crisis, but in 2012 around 6,000 jobs were lost. In addition, ABENGOA SOLAR (2013), dedicated to the implementation of solar thermal facilities, in its 2013 annual report published that its employment index decreased from 20.9% (2012) to 3.4% (2013), in one year. Even though the loss of jobs in 2012, the facility Gema Solar (with a capacity of 19.9 MW and 2,650 heliostats) generated 1,800 jobs during the construction period and 50 jobs for the operation phase (FENERCOM, 2012).

United States of America, as the second worldwide country in concentrating solar thermal power capacity, reported 2,600 workers for the construction and 86 jobs for the operation and maintenance activities of the CSP IVANPAH plant (377 MW of capacity and 173,500 heliostats). Meanwhile, in South Africa, KHI Solar (4,120 heliostats and 50MW of capacity) reported a total of 630 jobs in the same work areas (Abengoa solar, 2013; FENERCOM, 2012; IVANPAH, 2013).

Besides the solar industry workforce increments, the 2015 renewable global status report confirmed an increment in concentrating solar power capacity between the years of 2010 and 2013 [**Figure 2.4**] (Renewables global Status report, 2015).

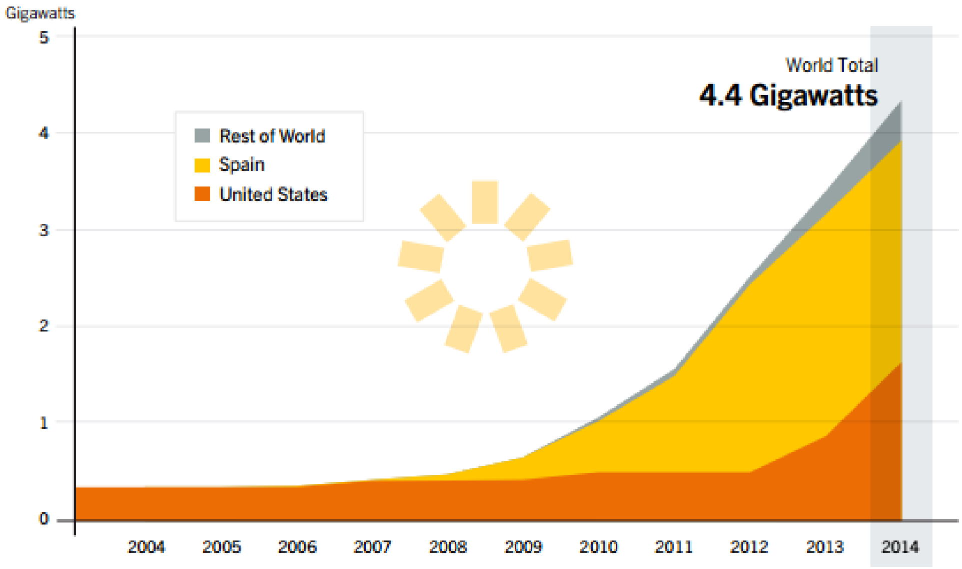

Figure 2.4. *Concentrating solar thermal global power capacity. Taken from Renewables global Status report, 2015.*

Governments are increasingly aware of renewable energy´s potential role in improving national development and with the markets becoming every day more global, renewables evolution has surpassed all expectations. TSF affirms that solar industry continues to exceed growth expectations at a rate nearly 20 times faster than the overall economy. Besides that, the global installed capacity and production also have increased substantially generating new jobs where a wider population faces new risks over shorter timescales (Ellwood, 2014; TSF, 2014; Renewables global Status report, 2015).

2.6 Methods for the environmental conditions assessment

CRS technology facilities are usually located in sunny places with high ultraviolet index and the contributors of the ultraviolet index are also the reflected solar radiation from mirrors and the receiver. The burn times (level of burning under unprotected sun exposure) have been used as safe level limits of sun exposure which imply the concept of acceptable extending exposures, and sometimes workers expose themselves to those environmental conditions with a lower protection. The overall goal, instead, is to avoid sunburns and cumulative exposure of UV radiation that can cause, in the future, cancer, damage to the eyes and nervous system. Even though, the exposure effects on human health depend on the amount and type of radiation and, therefore, the application of preventive methods should be taken into consideration (Franck, et al., 2010; Lucas, et al., 2006; WHO, 2002).

In 2013, Wolska proposed the modified skin exposure factor (F_{es}) method for the skin hazard assessment due to UV radiation exposure. It consisted in substituting the global solar UV index (IUV) from a particular day and geographical place (maximum IUV value to clear sky conditions) with the geographical latitude and season factor. Considering the most common clothing of outdoor workers in that location, that author introduced additional values of the clothing factor. Three additional values for clothing (0.40 for arms, head and neck exposed, 0.35 for arms and neck exposed, and 0.7 for head and neck exposed) were considered, plus the cloudiness condition of 0.5. The SED, per work shift (8 h), was defined as 10 SED (1000 J/m^2 per 8 h), which means that the dose rate, in a period of 8h, should not exceed 1.25 SED in one hour (1.25 SED/h). The dose rate was suggested per hour because the duration and time of work activities may vary within the work shift.

In 2014, Blazejczyk et al. developed a method in order to estimate the incidence of Squamous Cell Cancer (SCC), where basically they assessed the anatomical exposures to solar UV with the Sim UVEx (Simulating UV Exposure). The model predicts the dose and the anatomical distribution of radiation received on the basis of ground irradiance and morphological data. It allows taking into account parameters such as body inclination, orientation to the sun and shading body parts. It also requires some input parameters such as the direct irradiance, diffuse irradiance, ground reflected irradiance and sun position (azimuth and zenith) (Blazejczyk, et al., 2014; Vernez, et al., 2015). The ambient UV data were both simulated and measured with radiometers. Then the estimation of SCC risk was expressed as a function of age and cumulative exposure UV dose (see Appendix B; eq. B.9-10).

In similitude with other methods, some factors had not been taken into account such as the access to shaded spots, indoor working periods, taking lunch outside, absences at work or clothing, and, besides that, the model assumes a constant for the annual exposure without any variation (long periods outside, no protective clothing and no shade) so the values should be considered upper values (Blazejczyk, et al., 2014; Vernez, et al., 2015).

Ho et al. (2009; 2011) proposed a short-term exposure parameter in order to assess the bright light sources in CSP installations. In the study, two variables were defined as necessary for the evaluation of the impact of solar radiation in the eyes. The eye and skin differ in sensitivity toward exposures to solar radiation, therefore the damage mechanisms are different in the two of them and should be assessed separately. The eye is protected against the bright light by natural responses that commonly are the action of blinking or the action of looking to another side instead of looking at bright source, ending this process in a momentary exposure. Even if the workers are exposed to lower momentary intensities, the cumulative exposures might cause an acute damage (Franck, et al., 2010; Sliney, 1994; Sliney, et al., 2005).

In 2009, Parsons pointed out that one person in thermal comfort needs to be in heat balance, which basically refers to a thermal neutrality state. This state occurs in the moment in which the heat gains are equal to the heat losses. In other words, a constant heat-exchange between the body and the environment is required to achieve this equilibrium (Epstein and Moran, 2006; Kenny, et al., 2008; 2009).The equation of heat balance in defined by (Da Silva, 2002; Mairiaux and Malchaire, 1990).

Equation 1. *Heat balance*

$$M - W = (C + R + E_{sk}) + (C_{res} + E_{res}) + S_{sk} + S_C \qquad (1)$$

where: M is the rate of metabolic heat production (W m^{-2}), W is the rate of mechanical work (W m^{-2}), C is the perceptible heat loss from skin by convection (Wm^{-2}), R is the perceptible heat loss from skin by radiation (W m^{-2}), E_{sk} is the rate of total evaporative heat loss from skin (W m^{-2}), C_{res} is the rate of convective heat loss from respiration (W m^{-2}), E_{res} is the rate of evaporative heat loss from respiration (W m^{-2}), S_{sk} is the rate of heat storage in the skin (W m^{-2}), S_c is the rate of heat storage in the core (W m^{-2}).

In practical applications of human heat balance, the radiant fluxes play an important role, being: (1) solar radiation or short-wave radiation with wavelength of 0.3 to 0.4 µm divided in UV, VL and IR, and (2) thermal radiation or long-wave radiation (terrestrial radiation) with a wavelength between 4.1 and 50 µm. The radiant fluxes differ in description within the literature (Kenny, et al., 2008; Blazejczyk, 2004) which established that the solar radiation received as ~0.3-4 µm from VL and IR and the terrestrial radiation around ~4-100 µm. Also, the radiant fluxes vary in space and time due to the dynamic behavior of the meteorological variables and the space-depending properties of irradiant surfaces in the surroundings (Jendritzky, 1981).

Equation 2. *Net radiation absorbed by a person*

$$Q = R + L \qquad (2)$$

where
L is the net long-wave radiation in a person and R is the short-wave radiation.

Based on the components of the human radiant energy budget presented by Jendritzky et al. 1981, the short-wave radiant fluxes required for the calculation are: direct solar radiation, diffuse solar radiation, reflected solar radiation from the ground, long-wave fluxes (atmospheric radiation from the open sky and radiation from solid surface in surroundings) (Mairiaux and Malchaire, 1990; Matzarakis, et al., 2010).

In the assessment of the influence of thermal environment conditions on the human body, there are several parameters or factors that should be measured or estimated, e.g., the air temperature, radiant temperature, humidity, air velocity, metabolic rate and clothing insulation (Da Silva, 2002). The effects of all these factors are considered in thermal environment indices used as the basis of risk management programs with the objective of avoiding the occurrence of unacceptable levels of heat stress in people (Parsons, 2009; Epstein and Moran, 2006; Höppe, 1999).

The precise estimation of the total absorbed radiation by a human body in an outdoor environment seems to be a very complex process, due to the interactions between the radiant fluxes in the sky and ground hemispheres, and the human body factors (Kenny, et al., 2008). There exist around 40 indices for the assessment of the thermal comfort and heat stress listed by Epstein and Moran (2006). These indices are divided into three groups: (1) rational indices, (2) empirical indices, and (3) direct indices based on the measurement of environmental variables. The third group is more friendly and daily applicable in workplaces than the other two groups. The first two groups require many factors for their calculation and they are considered comprehensive groups, but they have their own difficulty. It resides in that there is no practical way to record invasive measurements of too many variables (Epstein and Moran, 2006; Kenny, et al., 2008).

It can be said that the creation of a universal heat stress index is quite difficult, due to the complexity of the interactions between parameters, the number of the parameters and variability of location and time in the assessment process (Epstein and Moran, 2006). Furthermore, there are some considerations in the use of some indexes, e.g., the wet-bulb globe temperature (WBGT) requires specific measurements which are quite difficult to perform for long periods of time (Epstein, and Moran, 2006; Blazejczyk, et al., 2011). In the case of the Predicted Mean Vote (PMV), it cannot be applied in arid climates (as well as the Temperature Humidity Index), or places with extremely high air temperatures and low relative humidity in summer (Abdel, et al., 2014).

On other hand, the Physiological Effective Temperature (PET) index that gives an estimation of the thermal sensation for indoors or outdoors can be calculated with the Ray man model, which is free access (Matzarakis, et al., 2010; Blazejczyk, et al., 2011; Abdel, et al., 2014). The model takes simple inputs and avoids all complications of the two-node model required by the Standard Effective Temperature (SET). The SET is the appropriate index for finding the relationship between thermal discomfort and physiological effect of a wide range of environmental situations, clothing and activity levels including outdoor extreme weather conditions. The Universal Thermal Climatic Index (UTCI) also designed or wide ranges of activity, clothing, resistance and climatic conditions, can be calculated simply by using the UCTI free access calculator[7].

As it can be seen from the reviewed literature, there is no perfect or the best option in the index choice. Every index has its advantages and disadvantages inside its procedure so the users' choice might depend on the main and final objective of the assessment. With the purpose of analyzing the level of heat stress experienced by a worker, it is consider quite important the revision of the international standards developed by the International Standardization Organization (ISO) committee, i.e. ISO 7730 (2005), about the thermal comfort in working environments, ISO 7243 (1989), about the methodology for the estimation of the heat stress on a worker and ISO 7933 related to the determination and interpretation of heat stress.

[7] UTCI calculator at: http://www.utci.org/utcineu/utcineu.php

It can also be added that, during the literature search, any evidence about the application of any of those indexes on a thermal assessment specifically in CRS field was not found.

2.7 Non-ionizing radiation guidelines

The situation of being exposed to solar radiation at CRS on a daily basis is more often related to health impacts. The concerns about it, lead some international institutions to develop guidelines and assessment methodologies, establishing maximum permissible levels of exposure, in order to enable the employees to execute the risky tasks under the safest possible conditions.

One of these associations is The American Conference of Governmental Hygienists (ACGIH), 1993, which published the exposure maximum limits called "Threshold Limit Values" (TLV’s). The TLV’s aim to allow the accomplishment of work without the occurrence of negative health effects. These limits are based on data obtained from eye injury studies, as a result of looking directly to the sun and of being exposed to environments with strong visible radiant energy, e.g. deserts. Sliney in 1994, published a report about ocular hazards of light, which provides elements about human exposure limits based on the ACGIH´s threshold values for optical radiation (i.e., ultraviolet (UV), light and infrared (IR) radiant energy).

On the other hand, ICNIRP, in its way to the recognition of UV radiation as an occupational hazard cause, presented guidelines about limits of exposure and protection to UV, far infrared and non-ionizing radiation in general. In 2007 the commission published a standard with general information about UV exposures for both indoor and outdoor environments. Even though some preventive measures and maximum limits of UV exposure were suggested, it has been argued that the boundaries between the risks and the benefits of UV radiation are not quite clear. This fact means that, even that the UV health risks associated with excessive exposure are known, it is not clear if there exist benefits from UV exposure above the maximum permissible limits of exposure established on the guidelines (ICNIRP, 2004; 2010; Vecchia, et al., 2007). Also, in its point 8.9, about outdoor exposure, it is clearly explained that the use of the guidelines in an outdoor setting poses many problems in the establishment of the dose. According to Sliney (ICNIRP, 2010), the levels of exposure in mid-summer appear to exceed the limits, which happens in the opposite way for ocular exposure because it does not exceed the limits in long periods of time exposure under most situations. Even if the role of all factors is not yet clearly understood, the ICNIRP and the World Health Organization (WHO) strongly recommend the reduction of UV radiation exposures (Moore, et al., 2013).

The standard about long far-infrared wavelengths exposures (IR-C radiation) focuses on the protection of high-intensity artificial sources for industry workers in hot environments (ICNIRP, 2006); but the health hazards associated with hot environments, like heat strain and discomfort, are normally related with limits below thermal–injury due to IR-C exposures.

Among the European Standards[8], provided by the European Committee for Standardization (CEN), are the EN-ISO-8996 (2004) for the determination of the metabolic rate of workers and the EN-14255-3 (2008) and EN-14255-4 (2004) about the terminology and quantities used in UV, VL and IR exposure measurements.

The EN-14255-3, in its own judgment, qualified the assessment methods suggested, per se, with lower accuracy, and with limited precision. Also, it has been said that due to the exception of some important factors such as posture, clothing and time spent outdoors, the standard hasn´t direct relation to individual solar UV exposures, even though the safe limits are based on the MED instead of the SED. Since there are no limit values recommended based on the incidence of non-melanoma skin cancer due to radiant exposure, it has been proposed for skin cancer protection (in agreement with WHO and ICNIRP), the same sun protection used against erythema.

[8] European standards are applied in Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

The wide concern leads the countries over the world to implement their own standards. E.g., the Spanish National Institute of Safety and Health at Work (abbreviation in Spanish; INSHT), in 2007, defined the methodology steps for the assessment of occupational exposures to optical radiation (UV, LV and IR) (ICNIRP, 2004). In a similar way, Venezuela published the standard COVENIN 2238:2000 (2006) about non-ionizing radiation (180 and 315 nm) permissible limits, protection and control measures for occupationally exposed people and individual public members.

Meanwhile, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), in 2006, published a standard related to occupational UV exposure; and in its Annex 3 provides information about avoiding occupational skin hazards. Also, there are two Mexican standards on this issue, developed by the government, one of them (NOM-013-STPS-1993) about the safety and hygiene in workplaces with non-ionizing electromagnetic radiation, while the other (NOM-015-STPS-2001) provides the WBGT method for the evaluation of thermal outdoor conditions.

2.8 Discussion

The number and the increments in production capacity of solar industry and the respective impact on jobs growth raised concerns about new health risks, over short timescales that need to be faced (Ellwood, et al., 2014). In global economy, all people are valued and it is essential to provide working conditions that do not damage workers' health by following the principle of health for all human diversity. There has been a lot of research in how people respond to some environmental conditions and some of this gained knowledge has been included in international standards serving as the basis in working environment's design process, but the concept of identifying the requirements and design for all users has its owns limitations (Parsons, 2008).

For example, ICNIRP guidelines have its limitation with the adequacy of the dose for the assessment in the eyes and skin. It resides in the fact that the ocular exposure limit of 30 J/m^2 is exceeded only when a person is looking directly at the sun, in summer, and with clear sky conditions. It means that, under most conditions and in extreme exposure periods, the limit is not ever going to be exceeded, which appears quite remarkable for skin sensitive individuals who easily get sunburns (ICNIRP, 2010; Moore, et al., 2013).

Otherwise some standards are basing the safe skin limits on the MED ending in a subjective measure determined by the reddening of the skin (CEN, 2008) which means that it is referred to the perceptible impact in the skin 24h after being irradiated by the sun (ICNIRP, 2004; Moore, et al., 2013). The MED should be applied and assess according the different types of skins on individuals (Lucas, et al., 2006). If the main goal is the avoidance of sunburns, a general application to a population without considering the skin differences will be classified as a lack of prevention.

Djongyang et al. (2010) claim that the actual standards about thermal comfort help, but should not be considered as absolute references. The ISO 7730, for example, has been criticized because of its lacks of theoretical validity (Olesen and Parsons, 2002). The main problem for assessing the thermal outdoor conditions is that the variables might be more diverse than those for the indoor settings (Honjo, 2009). In reality, the conditions at workplaces are not uniform because the tasks are performed under a variation and combination of those conditions (degrees of physical work-load, heat stress and work periods, types of clothing, gender, acclimatization, age, etc.) according to the Center for Disease Control and prevention, CDC.

Besides these complex variables interactions, thermal comfort is defined so many times by the authors as that condition of mind which expresses satisfaction with the thermal environment; so, according to this definition, comfort is a subjective sensation (CDC, n.d.; Epstein and Moran, 2006; Kenny, et al., 2008; 2009). As an example of thermal subjective sensation, Höppe (2002), interviewed 250 people on a hot summer day, usually classified as thermally uncomfortable, but the curious fact was that most of the individuals perceived the weather conditions as comfortable conditions. One of the reasons showed that the interviewed population experienced a cold weather one day before the interview took place and the allowance of time to be spent outside made them happy. Finally, it was concluded that the tendency of people to perceive thermal conditions might be based on psychological aspects, which ends in subjective opinions.

The PET index is an example of the situation where subjective opinions are involved. For example, in a situation with a PET of 20°C, a person on swimming trunks could feel very cold while wearing a coat would feel thermally uncomfortable. It happens because the protective clothing will promote sweating and will reduce the ability to evaporate and cool down (Parsons, 2009). Another example: a person with working load can evaluate the same conditions as “too warm” as well, while such thermal conditions at rest state would be regarded as “too cool”. Therefore, the method has to be adjusted to the subjective characteristics in terms of clothing and activity too (Abdel, 2014).

The difficulties with various indices are that they provide different temperature thresholds with the same meaning of thermal sensations and/ or alert descriptions (Höppe, P., 1999). The interactions between the ambient temperature, radiant temperature, humidity, air velocity, clothing and metabolic rate are fundamental in defining thermal sensation; at the same time to construct safety regulations become rather complex. The election of one index for the assessment depends on the final application purpose or the final user. If the objective is implementing the method in industry the election of must to be suited to practical use by personnel (Parsons, 2006).

According to Parsons (2009), the elements or principles about how people respond to thermal conditions, and how those conditions impact in human health, are well understood due to the extensive timeline studies. On the other hand, the avoidance of unacceptable heat stress in specific populations and specific context through the application of those elements into guidelines is not yet well understood.

At the end, each occupational exposure situation must be evaluated individually for risks and benefits (Kwan-Hoong, 2003), because each environment has its own safety necessities of design and specificity. The central receiver solar power systems aren't an exception. The need of a designed working environment for CRS, based on occupational safety and standards, where its particular necessities are included, is a huge and challenging area of improvement opportunity.

2.9 Conclusions

Solar thermal plants are increasing in number and power generation capacity all around the world because of the motivation of countries to use renewable energy systems for electricity production. According to the literature, Central Receiver System (CRS) is the type of technology, among the CSP, moving to the forefront. Nowadays, it has been found that there exists evidence about risk assessments, carried on this kind of installations and that they are linked to green jobs, where exposures to solar radiation lead to consequent health effects.

The CRS installations are environments with their own environmental conditions and their own safety necessities; therefore the design for the assessment has to be according to those needs. As it can be seen, from the reviewed literature, there is no perfect option as regards the chosen method of evaluation. Although every method inside its procedure has its advantages and disadvantages, the choice may depend on the main objective of the application. It might be recommended departing from de Appendix A, which is the first step in the hazard assessment and risk management process, for the identification of possible risk situations due to intense and/or prolonged exposure to solar radiation in CRS facilities. On the other hand, the use of Appendix B could be very helpful for the risks analysis methodology. The method of evaluation proposed here to be included in the methodology for the risk assessment should be based on the available time for the analysis, founds, equipment for data collection, psychological aspects involved, environmental aspects involved. Afterward, the risk estimation could be based on real data and/ or simulations of solar radiation; e.g., simulation of outdoor extreme environmental working conditions, data gathering for the assessment of the level of heat stress experienced by a worker, and data gathering of direct and global solar radiation. In the following process, each situation of possible risk will be assessed through the methods of assessment based on the data gathered and the simulations. Once the evaluation of skin and ocular exposures, as well as the level of heat stress, is made, general safety measures for CRS installations have to be defined based on prevention.

To accomplish such goal, it will be necessary to analyze the human-interacting situations in CRS facilities, as listed in this section. The following chapters provide information about the assessment of the scenarios of risks represented in a case of study. This will allow defining more clearly security and safety/good practices in working environments with the presence of solar radiation. Those security and safety recommendations, i.e. the specification of maximum permissible levels and dose, will improve the definition of location and the operation process of CRS solar facilities. The good practices of security and safety must be regulated by monitoring activities, starting the procedure by training the workforce.

The present literature review may be seen as a base of information, and a contribution, about maximum safety levels and admissible doses of exposure to solar radiation, solar radiation effects and methods for the assessment of the level of risk due to exposures to solar radiation in CRS. It represents also a possible contribution for standards related with security principles in solar thermal energy industries. Based on a framework of the occupational health needs in CRS working environments, the following tasks deserve to be considered, as well in future works: Assessment of the work conditions in solar energy installations; evaluation of glint and glare of reflected solar light from the receiver and heliostats surface; simulation of outdoor extreme environmental working conditions, definition security and safety good practices related to working conditions; selection of criteria for the location and the operation of this kind of facilities; specification of safety measures such as time of the exposure according with the skin type, clothing sets and protective devices; proposition of a guideline.

3. CUMULATIVE AND MOMENTARY SKIN EXPOSURES TO SOLAR RADIATION IN CENTRAL RECEIVER SOLAR SYSTEMS

The content of this chapter is presented in:

Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2017. Cumulative and momentary skin exposures to solar radiation in central receiver solar systems. Energy. doi.org/10.1016/j.energy.2017.02.170

3.1 Introduction

It is known that UV radiation is classified with significant skin risk damage because it has the potential to cause biologic changes on it. Even though studies in photo-dermatology have focused mainly on the UV part of the electromagnetic radiation spectrum, there is also enough evidence about effects resulting from visible light (VL) exposures (Ipiña, et al., 2014; Mahmoud, et al., 2008; Polefka, et al., 2012). People's behavior in the sun is considered a major cause for the rise in skin cancer rates in recent decades. Sometimes outdoor workers expose themselves to environmental conditions in sunny locations with insufficient protection, probably because they are not fully aware of the circumstances and/ or the available security alternatives. In order to prevent momentary and cumulative exposures to solar radiation (UV, VL, and IR) that can cause health effects in the future time, the education of outdoor workers, and also the implementation of preventive measures, should be considered a necessity (WHO, 2002).

The following section addresses skin exposures to solar radiation and presents a case study about one of the CSP technologies moving to the forefront. It also briefly outlines the relation between solar radiation and skin, solar effects on skin subjected to momentary and accumulative exposures. This will be followed by the presentation of some evaluation methods, safety doses and the usage of the ultraviolet index. At the end of the section, a case study is presented, where the results obtained are discussed.

3.1.1 Solar radiation and skin

Solar radiation interacts with the skin through absorption, reflection, and scattering mechanisms, which are determined largely by the layers of the skin and the physical characteristics of the type of radiation (Polefka, et al., 2012).

The two primary layers of the skin are the epidermis and dermis. The epidermis is the outermost layer and serves as the body's point of contact with the environment. The dermis underlies the epidermis and harbors cutaneous structures, immune cells, and fibroblasts, which actively participate in many skin physiologic responses. The epidermis is a self-renewing tissue composed mainly by keratinocytes. The nascent epidermal keratinocytes formed as a result of cell division by keratinocyte stem cells in the stratum basale where keratinocytes move outward through the epidermis undergoing a programmed series of differentiation.

In other words, they migrate outward toward the surface of the skin in order to form corneocytes which are linked to dead (but intact) cells that form the principal barrier of the outermost epidermal layer. Keratinocytes also receive melanin from melanocytes, where it is accumulated to function as a natural sunscreen against the incoming UV, so the amount and type of epidermal melanin is the main factor that determines skin complexion and UV sensitivity (D'Orazio, et al., 2013).

Skin sensitivity to UV is measured using the Fitzpatrick classification [**Table 3.1**], with a six-level scale ranging from subjects who always tan and never burn to subjects who always burn when exposed to the sun (Gandini, et al., 2016).

Table 3.1. *Fitzpatrick skin classification types*

Skin type		**Burns in the sun**	**Tans after sun exposures**
I	Melano-compromised	Always	Seldom
II		Usually	Sometimes
III	Melano-competent	Sometimes	Usually
IV		Seldom	Always
V	Melano-protected	Naturally brown skin	
VI		Naturally black skin	

Note: Reproduced from WHO (2002) *based on Fitzpatrick TB, et al., reported in TB Fitzpatrick and JL Bolognia, Human melanin pigmentation: Role in pathogenesis of cutaneous melanoma. In: Zeise L, Chedekel MR, Fitzpatrick TB (eds.) Melanin: Its role in human photoprotection. Overland Park, KS,Valdenmar Publishing Company, 1995:177-82.*

The ozone layer protects life on Earth from the UV radiation harmful effects by filtering almost all the UV-C radiation and nearly 95% of UV-B radiation emitted by the sun. However, it only minimally filters UV-A radiation, ending in more than 95% reaching the surface of the Earth. In theory, around 5% of UV-B and 95% of UV-A of UV radiation, impinges upon the skin's surface (Polefka, et al., 2012; Mancebo and Wang, 2014).

Although the UV-B it is characterized by greater energy than UV-A, it has more difficulty to penetrate the skin; when the energy carried by each photon decreases (e.g. UV-B to UV-A to VL to IR), the ability to penetrate the biological tissue increases (Polefka, et al., 2012). From this relationship it can be then concluded: the UV-C never reaches the surface of the skin, the UV-B is susceptible to penetrate the outermost layer of the skin (which is the epidermis), and the UV-A can penetrate deeper, reaching the dermis (Polefka, et al., 2012; Amaro, et al., 2014; D'Orazio, et al., 2013; Grigalavicius, et al., 2016) [**Figure 3.1**].

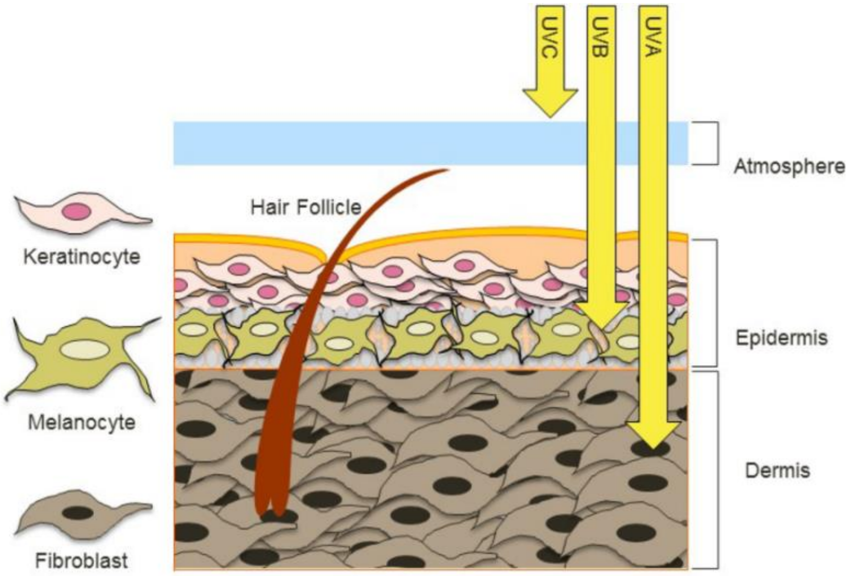

Figure 3.1. *UV light outcomes. Taken from Amaro, et al., 2014.*

The skin has an adaptation process to solar radiation in order to provide protection through natural mechanisms. The pigmentation of the skin, noticeable within a day or two after sun exposure, is known as tanning. Indeed, a tanned skin does confer an increased degree of protection, which seems to be no more than a 2-3 sun protection factor (SPF) in the absence of skin thickening. The SPF is defined by McGregor and Young (1996) as the ratio of the minimum erythemal dose of simulated sunlight on protected skin compared with unprotected skin. On the other hand, skin thickening is a significant component of a mild sunburn reaction and single moderate exposure to UV-B can result in up to three-fold thickening of the outermost layer of the epidermis within one to three weeks (Vecchia, et al., 2007).

Multiple exposures every, one or two days for more than seven weeks will thicken the epidermis in three to five folds (Vecchia, et al., 2007). Skin thickness returns to the normal state in one or two months after ceasing the exposures to radiation. This can increase the protection against UV by an SPF of five or even higher. An adapted skin to solar radiation infers at least three weeks of exposure to solar irradiance without presenting sunburn.

The best-established beneficial effect of solar UV radiation, on the skin, is the synthesis of vitamin D. Vitamin D is known to be essential for the body's proper uptake of calcium, which is important for bone and musculoskeletal health. The Vitamin D synthesis begins when solar radiation, in the UV-B wavelength, photochemically converts dehydrocholesterol in the epidermis to pre-vitamin D3, which is converted later into vitamin D3. Due to the photo-instability of pre-vitamin D3, repeated short exposures to sunlight are more beneficial than rare but extended exposure. It is acquired right before there is a danger of acute effect to the skin called erythema (Vecchia, et al., 2007).

3.1.2 Skin effects due to momentary and cumulative exposures to solar radiation (Acute vs. Chronic)

Small amounts of UV radiation are beneficial for people and essential in the production of vitamin D, but prolonged human exposure to solar UV radiation may result in acute and chronic health effects on the skin (Polefka, et al., 2012). Clinically, the acute effects include erythema (sunburn), pigment darkening, delayed tanning, thickening of the epidermis, and vitamin D synthesis. Photo-aging and skin cancer are discussed as chronic reactions produced by prolonged or repeated UV exposures (Amaro, et al., 2014; Diffey, 1996; Sklar, et al., 2013).

Some of those effects are reversible while others, permanent. The ones classified as reversible damage occur when the effect is physiologically healed or disappear with time; contrarily, permanent damages are not healed because of the occurred alteration (Toet, et al., 2013). Usually a permanent damage is related to UV chronic exposures (cumulative exposures) and reversible effects are related to acute exposures (momentary exposures) (Polefka, et al., 2012).

3.1.2.1 Cumulative exposures

Skin cancer

Chronic UV irradiation leads to deregulation of biological mechanisms which promote abnormal proliferation of cells with DNA damage. Exposure to UV-B induces direct damage to DNA. Besides, DNA damaged due to UV-A exposure is mediated by reactive oxygen species (ROS), resulting in the formation of oxidative products. If the lesion occurs in one or more genes involved in regulating growth and proliferation, or tumor suppression, the cell must rapidly repair the damage. Incomplete repair of the DNA and removal of these mutagenic photo-products result in an uncontrolled proliferation of the cells, leading to the development of skin cancer (Polefka, et al., 2012; Mancebo and Wang, 2014; Vecchia, et al., 2007).

People who spend working-periods outside are chronically exposing themselves to solar radiation. Cumulative exposures to UV radiation are responsible for Basal Cell Cancer (BCC) and Squamous Cell Cancer (SCC) (Vecchia, et al., 2007). SCC results mainly from chronic exposure and BCC are predominantly related to intermittent and acute UV exposure (Milon et al., 2014). Cutaneous Melanoma (CM) is also associated with UV exposure, but the responsible mechanisms and wavelengths are unclear (Grigalavicius, et al., 2016).

Even though the recognition of skin cancer as occupational hazard remains scarce, it is still the most frequent carcinogenic agent in many countries (Milon et al., 2014).

Photo-aging

Solar radiation (UV-A, VL and IR) has an oxidative stress on the skin by triggering the reactive ROS which can inappropriately activate cellular pathways causing damage. The resulting ROS affect the expression of several key transcription factors which enhances the breakdown of collagen and also down-regulates its synthesis. Photo-aged skin is described with clinical signs such as deep wrinkles, dryness, dilatation of blood vessels, multiple dark spots on the sun-exposed skin, sallowness, telangiectasia, significant laxity, pre-cancerous lesions, and a leathery skin appearance (Polefka, et al., 2012; Sklar, et al., 2013).

3.1.2.2 Momentary exposures

Solar radiation has different acute effects on skin physiology, with some consequences occurring acutely and others in a delayed manner. Those will be described in the following paragraphs.

Pigmentation

The ultraviolet radiation causes a skin pigmentation reaction, which is an immediate change in skin color followed by delayed tanning with a new pigmentation formation. These two processes are known as pigment darkening and delayed tanning.

-Pigment darkening

There are two types of pigment darkening: immediate pigment darkening (IPD) and persistent pigment darkening (PPD). These two reversible processes result from oxidation and redistribution of pre-existing melanin and occur in less than 24 hours sun exposure. The first one results from exposure to low dose UV-A (1–5 J/cm^2) causing gray skin pigmentation, which disappears within minutes. On the other side, PPD results from exposure to higher doses of UV-A radiation (> 10 J/cm^2) causing brown skin pigmentation that can persist for more than 24 hours (Mahmoud, et al., 2008; Mancebo and Wang, 2014; Sklar, et al., 2013).

The duration time, skin type and possible side-effects of the pigment darkening process, according to the wavelength of radiation, are shown in

Table 3.2.

***Table 3.2**. Radiation-induced pigmentation*

UV-A	Induces immediate pigment darkening that fades within 2 h Delayed tanning appears within 3–5 days after exposure, may persist for months
UV-A I	Induces immediate pigmentation and delayed pigmentation in all skin types
UV-A II	In skin types I and II erythema precedes pigmentation In skin types III and IV induces immediate pigmentation with no visible erythema
UV-B	Pigmentation occurs when preceded by erythema
Narrowband UV-B	Peaks between 3–6 days, pigmentation returns to baseline at 1 month
Broadband UV-B	Peaks between 4–7 days, pigmentation returns to baseline at 3 months
Visible Light	Immediate pigment darkening and delayed tanning in skin types IV–VI, pigmentation may last for 2 weeks
IR	None

Reproduced from Sklar, et al., 2013.

-Delayed tanning

In contrast, to IPD and PPD, delayed tanning (DT) is related to the synthesis of new melanin, resulting from both UV-A and UV-B radiation exposure. However, DT induced by UV-A is preceded by IPD and PPD without noticeable redness on the skin, while that one induced by UV-B is more efficient in inducing erythema. Clinically, DT causes changes in pigmentation that can only be seen three days after sun exposure. The color changes on skin fade as the surface layer of the skin is shed (Mahmoud, et al., 2008; Mancebo and Wang, 2014).

Erythema (sunburn)

The most recognizable acute clinical effect of UV exposure on the skin is erythema, well known as sunburn. It is defined by Sklar et al. (2013) as a cutaneous inflammatory reaction that can be accompanied by warmth and tenderness. Erythema, depending on the UV wavelength, is caused due to direct damage to DNA or an indirect oxidative damage. As a consequence of the DNA damage, Cytokines (proteins secreted by specific cells of the immune system) and inflammatory mediators are synthesized and released into the skin. These substances regulate the adhesion of molecules on blood vessels and keratinocytes. As a result, recruitment and activation of inflammatory cells cause vasodilation and inflammation (Mancebo and Wang, 2014; D'Orazio, et al., 2013). The solar spectrum is shaped by three types of wavelength, as discussed earlier. VL comprises almost 39%. VL at high doses, and depending on the skin type, can cause erythema (Mahmoud, et al., 2008; Mancebo and Wang, 2014). VL induces erythema surrounding the IPD response on skin types IV–VI, but erythema response fades within 2h. For these skin types, the degree of erythema increases with increasing doses of VL. Mancebo and Wang (2014), in their review of the erythema response to VL, UV and IR, found that other skin types (II-IV) could develop an erythema due to a greater output of UV contained in the VL source and also thermal effects. The severity of erythema formation depends on environmental and host factors. In the case of the host, the main factors are the skin color, age, and anatomic site. Individuals with darker skin pigmentation require up to 30 times more UV exposure to induce erythema compared to individuals with fair skin. In the case of the environmental factors: latitude, altitude, and time of day may affect erythema formation (Mancebo and Wang, 2014; Vecchia, et al., 2007). In some cases, the environmental factors around the globe would determine the host-factors based on the human body adaptation.

The duration, skin type, and possibly side-effects, according to radiation wavelength, appear in **Table 3.3**.

Table 3.3. *Radiation-induced erythema*

UV-A	Biphasic: peaks immediately to 4 h and then 6–24 h Induces erythema in skin type I; in individuals with higher skin phototypes, it requires significantly high doses to do so.
UV-B	In lighter skin types, fades within 1–2 weeks In darker skin types, fades within 1–3 days
Narrowband UV-B	Milder and shorter than BB-UV-B
Broadband UV-B	Abrupt increase at 12 h and peaks at 6–24 h Immediate erythema only in skin types I and II
Visible Light	Immediate, fades within 2 h
IR	Lasts less than 1h

Reproduced from Sklar, et al., 2013.

3.2 Ultraviolet index (UVI)

Anthropogenic activities have contributed to the loss of stratospheric ozone and its destruction has been exceeding its natural formation, resulting in UV radiation increment reaching the Earth's surface (Polefka, et al., 2012; Lim and Cooper, 1999). Among other factors influencing the amount of UV radiation that reaches the Earth´s surface are atmospheric and environmental conditions, time of day, altitude, season, and most importantly, latitude (Polefka, et al., 2012).

The Global Solar UV Index (UVI) describes the level of solar UV radiation at the Earth's surface (WHO, 2002). It was formulated by the World Health Organization (WHO), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) to communicate the general level of risk regarding the UV exposure conditions during the day. The UVI may be used to plan outdoor activities since it indicates the risk of sunburn at a given meteorological conditions (weather and sun position) (Vecchia, et al., 2007; ICNIRP, 2010).

The exposure category of the UVI ranges from 1 to 11 and over [**Figure 3.2**]. The values 1-2 (green) are classified as low risk, 3-5 (yellow) moderate, 6-7 (orange) high, 8-10 (red) very high, and 11+ (pink) as extreme risk. There are some organizations around the world reporting the solar UV by providing data to the public in the form of the UVI exposure values in category scale.

Figure 3.2. *UVI exposure category. Taken from Sklar, et al., 2013.*

The reporting values of UVI, provided by local forecasts are available as a single value rounded to the nearest number in the exposure UVI category. The values in **Figure 3.2** are attached to a suggested level of protection against the outside conditions. Also, the forecast report, at least, the daily maximum UVI value and the unsafe sun exposure period of the day. When necessary, the forecast includes the effect of cloud on UV radiation transmission through the atmosphere as a range of values. Otherwise, it should be interpreted as clear sky (WHO, 2002). As an example, **Figure 3.3** shows a map of a worldwide UVI report, relative to May 2016, in which are shown the countries that require extra protection and careful attention for outside workers due to the very high (8-10, red color) and extreme risk (11+, pink color) levels. The registered UVI was attached to the conditions of clear sky at local solar noon for the vulnerability of Caucasian skin (skin type III) to develop erythema reaction (Zaratti, et al., 2014).

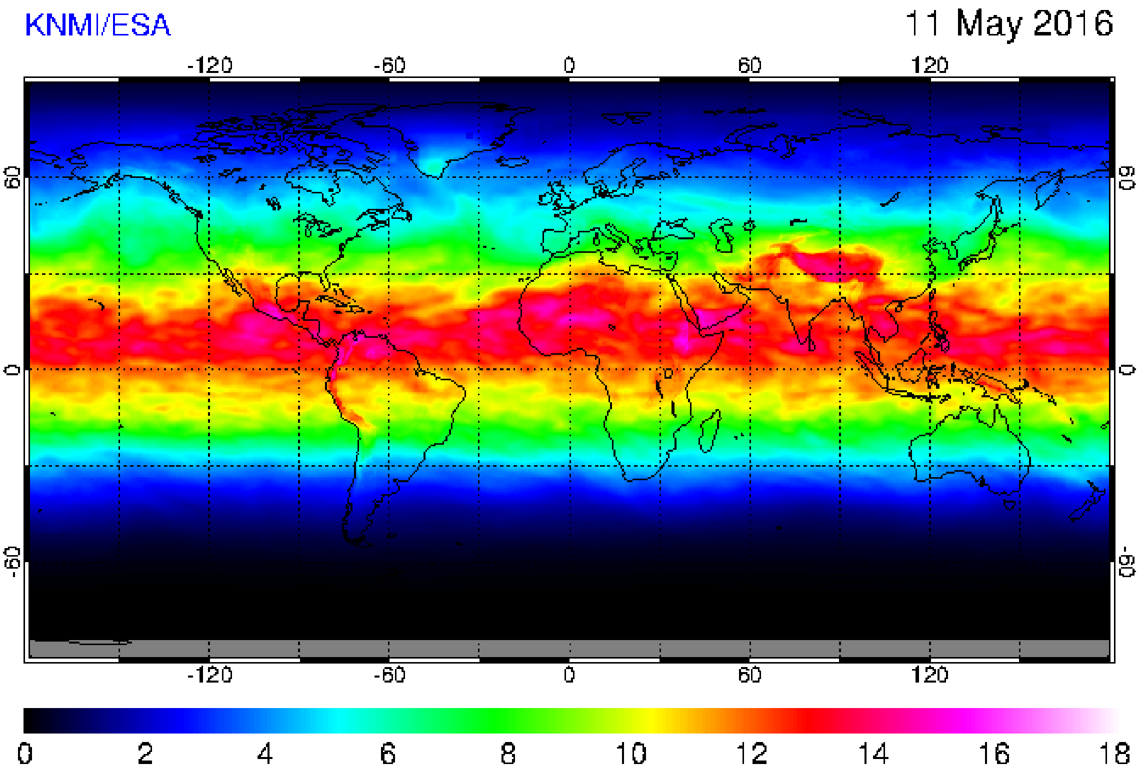

Figure 3.3. *Global Solar UV Index worldwide reported with clear sky conditions.*[9]

Zaratti et al. (2014) published the time of exposure (in minutes) before skin damage is noticeable in each skin type in the Fitzpatrick skin scale [**Figure 3.4**.] The classification is weighted in 1 MED (Minimal Erythema Dose) as a function of the UVI and skin type.

[9] http:www.temis.nluvradiationUVindex.html

Time for 1 MED as a function of UVI and skin type

Skin type	I	II	III	IV	V	VI
Example	Celtic	Pale	Caucasian	Mediterranean	South American	Negro
Sensitivity	Always burns	Easily burns	May burn	Rarely burns	Rarely burns	Rarely burns
SED/MED*	2.5	3.0	4.0	5.0	8.0	15.0
UVI	Minutes of unprotected exposure before perceptible skin damage					
1	167	200	267	334	534	1001
2	83	100	133	167	267	500
3	56	67	89	111	178	334
4	42	50	67	83	133	250
5	33	40	53	67	107	200
6	28	33	44	56	89	167
7	24	29	38	48	76	143
8	21	25	33	42	67	125
9	19	22	30	37	59	111
10	17	20	27	33	53	100
11	15	18	24	30	49	91
12	14	17	22	28	44	83
13	13	15	21	26	41	77
14	12	14	19	24	38	71
15	11	13	18	22	36	67
16	10	13	17	21	33	63
17	10	12	16	20	31	59
18	9	11	15	19	30	56
19	9	11	14	18	28	53
20	8	10	13	17	27	50
21	8	10	13	16	25	48
22	8	9	12	15	24	45
23	7	9	12	15	23	44
24	7	8	11	14	22	42
25	7	8	11	13	21	40

Figure 3.4. *UVI Time of Exposure. Taken from Sklar, et al., 2013.*

The MED is the required UV dose to produce a noticeable impact (erythema) on the human skin that has been exposed to solar radiation. The MED is equivalent to a radiant exposure of 200 J/m^2, equivalent to 2 SED. The SED is defined as the amount of UV radiation reaching the skin surface and its unitary value is equivalent to an erythemal effective radiant exposure of 100 J/m^2. This indicates that the MED is the minimum dose to produce a notorious impact in the skin 24h after being exposed to the sun. In other words, MED represents a sunburn limit (WHO, 2002; Vecchia, et al., 2007; ICNIRP, 2010; Webb, et al., 2011; Moore, et al., 2013; Heisler and Grant, 2000; CEN, 2006; 2008; ICNIRP, 2004; Lucas, et al., 2006).

Figure 3.4 shows the duration of the exposure in time as a function of 1 MED/200 J/m^2 according to the skin type. It can be noticed the corresponding time for those countries in **Figure 3.3** with levels of 10+ UVI. The exposure time for Fair skin (type I-II) corresponds to 7-17 minutes which varies from skin type VI (melano-protected) that corresponds to a period between 40-100 minutes in the same UVI levels of 10+.

According to Lucas et al. (2006), a daily exposure of 6-10% of the body surface (one arm, one lower leg, or face and hands) to 1 MED should be sufficient to avoid disease load due to vitamin D deficiency. In terms of acute skin effects from solar exposure, it is equivalent to approximately 1.0 –1.3 SED (Standard Erythema Dose) (Vecchia, et al., 2007; ICNIRP, 2010).

The suggested safe SED, per day, in an experimental solar central receiver institution is around 200 J/m^2 a day (2 SED/day), according to Azizi and Kudish (as cited in Franck, et al., 2009). Even though, the exact energy equivalent to 2 SED differs upon the individual sunburn sensibility. The ICNIRP standard 14 published in 2007 the skin dose for adapted and non-adapted skin to solar radiation. The dose for adapted skin infers that the skin has been passed through at least three weeks of solar exposure without receiving erythema. The dose for non-adapted skin types III-IV is 7 SED, for the skin type V is 10 SED and for the skin type VI is 15 SED. The standard also issued the dose for adapted skin, which is 6 SED for the skin type I-II, 10 SED for the skin type III-IV, 60 SED for the skin V, and 80 SED for the skin type VI.

A forecast from the United Kingdom[10] suggests to the public the dose for each type of skin without adaptation [**Table 3.4.** Skin type dose].

Table 3.4. *Skin type dose*

Skin type	MED	MED	SED /8h	SED /h
I -II	200 J/m^2	1	2	0.25
III- IV	600 J/m^2	3	6	0.75
V	800 J/m^2	4	8	1
VI	1000 J/m^2	5	10	1.25

The knowledge about the UVI can be a useful tool in educating the workforce. Training and awareness of workers is the key in achieving the goal of reduction of health issues due to UV exposures. The UVI could guide enterprises in the way of changing the level of overhead UV radiation exposure and the level of protective measures for outdoor workers (Vecchia, et al., 2007; ICNIRP, 2010). Encouraging

[10] http://www.weatheronline.co.uk/reports/wxfacts/Burning-Time.htm

people to reduce or expose wisely to the sun. If the objective is successfully achieved it can decrease harmful health effects and significantly reduce health care costs (WHO, 2002).

3.3 Methods for the assessment

3.3.1 Acute exposures

The climatological factors and personal factors (sensitivity, sunburn history, and adaptation) to UV radiation significantly influence in the magnitude of the risk for the skin (ICNIRP, 2010). The skin exposure factor ($\mathbf{F_{es}}$) is an indicator used for the assessment of the impact of the environmental conditions on the skin (WHO, 2002; ICNIRP, 2010).

Six factors (f_n), related with the environmental conditions of a particular location, are involved in the result of $\mathbf{F_{es}}$: f_1- geographical latitude and season (spring & summer (4, 7 and 9); autumn & spring (0.3, 1.5 and 5), f_2- cloud cover (clear sky = 1, partial cloudy =0.7, overcast sky = 0.2), f_3- duration of the exposure (all day = 1, one or two hours in midday = 0.5, early morning or late afternoon = 0.2), f_4- ground reflectance (fresh snow = 1.8, dry sand = 1.2, all the others = 1), f_5- clothing (unprotected = 1, arms and legs exposed = 0.5, hands and face exposed = 0.02), f_6- shade (no shade = 1, partial shade = 0.3, good shade= 0.02) (Vecchia, et al., 2007).

Equation 3. *The skin exposure factor*

$$\mathbf{F_{es}}=f_1*f_2*f_3*f_4*f_5*f_6 \quad (3)$$

According to the ICNIRP 14/2007 (Vecchia, et al., 2007), the levels shown in **Table 3.5** should be used as categories of the exposure based on the minimum level of protection for a workplace.

Table 3.5. *Minimum level of protection required for the workplace*

Exposure factor	**Required skin protection**
<1	None
>1 but < 3	Shirt, brimmed hat
>3 but < 5	Long-sleeved shirt, trousers, brimmed hat and SPF 15+ sunscreen
> 5	Modify work environment and practices. Shade, long-sleeved shirt, trousers, brimmed hat and SPF 15+ sunscreen

Reproduced from Vecchia, et al., 2007.

In 2013, Wolska proposed a $\mathbf{F_{es}}$ modified method for the skin hazard assessment due to UV radiation exposure. It consisted in including the Solar UVI from a particular day and geographical place (maximum value to clear sky conditions) in the formula for the calculations of the $\mathbf{F_{es}}$. As skin tumors related to UV radiation are often found on the neck and head, and on the torso and arms, includes three additional values for the clothing factor (0.40 for the arms, head and neck exposed, 0.35 for the arms and neck exposed, and 0.07 for the head and neck exposed), plus the cloudiness condition (0.5).

The SED per work shift is defined as 10 SED (1000 J/m^2 per 8 h). It means that the dose rate should not exceed 1.25 SED in one hour (1.25 SED/h). The dose rate was suggested per hour because the duration and time of work activities may vary within the work shift (Wolska, 2013).

Equation 4. *The* $\mathbf{F_{es}}$ *as a function of the UVI*

$$\mathbf{F_{es}} = UVI * F_2 * F_4; \quad (4)$$

$F_{es} \leq 1$ low risk, no additional preventive measures needed.

$F_{es} > 1$ preventive measures are necessary

where

F_2= cloud cover; F_4= ground reflectance.

If $\mathbf{F_{es}}$ is greater than 1, preventive measures are needed and the corrected Skin exposure factor ($\mathbf{F_{es}*}$) should be calculated as:

Equation 5. *The corrected Skin exposure factor*

$$\mathbf{F_{es}}* = (F_{es})*(F_3)*(F_5)*(F_6) \tag{5}$$

where

F_3= duration of the exposure;

F_5=clothing factor

F_6= shade factor

3.3.2 Cumulative exposures

People who spend working-periods outside are exposing themselves to solar radiation almost every day. Cumulative exposures to UV radiation are responsible for some forms of melanoma (MM) (ICNIRP, 2010; Moore, et al., 2013; Blazejczyk, et al. 2014).

Blazejczyk et al. believe that it is still the most frequent carcinogenic agent in many countries and, in 2014, developed a method to estimate the incidence of SCC, where basically the anatomical exposures to solar UV are assessed by simulating the exposures with the Sim UVEx (Simulating UV Exposure).

The model predicts the dose and the anatomical distribution of radiation received on the basis of ground irradiance and morphological data (Blazejczyk, et al., 2014; Vernez, et al., 2015). After the ambient UV data is estimated through simulation, and/or measured with radiometers, the estimation of SCC risk is expressed as a function of age and cumulative exposure UV dose by:

Equation 6. *The SCC risk*

$$SCC_{risk} = Risk\ \alpha\ (age)^{\alpha} \times (UV_{tot})^{\beta} \tag{6}$$

where:

α = age-dependent factor

β=biological amplification factor

UV_{tot}= cumulative UV exposure dose received

The cumulative UV dose is expressed as a sum of the exposures during the work (UV_{occ}) and lunch (UV_{lunch}) during ***n*** years of occupational activity and recreational (UV_{recr}) time from 0 to ***n***:

Equation 7. *Cumulative UV exposure dose received*

$$\sum_0^n UV_{tot} = \sum_{n1}^{n2}(UV_{occ} + UV_{lunch}) + \sum_0^n UV_{recr} \quad (7)$$

The UV_{occ}, and UV_{lunch} were obtained from SimUVEx model, and UV_{recr} from a survey.

Note that some factors are not taken into consideration, e.g. the access to shaded spots, indoor working periods, taking lunch outside, absences at work or clothing. Besides, the model assumes a constant for the annual exposure without any variation (long periods outside, no protective clothing and no shade) therefore the results should be considered as upper values (Blazejczyk, et al., 2014; Vernez, et al., 2015).

3.3.3 Time of the exposure

According to the ICNIRP standards (14/2007, 2004 and 2010) the way to find the effective irradiance of a broadband source, weighted against the peak of the spectral effectiveness curve (270nm), is given by the following weighting formula:

Equation 8. *Effective irradiance*

$$E_{eff} = \sum(E_\lambda)(S(\lambda))(\Delta_\lambda) \quad (8)$$

where:

E_{eff}= effective irradiance in W/m^2 normalized to a monochromatic source 270nm

E_λ= spectral irradiance from measurements in W/m^2

$S(\lambda)$= relative spectral effectiveness (unitless) [Appendix C]. Note that the values for wavelengths that are not listed in [Appendix C] may be interpolated.

Δ_{λ}= measurement intervals

The product of the E_{eff} (in W/cm^2) and the duration of the exposure (t, in seconds) results in the effective exposure dose (H_{eff} in J/cm^2) (Vecchia, et al., 2007):

Equation 9*. Effective exposure dose*

$$H_{eff} = \left(E_{eff}\right)(t) \tag{9}$$

Permissible UV exposure time (t_{max} in seconds) for constant incident irradiance upon unprotected skin is found by dividing 30 J/m^2 by the value of E_{eff} in W/m^2 as it shown in (Vecchia, et al., 2007):

Equation 10. *Permissible UV exposure time*

$$t_{max} = \frac{30}{E_{eff}} \tag{10}$$

The exposure duration, $t_{erythema}$, necessary to achieve a minimum erythemal dose (MED) in an individual would be the MED for that individual in summer with that type of skin I, e.g., 220 J/m^2 divided by the irradiance $E_{erythema}$.

Equation 11. *The exposure duration to achieve a minimum erythemal dose (MED).*

$$t_{erythema} = \frac{MED}{E_{erythema}} \tag{11}$$

3.3.4 Limit of the skin exposure

The ICNIRP (2004) provided the exposure limits for working population and general public showed in **Table 3.6**, which presents the representative time of exposure corresponding to effective irradiances.

Table 3.6. *Maximum limit of exposure*

Time of the exposure per day	*Effective irradiance E_{eff} (W/m^2)*
8 h	0.001
4 h	0.002
2 h	0.004
1 h	0.008
30 min	0.017
15 min	0.033
10 min	0.05
5 min	0.1
1 min	0.5
30 s	1.0
10 s	3.0
1 s	30
0.5 s	60
0.1 s	300

In terms of acute skin effects from solar exposure, the ICNIRP 14 standard (Vecchia, et al., 2007) described the maximum limit of efficient radiant skin exposure as 30 J/m^2 (3 mJ/cm^2) which is equivalent to approximately 1.0–1.3 SED or approximately one-half of an MED for fair skin (ICNIRP, 2004; 2010). The ICNIRP (2010) classified this limit as a desirable goal limit for skin exposure to minimize the long-term risk. Besides, it must be recognized that this limit has its difficulties for being achieved in sunlight and some judgment must be used in its practical application. Many workers have not experience sunburn, meaning that their skin has adapted to solar exposure.

Even though, the accumulation of solar UV radiation exposures on the skin may still have implication for the induction of skin cancer in the future. Minimizing the exposures to UV radiation in outdoor workers is clearly challenging.

3.4 Case study and results

The present study was conducted in the Experimental Field of Heliostats (CPH: initials of "Campo de Prueba de Heliostatos", in Spanish) located in Hermosillo Sonora, Mexico (29°05′44″N 110°57′03″ W) [**Figure 3.5**]. The CPH counts with a tower of 36m height, a control room and a field of 29 heliostats. Each installed heliostat has total surface of 36 m^2 (each one having 25 flat mirrors of 1.2m X 1.2m). The total reflecting area is then close to 1,070 m^2. The heliostats installed on the field allow reaching a theoretical solar radiation concentration factor of 25, which corresponds to a thermal power of approximately 1 MWt.

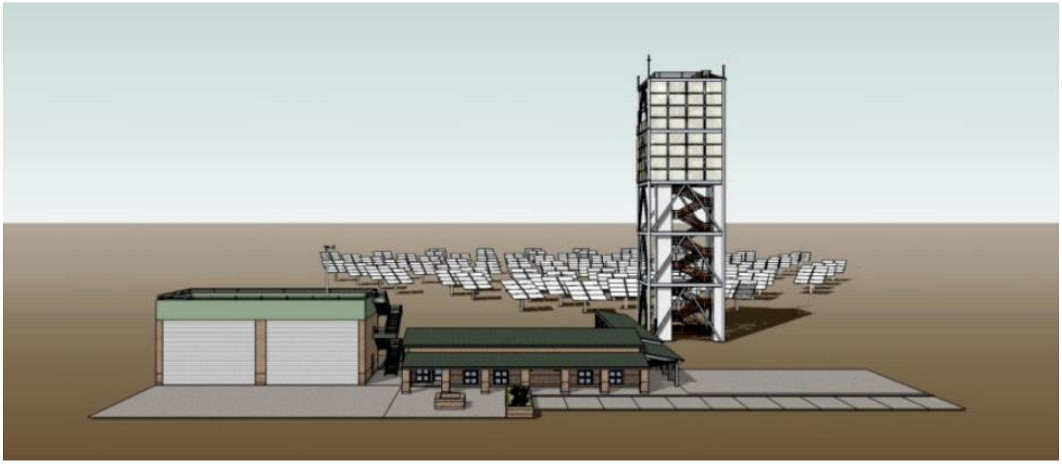

Figure 3.5. *Experimental installation CPH. Taken from Iriarte, 2013.*

Measurements of direct solar radiation were collected through a pyrheliometer every second. The pyrheliometer, sun tracking equipment with a sensor used to the solar radiation flux in W/m^2 (Iqbal, 1983), was connected to a NI cRio-9074 data acquisition system. The calibration uncertainty of the equipment is <1% and the measurement uncertainty is 1.5%. Every period of 60 seconds, the mean value of each variable was calculated and stored in files. Those files were date-renamed after reaching three megabytes of collected data. The measurements selected for this study were those recorded values during a working period, between 9 am and 5 pm (8 hours).

In the present case study was made the assumption of an operational worker with arms and legs exposed (0.5), during one or two hours around midday (0.5) of a spring/summer day (9) with clear sky (1) in the CPH outdoors with access to partial shade (0.3). The analysis started by using the skin exposure factor ($\mathbf{F_{es}}$) method presented in ICNIRP 14 and its modification by Wolska; both described in the section **3.3.1** in the present document. The resulting skin exposure factor was 0.675, which means preventive measures are not required within the minimum level of protection required scale, in **Table 3.5**.

In the case of a worker, involved in the installation of the CPH, the result of the skin exposure factor, conditioned by working outdoors all day (1), with no shade spots (1), but fully clothed (only hands and face exposed= 0.02), was 0.18. In the case of a worker involved in the construction of the CPH with the arms and legs exposed (0.5), the $\mathbf{F_{es}}$ was 4.5. At this skin factor exposure value, it is recommended to modify clothing and add sunscreen protection according to the ICNIRP guidelines.

The skin exposure factor modification methodology, proposed by Wolska in 2013, allows adding information to the results by considering a UVI value. In the case of Hermosillo city during May (2016), clear sky day (1) and with a ground reflectance of about 1, the UVI was around 12[11]. The results showed a $\mathbf{F_{es}}$ higher than 1, which means that preventive measures are necessary for safety. The corrected skin exposure factor ($\mathbf{F_{es}}$*) for the worker exposed to those environmental conditions with arms and neck exposed (0.35 corrected value by Wolska) all day (1) and no shade spots allowed (1) was 4.2. Even though the resulted value was lower than the safety limit value of 10 SED per day suggested by the method, it can still be adjusted to 1.26 by adding partial shade (0.3). It has to be noticed that the suggested safety dose by this method (10 SED) is the equivalent dose for adapted skin type III-IV (Melano- competent) or non-adapted

[11] http://www.weatheronline.co.uk/Mexico/Hermosillo.htm

skin type V (Melano- protected). The methodology seems to be logical about managing the factors that can be controlled, such as clothing, shade, and duration of the exposure. Even though Wolska (2013) included some extra values for clothing and shade as protective factors, the values for the duration of the exposure remain the same. This put the assessment on a limited scale of time of the exposure, which is a common approach when using semi-quantitative methods.

The measurements of direct solar radiation, recorded during work-shifts of eight hours, were used for the purpose to estimate the duration of sun exposure in the CPH field. In order to assess the health risk, in this particular case skin risk, it must be addressed the worst possible scenario within the data available. This happens because the security measures must include the worst scenario. In this case, the worst frame could be attributed to a person with non-adapted fair skin (skin type I-II) working during the highest flux of direct solar radiation of the day, clear sky, and with lower protection (clothes or sunscreen). The maximum direct solar irradiance values, for each month, are presented in **Table 3.7**, where the higher irradiance fluxes were registered around midday, between 10 am and 1 pm.

Table 3.7. *Direct solar irradiance fluxes over the year lux.*

Month	Time	Irradiance highest fluxes (W/m^2)
January	1/14/ 1:10 PM	998.07
February	2/13/ 12:52 PM	1012.75
March	3/1/ 12:43 PM	998.15
April	4/12/ 1:16 PM	996.89
May	5/18/ 10:39 AM	961.37
June	6/28/ 11:31 AM	940.79
July	7/2/ 11:46 AM	897.27
August	8/27/ 1:07 PM	953.56
September	9/29/ 12:43 PM	918.91
October	10/2/ 12:27 PM	971.78
November	11/24/ 12:16 PM	1005.69
December	12/6/ 12:07 PM	968.43

In **Figure 3.6**, it can be noticed that those values were recorded in February and November, 1012.75 and 1005.69 W/m^2 respectively. Instead of summer, the peak values of solar radiation were documented in winter months because summer season is the rainy season of the year in this specific region of Mexico. The region has more clear sky conditions in the winter.

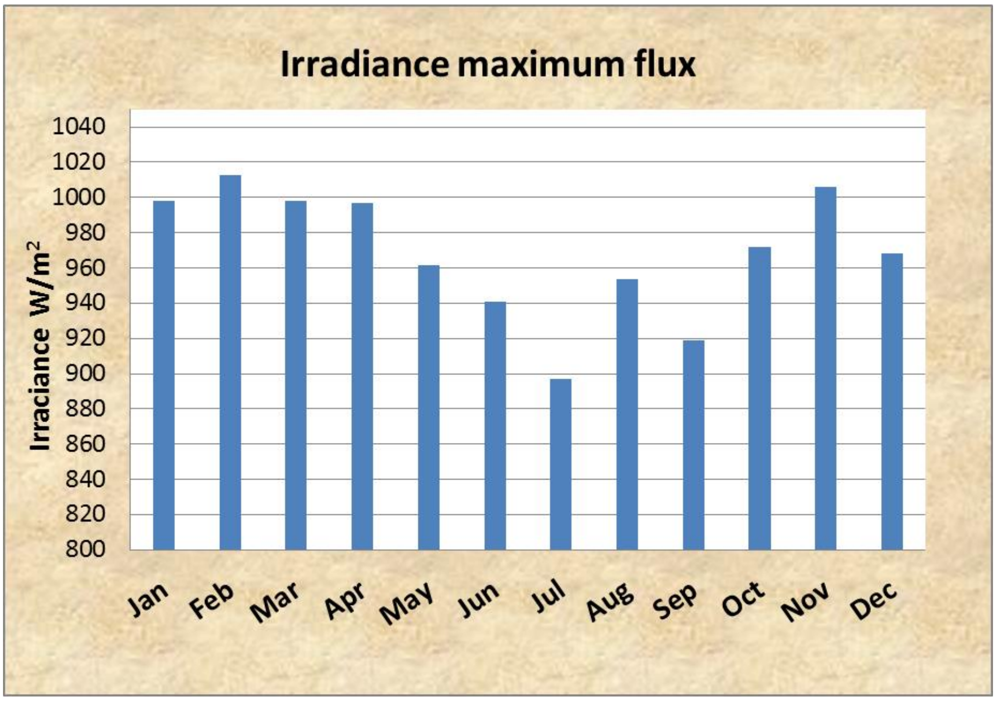

Figure 3.6. *Direct solar irradiance highest flux per month.*

It was possible to evaluate the effective irradiance reaching the skin during highest fluxes of direct solar irradiance exposure by applying the methodology and maximum security time exposure limits specified in ICNIRP standards (2004, 2007 and 2010), described in section **3.3** of the present document. **Table 3.8** shows the time of exposure (before sunburn) to the highest flux of the direct solar irradiance measured in the CPH. The calculation was based on the minimum sensitivity (ICNIRP 14, 2007; pp 51) in terms of measured irradiance calculated by the dose and the expected duration of exposure (work shift of 8h).

Table 3.8. *Time of continuous exposure to the highest flux of direct solar in the CPH.*

Skin type	Time of exposure to stay unprotected for non-adapted skin (Forecast)	Time of exposure to stay unprotected for non-adapted skin (By ICNIRP)	Time of exposure to stay unprotected for adapted skin (By ICNIRP)
I -II	≤ 5 min	5 min	13 min
III- IV	13 min	15 min	21 min
V	17 min	21 min	2hr
VI	20 min	31 min	2hr 45 min

Note that the exposure time recommended for the dose established by the forecast to the public slightly differs from those recommended by the standard ICNIRP 14 for each type of the skin in the Fitzpatrick classification. It appears that the dose recommended by the ICNIRP standards is quite more tolerant respect to the time of exposure. It may be interpreted as a difference in the adaptation of the skin of the addressed public. The ICNIRP standards are addressing nonspecific outdoor workers and indoor workers exposed to artificial UV sources, meanwhile, the forecast suggested the dose for the public in general and probably most of them without minimal skin adaptation.

The **Figure 3.7** shows the comparison between the forecast and the standards values of permissible UV exposure time for constant incident irradiance upon non-adapted and adapted skin. It can be said that the values vary considerably, according to the type and level of adaptation in the skin of individuals. As it was explained in pp. 44, the skin tends to adapt to the radiation received and for considering the skin adapted it requires a period of at least three weeks of solar adaptation without noticeable sunburn. Outdoor workers seem to pass through this process because of their frequent exposition to solar irradiance.

The ICNIRP dose values suggest 80 SED for adapted skin type VI and 60 SED for adapted skin type V which are four to six times more tolerant values for those skin types with non-adaptation (15 and 10 SED). Non-adapted fair skin (type I-II) has thirty times less tolerance than the adapted skin type V in terms of dose. These values are reflected in **Figure 3.7**. The individual that usually works inside, needs to pass through a transition in terms of skin adaptability.

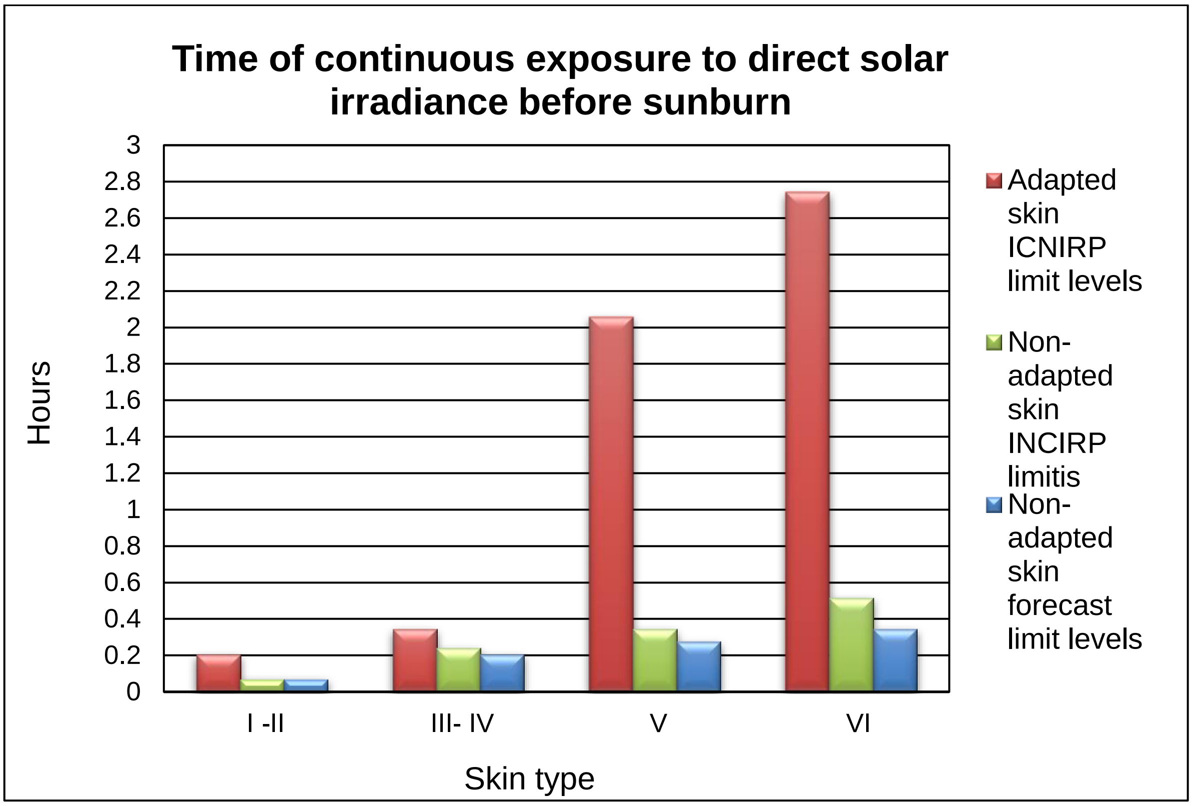

Figure 3.7. *Time of continuous exposure to solar irradiance before sunburn.*

In conclusion to **Table 3.8** and **Figure 3.7**, it could be said that the maximum time to stay unprotected without receiving a noticeable impact (sunburn) on fair non-adapted skin (skin type I-II), during a constant peak flux within CPH installation, is around five minutes. It means that workers with this type of non-adapted skin will be achieving the dose of 1 MED (200 J/m^2) in less than five minutes. For those with non-adapted skin type II-III, the limit time of exposure without sunburn is around 15 minutes. Skin types V and VI without adaptation will achieve the corresponding dose in 17-30 minutes. Comparing those results with the time of a required dose to produce a noticeable impact on the skin as a function of the UVI in **Figure 3.4**, the values are considered extremely risky which demands extra skin protection. The final conclusion of the assessment to the case study addressed in this section is that skin that hasn't been adapted and adapted skins types I-IV requires strong protection.

The relationship between the sun and the skin is quite complex. The skin response to solar radiation could be variable due to biological systems differs on sensibility. Also, the level of severity ends in a depending relation between the surrounding conditions and the host, where the skin color, age, burn history, amount of radiation, environmental conditions, time of day, altitude, season, and latitude, are involved. The environmental conditions assessment through different methods showed that there exists variability in results among them. The evaluation methods have its advantages and disadvantages. The semi-quantitative methods have a limited scale of values and put in judgment its accuracy, but the advantage is that they are more practical for its application. On the other hand, methods of assessment that are more precise require irradiance measurements and are time-consuming.

3.5 Limitations

The individual UV exposure depends on some factors such as the ambient solar UV radiation, the fraction of ambient exposure received on different anatomical sites, the behavior of the individual, and the duration of time spent outdoors. The ICNIRP considered therefore that the hazard assessment for specific outdoor work environments can only be semi-quantitative. Also, specific measurements from a site are limited to provide an indication of individual worker exposure since exposure changes considerably with time of day and season. In this regard, the UVI may be useful to establish baseline exposure values (WHO, 2002; ICNIRP, 2010).

The ICNIRP for exposure, in an outdoor setting, poses many problems in adequating the radiation dose for the skin due to:

- The strong dependence upon the position of the sun (latitude, altitude, and elevation angle).
- Dependence upon posture, exposure duration, a particular environment, daytime, and season, the work task, and characteristic of the work shift. For example, some tasks are performed during midday hours when the UV

radiation is more intense and some of them are intermittent tasks. Also, the duration of lunch breaks can influence the daily UV exposure.

- The strong dependence of the individual characteristics. An outdoor worker with or without low skin adaptation has an important level of risk of severe sunburn and possibly melanoma; even though, it is an intermittent outdoor exposure.

3.6 Conclusions

There is a need to address the global warming as a direct issue of fossil fuels usage for energy production. It is a worldwide problem which has contributed to air pollution and for the ozone layer damage. Besides the environmental problems, the oil price has been increasing gradually. Countries are concerned about following the fossil-fuels-based practices for energy generation and are opting for developing new technologies based on renewable sources as alternatives to supply the energy demand. Among the renewable energy technologies developed, solar energy, in some contries seems to be a promising option in the market penetration. In order to achieve the growing energy demand the solar industries grew in its installed capacity and, subsequently, increment in job generation. This means that every year the number of people working in solar industries is increasing.

Solar facilities are usually located in areas with high ultraviolet index due to its requirements for power generation. Meanwhile, the ozone layer loss has been exceeding its natural restoration and a growing level of UV radiation reaches the surface of the Earth, the solar industry workers will be facing new risks. This study tempts to address the safety issue related to skin solar exposures exemplified in a case study carried on one of the leading CSP solar technologies within the energy market. The analysis guides through crucial information to understand the relationship between skin and sun, its health effects, the dose and the methods available for skin-risk assessment. The assessment was based on direct solar radiation measurements carried in the location of an experimental CRS solar facility in Mexico.

The results showed that the maximum time to stay unprotected without receiving a noticeable impact on skin (type I-II), under the highest constant flux of solar radiation recorded was less than a quarter of an hour. Recommendations are provided in 6.2 Recommendations for skin exposures, in order to minimize the level of risk. The results of this research could be seen as a basic evidence and information recompilation of an area with improvement opportunities within solar industry. It could also assist the development of security procedures for the solar working environments. Knowledge is the key in preventing the workers of exposing themselves with non-adequate protection to solar radiation in locations with high UVI. Training the workforce and make them aware of how they could address solar exposures, will influence in health effects prevention and health care costs.

Clearly further studies are needed to understand deeply the momentary and cumulative exposures of the skin to solar radiation. Further assessments should include the global and reflected solar irradiance besides the direct solar radiation for the analysis. The evaluation of skin risk in a commercial scale facility is highly suggested. The establishment of security measures, training procedures, monitoring systems and methods of evaluation adapted to the solar industry requirements should be done.

The number of studies about the interaction between skin and solar radiation and its assessment has been increasing, contributing with a good amount of complementary information to science. The new challenge should be centered in spreading the voice of the awareness and the implementation of preventive tools in solar energy industry.

4. OCULAR RISKS ASSESSMENT IN CENTRAL RECEIVER SYSTEM SOLAR POWER PLANT BASED ON MEASURED DATA.

The content of this chapter is presented in:

Samaniego, D. R., Ferreira, A. D., and Da Silva M. G., 2015. Risk assessment in a CRS. 14th International Conference on Sustainable Energy Technologies (SET 2015), Nottingham, UK. ISBN: 9780853583134, vol. I.

Samaniego, D. R., Ferreira, A. D., and Da Silva M. G. Review of glint and glare assessments in central receiver systems: a case of study based on measured data of direct solar radiation (Submitted).

4.1 Introduction

This section aims to contribute with crucial information about ocular exposures to solar radiation. It includes a brief outline of solar effects on eyes subjected to momentary exposures followed by the presentation of safety doses and the methodology about the evaluation of specular reflections from the surface of the heliostats and diffuse reflections from the receiver. Following by the assessment of eye hazards in a CRS based on solar radiation measurements, represented as a case of study. At the end of the section, the results obtained from the analysis of the case study are presented and discussed.

4.1.1 Physiological response to solar radiation: Occupational health effects on eyes

The human eye has the natural aversion response against bright light sources. This response protects it from getting injured by viewing bright sources like the sun. Since this aversion limits, the duration of exposure lasts a fraction of a second (around 0.15 s) (Ho, et al., 2011). It means that the eye will naturally avoid the bright source by blinking or/ and the person will instinctively shift his view from the bright source in order to minimize incident visible light (Franck et al., 2010). In solar radiation exposures, the variation in eyelids opening plays a major role in terms of impact. The eyelids control the amount of light that enters into the eye. For example, the lids are more open during cloudy days as the irradiance is reduced due to the cloud cover. Ocular exposure is affected by the geometry of exposure, which means that solar irradiance reaching the eye is near limited to the indirect radiation that has been diffusely scattered by the atmosphere and reflected from all the surfaces (Vecchia, et al., 2007).

Besides, the unforeseen incidence of flashlight on a visual scene naturally attracts the attention which could distract someone from his/her ongoing task and/ or produce a shock and panic reaction (Toet, et al., 2013).

Even though the avoidance instinct of the eye, the intensity of the bright light source, time of exposure, incidence of the exposure and flickering pattern of light might cause temporary and permanent effects (Toet, et al., 2013; Ho, 2011). The visual disturbances could appear as a result of the neural processing in the retina after the light has been absorbed by the photoreceptors (Toet, et al., 2013).

There are several effects (physiological and psychological) that could represent a temporary impact or a permanent damage according to the type of wavelengths that define light intensity absorbed by the retina of the eye.

4.1.1.1Temporary effects

Glare is the temporary incapability to see details in the area around a bright light (visual field). Sometimes is called dazzle, being known as the first eye reaction to bright light (Franck et al., 2010). It is not classified as biological damage because it lasts only as long as the bright light exists within the individual's visual field (Toet, et al., 2013). Glare, relative to the ambient lighting, is defined as a result of the exposure to a source of continues excessive brightness while glint is attributed to a momentary flash of light (Ho, et al., 2011).

Disability glare

The moment that glare impact vision is called disability glare, which is caused by the diffractions and scattering of light inside the eye. It is also called physiological glare and it reduces the visual performance (Osterhaus, 2005). The light that is scattered overlays the retinal image and, consequently, reduces the visual contrast. The result of the overlaying scattered light distribution is usually called veiling luminance.

Veiling luminance is the decrement of contrast in the scene in the human eye (Toet, et al., 2013). Workers under the presence of disability glare immediately notice the reduction in their ability to see and/or to perform a visual task (Osterhaus, 2005).

Discomfort glare

Discomfort glare, also called psychological glare, does not necessarily affect the visual performance but it produces discomfort. An individual under discomfort glare might not notice any negative impact on his work performance but can experience side effects after a period of time, such as a headache (Osterhaus, 2005).

Flash blindness

The retina adapts physiologically to light and when the light is more intense than that amount at which the retina is adapted at that moment, a temporary and immediate loss of vision is produced. Flash blindness is produced by the bleaching of the retinal visual (light-sensitive) pigments caused by bright light exposures (Toet, et al., 2013; Ho, et al., 2009; Franck, et al., 2010). Most of the people have experienced flash blindness after viewing a flashlight from a camera (Ho, et al., 2009). Dazzle and the “after-image” effects are the physiological responses to flash blindness (Franck, et al., 2010)

After-image

The after-image is a temporary scotoma (blind spot), or a lasting image, after looking directly at a bright source as the sun. It is caused by the visual impression which lasts after the image has disappeared. The after-image effect persists from several seconds to several minutes in the visual field in which target spots are partly and/or completely buried. These blind spots are stuck and move with the eyesight. The time to blind spots fade depends on the intensity and duration of light exposures, among other factors, such as target contrast, color, size, observer age, and the total adaptation state of the visual system (Franck et al., 2010; Toet et al., 2013).

Effects such as after-image, flash blindness and veiling can be a product of experiencing disability glare caused by solar glare. Meanwhile, retinal burn can occur with exposure to concentrated sunlight and solar retinitis with associated scotoma results from staring at the sun (Sliney, 1994).

The prolonged exposures to some of these effects, such as discomfort glare and disability glare, can lead to side effects like headaches and/or other physiological impacts, and reduction of the visual performance (Ho et al., 2014). Glare and flash blindness might be followed by irreversible impairments such as thermal lesions (Toet, et al., 2013).

The recovery time, strongly dependent on the brightness of the projected image, ranges from 0.8 to 2.7 seconds, for approximately 1–3 W/m^2 of solar irradiance at the eye (Saur and Dobrash, 1969; Franck et al., 2010).

For the evaluation of the repercussion effects on a viewer located in the installations of a solar power facility, it is necessary to take into consideration that the effects are directly related to the ambient and background light conditions. In daylight conditions flash blindness is not considered to be a problem since the locations usually have bright surroundings and high global and diffuse radiation (Franck et al., 2010).

4.1.1.2 Reversible and permanent damages

Exposures to solar radiation, mostly UV radiation, are associated with a variety of impairments on cornea, lens, and retina. The health disorder depends on the amount and wavelength of radiation that reaches the internal structure of the eye (ICNIRP, 2010; Vecchia, et al., 2007; Diffey, 1991). For example, viewing intense VL radiation can be potentially risky for the retina and intense UV can be hazardous for the cornea and lens (Sliney, 2001).

The principal hazard resulting from looking directly at the sun is photoretinitis (solar retinitis with scotoma) which is a retinal damage. Intense exposure to short-wavelength of light can cause thermal lesions, which are burns of the retinal tissue that result in permanent scotomas (Sliney, 1994; 2001; Toet, et al., 2013).

Even though the retina is sufficiently protected by the cornea and crystalline lens against health effects (less than 1% of UV-A is available to reach the retina), solar retinitis is the consequence of a photochemical injury mechanism subsequent to the exposure of the retina to shorter wavelengths in the visible spectrum (Sliney, 1994; 2001; ICNIRP, 2004). Photoretinitis may result from viewing an extremely bright light for a short period of time or it could be the result of looking at a lesser bright light source for longer periods of exposure (Sliney, 2001).

Studying the physiology of the retina, light damage and the renewal process of the retina had been the concern between the adverse impacts to UV-A, and blue light upon the retina (Sliney, 2001).

On the other hand, the cornea does not pass through an adaptation process (increment in the capacity of protection) due to repeated exposures; therefore it is equally vulnerable day after day to the same amount of radiation (ICNIRP, 2010; Vecchia, et al., 2007; Knave, et al., 2001).

Acute effects such as photokeratitis and photokeratoconjunctivitis are produced by an inflammatory reaction in the cornea and the conjunctiva, respectively, and both can be very painful but don’t result in a permanent damage. They appear a few hours after the exposure and last one or two days (Knave, et al., 2001). Another effect of unprotected eyes exposures to the sun is fibrous ingrowth of the cornea´s tissue (pterygium). Other effects could be attributed to a nonmalignant tumor in the conjunctiva (pingueculum) and cataracts (opacity of the lens). Usually, cataracts that eventually lead to blind eye appearance in individuals depend on the age and sun exposure (mostly UV-B exposures) (Diffey, 1991; WHO, 2002; Vecchia, et al., 2007).

Risks from glint and glare from bright sources within concentrating solar power plants include the potential of permanent damage in the eye and also temporary effects. Those effects could impact in people within the facility and also in the surroundings (working nearby, pilots flying overhead or motorist driving alongside the site). Assess the potential hazards coming from the glint and glare in concentrating solar power plants is an important requirement to ensure public safety (Ho, et al., 2011).

4.2 Methodology

Ho et al. (2009) and Brumleve (1984) proposed short-term exposure parameters in order to assess the bright light sources in CSP installations. In those studies two variables were defined as necessary for the ocular impact assessment:

i) The retinal irradiance (E_r);

ii) The subtended angle (size) of the glare source (ω) [**Figure 4.1**].

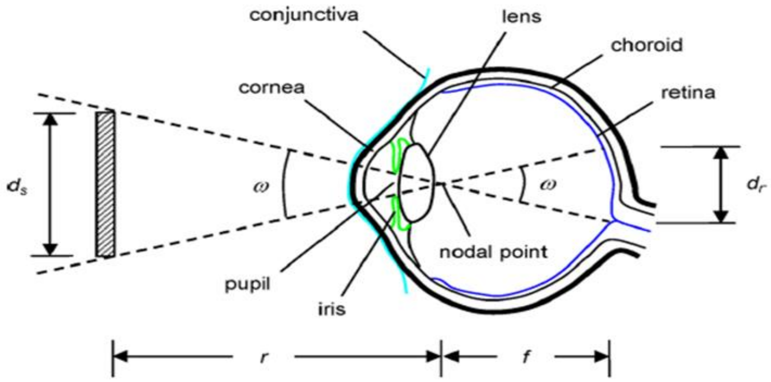

Figure 4.1. *Image projected onto the retina of the eye. Taken from Ho, et al., 2011.*

The retinal irradiance can be calculated from the total power entering the pupil and the retinal image area, as follows:

Equation 12. *Subtended angle of the glare source*

$$\omega = d_s / r \qquad (12)$$

Equation 13. *Diameter of the image projected onto the retina*

$$d_r = f\omega \qquad (13)$$

where $d_r = f\omega \mathrm{d_r} = \mathrm{f\omega}$, is the product of the focal length of the eye (f =0.017 m) by the subtended angle (ω, in radians) (Sliney and Freasier, 1973); d_s is the source size, and r refers to the distance between the eye and the source (Ho et al., 2009) [Figure 4.1]

The power entering to the pupil (E_r, retinal irradiance) is calculated as the product of the irradiance in the frontal plane of the cornea, E_c (W/m^2), and the pupil area (d_p). The power in the retina is divided by the retinal image area (d_r) and multiplied by the transmission coefficient (τ~0.5, as indicated by Brumleve, 1984), i.e.:

Equation 14. *Power entering to the pupil.*

$$E_r = E_c\left(\frac{dp^2}{dr^2}\right)\tau \qquad (14)$$

where d_p is the daylight adjusted pupil diameter (~2mm) (Brumleve, 1984).

By substituting the **Equation 13** into **Equation 14** gives:

Equation 15. *Retinal Irradiance*

$$E_r = E_c\left(\frac{dp^2}{f^2\omega^2}\right)\tau \qquad (15)$$

The calculated irradiances and thresholds for the determination of the ocular impacts are based on the solar spectral distribution (ASTM G 173-03) within the visible spectrum (from 380 to 800 nm, according to Ho et al., 2011). A potential risk to the eye resides in the moment when ω increases and the safe threshold for E_r decreases proportionally. In other words, the permanent eye damage might occur when the delivery of power into the retina occurs in a larger amount. This happens because a larger subtended angle of a source ends in a larger retinal image, so it ends delivering an amount of power that the retina cannot easily dissipate.

The threshold for the burn in the retina can be represented by $E_{r,burn}$ (W/cm^2) and, according to Brumleve (1984), should be delimited by the threshold limit:

***Equation 16**. Threshold for the burn in the retina*

$$E_{r,burn} = \frac{0.118}{\omega} \ for \omega < 0.118rad \ ; \ E_{r,burn} = 1 for \omega \geq 0.118rad \quad (16)$$

As the burns in the retina, the temporary blindness, caused by a flash (after-image effect), depends also on the size of the subtended angle of the source but differs on the severity of the impact. For instance, for a given irradiance, a lesser or greater source ends in smaller/bigger after-image effect. Several authors (e.g., Ho, et al., 2009; Brumleve, 1984) affirm that the size of the after-image and the impact is minor with small angles (ω). The potential threshold of after- image ($E_{r,flash}$) (W/cm^2) can be calculated as indicated in:

***Equation 17.** After- image effect threshold*

$$E_{r,\,flash} = \frac{3.59x10^{-5}}{\omega^{1.77}} \quad (17)$$

Once the values of E_r are determined, they can be compared with security metrics as provided by Ho et al. (2011).

The potential impacts in the eye for short-term exposures are resumed in **Figure 4.2**, where three potential risks of impact regions are defined:

- The risk of permanent damage to the eye or retinal burn in 0.15 seconds (typical average time of blink response)
- Potential for a temporary after-image effect
- Low potential to produce after-image effect.

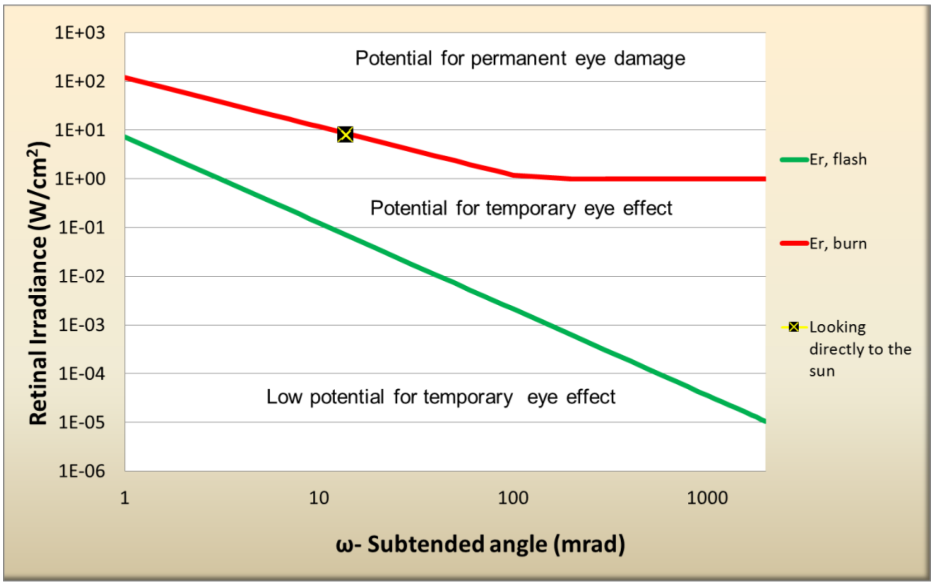

***Figure 4.2.** Potential impacts represented as a function of the subtended angle. Reproduced from Ho et al., 2011.*

The retinal irradiance, E_r, caused by the action of looking directly to the sun (~8 W/cm^2), in **Figure 4.2**, is settled up as a situation of reference and is delimited by the parameters: β= 9.4 mrad, ω =0.0094 rad, , d_p= 0.002 m, f= 0.017m, τ=0.5 and a direct normal irradiance of 1000 W/m^2 (E_{DNI}=0.1 W/cm^2). It is important to notice the fact that the quantified metrics and retinal irradiance estimations do not consider all the factors and situations, e.g., the situation of a person is wearing sunglasses, other human factors and behaviors, and also multiple beams from adjacent receiver(s) (Brumleve, 1984).

4.2.1 Specular reflections from the surface of the heliostats

Situations can lead to glint and glare hazards when the surface of the heliostats is in a position that allows the reflection of the sun reach other locations besides the receiver. In order to evaluate the situations under the conditions to produce the largest beam irradiance, some assumptions should be made, according to Ho et al., (2011).

Such assumptions will be considered for the calculations of the beam irradiance (E_{beam}), expressed in W/cm^2, as given in **Equation 18**, which is defined as the irradiance outside the eye based on the reflection coefficient, or mirror reflectivity, (ρ), and the area of concentration ratio (C) [**Equation 19**].

Equation 18. *Beam Irradiance*

$$E_{beam} = \rho E_{DNI} C \tag{18}$$

Equation 19. *The area concentration ratio*

$$C = \left(\frac{x\beta}{D_h} + \left| \frac{x}{b} - 1 \right| \right)^{-2} \tag{19}$$

In **Equation 18**, E_{DNI} is the direct normal irradiance at the Earth´s surface and ρ is assumed equal to 0.92 (Ho., et al., 2011). Additionally, b is the focal length (set as $b = \infty$ for a flat mirror), x is the distance between the mirror and the observer, being β the total beam divergence angle (assumed as 9.4 mrad, according to Ho et al., 2011), and D_h is the effective diameter of the mirror (calculated from the total reflective surface of the mirror).

The size of the sun image that is reflected on the surface of the heliostats is different from the one observed by the individual (Ho et al., 2011). Therefore it is necessary to calculate the size of the reflected sun image in the mirror that is being observed, in order to determine the retinal irradiance (E_r) and the subtended angle of the source (ω)

According to Ho et al. (2011), it is necessary to take into consideration the spot size of the image, proportional to the measured irradiance which is projected onto the surface and observed by a person at a given distance (x). The concentration ratio "C", is proportional to the area of the reflected spot image (A_{spot}) on the flat mirror viewed by the observer. Therefore, C is also equivalent to the square of the diameter´s ratio of the reflected area on the mirror (d_{spot}).

Equation 20. *Concentration ratio*

$$C = \frac{A_{spot}}{A_{spot,\,flat}} = \left(\frac{d_{spot}}{d_{spot,\,flat}}\right)^2 = \left(\frac{x\omega_{spot}}{x\beta}\right)^2 \qquad (20)$$

where ω_{spot} is the subtended angle of the reflected image on a mirror, as observed from a given distance, and ($x\beta$) is the diameter of the reflected sun at a x distance away from an infinitely large flat mirror.

The subtended angle, of the reflected image on a mirror as observed from a given distance, it is express by:

Equation 21. *The subtended angle*

$$\omega_{spot} = \beta\sqrt{\frac{E_{beam}}{\rho E_{DNI}}}\ ; \qquad (21)$$

where: $E_{beam} = E_c$

The retinal irradiance (from specular reflections), in Equation 22**,** is obtained from using the **Equation 21** in **Equation 12**, **Equation 13** and **Equation 14**.

Equation 22*. The retinal irradiance from specular reflections*

$$E_r = \frac{\rho E_{DNI} {d_p}^2 \tau}{f^2 \beta^2} \qquad (22)$$

Referring to the **Equation 22**, Ho, et al. (2011) in their work, indicate that:

> *"The retinal irradiance does not depend on distance from the source (neglecting atmospheric attenuation). As the distance increases, both the power entering into the pupil and the retinal image area (which is proportional to the square of the subtended source angle) decrease at the same rate. Therefore, the retinal irradiance, which is equal to the power entering to the pupil divided by the retinal image area, is independent of distance"*

In the application of the methodology for the evaluation of ocular impacts, the equations **Equation 12**, **Equation 13**, and **Equation 14** are used to convert E_c into E_r; where ω is represented by the ω_{spot} (**Equation 21**). The **Equation 22** can be used for comparisons to the safe retinal irradiance levels in **Figure 4.2**.

4.2.2 Diffuse reflections from the receiver

The receiver, located on the top of the tower, is designed to absorb the solar radiation coming from the heliostats field (Brumleve, 1984) and in order to assess the action of seeing the reflection of bright light coming from it and its impact on eyes, the receiver surface can be interpreted as a diffuse source. Samaniego, et al., 2012, proposed a way to evaluate the reflected irradiance coming from diffuse sources based on the methodology proposed by Ho et al. (2011). The angular size of the source is determined by the effective area reflected on the receiver surface which is seen by the observer [**Figure 4.3**].

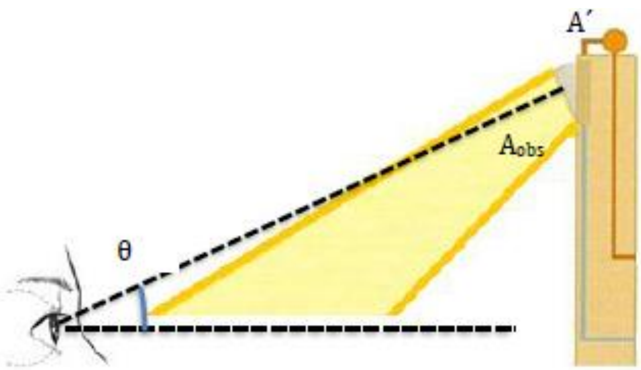

Figure 4.3. *Observer interaction with the receiver. Taken from Samaniego, et al., 2012.*

The effective area seen by the observer (A_{obs}) can be calculated using **Equation 23**, where the angle between the tower and the observer depends on the distance between them and the tower height.

Equation 23. *Effective area seen by the observer*

$$A_{obs} = A' \cos\theta \tag{23}$$

being A_{obs} the area seen by the observer, θ the angle, and A' the area of the reflecting surface.

Once the total illuminated area is known, the reflected irradiance (E_{ref}) can be calculated by multiplying it by the reflection coefficient ρρ (0.8 to 0.2) and the amount of irradiance seen by the observer (E'):

Equation 24. *Reflected irradiance*

$$E_{ref} = \rho E' \tag{24}$$

However, there is a difference between the total reflected radiation and the total amount of radiation outside the eye (E_c in W/cm^2). The main reason is the distance and the angle in which the observer is located with respect to the receiver. The irradiance outside of the cornea is defined by:

Equation 25. *Irradiance outside the cornea*

$$E_c = I_{ref} A' \frac{X_{obs}}{\left(z_{obs}^2 + X_{obs}^2\right)^{\frac{3}{2}}} \tag{25}$$

where $I_{ref} = \frac{E_{ref}}{\pi}$, due to the circular shape of the image; Z_{obs} is the tower height minus the height of the observer; X_{obs} is the distance between the observer and the tower.

On the other hand, the quantity of irradiance (per cm^2) that enters through the pupil (E_r) is equal to the multiplication of energy that is outside of the cornea by the area of the pupil (A_p) for a certain distance "r_{obs}" (location of the eyes of the observer) divided by the area seen by the observer.

Equation 26. *The quantity of irradiance (per cm^2) that enters through the pupil*

$$E_r = \frac{E_C A_p \tau \, r_{obs}^2}{A_{obs} f^2} \tag{26}$$

Here the transmission coefficient (τ) is equal to 0.5 and the focal distance of the eye (f) is equal 0.017m (Ho et al., 2011).

***Equation* 26** refers to the amount of radiation on the retina produced by a single heliostat. Therefore, the amount of reflected irradiance coming from "**n"** heliostats in the field and reaching the retina is determined by an equivalent area (A_{equiv}) for an equivalent irradiance (E_{equiv}) as follows:

Equation 27. *Equivalent area*

$$A_{equiv} = \sum_{i=1}^{n} \frac{nA'_{i-n} nE'_{i-n}}{nE'_{i-n}} \tag{27}$$

The equivalent irradiance, E_{equiv}, is represented by the sum of the amounts of reflected irradiance coming from the heliostats. As it can be seen in:

Equation 28. *Equivalent irradiance*

$$E_{equiv} = \sum_{i=1}^{n} nE'_{i-n} \tag{28}$$

4.3 Case study and Results

4.3.1 Case study: Simulation

In Ivanpah (Ho, et al., 2014), over 170,000 heliostats with 2.6 million square meters of mirrors reflect and concentrate sun irradiance. It counts with three receivers, at 140m (459 ft) height, that produce steam for the power cycle. In order to assess the case of glare coming from the receiver's surface and a heliostat in its focal point, sibling to the activity of cleaning the heliostat' surface, a design of evaluation is proposed. The method seeks to evaluate the situation of seeing the diffuse radiation from the receiver when the heliostats are reflecting the sunbeams on it. The analysis is accomplished in order to find an analytical solution to evaluate the radiation from sources (heliostats and receiver of the tower).

There are two scenarios of evaluation. In the first situation, a heliostat is simulated at different distances, passing through its focal point (the point with the highest beam concentration). The data with more relevance is the irradiance peak flow since what is being sought is to detect the worst possible situations.

The second situation summarizes the irradiance and ocular impact of the glare of the receiver in the top of the tower. The equivalent irradiance (E_{equiv}) refers to the sum of the irradiance of ***n*** heliostats' images overlapping in the receiver' surface. Taking into account the characteristics of the facility Ivanpah, the heliostats within 3 km are candidates to simulations [**Figure 4.4**].

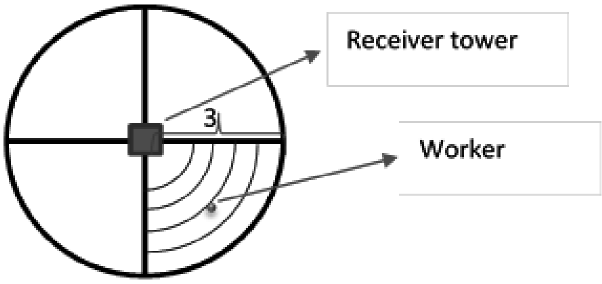

Figure 4.4. *Observer position respect to the receiver.*

Heliostats groups are defined at representative distances and the average of the irradiance in each of the groups is taken as a representative irradiance.

- Group 1: localized at 50 m representing 20 heliostats
- Group 2: localized at 100 m representing 40 heliostats
- Group 3: localized at 200 m representing 80 heliostats
- Group 4: localized at 500 m representing 201 heliostats
- Group 5: localized at 1000 m representing 403 heliostats

The software "SolTrace"[12], tool developed by the NREL, is used to simulate the irradiance flow in a solar facility. The flux of irradiance within the facility is simulated at each heliostat group distance that will represent the irradiance of each group of heliostats in calculations [**Figure 4.5**].

[12] https://www.nrel.gov/csp/soltrace-download-submitted.html

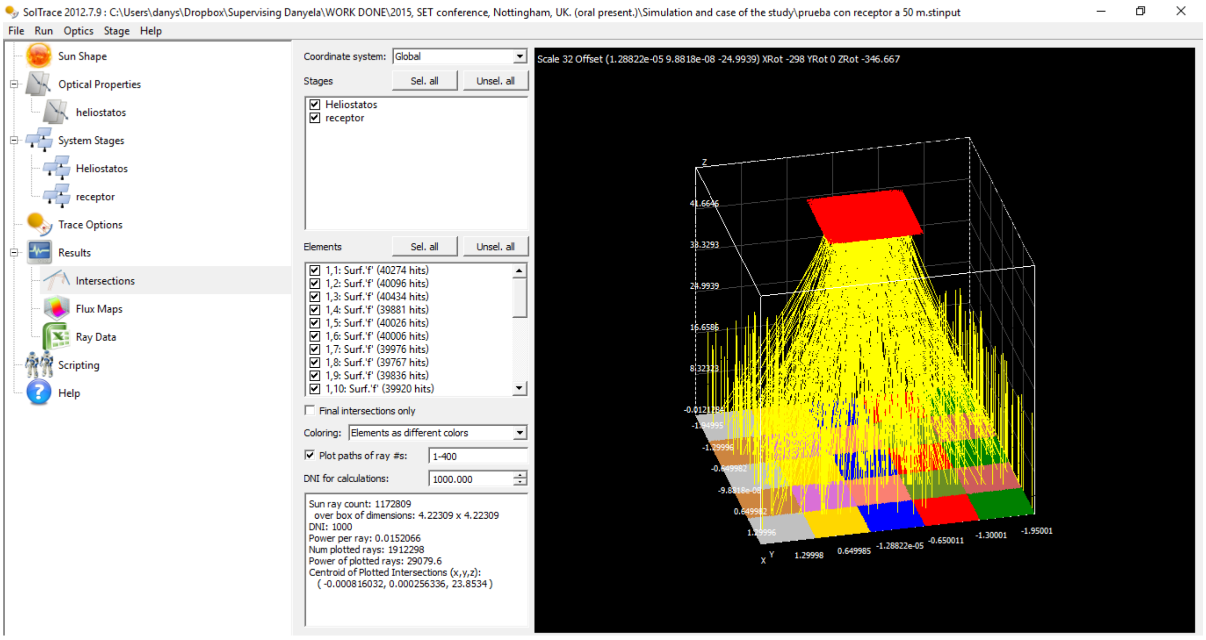

Figure 4.5. *Simulation of the irradiance flux of a heliostat surface located at 50m distance from the receiver.*

In **Figure 4.6**, it can be seen the intensity of the incident irradiance flux simulated on the surface of the receiver.

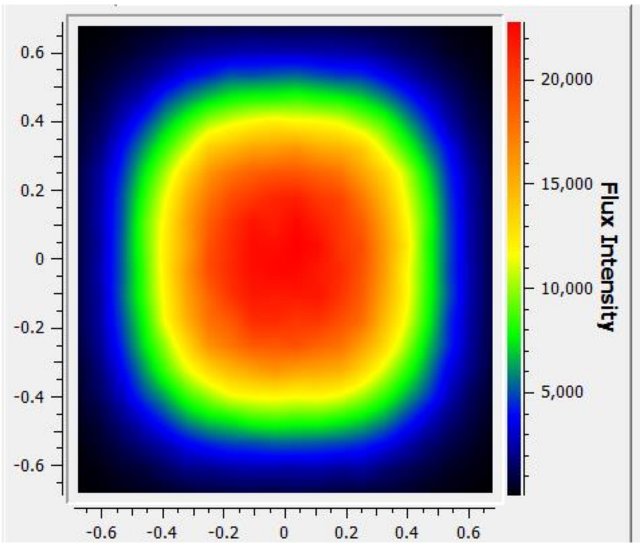

Figure 4.6. *Simulation of the incident irradiance flux on the surface of the receiver.*

Subsequently, the results from the simulation of the two previously defined situations are compared with the security metrics established in **Figure 4.2**.

The application of the method and the equations developed in the part of methodology of previous section, were applied under the following parameters values: as: β= 9.4 mrad, ρ=0.92, d_p= 0.002 m, f= 0.017m, and τ=0.5 and E_{DNI} from simulations.

The irradiance reaching the retina, as a result of the refection of the heliostat's surface in its focal point, is compared with $E_{r,flash}$ and $E_{r,burn}$ limits settled by the authors of the literature reviewed in the previous section. As a result, the power of the irradiance coming from the heliostat surface is sufficiently high to cause a permanent damage in the eye [**Figure 4.7**]. The irradiance received in the retina of the eye is powerful enough to cross the limit of permanent damage within 100m [**Figure 4.8**].

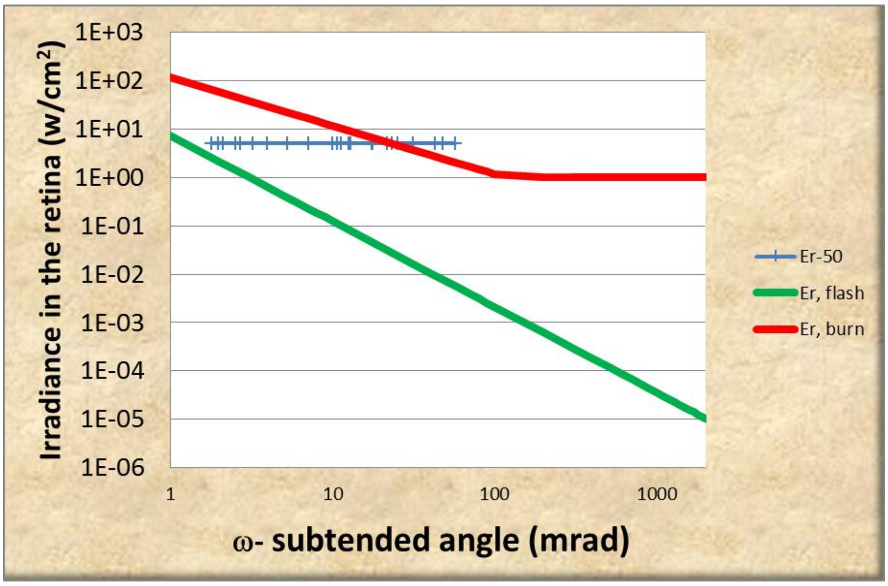

Figure 4.7. *The action of looking at the heliostat' surface.*

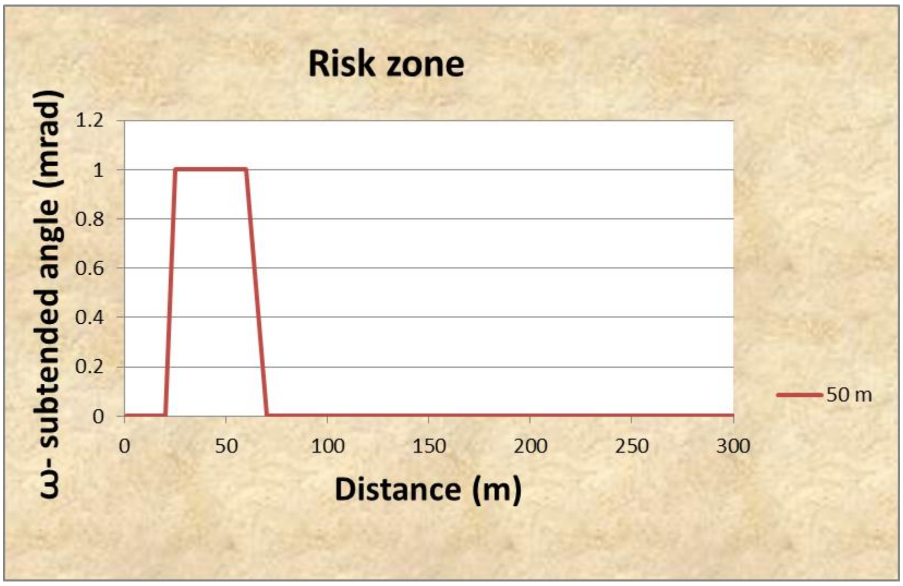

Figure 4.8. *Risk zone for the action of looking directly to the heliostat' surface*

The second situation consists in the evaluation of the reflection of the sunlight on the surface of the receiver, subject area that is seen by the observer and its particular angle, as well as the distance (1 to 3 km). For the evaluation, it was defined 744 heliostats' images overlapping on the receiver. The results show that the irradiance has sufficient power to produce a temporary effect (after-Image) [**Figure 4.9**]. This effect could occur within an area of 150 m as shown in **Figure 4.10**.

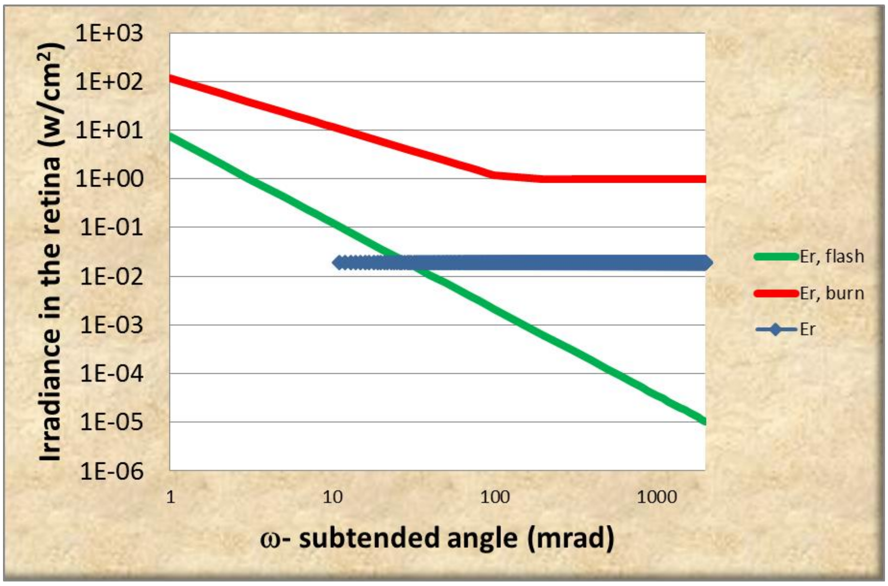

Figure 4.9. *The diffuse radiation from the receiver.*

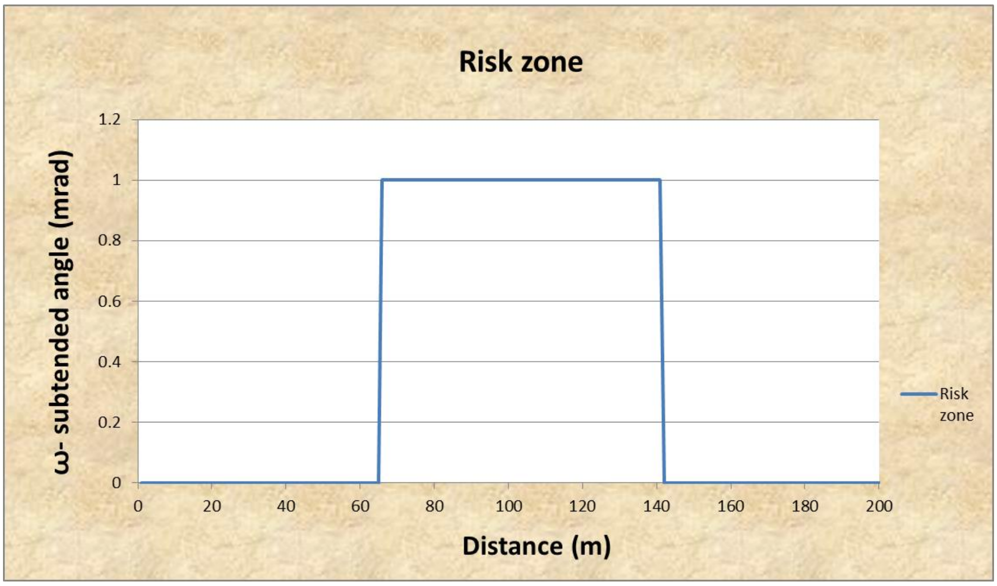

Figure 4.10. *Risk zone for the action of looking at the receiver.*

There exists an increase in publishing studies on health effects as a result of exposure to the sun. In order to ensure occupational health and safety based on the concept of prevention, the assessment of potential risks due to exposure become necessary in solar industry.

Such analyses help to detect situations where the maximum permissible limits of exposure are exceeded and ends in a potential permanent damage or after-image effect. Also, it is possible to define the zone risk with potential impact on workers' health. Besides, ocular risk assessment based on measured direct solar radiation data is highly recommended.

4.3.2 Case study: Collected data from measurements

Like many other countries, Mexico has a considerable potential for applications in solar energy due to the high amounts of solar radiation over its territory, in particular in the states located in the north region, namely Sonora, Baja California, and Chihuahua.

The NREL, in its website (http://maps.nrel.gov/swera), includes a geographic information system, which displays worldwide information of direct normal solar radiation [**Figure 4.11**]. The state of Sonora is indicated as having one of the highest solar irradiance levels in the whole country (Arancibia et al., 2014).

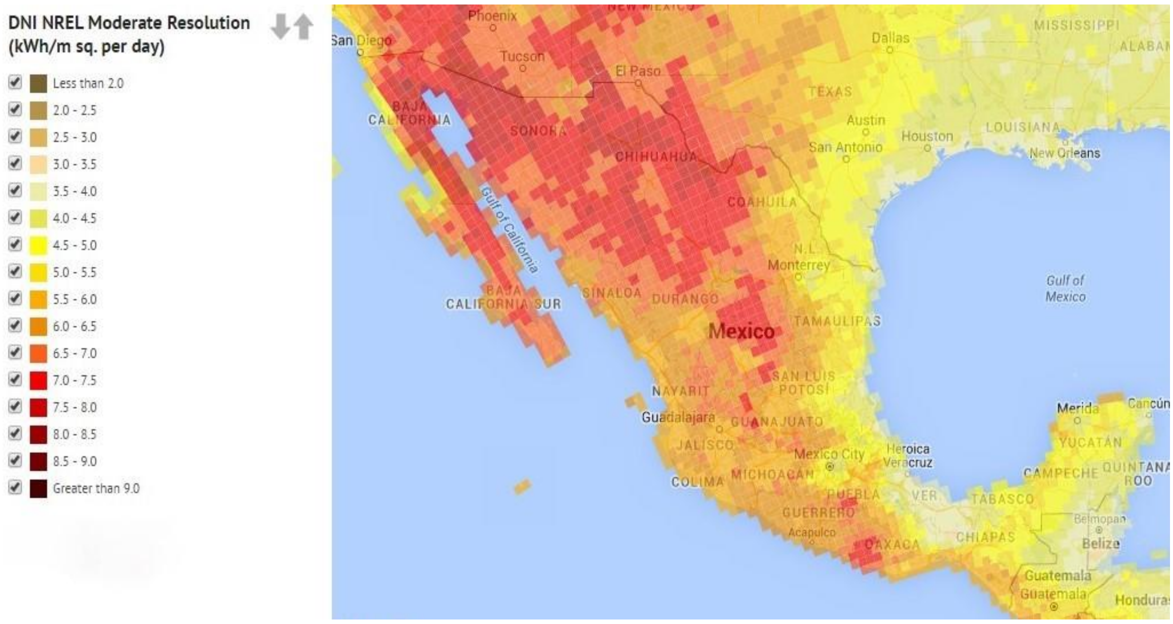

Figure 4.11. *Direct normal irradiance in Mexico (NREL: http://maps.nrel.gov/swera)*

A study over three regions of Sonora, based on beam solar radiation measurements, showed that the capital of Sonora, Hermosillo, has a beam normal solar radiation of 7.8 kWh/m^2/day. Furthermore, in that city, the number of hours in a day with irradiance above the average value exceeds 10 hours, which is an excellent value for concentrated solar energy uses (Arancibia et al., 2014).

The present study was conducted in the Experimental Field of Heliostats (CPH: initials of "Campo de Prueba de Heliostatos", in Spanish), located in Hermosillo, Sonora, México. Such scientific and technological research installation is supervised by the University of Sonora and by the National Autonomous University of Mexico. The CPH counts with a tower of 36m height, a control room and a field of 29 heliostats. The heliostats have a total surface of of 36 m^2 (with 25 flat mirrors of 1.2m X 1.2m) (Iriarte, 2013). The total reflecting area is then close to 1,070 m^2. The heliostats installed on the field allow reaching a theoretical solar radiation concentration factor of 25, which corresponds to a thermal power of approximately 1 MWt. In its final stage, the CPH field aims to reach a total of 82 heliostats (total reflecting area of about 3,000 m^2) and a theoretical thermal power of 2 MWt (Samaniego et al., 2012). The workers of CPH have the following tasks:

- Operation of the heliostats field: Verification of the operation of the field, heliostat calibration routines and calibration parameters, feedback control system, running the control and monitoring system.
- Monitoring system (direct, diffuse, global measurements): Cleaning and maintenance of the equipment located at the top of the tower (gardon gauge, pyranometer and pyrheliometer), supervising the equipment operation and backup the stored data.

The monitoring system was designed in two stages; the first one, dealing with the acquisition and recording of data and, the second one, with the processing and analysis of the information in the central control system. The first stage was installed on the hardware cRIO-9074 controller with the FTP- Server enabled for access to historical information from the system module. The system was installed in the upper part of the tower with the function of obtaining measurements of solar radiation, and weather conditions (Iriarte, 2013).

The monitoring system is integrated for a sensor designed to measure the flux density of radiation, global radiation and the direct normal irradiance. The instrument that is used to measure the flux of direct solar radiation at normal incidence is called Pyrheliometer. This instrument is a type of telescope that follows the solar movement (Iqbal, 1983; Kalogirou, 2009). The calibration uncertainty of the equipment is <1% and the measurement uncertainty is 1.5%.

The sampling rate of the various variables (global, diffuse, and direct radiation) was 1 Hz. After a period of 60 seconds, the average of each variable was computed and stored into files. Those files were named based on the date, and new files were created every time the file size exceeded three megabytes. The measurements selected, for the present study, were those obtained during a working period between 9 am and 5 pm, on each day, and processed by the monitoring system. The corresponding peak irradiance fluxes of each month are presented in, **Table 4.1**, where it can be seen that the highest solar irradiance, in a month, ranges from a minimum of 897 to approximately 1013 W/m^2.

Table 4.1. *Solar irradiance over a year*

Temperature C°	**Month**	**Irradiance peak flux in a day (W/m^2)**	**Averages of maximum levels of irradiance per month (W/m^2)**
29.90	January	998.07	882.699
32.61	February	1012.75	935.529
25.33	March	998.15	894.921
30.87	April	996.89	895.191
34.21	May	961.37	898.771
38.62	June	940.79	890.758
36.84	July	897.27	889.231
39.33	August	953.56	906.275
36.62	September	918.91	900.596
35.52	October	971.78	930.128
26.09	November	1005.69	931.872
25.19	December	968.43	851.510
	Average	968.64	

In **Figure 3.6**, it can be noticed a diminution of the beam irradiance during the months around July due to the fact that such period corresponds to the local rainy season of the year, when the amount of cloudiness increases, despite being summer there.

The irradiance measurements were assessed following the methodology proposed by Ho et al. 2011, as explained previously, in order to compare the short-term exposure of specular reflections from the surface of the heliostats against the safety threshold limits presented already in **Figure 4.2**. The parameters were defined as: β= 9.4 mrad, ρ=0.92, d_p= 0.002 m, f= 0.017m, and τ=0.5 (Ho et al., 2011; 2009; Brumleve, 1984) for a distance of 200 m and the irradiance on a 36 m2 heliostat of surface with focal length of 100 m.

The results, in **Table 4.2**, show a retinal irradiance -E_r- which is close to the threshold of 8 W/cm^2 (Ho, et al., 2011) that represents the irradiance that enters into the eye of a person staring at the sun and which has a considerable potential to damage the eye in a permanent way.

Table 4.2. *Conversion of the irradiance outside of the cornea (E_c) to the irradiance that enters to the eye (E_r)*

E_{DNI} (W/m^2)	E_c (W/m^2)	β (rad)	ω_{spot} (rad)	(mrad)	E_r (W/m^2)	(W/cm^2)	$E_{r,burn}$ (W/cm^2)	$E_{r,flash}$ (W/cm^2)
998.073	562.465	0.0094	0.007	7.357	71916.189	7.192	16.039	2.143
1012.752	570.737	0.0094	0.007	7.357	72973.851	7.297	16.039	2.143
998.148	562.507	0.0094	0.007	7.357	71921.547	7.192	16.039	2.143
996.891	561.799	0.0094	0.007	7.357	71831.040	7.183	16.039	2.143
961.375	541.783	0.0094	0.007	7.357	69271.891	6.927	16.039	2.143
940.787	530.181	0.0094	0.007	7.357	67788.395	6.779	16.039	2.143
897.270	505.657	0.0094	0.007	7.357	64652.842	6.465	16.039	2.143
953.560	537.379	0.0094	0.007	7.357	68708.763	6.871	16.039	2.143
918.910	517.852	0.0094	0.007	7.357	66212.061	6.621	16.039	2.143
971.783	547.649	0.0094	0.007	7.357	70021.816	7.002	16.039	2.143
1005.687	566.756	0.0094	0.007	7.357	72464.814	7.246	16.039	2.143
968.431	545.760	0.0094	0.007	7.357	69780.296	6.978	16.039	2.143

In **Figure 4.12**, the actions of looking directly at the sun and looking directly at the surface of the heliostats are compared with the safety levels. Based on measurements performed within a work shift of 8 hours (9 am to 5 pm) over a year, the results revealed that the environmental conditions have the potential to cause after-image effect in momentary exposures, even though not sufficient potential to cause permanent eye damage.

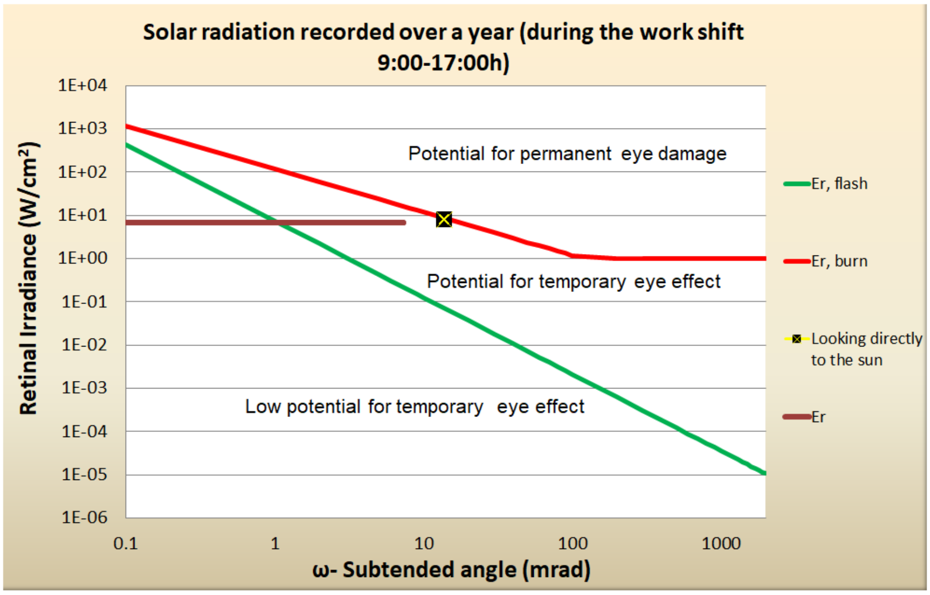

Figure 4.12. *Potential impacts represented in function of the subtended angle.*

In the design of the case for analyzing the diffuse reflection from the receiver, one person (1.65m average height) is supposed to be looking at the receiver surface reflecting the bright light of the entire field (composed by 82 heliostats). The highest flux of irradiance was registered around 1 p.m. during the warmest day of the year; where the direct normal irradiance was 1012.75 W/m^2. The parameters that represent the characteristics of the facility are: receiver of 4m^2 area with a reflectivity of 0.2 and the height of central tower 27m.

The analytical model of diffuse reflections evaluates the total reflected irradiance coming from the bright source which is represented by an equivalent irradiance by using the **Equation 28**; based on the results of the appliance of the **Equation 26**. Therefore in the evaluation, three heliostats at different distances, **Figure 4.13**, were chosen and its results were reproduced as representative information of the equivalent irradiance of each group of a total of three. The selection of the heliostats for evaluation in the study was led by strategic decision based on its distance from the central tower.

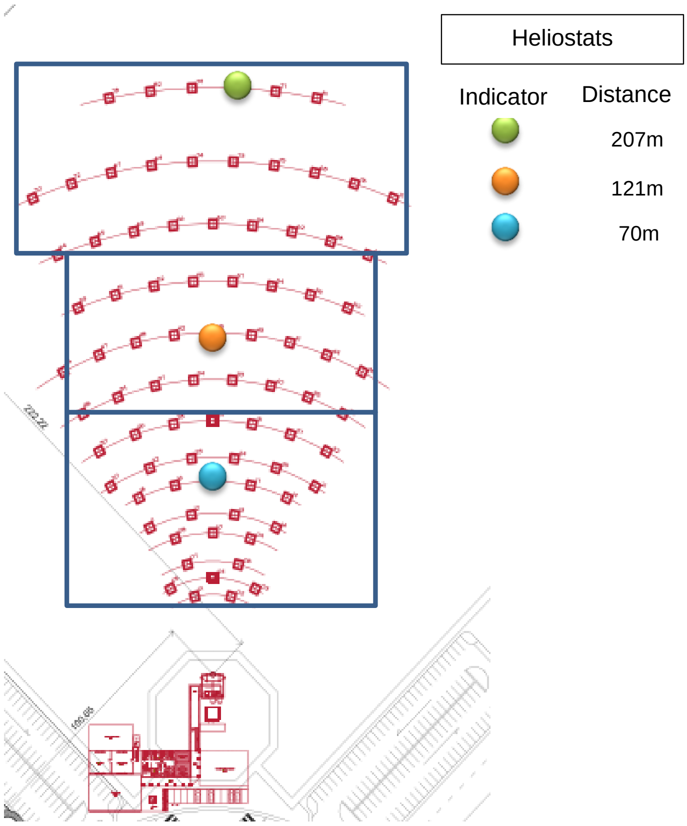

Figure 4.13. *Map of the groups of heliostats in the experimental field.*

The group 1 was composed by 32 heliostats at a representative distance from the receiver of 70 m. The 25 heliostats of group 2 were representing the fringe located at 121 m from the tower and the last group of 25 heliostats at distance of 207m. It is supposed that the person is seeing the 82 bright images overlapping in one point on the receiver. Therefore, it is hypothetical determined that the location of this individual is far enough to see the entire field of heliostats reflecting the solar radiation from the receiver.

Since the total amount of reflected radiation differs from the total amount of radiation outside the eye due to the distance and the angle in which the observer is located respect to the receiver, the evaluation of the irradiance outside the eye (E_c) as a function of the distance was made **Figure 4.14**.

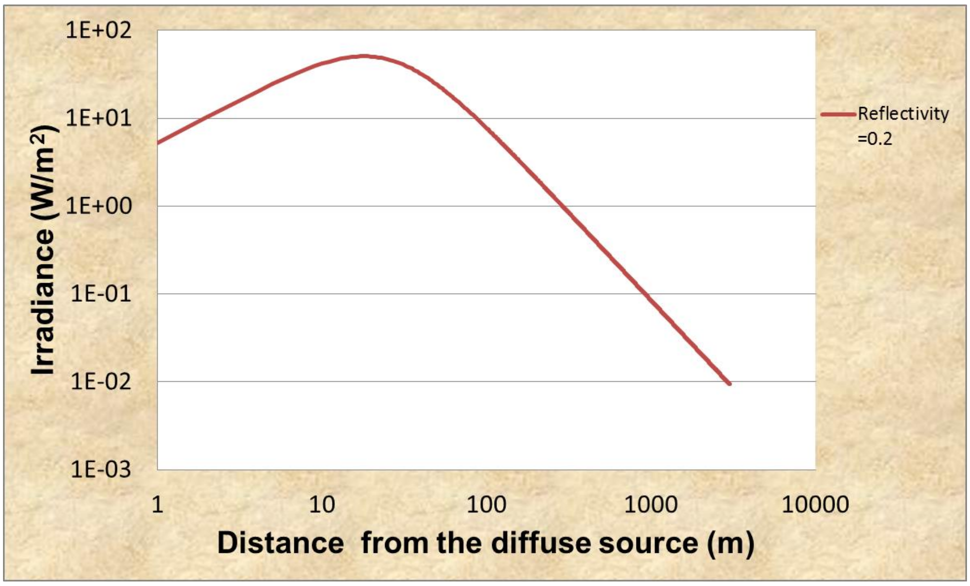

Figure 4.14. *Irradiance outside of the cornea as a function of the distance between the observer and the diffuse source.*

It can be noticed, in **Figure 4.14**, that the irradiance drops (near 1 m) because the visible source area is affected by the angle (modified by cosθ). This means that the observer is near to the structure of the tower and the worker is not able to see the whole reflected image of the receiver. The more the worker is displaced in distance the more the worker will be available to see the reflected image. Also, it can be seen that the irradiance outside the eye decreases as the distance increases. This happens because the image of the reflected bright area reduces at large viewing angles.

Besides the angle and distance, the receiver reflectivity could affect the amount of E_c. If the receiver is replaced by another one with higher reflectivity (e.g. 0.8), a considerable increment of the radiation in front of the eyes (within 100 meters) occurs [**Figure 4.15**]. Even though the level of risk would increase in a receiver with higher reflectivity, the receivers for industrial applications require a lower reflectivity in order to concentrate higher levels of irradiance.

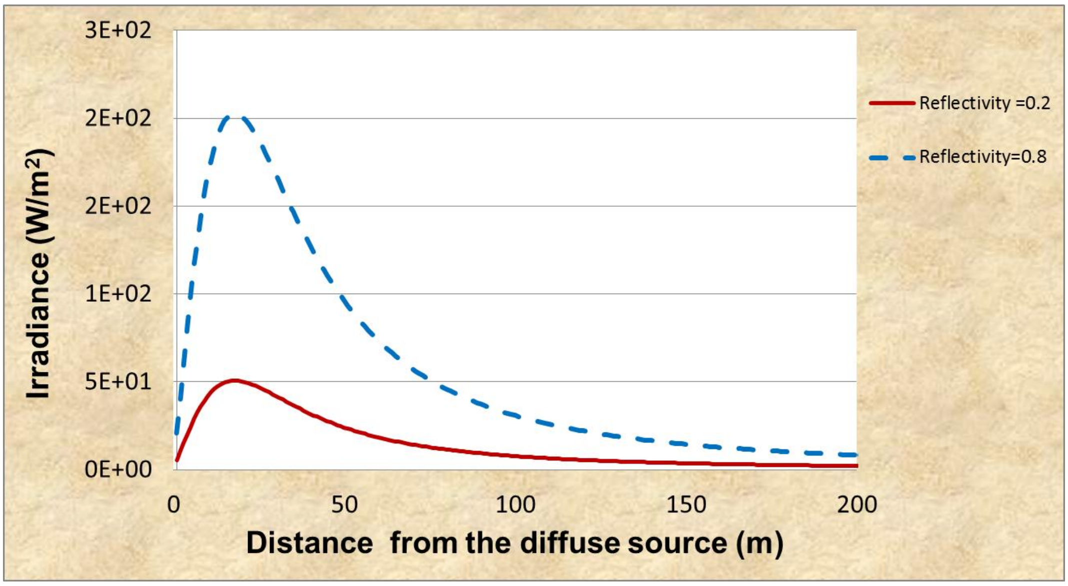

Figure 4.15. *Irradiance outside of the cornea as a function of the distance from the diffuse source with different reflectivity.*

After obtaining the irradiance that enters into the eye from each group of heliostats reflecting the sunlight on the receiver and its equivalent irradiance, a comparison against the safety limits of exposure is shown in **Figure 4.16**.

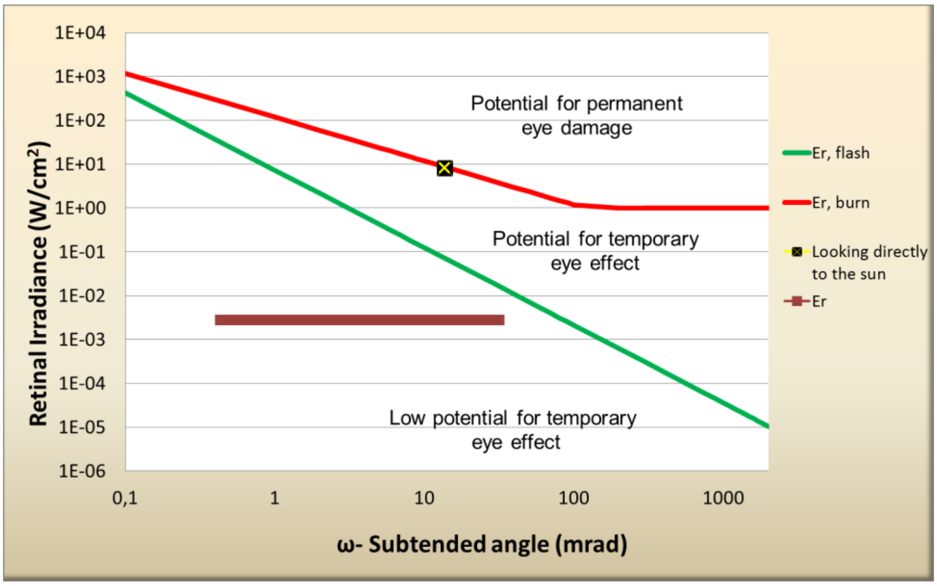

Figure 4.16. *The action of looking at the receiver reflecting the irradiance of 82 heliostats.*

The results revealed that the short exposure to diffusely reflected irradiance, coming from a receiver with a reflectivity of 0.2, has a low potential to cause a temporary effect as after-image effect in a person.

4.4 Conclusions

This chapter aims to contribute with information about eye exposures to solar radiation in CRS installations for the development of standard procedures in order to ensure the occupational health and safety of the solar industry workforce.

To accomplish such objective, field data measurements of solar radiation were conducted, during nearly a year, in a solar experimental facility located in Mexico.

The analysis, based on such real data, provided relevant information about the actions of looking directly at the surface of the heliostats and looking directly to the surface of the receiver. In the case of seeing the solar radiation reflected on the receiver there exist a low potential to cause a temporary effect on the eye. This happens because the irradiance outside the eye decreases while the distance increases, in other words, the image of the reflected bright area on the receiver reduces at large viewing angles. On the other hand, the results revealed a potential temporary effect (after-image) when a person is looking at the surface of the heliostat. Even though the after-image effect is classified as reversible impact, in other words, physiologically healed with time, those situations may lead to secondary effects (headache, degradation of vision, dazzle and temporary loss of the vision, dizziness and vertigo) or accidents at work. Therefore, it would be desirable to mitigate the situations of risk. Recommendations for ocular exposures are suggested in section 6.3.

Clearly further studies are needed to understand more in deep the ocular exposures to solar radiation. The reproduction of this study on a commercial solar facility, the establishment of security measures, training procedures, monitoring systems and methods of evaluation adapted to the solar industry requirements are highly recommended. Address solar exposures will influence in the effects on health prevention and costs in health care.

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5. ASSESSMENT OF THE LEVEL OF HEAT STRESS IN A SOLAR ENERGY FACILITY

The content of this chapter is presented in:

Samaniego, D. R., Ferreira, A. D., and Da Silva M. G. Assessment of the level of heat stress in central receiver system solar power plant based on measured data (manuscript in final preparation).

5.1 Introduction

The impact of global warming on population health is a growing concern (Lin and Chan, 2009). Solar energy workers often work in very hot weather; where the Occupational Safety and Health Administration (OSHA) supports that there exist some hazards attempting to the health and safety of the workforce (manufacture, installation, and maintenance). Among the heat-related effects, defined as a consequence of exposures to hot environments, are dehydration, heat exhaustion, heat stroke and death[13] (OSHAa, n.d.; Hamilton, 2011).

Due to the heat discomfort and psychological stress, there also exist behavioral disorders that can negatively influence the performance capacity of the workers, leading to a considerably fall on productivity and efficiency (Epstein and Moran, 2006; Parson 2009, Lin and Chan, 2009; Abdel, 2013; 2014; Lundgren, 2013; Kjellstrom, 2009a; 2016; Quiller, et al., 2017).

The present chapter briefly outlines the relation between solar energy, heat stress, heat-related health effects, climate change and productivity. This will be followed by the method for the assessment and safety limits of exposure. At the end of the chapter, it will be provided an assessment of the level of heat stress represented in a case study carried out in one of the solar technologies within the energy market, where the results obtained are presented and discussed.

The present study aims to contribute with some guidelines points directed to solar energy enterprises, policy-makers and environmental scientists about heat-related occupational safety and health in the way of minimizing natural hazards and health care costs on solar working population.

[13] https://www.osha.gov/dep/greenjobs/solar_heat.html

5.1.1 Physiological response to hot environments: occupational health effects

The energy from the sun comes in the form of electromagnetic waves and it is called solar energy. The solar radiation that passes through the atmosphere is represented by the solar spectrum divided by wavelength into three regions: Ultraviolet (UV), visible light (VL) and infrared (IR). Among these types of non-ionizing radiation (NIR), VL is the portion of the solar spectrum visible to the human eye; the rest can be perceived by feeling heat when the source has a high intensity. Temperature is the measure of the intensity of energy transitions of molecules, atoms, and electrons of substance from those activities, the electromagnetic radiation emitted as a result is thermal radiation.

All objects with a temperature above zero emit thermal radiation and the rate of its emissions increase with increasing temperature. Thermal radiation includes a portion of the UV radiation and the entire VL, IR radiation (Yunus, 2002; Kwan-Hoong, 2003; Givoni 1976 cited by Hodder and Parsons 2006).

Through radiation, the body exchanges heat with its surroundings. When a body surface is exposed to such incident irradiance, scatters a part of it and absorbs the other portion. The body that is exposed to solar radiation will raise its temperature by absorbing part of the radiation ending the process in a heat exchange. Depending on the intensity of the source, the absorbed fraction of the radiation will induce physiological, biochemical or behavioral changes in the organism (Kwan-Hoong, 2003; Brauer, 2006; Carrasco, 2003; Stanojević, et al., 2004; Yunus, 2002).

The human body is physiological regulated, which means that the human body system tends to maintain the internal stability when environmental conditions change. This internal stability depends on the rate at which metabolic heat produced is balanced by the rate at which heat is externally lost. If the internal heat in the body is dissipated really fast, the body will experience cold. Otherwise, if the loss happens slowly, the body experiences heat (Brauer, 2006). There are different ways of losing heat into the environment [**Figure 5.1**] happens through convection, conduction, respiration, and evaporation (sweat) (Blazejczyk, et al., 2014).

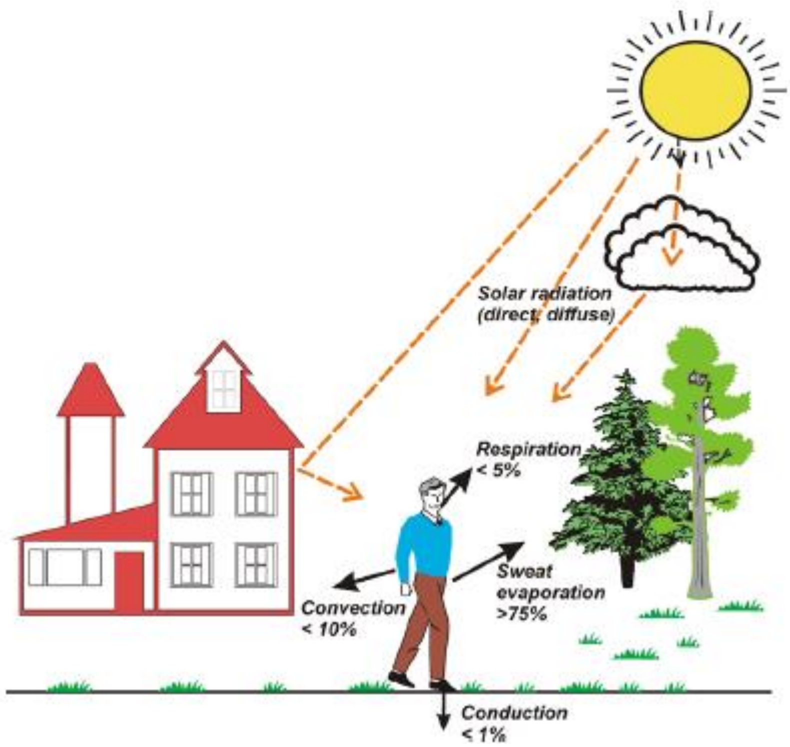

Figure 5.1. *Heat loss into the environment. Taken from Blazejczyk, et al., 2014.*

When subjected to heat stress conditions, in hot weather, the body protects itself through thermoregulation by losing heat. The body, with the purpose of conserving its normal function, has the crucial requirement of maintaining, within ±1 ºC, the acceptable core temperature of 37 ºC. Achieving this equilibrium in body temperature (heat balance) depends on the heat exchange between the body and the environment. The human body will promote heat dissipation through sweat evaporation in order to achieve the equilibrium; 75% of the total of heat losses happens through evaporation.

Sweat will vaporize in order to cool down the surface of the body, but the process depends on the saturation of water in the air. If the heat persists, the cooldown process leads into abundant sweating and, in such state, the body is susceptible to dehydration by water and salt depletion. Eventually, when the skin is completely wet, the sweat glands present an inflammation which induces a reduction in sweating (hidromeiosis).

The decrements in sweating allow the rapid rise of the deep-body temperature, ending the process in a whole system collapse. The life-threatening result occurs in a body-temperature above 40 ºC. The nervous system collapse or heat stroke happens due to the absence of thermal equilibrium between the body and the environment due to a thermoregulatory failure (Yunus, 2002; Bouchama and Knochel 2002; Epstein and Moran 2006; Parsons, 2009; Kjellstrom, et al., 2009b; Lemke and Kjellstrom, 2012; Blazejczyk, et al., 2014; No and Kwak, 2016; NIOSH, 2016).

At this level of core temperature, the presence of mental confusion, behavioral changes, decrements in sweating and the failure in the central nervous thermoregulation could eventually end in the death of the individual (Parsons, 2009). At a lower heat exposure and before this serious health effect occurs, the mental task ability reduces and the risk of accident increases leading to a reduction in work capacity which negatively impact in productivity (Kjellstrom, et al., 2009b).

In the following sections, the physiological responses due to heat exposures are explained more in detail by addressing acute and chronic heat–related impairments, the physiological ability to regulate the temperature and how global warming could interfere with heat-related occupational safety and health.

5.1.1.1 Heat stress

Kovats and Hajat in 2008 classified the heat as an environmental and occupational hazard with its physiological effects due to high-temperature exposures. Stress due to heat might happen when the exposure to hot environmental conditions brings to the individual discomfort and physiological strain.

The level of heat stress is influenced by the metabolic heat production of the body, which increases with the level of activity. In other words, physical work could accelerate the perception of the symptoms of heat. It also depends on the ability of the body to lose heat. If the body is available to cold down, the heat stored in the body will not raise the core temperature to unacceptable levels (Bouchama and Knochel 2002; Parsons, 2009).

Heat stress can be defined as the total heat load on a worker exposed to combined contributions of heat exchange between the body and the environment (metabolic heat, heat gained from the exterior minus the body heat losses to the environment) that can result in an increase in heat storage in the body (Kjellstrom, et al., 2016; NIOSH, 2016).

The human body’s response to heat stress is called heat strain and the National Institute for Occupational Safety and Health (NIOSH) (2016) defined it as:

> *“Physiological response to the heat load (external or internal) experienced by a person, in whom the body attempts to increase heat loss to the environment in order to maintain a stable body temperature”.*

Heat strain is derived from some physiological responses to promote heat transfer from the body back to the environment in order to maintain core body temperature. The increased heart rate, blood flow, and prominent sweating could possibly end in dehydration (Parsons, 2009; Kjellstrom, et al., 2016). Once the compensatory mechanism of the human body is no longer capable to maintain the inner temperature of the body at the required level, these physiological responses end with heat-related clinical diseases/ illnesses and health impairments (clinical damage to organ function, physical activity capacity reduction and heat stroke) (Kjellstrom, et al., 2016; Parsons, 2009; NIOSH, 2016). The severe heat-related health impairments that could cause permanent damage to a person’s organs, such as the heart, kidneys, and liver, are called chronic heat–related disorder (NIOSH, 2016).

Besides chronic heat–related disorders, other occupational health effects due to exposures to hot environments have being reported (Kjellstrom, et al., 2016) and they are classified by the NIOSH as acute heat–related disorders:

Heat fatigue

Heat fatigue is a behavioral disorder due to heat exposures and it can be classified as transient or chronic. Transient heat fatigue decreases the performance of sensory and motor functions of the worker, as well as mental performance, during the development of tasks in heat due to discomfort and physiologic strain. Chronic heat fatigue reduces the performance capacity due to inability to concentrate and social behavior under psychosocial stress that may involve hormonal imbalance (Brauer, 2006; Parsons, 2009).

Heat rash

Heat rash (prickly heat /miliaria rubra) is characterized by small eruptions (red vesicles/ papules) on skin giving a prickly sensation due to constant exposure to humid heat. The skin persistently wet with unevaporated sweat will obstruct sweat gland ducts with retention of sweat ending in an inflammatory reaction.

Another skin disorder (miliaria crystallina) appears in areas in skin previously injured or sunburned areas. These areas start to sweat, but the damage prevents the escape of sweat ending in the development of small to large watery vesicles, which rapidly diminish once the mechanism of sweating stops.

The Anhydrotic heat exhaustion (miliaria profunda) appears in areas of the skin which don’t sweat during heating loads because the sweat ducts are clogged below the skin surface. Sweat retention deep in the skin, reduced evaporative cooling causing heat intolerance. This type of heat rash might also occur in previous skin injury. The skin presents goose-flesh appearance and pale elevations during the exposure. Mostly these heat rashes subside with the return to a cool environment.

Even though heat rashes are not dangerous themselves, each one could influence in thermoregulation due to the reduction in sweating that reduces evaporative heat loss back to the environment (Brauer, 2006; Parsons, 2009; NIOSH, 2016).

Heat syncope

Heat syncope is a collapse and/or loss of consciousness (fainting) as a result of heat exposure. It usually occurs without an increase in body temperature or cessation of sweating, in prolonged standing or sudden rising from a sitting or supine position. The redistribution of blood to peripheral tissue decreases the flow of blood to the brain inducing the faint in workers.

Heat syncope could be the result of dehydration and/or lack of acclimatization, and its symptoms include light-headedness, dizziness, and fainting (Brauer, 2006; NIOSH, 2016).

Heat cramps

Heat cramps are a heat-induced illness characterized by spasms/ spastic contractions in the muscles in arms, hands, legs, feet or abdominal area (during or after working hours). Heat cramps are usually associated with salt depletion due to sweating.

The body in profuse sweating presents no significant body dehydration because it is accompanied by abundant water intake (without salt replacement), where it dilutes electrolytes and water enters to the muscles causing the spasms (Brauer, 2006; Parsons, 2009; NIOSH, 2016).

Rhabdomyolysis

Rhabdomyolysis is a medical condition related to heat stress and prolonged physical action resulting in the death of most or all of the cells in muscle tissue. After the breakdown of muscle and its necrosis, electrolytes, mainly potassium, and large proteins are released into the blood. Besides large muscle proteins can damage the kidneys filtration system, high potassium levels might be the reason for irregular and dangerous heart rhythms and seizures (NIOSH, 2016). Although symptoms can vary between individuals, NIOSH defined them as:

- Muscle pain, cramping, swelling, weakness, dark or tea-colored urine and decreased range of motion of joints.
- Some experiencing nonspecific symptoms such as fatigue, exercise intolerance abdominal pain, back pain, nausea or vomiting, and confusion.

Sometimes, the presence of muscle cramps and dark urine, after physical work with heat load, may be the only symptom and rhabdomyolysis may be misdiagnosed for another heat-related disorder and dehydration (NIOSH, 2016).

Heat exhaustion

Heat-related moderate illness resulting from water and salt losses due to hot environmental exposures. It is characterized by a failure to replace water and it is usually considered forerunner of heat stroke (NIOSH, 2016). Symptoms are described by Parsons 2009; OSHAa, n.d.; Bouchama and Knochel 2002; Brauer, 2006; NIOSH, 2016 as:

- Heavy sweating, intense thirst, weakness, discomfort, anxiety, dizziness, nausea, vertigo, and headache.
- Clammy and moist skin, completion pale, and muddy or hectic flush behavior.
- Fainting, rapid thready pulse, and low blood pressure.
- Decreased urine output

Core temperature could be normal, below normal or slightly elevated (38 or 39 ºC). Oral temperature normal or low, but rectal temperature usually elevated (>34 but < 40 ºC).

Heat stroke

Heat-related severe illness characterized by central nervous system abnormalities resulting from exposure to environmental heat. It starts with a core temperature abnormally high (above 40 ºC) caused by a thermoregulatory failure in the body´s system. This failure of the central drive for sweating lead to loss of evaporative cooling and ends in an uncontrolled increment in the temperature (NIOSH, 2016). Some signs and symptoms described by Bouchama and Knochel (2002), Brauer (2006), OSHAa (n.d.) and NIOSH (2016), are:

- Confusion and altered mental status, slurred speech and delirium, seizures or convulsions, lack of sweating, very high core temperature, loss of consciousness (coma) and death. Heat stroke is frequently fatal and those who persist may sustain irreversible neurological damage.

The occupational heat–related health effects previously described are interrelated and each has its unique clinical characteristics and differs in severity (NIOSH, 2016; Bouchama and Knochel 2002). Even though it is not known whether radiation energy (with different wavelength characteristics) will have different effects on human perception of thermal sensation and whether people are sufficiently sensitive to react physiologically, visible radiation has a very high intensity of energy. Therefore, climatic health hazards need to be placed on a developing relationship between climate and its effects on occupational health. A combination of the internal body heat production from physical activity and some factors involved in the ability to lose and gain heat (number of working hours, season, clothing, etc.) can cause health issues in workers, ranging from heat stress to heat stroke leading to death (Hodder and Parsons, 2007; Blazejczyk, et al., 2014; Kjellstrom, et al., 2016).

Heat strain could end in heat stroke due to the existence of a thermoregulatory failure, exaggeration of the acute-phase response, and alteration in the expression of heat-shock proteins. This fatal acute disorder (heat stroke) is a preventable illness and thorough awareness and administrative and engineering controls could be detectable by monitoring the heat stress level in workers (Bouchama and Knochel 2002; NIOSH, 2016).

5.1.1.2 Acclimatization

The level of heat stress at which heat strain will result in heat-related impairments on a worker depends on the physiological ability of the worker to tolerate heat. One of the many physical responses to heat exposure is that the body attempts to regulate its temperature and appropriate repetitive exposures causes a sequence of physiologic adaptations, known as acclimatization (NIOSH, 2016).

The NIOSH defines acclimatization as:

> *"The physiological changes that occur in response to a succession of days of exposure to environmental heat stress and reduce the strain caused by the heat stress of the environment; and enable a person to work with greater effectiveness and with less chance of heat injury".*

In most workers, appropriate increments in the level of work performed and repeated exposures to hot environments eventually allow the workers to perform their tasks under safety at levels of heat that were previously intolerable. Under acclimatization, the body becomes more efficient in dealing with heat loads. An individual that has been passing through this process should tolerate a greater heat stress levels before a harmful level of heat strain occurs.

The process of acclimatization to hot environments might take several weeks, but after continuous heat exposure, from 7 to 14 days, workers perform their tasks with a lower core temperature. Acclimatization in workers also involves the increase in the capacity to secrete sweat and the stabilization of the circulation by the improvement of cardiovascular performance (Bouchama and Knochel 2002; NIOSH, 2016).

In order to achieve the full heat acclimatization, unacclimatized workers should pass through brief daily exposures to heat and gradually increase the time exposure. The minimum heat time exposure for a worker to develop acclimatization is at least two hours per day; which may be broken into 1-hour exposures. The rest periods of time break the continues-heat-exposures and contribute to the acclimatization process and workers safety; opposite to long rest periods e.g. 24hr of rest after long time heat exposures at work. Excessive exposures could result harmful to workers without heat acclimatization because it is difficult for those individuals to replace all of the water loss in sweat. The level of acclimatization will depend on the initial level of physical capability and the amount of heat stress experienced by the worker (DOD 2003, cited by NIOSH, 2016).

Even though most healthy workers will be available to accomplish the acclimatization process, some of them will not be able to sustain heat. The workers whose temperature will start rising prior, and at a higher rate, than those others under the same conditions, could be heat intolerant. Heat intolerance may be associated with many factors, such as low physical fitness, lack of acclimatization, low work efficiency, reduced skin area to body mass ratio, sweat gland dysfunction, dehydration, infectious disease, x-ray irradiation, previous heat stroke, large scarred burns, and/or drugs. Especially after an episode of heat exhaustion or exertional heat stroke, a test can be used for the evaluation of individual's tolerance (Epstein et al. cited in NIOSH, 2016; Moran et al. 2007).

The multi-center health research and prevention program Hothaps is used to calculate the degree of the heath impact or adaptation in workers to heat exposure while working. Also, the program evaluates how climate change may increase heat-related effects on workers. This kind of program leads to future heat-related occupational safety and health regulations by documenting the emerging heat-related events (NIOSH, 2016).

5.1.1.3 Climate change and its effects on outdoor working population

Unfortunately, the risk of heat stroke was increasing its incidence by 2002 since global warming was already causing heat waves in mild climates. Around 70,000 heat- related deaths all over Europe were reported during a summer heat wave in 2003 (no analysis of occupational health component was carried out) (Bouchama and Knochel, 2002; Lundgren et al., 2013, Kjellstrom, et al. 2016). These periods of high levels of atmospheric heat could end in a modification of the population lifestyle (Lundgren, et al., 2013). There exists the big dilemma between those countries who can adapt fast to environmental changes and some others who cannot (Oncel, 2017).

As it was mentioned previously, the effects of climate disturbances (natural disasters, high temperatures and diseases) will cost 320,000 lives per year by 2020, (Mekhilef, et al., 2011). With changes in the climate that impact in human lives, the need for a better understanding is increasingly important (Leon 2008 cited by NIOSH, 2016).

The industrial revolution era left a growing footprint (Oncel, 2017). Depending on the fossil fuel-based technology, a considerable amount of pollutants called greenhouse gases (GHG), are released into the atmosphere (Wiser, et al., 2016). Among the GHG, mainly combustion gases, such as CO_2 (carbon dioxide), emissions are contributing to global warming (Comodi et al., 2016). The CO_2 and water vapor in the atmosphere transmits the majority of solar radiation but absorb the IR radiated from the surface of the Earth, resulting in the so-called greenhouse effect. This effect traps the energy by allowing solar radiation to pass through the ozone layer, but it does not allow the IR radiation going out through it [**Figure 5.2**], which ends in a temperature rise (Yunus, 2002).

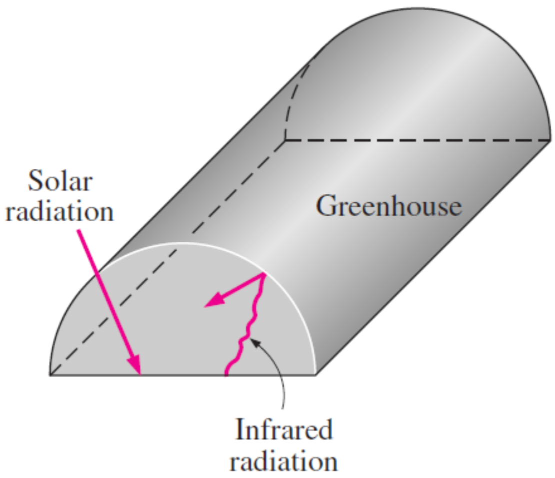

Figure 5.2. *Greenhouse effect. Taken from Yunus, 2002, pp.585.*

In addition, the release of the GHG into the atmosphere contributes to the damage of the ozone layer, which allows a higher amount of UV radiation reaching the Earth´s surface (Schulte and Chun, 2009; Schulte, et al., 2016). Thereby, it is expected that during global warming global temperature averages increase (Kjellstrom, et al. 2009b). The increment in the levels of ambient temperature and shifts in the distribution of daily peak temperature (Kjellstrom, et al. 2009a; 2009b) can cause indirect and direct effects on society (Lundgren, et al., 2013). Even though climate change will not necessarily result in new impairments, the already known effects on health could become more frequent, prevalent, and spread (Lin and Chan, 2009; NIOSH, 2016; Kjellstrom, et al. 2016).

Besides the clinical effects (acute and chronic heat–related disorders) previously described, the natural reaction of the body exposed to heat is to reduce its internal heat production by reducing the physical activity. This leads to a reduction in the human performance and work capacity ending in a decay of labor productivity and loss of income (Lundgren, et al., 2013; Abdel, et al., 2014; Kjellstrom, et al. 2016; NIOSH, 2016). In resume, productivity, which is the expected outcome, strongly depends on thermal conditions and physical work (Lundgren, et al., 2013).

High physical activity during extreme thermal conditions could cause distraction due to discomfort, fatigue and psychological strain which modifies the expected output by decreasing cognitive and behavioral performance. Also, it could increase accident rates by affecting the reaction time, tracking and attention, memory and ability to concentrate on the workers exposed (Kjellstrom, 2009a; Lundgren, et al., 2013).

The local community and economy will be affected also by the negative effects on health, low performance, and productivity. An Australian report about absenteeism and work performance reduction due to heat reported US$655 economic losses per person, which translated into an economic burden that sums the total on US$6.2 billion (Kjellstrom, et al., 2016). This projection can be seen as an indicator of the relevance of heat exposure to the economic output which makes a clear reminder of the importance of assessing the impact of climate change on workers’ health and productivity (Lin and Chan, 2009). Lundgren, et al., (2013) also, provides some evidence of studies that indicate productivity loss and economic impact due to heat exposures while working population is facing the climate change.

Even though the exposure to hot environments is known as a health threat, heat-related effects on health and performance reduction are often unnoticed in climate change health impact analysis due to the scarcity of quantitative field studies on occupational health (Kjellstrom, et al., 2016).

In the journey of avoiding the usage of fossil fuel technologies for power generation due to its contribution to the global warming, solar energy is considered as a promising alternative among renewable energy for solving the environmental concerns (Ashouri, et al. 2015). Under climate change conditions, the proper usage of solar energy is a key point in the adaptation of workers´ competence to carry out physical activities without harm (Oncel, 2017). This highlights the need of going more in deep into analyzing the interface between heat and health (Kjellstrom, et al., 2016).

5.2 Methodology for the heat stress assessment and limits of exposure to hot environmental conditions

According to the American Industrial Hygiene Association (AIHA), workers and supervisors should be aware of the basics of thermoregulation and control exposure. Therefore, agencies such as the International Standards Organization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH), OSHA and NIOSH have been overviewing exposure limits available, time-weighted averages, recommendations, etc., in order to protect workers from heat stress due to hot environmental exposures (NIOSH, 2016).

The standards are directed for unacclimatized and acclimatized workers exposed to heat. Most of them use the “Wet-bulb Globe Temperature” (WBGT) index, which is, by far, widely used to estimate the level of heat stress in outdoor conditions with solar load (Epstein and Moran, 2006; Kjellstrom, et al., 2009b; Blazejczyk, et al., 2014; Abdel, et al., 2014). Also, it is the heat index used for workplace assessments due to its recommendations about resting/work schedules at different WBGT levels and work intensity (Lemke and Kjellstrom, 2012).

The factors affecting human heat stress level can be classified as environmental factors and physiological factors. The amount of heat experienced by a worker is represented by measuring the temperature of the air, humidity (water vapor pressure), air velocity and radiant energy. Besides, the body metabolic heat generation rate also impact the level of heat stress and it depends on different factors such as personal activity, sex, age, ethnicity and type of clothing. Therefore, these factors vary between individuals (Abdel, et al., 2014).

The WBGT index, described by the ISO 7243, resides in the variable weighting of the dry-bulb temperature (T), natural wet-bulb (static) temperature (T_{nw}) and black–globe temperature (T_g) in the following equations (Epstein and Moran, 2006; Brauer, 2006; Kjellstrom, et al., 2009a; Blazejczyk, et al., 2014; NIOSH, 2016):

Equation 29. *WBGT index (with solar load)*

$$WBGT_{out} = 0.7\,T_{nw} + 0.2T_g + 0.1T \qquad (29)$$

Equation 30. *WBGT index (without solar load)*

$$WBGT_{in} = 0.7\,T_{nw} + 0.3T_g \qquad (30)$$

In the case of a worker being exposed to different thermal environments during a work shift, an average value of WBGT, based on the time of the exposure (t_n), is suggested (Brauer, 2006):

Equation 31. *WBGT average value*

$$WBGT_{avg} = \frac{(WBGT_1 \times t_1) + (WBGT_2 \times t_2) + \cdots + (WBGT_n \times t_n)}{t_1 + t_2 + \cdots + t_n} \qquad (31)$$

The WBGT index evaluates the effect of air movement (v in m/s) and humidity (RH in %) in T_{nw}. The combination of air temperature (T_a) and radiation is evaluated by the black–globe temperature (T_g) and the air temperature is measured by the dry-bulb temperature (T) (NIOSH, 2016).

In general, the components necessary for the WBGT calculation result from measurements with particular equipment (Blazejczyk, et al., 2014; NIOSH, 2016). The measuring instruments give T_{nw}, T_g and Ta separately or as combined WBGT readouts (NIOSH, 2016). The equipment required to perform the measurements is a black globe thermometer, a natural (static) wet-bulb thermometer, and a dry-bulb thermometer (OSHA, 1999). The thermometers could be suspended over a stand, in order to avoid the shade around the globe thermometer, and allow the free air flow around the bulbs and the wet-bulb. Also, placing the thermometers the measurements would be illustrative of the employee's working or resting areas. The range of the dry and the natural wet-bulb thermometers should be -5°C to +50°C, with an accuracy of ±0.5°C. On the other hand, the range of globe thermometer should be from -5°C to +100°C with an accuracy of ±0.5°C.

The globe thermometer should be exposed between 10-25 minutes before its reading, and its bulb sensor must be fixed in the center of the sphere. In the case of the dry bulb thermometer, it must be protected from the sun or radiant surfaces without interfering with the airflow. Further, the wick of the natural wet bulb thermometer needs to be clean and wetted with distilled water for at least one-half hour before the temperature readings are performed (OSHA, 1999).

The measurements of environmental factors used to determine the degree of heat stress on a worker should be performed at, or as close as possible, to the work area where the worker is usually exposed. If the task performed is not a continuous task in one spot (the worker develops the task in different working areas), and/or if the heat varies at one single hot area, the measurements should be carried on each working spot under a continuous heat level of exposure. The data should be gathered at least each hour, during the hottest period of the work shift and during the hottest season of the year (NIOSH, 2016).

The resulting WBGT index values obtained by applying the previous formulas can be compared to the WBGT ranges [**Table 5.1**] in order to follow the recommendations for outdoor exposures with heat load. Under climate change conditions, relative humidity is expected to remain constant so the WBGT- based occupational exposure limits are suggested to remain unaffected (Ingram cited by NIOSH, 2016).

Table 5.1. *Recommendations for WBGT values in outdoor activity.*

WBGT (ºC)	Recommendations
<18	Unlimited
18-23	Keep alert for possible increases in the index and for symptoms of heat stress
23-28	Active exercise for non-acclimatized person should be curtailed
28-30	Active exercise for all except the well-acclimatized should be curtailed
> 30	All physical activities should be stopped
Source: WBGT index 1991 (Blazejczyk, et al., 2011; 2014)	

Besides estimating the level of heat stress, occupational heat exposure guidelines, such as the NIOSH and ISO 7243, define the maximum level of exposure in relation to the work intensity (in watts) (Kjellstrom, et al., 2009a). **Table 5.2** shows the reference values of WBGT levels of exposure corresponding to different work intensity levels. The ISO 7243 suggests reducing heat stress if any of those levels are exceeded.

Table 5.2. *Reference values for WBGT (ºC) at corresponding work intensity*

Work intensity	**Resting**	**Light work**	**Moderate work**	**Heavy work**	**Very heavy work**
Metabolic heat Kcal/h	100	200	300	400	500
M (Watts)	M<117 W	117< M< 234 W	234< M< 360 W	360< M< 468 W	M>468 W
WBGT (ºC)	33	30	28	26 - 25	25 - 23
(ºF)	91.4	86	82.4	78.8 -77	77- 73.4
Source: ISO 7243 (Kjellstrom, et al., 2009a; NIOSH, 2016)					

These WBGT values are set to avoid overheating (> 38 ºC) in a standard human with light clothing. This means that if the worker is sensitive to heat, or is not using light clothing, the levels need to be adjusted below the present levels suggested in **Table 5.2** (Kjellstrom, et al., 2009a).

The NIOSH (2016) compared the recommended WBGT reference values from some institutions, among them AIHA, ISO, ACGIH and the OSHA, and concluded that there exists a slight variation between values recommended, but they are basically equivalent.

Depending on the WBGT level and work intensity, the worker will need to rest periods of time in order to maintain the core temperature under 38 ºC. The **Table 5.3**, shows the proportion of total work (100%) that can be performed under a body core temperature below 38 ºC; for the remaining proportion of time the worker is assumed to be resting (Kjellstrom, et al., 2009a; 2009b; NIOSH, 2016).

Table 5.3. *WBGT exposed levels in ºC at different work intensities and rest/ work periods for an average worker with light clothing*

Acclimatized worker					
Work demands	**Rest periods in min (per hour)**	**Light work WBGT (ºC)**	**Moderate work WBGT (ºC)**	**Heavy work WBGT (ºC)**	**Very heavy work WBGT (ºC)**
100% work; 0% rest	0 min	31	28	27	25.5
75% work; 25% rest/ hour	15 min	31.5	29	27.5	26.5
50% work; 50% rest/ hour	30 min	32	30.5	29.5	28
25% work; 75% rest/ hour	45 min	32.5	32	31.5	31
0% work; 100% rest/ hour	60 min	39	37	36	34
Source: Kjellstrom, et al., 2009a					

Table 5.3, also, shows the work/resting periods for an acclimatized worker, WBGT levels that require continued work and those that require stopping work activities. It can be noticed that heavy work intensity at higher WBGT levels will need longer periods of rest. Kjellstrom et al. (2009a) suggest that these recommendations are limited to clothing as it slows down the rate of heat exchange between the body and the environment (Brauer, 2006); heavier clothes will be required, also, longer

resting periods. The ACGIH suggests the permissible heat exposure threshold limits values (TLV) for heat stress conditions. Basically, TLV's suggested the levels under which acclimatized and unacclimatized workers could be continuously exposed without harm and those conditions under the worker have to take a rest from the job activity [**Table 5.4**] (Epstein and Moran 2006; Brauer, 2006; Blazejczyk, et al., 2011; 2014).

Table 5.4. *American Conference of Governmental Industrial Hygienists (ACGIH) WBGT- based heat load levels in ºC*

Acclimatized worker				
Work demands	**Light work**	**Moderate work**	**Heavy work**	**Very heavy work**
100% work	29.5	27.5	26.0	-
75% work; 25% rest	30.5	28.0	27.5	-
50% work; 50% rest	31.5	29.5	28.5	27.5
25% work; 75% rest	32.5	31.0	30.0	29.5
Unacclimatized worker				
Work demands	**Light work**	**Moderate work**	**Heavy work**	**Very heavy work**
100% work	27.5	25.0	22.5	-
75% work; 25% rest	29	26.5	24.5	-
50% work; 50% rest	30.0	28.0	26.5	25.0
25% work; 75% rest	31.0	29.0	28.0	26.5
Source: adapted from Epstein and Moran 2006				

The NIOSH specifies the level of exposure at which workers should not be expected to perform the ongoing tasks (Kjellstrom, et al., 2009a). The levels, called Recommended Alert Limits (RALs) and Recommended Exposure Limits (RELs), aim to protect the workers with no health impairments, who are exposed to internal or external heat, from developing heat-related health effects. The exposure limits are determined by the following equations (NIOSH, 2016):

Equation 32. *Recommended Alert Limits (RALs)*

$$RAL[°\mathrm{C} - \mathrm{WBGT}] = 59.9 - 14.1 \log_{10} \mathrm{M} \qquad (32)$$

Equation 33. *Recommended Exposure Limits (RELs)*

$$REL\ [°\mathrm{C} - \mathrm{WBGT}] = 56.7 - 11.5 \log_{10} \mathrm{M} \qquad (33)$$

where

M is the metabolic rate in Watts (W)

The RALs were developed by NIOSH for the protection of unacclimatized workers who are exposed to environmental and metabolic heat and the RELs for workers who are acclimatized to the same conditions (NIOSH, 2016). These limits suggest work/rest schedules based on the concept that workers are able to work for short intervals of time at higher temperatures without showing heat-related health effects.

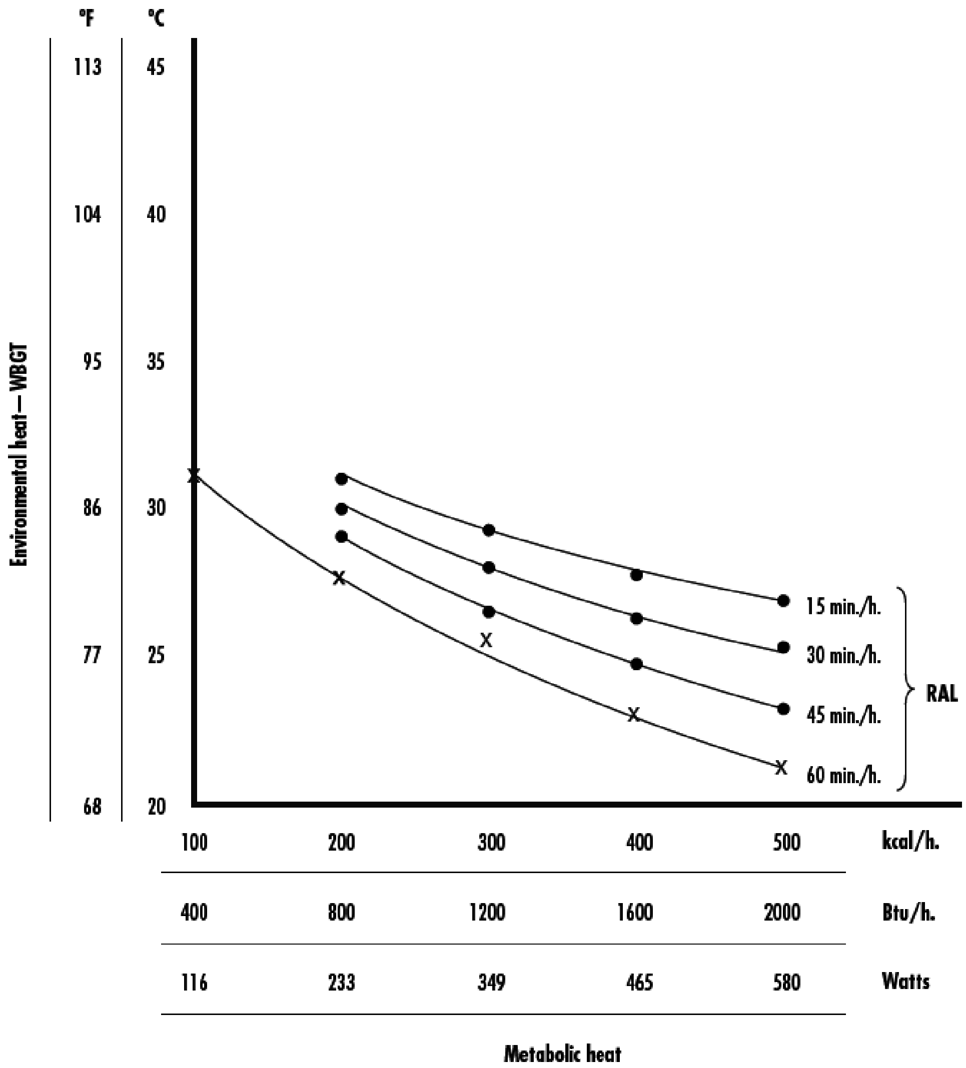

Figure 5.3. *Recommended heat stress alert limits (RALs) for unacclimatized workers. Taken from NIOSH, 2016, pp.94.*

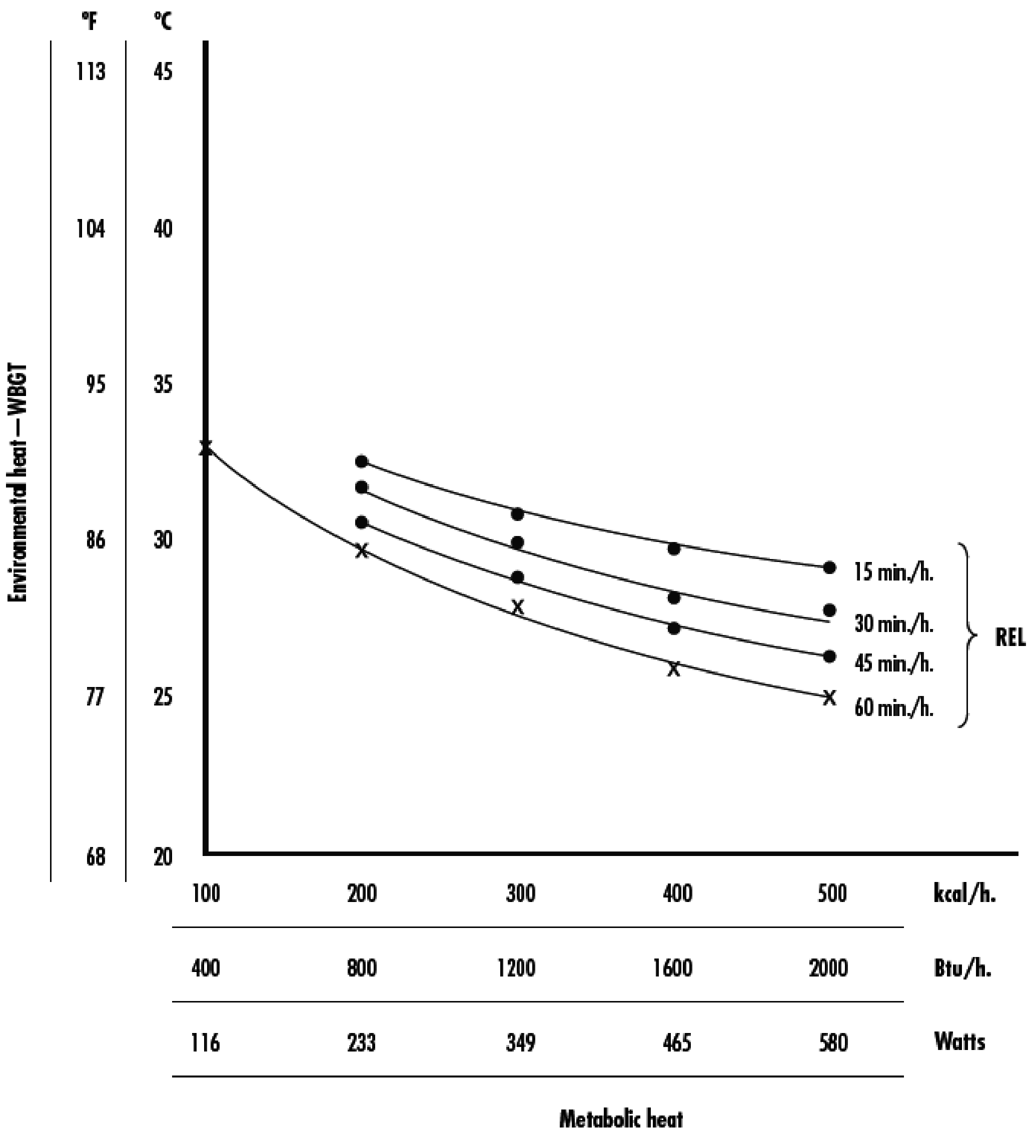

Figure 5.4. *Recommended heat stress exposure limits (RELs) for acclimatized workers. Taken from NIOSH, 2016, pp.95.*

In **Figure 5.3** and **Figure 5.4**, resting time periods of 60, 45, 30, and 15 minutes for work/rest schedules are shown. The NIOSH (2016) supports that shorter periods of time and rest breaks allow the workers to dissipate the heat accumulation in the body. Workers will be protected from developing heat-related health impairments if they maintain the expositions to environmental and metabolic heat below the appropriate NIOSH RALs or RELs.

The RALs and RELs are based on the concept of a “standard man” (70 kg body weight and 1.8 m^2 body surface) in order to normalize the data (NIOSH, 2016).

Even though in some studies the men and women are considered with a similar ability to tolerate and adapt well to heat (NIOSH, 2016), Lundgren et al. (2013) affirm that women are more prone to heat loss and tolerate humid heat, but have higher core temperature.

The percentage of a working hour where the worker is available to perform the planned work is seen as work capacity (Kjellstrom, et al., 2009a). If the thermal conditions and the working load allowed to work during the entire hour continuously, the work capacity will represent 100%. If the worker needs to rest 45 minutes of an hour, due to thermal conditions or/ and physical activity, then the work capacity will be 25%. Based on the ISO and NIOSH standards for acclimatized workers, Kjellstrom et al. (2009b) provide, in **Figure 5.5**, information about the percentage of an hour that a worker should be engaged performing the work task depending on thermal conditions and work intensity.

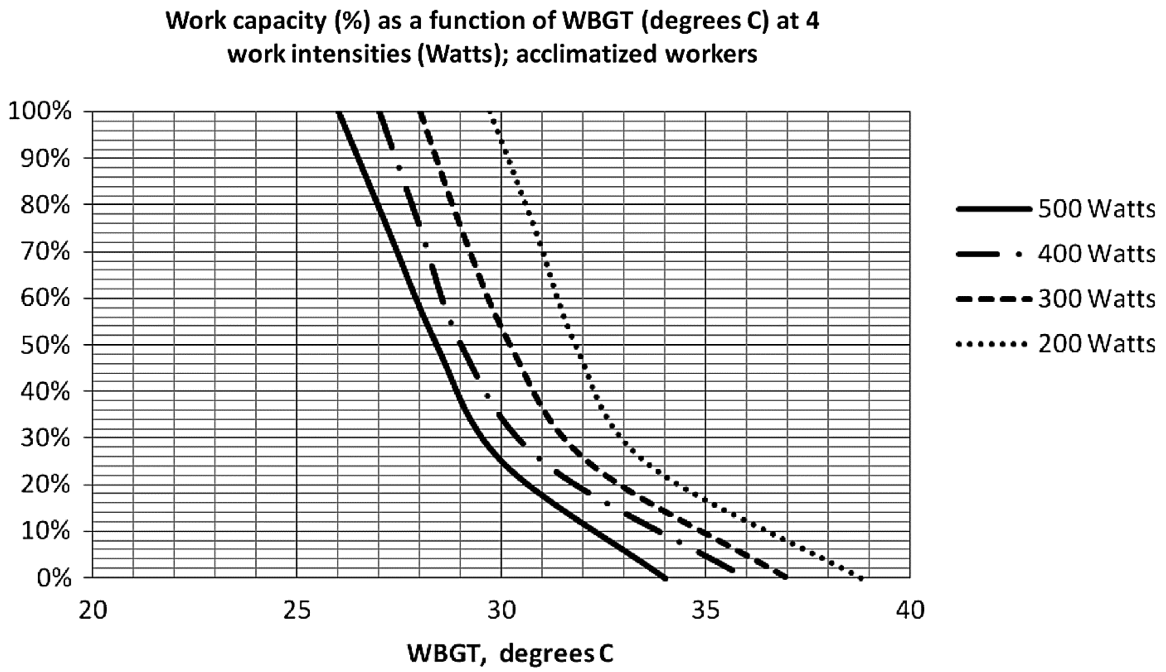

Figure 5.5. *Work capacity as a function of WBGT. Taken from Kjellstrom, 2009a, pp.7.*

Lemke and Kjellstrom (2012) reviewed different published methods to calculate WBGT from available meteorological data, such as temperature, humidity, wind speed and solar radiation. The main objective of using the data from meteorological stations for the calculation of the WBGT was that it allows assessing time trends of current and future human heat exposure, as well as monitoring continuously the working environment under climate change (Kjellstrom, et al., 2009a; Liljegren, et al., 2008).

Liljegren (2008) made comparisons between the calculated WBGT and measured WBGT. He found that the difference between them varied by less than 1 ºC for 91-100% of the time when the equipment was working correctly. Despite the fact, the methods for WBGT calculation are not simple as it requires the construction of extensive formulas and a computer program (Lemke and Kjellstrom, 2012).

Australian Bureau of Meteorology (ABM) has published on its website (Kjellstrom, et al., 2010; Lemke and Kjellstrom, 2012) a simple method which requires only the values of water vapor pressure (vp) and air temperature (T_a) for the calculation of the WBGT. Kjellstrom et al. (2009b) used the following equations for the assessment WBGT levels and its potential impact on productivity:

Equation 34. *WBGT productivity*

$$WBGT_p = 0.567\,T_a + 0.393\,vp + 3.94 \tag{34}$$

Equation 35. *Water vapor pressure*

$$vp = \left(\frac{RH}{100}\right) \times 6.105\ \times \exp\left(\frac{17.27T_a}{(237.7 + T_a)}\right) \tag{35}$$

where

T_a = 24-hour average shaded dry bulb air temperature (°C); vp = 24-hour average absolute humidity (water vapor pressure in hPa); RH= 24-hour average relative humidity (in %). The constant (3.94) represents the impact of WBGT from heat irradiated from the sun in outdoor work in calm wind conditions.

In the next section, a case study is designed and, following the WBGT method for heat stress assessment in outdoor working population, it is intended to evaluate the impact of thermal conditions in health, work capacity and productivity. The results obtained are discussed at the end of the section.

5.3 Design of the case study and results

In 2016, Kjellstrom et al. exposed the monthly averages of the in-shade-afternoon WBGT (Wet bulb globe temperature) heat index levels for the hottest month in each geographic region between 1980 and 2009 [**Figure 5.6**]. Those authors believe that heat exposures, over the specified period, were enough to affect work activities in most of the tropical and subtropical zones.

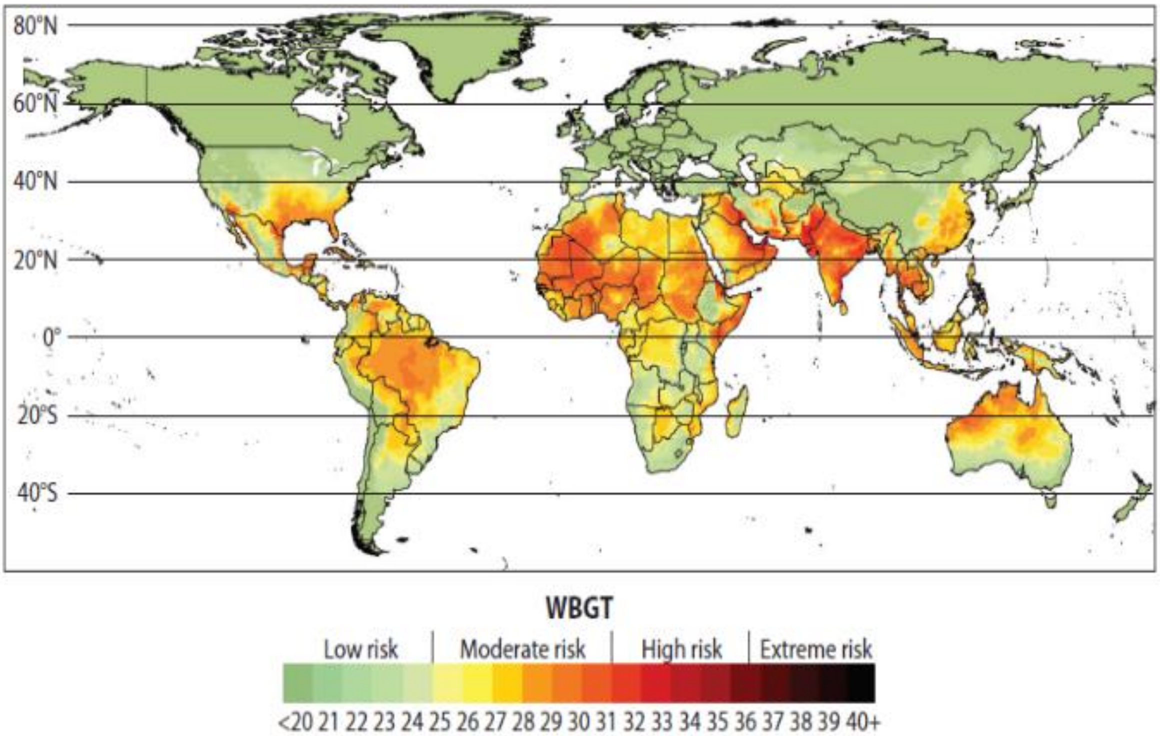

Figure 5.6. *Grid cell–specific monthly average wet bulb global temperature (WBGT). Taken from Kjellstrom, 2016, pp.4.*

It can be seen that Mexico isn't the region with maximum WBGT, but it has a considerable potential for applications in solar energy. Within Mexico's territory, the state of Sonora is specified as having a potential for highest solar irradiance levels in the whole country. The National Renewable Energy Laboratory (NREL) includes on its website (http://maps.nrel.gov/swera) geographic information of direct normal solar radiation worldwide [**Figure 4.11**].

Arancibia et al. (2014) evaluated three regions of Sonora, based on solar radiation measurements. The results showed that the normal solar radiation in Hermosillo, Sonora, was 7.8 kWh/m^2/day. Besides, the region has more than 10 hours a day with irradiance above the average value, which is an optimum value for solar energy purposes (Arancibia et al., 2014).

The present study was conducted in the Experimental Field of Heliostats (CPH: initials of "Campo de Prueba de Heliostatos", in Spanish), located in Hermosillo, Sonora, Mexico (29º 05'44" N 110º 57' 03" W). The CPH[14] [**Figure 5.7**], at present year, counts with a tower of 36m height, a control room and a field of 29 heliostats. The total of the installed heliostats can be separated in two sizes, as follows: 12 heliostats of 36 m^2 (each one having 25 flat mirrors of 1.2m X 1.2m); 17 heliostats of 37.44 m^2 (each one with 32 flat mirrors of 1.3m X 0.9m). The total reflecting area is then close to 1,070 m^2. The heliostats installed on the field allow reaching a theoretical solar radiation concentration factor of 25, which corresponds to a thermal power of approximately 1 MWt. In its final stage, the CPH field aims to reach a total of 82 heliostats (total reflecting area of about 3,000 m^2) and a theoretical thermal power of 2 MWt.

Figure 5.7. *Experimental solar installation. Taken from Samaniego et al., 2012.*

[14] Since the CPH is considered as a scientific project the solar experimental facility was changing while this research has been carried out. It is expected that it will continue changing until it achieve its final stage. http://psh.isi.uson.mx/index.php?option=com_content&view=category&layout=blog&id=6&Itemid=4

In order to evaluate the level of heat when the humidity is combined with temperature, air movement, and radiant heat, heat stress meters HT30 and HT200 were used for collecting data (WBGT in ºC) every 30 minutes in the open field. The HT30 considers the effects of temperature, humidity, and direct or radiant sunlight. The Black Globe Temperature (T_g) monitors the effects of direct solar radiation on an exposed surface. Its temperature range is 0 -50°C with a basic accuracy of ±2°C. The HT200 heat stress WBGT meter allows accurate measurements of WBGT, Black Globe Temperature (T_g), Humidity ($\%RH$), Air Temperature (T_a), Wet Bulb (WT) and Dew Point (DEW). Its temperature range in presence of sunlight is 0 -56°C with a basic accuracy of ±1.5°C

The HD32.2 was used to measure the WBGT index in the presence and in absence of solar radiation every 10 minutes. It was positioned in three locations: a) top of the tower, b) cabin of the receiver and c) in the middle of the field of the heliostats. The readings were recorded from 9 am to 5 pm. Its uncertainty is ±1 digit @ 20 ºC. The temperature range at work is -5 to +50 ºC and the range of humidity is 0 to 90 % H.r. without condensation.

The environmental parameters T_a and $\%RH$ measurements were carried out during summer and over the work shift (from 9h to 17h). The data were reordered and averaged in periods of 60 seconds with a climate data logger (Trotec BL30). The equipment was positioned in the middle of the field of the heliostats. Its technical specifications for the air temperature are -40°C to +70°C with an accuracy of ± 1°C. In the case of the relative humidity is 0% H.r to 100% H.r and the accuracy of maximum 3% de H.r. **Figure 5.8**, shows the behavior of the air temperature and humidity from the data collected in summer. In arid regions, the levels of heat stress are expected to be classified as a risk due to high air temperature, low humidity, and intense solar radiation.

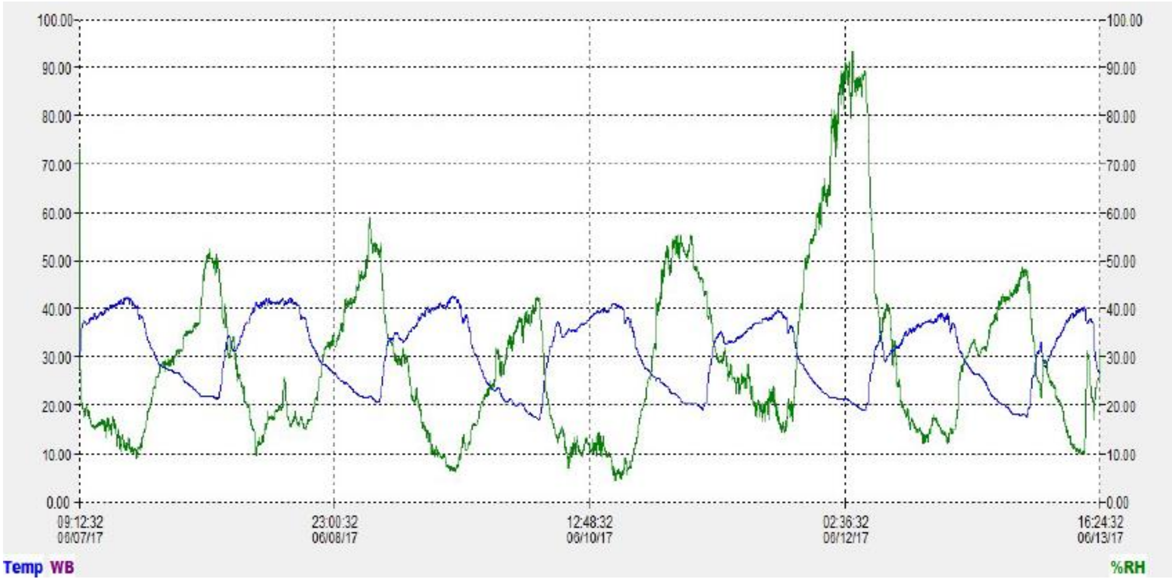

Figure 5.8. *Air temperature vs humidity.*

The flux of the temperatures recorded during 24h in summer, **Figure 5.9**, shows that the levels of temperatures are high in mostly all hours of the day. The T_{nw}, which represents the combination of air humidity (RH in %) and air movement (v in m/s), shows a decay in its calculated values because the percentage of humidity decrease during the day (between 8 am and 8 pm).

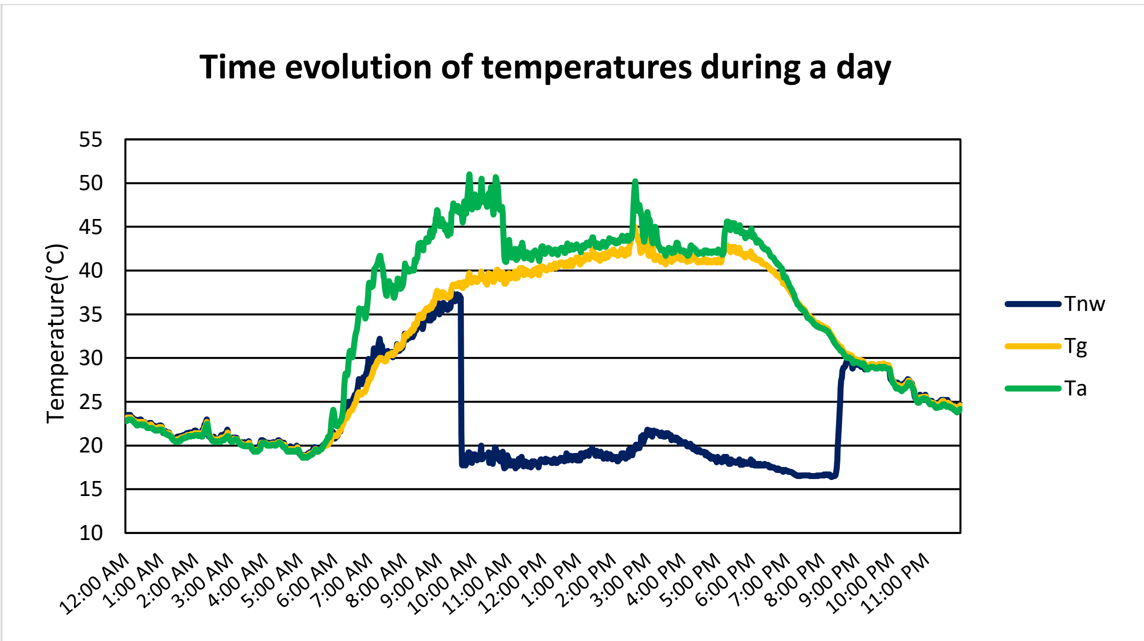

Figure 5.9. *Time evolution of temperatures during a day*

Figure 5.10 shows the time variation of the WBGT (°C) in outdoor conditions indicating the RAL and REL limits of exposure of a person with moderate- light work intensity and the corresponding level of heat stress along a summer day. It can be noticed that a person would be exceeding the recommended exposure levels during the morning and workers would develop their tasks under conditions above the alert limits of exposure during the work shift (8:30 am–5:00 pm). The RELs are exceeded also at night, which means that people would feel the heat even during the night.

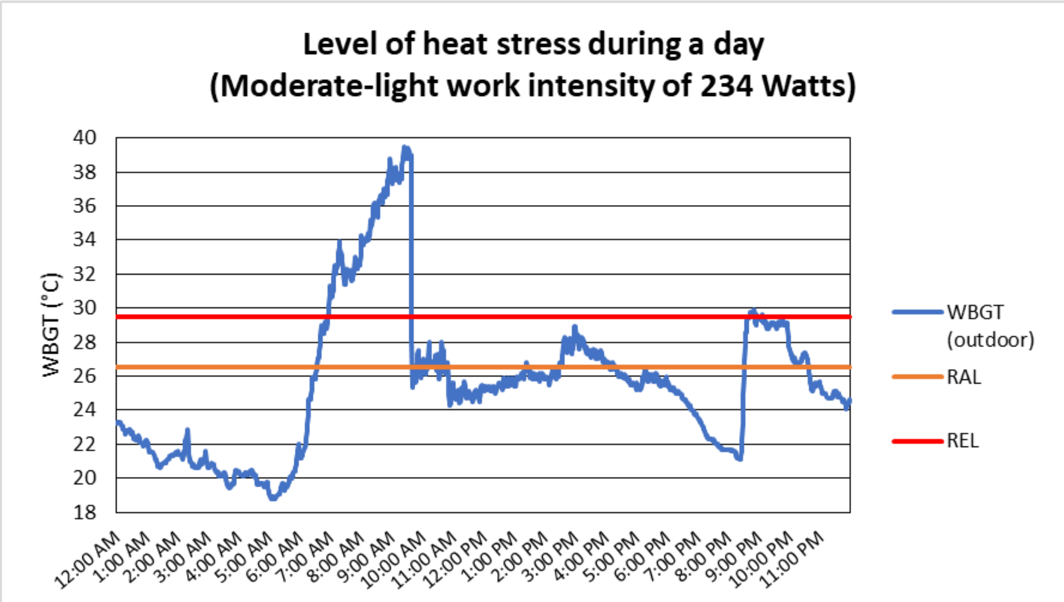

Figure 5.10. *Time evolution of WBGT index during a typical day*

Figure 5.11 shows the monitored levels of WBGT (°C) recorded along one week of summer during the work shift (8:30 am–5:00 pm). Under arid and moderate-light work conditions, the levels of heat stress are exciding the RELs and RALs indicated. This means that the individuals in outdoor conditions in the CPH are developing work tasks above the recommended alert levels of exposure along the week. It can be also noticed that in several times all physical activities required to be stopped in the location.

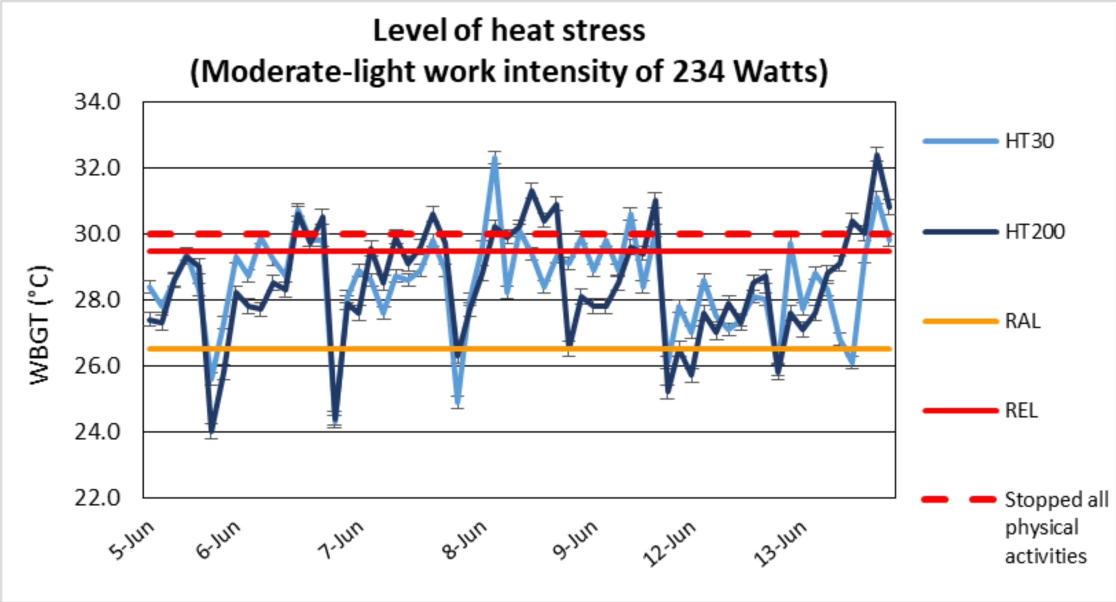

***Figure 5.11**. WBGT during a work shift*

Assuming different work intensities, labor productivity is estimated as a weighted average based on the work shift activities during the recollecting data period. The percentage of work capacity, for acclimatized and unacclimatized workers depending on the intensity of the work and WBGT levels, are shown in **Figure 5.12**. Non-acclimatized workers with very heavy workload (500 kcal/h) requirements are not available to work under the environmental conditions described. Workers with no acclimatization and heavy workload (400 kcal/h) requirements need to rest 75% of each hour and 50% when the workload is moderate (300 kcal/h), which means resting periods of 45 and 30 minutes per hour, respectively. In addition, the non-acclimatized worker under the CPH environmental conditions will be available to work a maximum 75% of an hour with resting periods of 15 minutes when the work intensity is light (200 kcal/h).

On the other hand, the acclimatized worker may reach the 100% of working hour when the work is light and only 50% when the work intensity is very heavy. Even though, sometimes the employee that is acclimatized to the environmental conditions in the CPH will be forced to stop all work activities (rest 60 minutes per hour) when the work intensity is heavy or very heavy. Employees under acclimatization will rest maximum 15 min per hour when the workload is moderate and 30 min when the workload is heavy.

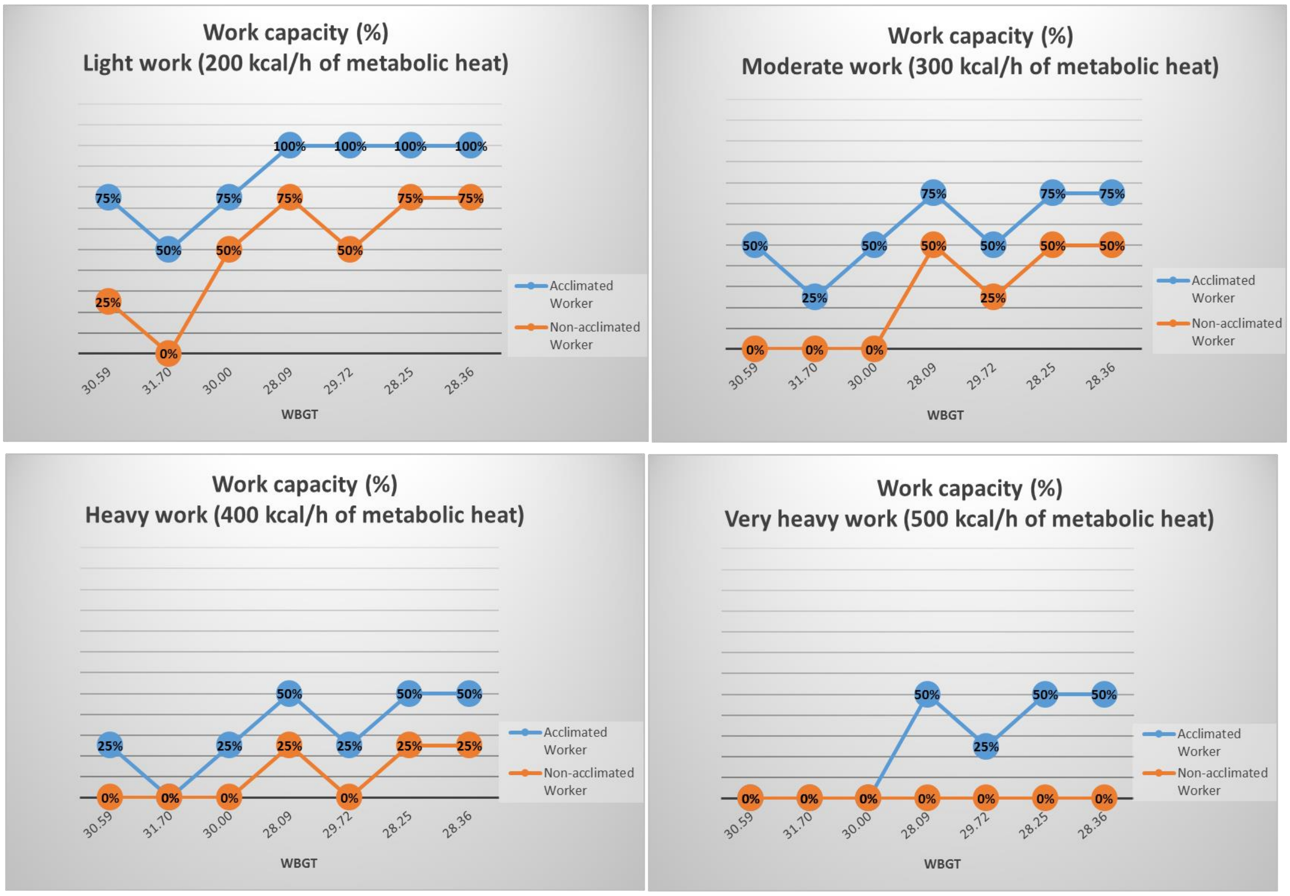

Figure 5.12. *Percentage of work capacity depending on the intensity of the work and WBGT levels.*

Since the percentage of work capacity for acclimatized and non-acclimatized workers evaluated on Figure 5.12 is related to outdoor conditions, the case of a worker being exposed to different thermal environments during work shift was also evaluated. For the estimation, the sequence of the different values of WBGT, in determined time of exposure, was represented by an average ($WBGT_{avg}$) [**Table 5.5**].

Table 5.5. *Work capacity based on the* $WBGT_{avg}$ *from different heat environments exposures*

			WORK CAPACITY % MODERATE WORK (300 KCAL/H OF METABOLIC HEAT) 234< M< 360 W		**WORK CAPACITY % LIGHT WORK (200 KCAL/H OF METABOLIC HEAT) 117< M< 234 W**	
WBGT*avg*	RAL	REL	Acclimatized Worker	Non-acclimatized Worker	Acclimatized Worker	Non-acclimatized Worker
26.1	*26.5*	*29.5*	*100%*	*75%*	*100%*	*100%*

In this particular case, the measurements were taken at the top of the tower, in the cabin of the receiver and in the field of heliostats simulating random daily scheduled activities. It is important to mention that the data was recollected while 7 of the 25 heliostats where reflecting their images in the center of the receiver. The results provide evidence that non-acclimatized workers will need to rest 15 minutes per hour when the work intensity is moderate (234< M< 360 W).

5.4 Conclusion

The present chapter aims to contribute with information about heat exposures in solar installations for the development of standard procedures, in the future, in order to ensure the occupational health and safety of the solar industry workforce.

The present study briefly outlines the relation between solar energy, productivity, safety and health effects. This was followed by the description of the assessment method and safety limits. The assessment of levels of heat stress was represented in a case study where real data was collected in the Experimental Field of Heliostats (capitals in Spanish, CPH), located in Mexico. The sequence of exposures to different heat-related environmental conditions has also been evaluated. The percentage of work capacity (productivity) and the resting periods for acclimatized and unacclimatized workers are also presented.

The obtained results showed that CPH workers are exposed to conditions exceeding the recommended exposure levels. Sometimes workers develop their tasks under conditions above the alert limits of exposure during the work shift (8:30 am–5:00 pm). The employees that have not pass through the process of acclimatization and have very heavy workload are suggested to take resting periods to work under the WBGT levels analyzed in the facility. Individuals with heavy workload requirements need to rest 45 minutes during each hour, and 30 minutes when the workload is moderate. Additionally, workers need to pass through an acclimatization process and required to be introduced to preventive measures due to environmental conditions with elevated heat levels.

The results of this research could be seen as a basic evidence and information recompilation of an area with improvement opportunities within solar industry. It could also assist the development of security procedures for the solar working environments.

Additional studies should include the evaluation of working conditions under a heat wave. Also, the evaluation of the level of heat stress in workers related to the construction and installation of solar facilities need to be addressed. The evaluation of heat stress level in a commercial scale facility is suggested. The establishment of security measures, training procedures, monitoring systems and evaluation methods adapted to the solar industry requirements should be considered.

Knowledge is the key in prevention while workers are exposing themselves with non-adequate protection to solar radiation in locations with high UVI. Training the workforce and make them aware of how they could address solar exposures will have a strong influence on health effects prevention and in the reduction of health care costs.

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6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Solar facilities are usually implemented in locations with high ultraviolet index due to its requirements for power generation. Even though populations are adapted to their local climate, the ozone layer loss has been exceeding its natural restoration and a growing level of UV radiation reaches the surface of the Earth which means that the solar industry workers are continuously facing risks. The impact of global warming on population health is a growing concern. Solar energy workers often work in very hot weather; where OSHA supports that there exist some hazards attempting to the health and safety of the workforce (manufacture, installation, and maintenance). Among the heat-related effects, defined as a consequence of exposures to hot environments, are dehydration, heat exhaustion, heat stroke and death. Also, the literature review provides information about health impairments on eyes and skin at permanent and reversible level.

This study intended to contribute with crucial information about the levels of heat stress under hot weather conditions, eye and skin risks due to solar radiation exposures. The investigation guides through crucial information to understand the relationship between heat-related impairments, productivity, and solar radiation. It, also, briefly outlines solar effects on eyes and skin subjected to momentary and cumulative exposures. This was followed by the description of the assessment methods and safety limits related to skin, eyes and the level of stress caused by exposures to hot environments.

The assessment of outdoor environmental conditions was based on a case study conducted in the Experimental Field of Heliostats (CPH), located in Mexico were real data was collected. The actions of looking directly at the surface of the heliostats and looking directly to the surface of the receiver were evaluated. Besides, the time of the exposure necessary to achieve a minimum impact on unprotected skin of non-adapted and adapted individuals according to the type of skin in the Fitzpatrick classification scale is presented. Also, the sequence of exposures to different heat-related environmental conditions in the solar installations has been evaluated and had been linked to work-capacity. The percentage of work capacity (productivity) and resting periods for acclimatized and non-acclimatized workers was also presented.

The results showed that the maximum time to stay unprotected under the highest constant flux of solar radiation recorded without receiving a noticeable impact on non-adapted skin type I-IV is 5-15 minutes; while adapted skin type I-IV achieve the dose from 13 to 20 minutes. Skin types V and VI without adaptation will achieve the corresponding dose in 17-30 minutes and 2-3hr when the skin is adapted. It can be concluded that the workers will require pass through a process of skin adaptation in order to increase the time of exposure and decrease the level of risk. Also, it can be concluded that the skin types I-IV with and without adaptation will need strong safety requirements.

In results from the glint and glare assessment provide sufficient evidence about the action of seeing the brightness of the receiver doesn’t have the potential to produce an after-image effect on the eye. In the case of the action of looking at heliostat surface, a person seeing the reflected radiation has a high potential to experience a temporary effect (after-image). Even though this action hasn’t the potential to interact with the eye in a permanent way, the amount of irradiance that is entering into the eye is close to 8 W/m^2, which represents the action of seeing directly to the sun. This amount of irradiance that is available to reach the retina could produce a permanent damage of the eye. It is highly recommended that the action of seeing directly to the heliostat surface be treated as close to permanent eye damage risk in terms of safety.

On the other hand, the workers are exposed to conditions exceeding the recommended exposure to heat stress levels. Sometimes workers develop their tasks under conditions above the alert limits of exposure during the work shift. The employees that have not pass through the process of acclimatization and have very heavy workload are suggested to take resting periods to work under the WBGT levels analyzed in the facility. Individuals with heavy workload requirements need to rest 45 minutes during each hour, and 30 minutes when the workload is moderate. Additionally, workers need to pass through an introductory acclimatization process and are required to be familiarized to preventive measures due to environmental conditions with elevated heat levels with the presence of solar radiation.

This research could be seen as a basic evidence and information recompilation of an area with improvement opportunities within solar industry. Even though, further studies are desirable to understand deeply solar industry and occupational safety. Additional studies should include the evaluation of working conditions under a heat wave. Also, the evaluation of the level of heat stress in workers related to the construction and installation of solar facilities need to be addressed. The evaluation of heat stress level, ocular and skin exposures in a commercial scale facility is suggested. The establishment of security measures, training procedures, monitoring systems and methods of evaluation adapted to the solar industry requirements should be done.

The present study provides safety elements towards the occupational health and safety in Central Receiver Systems. This information contribution headed for solar energy enterprises, policy-makers, and environmental scientists will enhance the education of outdoor workers exposed to environmental conditions. The implementation of preventive measures will prevent negative health impacts and health care costs on solar working population.

6.2 Recommendations for skin exposures

In order to achieve safety expositions to solar radiation and increase the length of time of exposure some mitigation measures are highly recommended in CRS solar power plants. ICNIRP and WHO protection measurements are suggested:

- Avoidance of sun exposures around noon hours (clear sky). Due to the highest levels of solar radiation recorded in the study, it is strongly recommended the avoidance of outside periods around noon time (10 am to 1 pm). Even though the UV intensities are at the highest under clear-sky condition, the days with thin clouds could transmit a sense of comfort while the level of UV is still high, eventually, this would encourage people going outside unprotected. In cases with sky cloudiness, the workers must stay aware that the UV intensities still impact on skin and must follow the recommendations.

- Monitoring solar radiation fluxes and/or using the UVI local forecast would help workers to be aware of real-time extreme values of exposure to solar radiation.
- Using skin protection would decrease the risk of getting a sunburn, such as clothing designed to provide a high-level protection from solar radiation and hats shading the face and neck. It is also recommended applying sunscreen, with an SPF (+15), over the parts of the skin exposed, in locations with an UVI of 3+. The sunscreen must be applied on dry skin and let it dry between 15-30 minutes before the exposition to solar radiation. Sometimes, due to high temperatures, the skin sweats and in those cases, the skin surface must be cleaned and the sunscreen has to be applied all over again. It should be reapplied repeatedly in abundant quantities in periods of 30 min- 2 hours depending on the skin type.
- Implementing shade spots could transform continuous exposures into intermittent exposures.

Training and educational programs will improve the safety exposures. Through educational guidance, the workers will be aware of the environmental conditions at work and will help them pass through the transition of skin adaptation according to their own skin type.

6.3 Recommendations for ocular exposures

The main objective in suggesting preventive measures is to reduce to the minimum the ocular exposure to solar radiation. In order to reduce the risk of the glint and glare and increase the visual perception, it is needed to (Knave, et al., 2001; WHO, 2002; Vecchia, et al., 2007):

- Avoid staring at bright surfaces within the solar installation. Prolonging the period of time of eye staring before the blinking effect (avoiding reaction of the eye) will bring effects and side effects to human health.
- Advising the surroundings. The solar facilities should put sings on the near surroundings in order to spread the awareness of glare and glint to individuals or drivers passing by the solar installations. Those facilities which aren't physically materialized or they are on a project state level should take into consideration the location of the facility.
- Ocular protection. UV protective eyewear is frequently used to reduce glare by decreasing the luminance of visible radiation reaching the eye. The selection of the ocular protection needs to be based on the intensity and characteristics of the bright source, the distance between the viewer and the bright source and time of exposure.
- Implement protection policies and monitoring program. In order to control health hazards to outdoor exposure, the monitoring program should include information about:

    - Global solar UV index (UVI). UVI describes the level of solar UV radiation at the Earth's surface. It could be monitored by using the UVI local forecast. The values of the index range from 0 to 11+ where higher the index value, greater is the potential for damage and the lesser the time for harm to occur
    - Self-protection and behavior
    - Shelter in shades

- Training and education of employees about safety and the importance of prevention providing information about protection policies, preventive measures, limits of exposure and symptoms of hazardous effects on health and its identification.
- Implementation of glare examinations in CSP through the development of a monitoring program or, in this particular case, include the calculation of the existing direct solar radiation monitoring program. The variables that would be changing in coming CRS studies are the level of direct solar irradiance, the

mirror reflectivity and the total surface of the heliostats which are factors needed for the calculations of the irradiance outside the eye. In the case of the irradiance outside the eye when a person is seeing directly the diffuse reflections coming from the receiver, the variables that would be required to be modified, are: the geometry of the tower respected to the observer, distance, the reflectivity of the receiver and its total surface. The monitoring program is expected to calculate the Irradiance outside the eye for the posterior calculation of the amount of the Irradiance that is entering into the eye and that is available to reach the retina.

6.4 Recommendations for Heat exposures

In order to avoid health impairments resulting from heat stress situations, some preventive measures are highly suggested by (Bouchama and Knochel, 2002; NIOSH, 2016).

- Introduction into acclimatization by reducing the metabolic heat load and promoting the adequate exposure to hot environments. Short repeated exposures, during 7 to 14 days, will allow the performance of work activity with a reduction in core temperature and thermoregulatory strain. New workers will need an acclimatization plan where they should be scheduled to a 20% of the total work duration on the first day. After the first day, the workers will gradually increase the exposure to heat by 20% each day. Those workers that have been passed through an acclimatization process before, the acclimatization regimen should be maximum 50% of the work duration on day 1, 60% on day 2, 80% on day 3, and 100% on day 4. The physical fitness of individuals is an important factor within the acclimatization process. The workers that are physically fit require 50% less time to develop acclimatization. The acclimatization also depends on other factors such as age, sex gender, body fat, drugs intake.
- Promote water intake and salty foods [**Table 6.1**]. The replacement of water lost in sweating will improve the development of physiologic adaptation. Heat acclimatization increases the sweating rate; therefore workers will

need to take water (and other fluids for salt and water replacement) during frequent intervals such as 236 ml every 15-20 min.

Table 6.1. *Recommendations for fluid replacement during warm weather conditions*

WBGT index		**Easy work (250 W)**		**Moderate work (425 W)**		**Hard work (600 W)**	
(°C)	**(°F)**	**Work/ Rest (min)**	**Water intake* ($L \cdot h^{-1}$)**	**Work/ Rest (min)**	**Water intake ($L \cdot h^{-1}$)**	**Work/ Rest (min)**	**Water intake ($L \cdot h^{-1}$)**
25-28	78–82	Unlimited	±0.5	Unlimited	0.70	40/20	0.70
28-29	82–85	Unlimited	±0.5	50/10	0.70	30/30	±1.0
29-31	85–88	Unlimited	0.70	40/20	0.70	30/30	±1.0
31-32	88–90	Unlimited	0.70	30/30	0.70	20/40	±1.0
32+	90+	50/10	±1.0	20/40	±1.0	10/50	±1.0

Source: NIOSH, 2016.

*Fluid needs can vary on the basis of individual differences (± 236 ml·h-1) and exposure to full sun or full shade (± 236 ml·h-1). Fluid intake should not exceed 1.42 L·h-1.

- Implementing work/ rest schedules where the administration should control the time of exposure of the workers by the establishment of the amount of time that they are allowed to be working outside within an hour. Reduction of the heat load in high temperatures and promoting the job activities in cooler periods of the day.
- Establishment of administrative controls such as the modification or reduction of the time of exposure and heat load, improving heat tolerance and training, and periodic medical evaluations of workers, in order to be aware of which individuals have low heat tolerance and/or low physical fitness.
- Heat surveillance through the establishment of engineering controls, heat alert programs, and medical monitoring program to prevent adverse outcomes and for early identification of signs that may be related to heat-related illness.
- Protective clothing such as water-cooled garments, air-cooled garments, cooling vests, wetted over-garments and heat reflective suits, in order to promote the heat exchange or cooling.

- Health and safety training for employees that includes information about recognizing symptoms of heat-related illness; proper hydration; care and use of heat-protective clothing and equipment; effects of various factors (e.g., drugs, alcohol, obesity, etc.) on heat tolerance; and importance of acclimatization, reporting symptoms, and giving or receiving appropriate first aid. It should also be provided training about how to monitor weather; reports and weather warnings.

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APPENDIX

Appendix A. *Solar radiation health effects*

Wavelength (nm)	Affected area	Primary effects	Description	Secondary effects	Side effects
380-1400nm UVA-VL-IR	Ocular	Thermal eye lesions	Most of the useful vision is lost	Burns in the retinal tissue	
1400nm-3000nm- 10 µm IRB, IRC	Ocular		Protein coagulation of the front and middle layers, and ulcers	Burns in the cornea	
315-400nm UVA; 780-3000nm IR	Ocular		Opacities in the lens	Cataracts	
180-400nm UV	Ocular		Inflammation on the cornea (the feeling of sand in the eye)	Keratitis	
400-700nm VL; 780-3000nm IR	Ocular		Vision loss in a portion of the visual field	Scotoma	
380-700nm UV-VL	Ocular		Inflammation of the retina of the eye	Retinitis	
400-780nm VL	Ocular	Glare disability	Veiling luminance (scattered light) in the human eye which reduces the contrast in the scene	Reduction of the visual performance, flash blindness, after image and retinal burns	Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Glare discomfort	Continues exposure to a bright source that reduces the ability to see details in the area of the visual field	Headaches	Falls or other kind of accidents ended in injuries

400-780nm VL	Ocular	Afterimage	Blind spot in the visual field which persists from seconds to a few minutes after the light in no longer in the visual perimeter		Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Flash blindness	Immediate and temporary vision loss produced when the retinal light-sensitive pigments are bleached by the intensity of light (usually the eye is exposed to higher intensities of those that it is adapted at that moment)		Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Luminanc e flicker	Temporal intensity modulations of bright lights	Vertigo, disorientation, mild headaches, muscle spasm ended in convulsions and epileptic seizures	Falls or other kind of accidents ended in injuries
315-1400nm UVA-VL-IR	Skin	Photo-aging	The skin is marked by fine lines and a modest skin laxity.		
290-400nm UV	Skin	Photo-immunosu ppression	The immune skin system is not available to recognize and destroy the invading pathogens and/ or skin cancer cells	Skin cancer	

290-700nm UV-VL	Skin	Photo-sensitivity (Photoder matoses)	Continues exposures that produce a sensitization phase resulting in a delayed-type of hypersensitivity reaction	Photoallergy and/ or Phototoxicity	Solar urticaria, porphyrias, polymorphus, light eruption, hiroa vaciniforme, actinic, prurigo, chronic actinic, dermatitis and others
380-3000nm UVA-VL-IR	skin	Sunburns	Skin tissue injury caused by the exposure to solar radiation	Red appearance of the skin due to the increment in blood content near the sink surface	Erythema (180-400nm): skin redness, edema, pain and skin swelling Apoptosis: delayed cell killing
	Skin	Heat rash	Pricking sensations during heat exposure	Skin irritation due to the excessive seating during hot and humid weather conditions	
	Skin	Anhidrotic heat exhaustion	Extensive areas of skin with no sweating but with gooseflesh appearance	Skin trauma (heat rash, sunburn) causes sweat retention in skin and reduce evaporative cooling	Temporary heat intolerance

	Nervous system	Heat exhaustion	Dehydration (loss of water and salt) and depletion of circulation blood volume	Fatigue, nausea, headache and giddiness, skin clammy and moist, pale complexion, muddy or hectic flush, may faint on standing with rapid thready pulse and breathing, and low blood pressure	
	Nervous system	Heat syncope	Lack of acclimatization by a prolonged standing or sudden rising from a sitting or lying position and dehydration	Light-headedness, dizziness and fainting	
	Nervous system	Heat cramps	Loss of body salt in sweat, water intake dilutes electrolytes, water enters to muscles causing spasm	Painful spasms of muscles used during work activities such as arms, legs and/ or abdominal	Heat exhaustion
	Nervous system	Transient heat fatigue	Behavioral disorders	Discomfort and physiologic strain	Decrement in productivity
	Nervous system	Chronic heat fatigue	Behavioral disorder	Psychosocial stress produce by the hormonal imbalance	Decrement in productivity

	Nervous system	Heat stroke	The regulation temperature system of the body fails when the body temperature rises, the sweating mechanism fails and the body is unable to cool down itself	Confusion, consciousness loss, convulsions, lack of sweating, dry skin, very high body temperature and hallucinations	Death
The effects differs in severity or has a low capability of impact in human health depending of the intensity of the source and time of exposure. Some of impacts begin as reversible effects and end as irreversible effects due to continue exposures in time.					

Appendix B. *Practical application of the methods of evaluation*

This appendix address some examples about the methods of evaluation explained in previous segments; with the objective of illustrating more clearly the application of the formulas from that section.

1. **Looking directly to the sun**

As an example, presented in Ho et al., 2011, the retinal irradiance caused by viewing the sun directly can be calculated by using the following formulas

$$E_r = E_c \left(\frac{dp^2}{dr^2}\right)\tau \qquad \text{(eq.B.1.)}$$

$$\omega = \frac{d_s}{r};\ d_r = f\omega \qquad \text{(eq.B.2.)}$$

where the parameters are set as: E_c=0.1 W/cm^2, d_p= 0.002 m, f= 0.017m, ω= 0.0094 rad and τ =0.5.

As a result a typical value for the retinal irradiance is around E_r=8 W/cm^2

2. **Direct specular reflections from the surface of the heliostats assessment**

Subtended angle of the reflected image on a mirror as observed from a given distance

$$\omega_{spot} = \beta\sqrt{\frac{E_{beam}}{\rho E_{DNI}}};\quad E_{beam} = E_c \qquad \text{(eq. B.3.)}$$

Retinal Irradiance (from specular reflections)

$$E_r = \frac{\rho E_{DNI} d_p{}^2 \tau}{f^2 \beta^2} \qquad \text{(eq. B.4.)}$$

Suggested information

Equation (B.4.) can be used to determine the equivalent retinal irradiance for comparisons against the safe retinal irradiance metrics.

Comparing with the maximum limits for exposures to the eye:

$$E_{r,burn} = \frac{0.118}{\omega} \quad for\ \omega < 0.118\ rad \qquad \text{(eq. B.5)}$$

$$E_{r,burn} = 1 \quad for\ \ \omega \geq 0.118\ rad$$

$$E_{r,flash} = \frac{3.59\ x\ 10^{-5}}{\omega^{1.77}} \qquad \text{(eq. B.6)}$$

3. Corrected skin exposure factor by Wolska (2013)

The UVI provided by a forecast in a determined location is 7.3 under clear sky conditions.

F_{es}= UVI *F_2*F_4; (eq.B.7)

F_{es}=7.3*1*1=7.3

Following: F_{es} › 1 preventive measures are necessary

Then, the calculation of the correction of F_{es} factor for a person which exposed 1-2 h during the day (0.5) with arms, head and neck exposed (added value by Wolska of 0.4) and access to no shade spots (1).

F_{es}*= (F_{es})*(F_3)*(F_5)*(F_6) ≤ 10SED (eq. B.8)

F_{es}*=7.3*0.5*0.4*1= 1.46, which corresponds a low risk.

The level of risk could decrease by modifying the level of clothing and adding a shaded spot.

4. Skin cancer estimation by Milon et al., 2014.

The cumulative UV dose was estimated for a person in the age of T=60 years with an outwork history of 25 years, but a person who took his or her lunch indoors. So the cumulative dose was expressed as the sum of the exposures during the work and lunch along “y” years of an occupational activity and recreational time from 0-T.

$SCC_{risk} = Risk\ \alpha\ (age)^{\alpha} \times (UV_{tot})^{\beta}$ (eq. B.9)

where:

α = age dependent factor, β=biological amplification factor, and UV_{tot}= cumulative UV exposure dose received

The cumulative UV dose is expressed as a sum of the exposures during the work (UV_{occ}) and lunch (UV_{lunch}) during ***n*** years of occupational activity and recreational (UV_{recr}) time from 0 to ***n***:

$$\sum_{0}^{60} UV_{tot} = \sum_{y=T}^{T+25}(UV_{occ} + UV_{lunch}) + \sum_{0}^{60} UV_{recr} \quad \text{(eq. B.10)}$$

The UV_{occ}, and UV_{lunch} were obtained from SimUVEx model, and UV_{recr}, from a survey.

The facial exposure of full -time outdoor worker with the lunch excluded was 1604 SED (an average of 5.8 SED per workday). The MED for skins types II and III in Fitzpatrick skin pigmentation scale is between 2.5-3 SED respectively.

Appendix C. *Values of $S(\lambda)$ for wavelengths*

λ^{a}(nm)	EL^{d} (J/m^2)	EL^{d} (mJ/cm^2)	$S(\lambda)^{b}$	λ^{a}(nm)	EL^{d} (J/m^2)	EL^{d} (mJ/cm^2)	$S(\lambda)^{b}$
180	2,500	250	0.012	310	2,000	200	0.015
190	1,600	160	0.019	313 [c]	5,000	500	0.006
200	1,000	100	0.030	315	1.0×10^4	1.0×10^3	0.003
205	590	59	0.051	316	1.3×10^4	1.3×10^3	0.0024
210	400	40	0.075	317	1.5×10^4	1.5×10^3	0.0020
215	320	32	0.095	318	1.9×10^4	1.9×10^3	0.0016
220	250	25	0.120	319	2.5×10^4	2.5×10^3	0.0012
225	200	20	0.150	320	2.9×10^4	2.9×10^3	0.0010
230	160	16	0.190	322	4.5×10^4	4.5×10^3	0.00067
235	130	13	0.240	323	5.6×10^4	5.6×10^3	0.00054
240	100	10	0.300	325	6.0×10^4	6.0×10^3	0.00050
245	83	8.3	0.360	328	6.8×10^4	6.8×10^3	0.00044
250	70	7	0.430	330	7.3×10^4	7.3×10^3	0.00041
254 [c]	60	6	0.500	333	8.0×10^4	8.0×10^3	0.00037
255	58	5.8	0.520	335	8.8×10^4	8.8×10^3	0.00034
260	46	4.6	0.650	340	1.1×10^5	1.1×10^4	0.00028
265	37	3.7	0.810	345	1.3×10^5	1.3×10^4	0.00024
270	30	3.0	1.000	350	1.5×10^5	1.5×10^4	0.00020
275	31	3.1	0.960	355	1.9×10^5	1.9×10^4	0.00016
280 [c]	34	3.4	0.880	360	2.3×10^5	2.3×10^4	0.00013
285	39	3.9	0.770	365 [c]	2.7×10^5	2.7×10^4	0.00011
290	47	4.7	0.640	370	3.2×10^5	3.2×10^4	0.000093
295	56	5.6	0.540	375	3.9×10^5	3.9×10^4	0.000077
297 [c]	65	6.5	0.460	380	4.7×10^5	4.7×10^4	0.000064
300	100	10	0.400	385	5.7×10^5	5.7×10^4	0.000053
303 [c]	250	25	0.120	390	6.8×10^5	6.8×10^4	0.000044
305	500	50	0.060	395	8.3×10^5	8.3×10^4	0.000036
308	1,200	100	0.026	400	1.0×10^6	1.0×10^5	0.000030

Reproduced from ICNIRP, 2004.

[a] Wavelengths chosen are representative; other values should be interpolated

[b] Relative spectral effectiveness.

[c] Emission lines of a mercury discharge spectrum.

[d] EL for a monochromatic source, but also limited by a dose-rate of 10 kW m^2 (1 W cm^2) for periods greater than 1s as well in order to preclude thermal fects.

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Appendix D.

Occupational health and safety for solar workers in central receiver systems facilities

(Standard structure draft)

Summary

Due to the environmental problems arising from use and exploitation of fossil fuels, countries are opting for developing technologies based on renewable sources as alternatives to satisfy the growing energy demand. Among the renewable energy technologies, in some countries, solar energy seems to be a promising solution to meet the energy supply due to its abundance and non-polluting character.

Based on solar energy industrial applications, the Concentrated Solar Power Systems (CSP) option is growing both the number of solar power plants and installed capacity, impacting also substantially in job generation. Among the CSP technologies that are dominating the market, are central receiver systems (CRS). CRS requires the use of heliostats to reflect solar radiation in its surfaces in order to concentrate it in a receiver. This process results in a considerable amount of concentrated solar radiation (visible light, infrared and ultraviolet radiation) inside and in the neighborhood of the installations.

Usually, solar power plants are located in sunny environments due to requirements for power generation. Meanwhile, as the ozone layer damage has been exceeding its natural restoration, a growing level of UV radiation reaches the surface of the Earth where solar industry working force will be facing new risks.

Some previous studies have provided information about exposure to high levels of solar radiation, indicating that it may negatively influence the biological system. Working

population performing activities outdoors and exposed to solar radiation may meet health impairments on skin, eyes and nervous system.

Scope

This document aims to contribute with crucial information and advice on protecting solar workers from solar occupational exposures. It briefly outlines the physiological response from eyes, skin and the nervous system subjected to momentary and cumulative exposures to light and heat. It also addresses the methodology, limits of exposure and safety doses, and preventive measures. The main objective is to contribute with information directed to environmental scientists, standard developers and the solar industry about the occupational health and safety in central receiver system's environments.

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Abbreviations

ACGIH= American Conference of Governmental Hygienists

AIHA= American Industrial Hygiene Association

ARPANSA= Australian Radiation Protection and Nuclear Safety Agency

BCC= Basal Cell Cancer

CEN= European Committee for Standardization

CM=Cutaneous Melanoma

CO_2= Carbon dioxide

CONACYT= Concejo Nacional de Ciencia y Tecnología

CRS= Central receiver system

CSP= Concentrated solar power

DNA= Deoxyribonucleic acid

DT= Delayed tanning

GHG= Greenhouse gas

ICNIRP= International Commission on Non-Ionizing Radiation Protection

IPD= Immediate pigment darkening

IR= Infrared radiation

IR-A= Infrared radiation type A

IR-B= Infrared radiation type B

IR-C= Infrared radiation type C

IRENA= International Renewable International Agency

ISO= International Standardization Organization

MED= Minimal Erythema Dose

MM= Melanoma

NREL= National Renewable Energy Laboratory

NIOSH= National Institute for Occupational Safety and Health

NIR= Non-Ionizing Radiation

OSHA =Occupational Safety and Health Administration

PPD= Persistent pigment darkening

RALs = Recommended Alert Limits

RELs = Recommended Exposure Limits

ROS= Reactive oxygen species

SCC= Squamous Cell Cancer

SED= Standard Erythema Dose

Sim UVEx= Simulating UV Exposure

SPF= Sun protection factor

TLV’s = Threshold Limit Values

UNEP= United Nations Environment Programme

U.S. = adj. of United States

UV = Ultraviolet radiation

UV-A= Ultraviolet radiation type A

UV-B= Ultraviolet radiation type B

UV-C= Ultraviolet radiation type C

UVI= Global Solar UV Index

VL= Visible light

WBGT= Wet-bulb Globe Temperature

WHO= World Health Organization

WMO= World Meteorological Organization

Symbols

Skin

Δ_{λ}= measurement intervals

α = age dependent factor

β=biological amplification factor

$\mathbf{F_{es}} *$ = Corrected Skin exposure factor

$\mathbf{F_{es}}$= Skin exposure Factor

F_2= Cloud cover

F_3= Duration of the exposure

F_4= Ground reflectance

F_5=Clothing factor

F_6= Shade factor

H_{eff} = Effective exposure dose in J/cm^2

E_{eff}= effective irradiance in W/m^2 normalized to a monochromatic source 270nm

$E_{erythema}$ = Irradiance

E_{λ}= spectral irradiance from measurements in W/m^2

SCC $_{risk}$ = Risk of squamous cell cancer

$S(\lambda)$= Relative spectral effectiveness (unitless)

$t_{erythema}$ = Duration of the exposure in seconds

t_{max} = Permissible UV exposure time in seconds

UV_{lunch}= The exposures during the lunch activity

UV_{occ}= The exposures during the work

UV_{recr}= The exposures during the recreational time

UV_{tot}= Cumulative UV exposure dose received

Eyes

---

f= Focal length of the eye (m)

ρ= Reflection coefficient

β= Total beam divergence angle (mrad)

ττ= Transmittance coefficient

ω= Subtended angle from the source (mrad)

ω_{spot}= Subtended angle of the reflected image on a mirror as observed from a given distance (mrad)

A_{spot}= Area of the reflected image on a surface viewed by the observer (m^2)

A_p = Area of the pupil (m^2)

A_{equiv} = Equivalent area of the ***n*** heliostats (m^2)

A_{obs}= Area seen by the observer (m^2)

A'= Area of the reflecting surface (m^2)

b= Focal length (m)

C = Concentration ratio

D_h= Effective diameter of the mirror (m)

d_{spot}= Reflecting area of the mirror (m)

d_s = Source size (m)

d_p= Daylight adjusted pupil diameter (m)

$d_r \mathrm{d_r} = \mathrm{f}\omega$= Diameter of the image projected onto the retina (m)

E_{beam}= Beam irradiance (W/cm^2)

E_c= Irradiance in outside the cornea (W/cm^2)

E_{DNI}= Direct normal irradiance at the Earth´s surface (W/m^2)

E_{equiv}= Equivalent Irradiance of the ***n*** heliostats (W/cm^2)

$E_r$$\mathrm{E_r}$= Retinal irradiance (W/cm^2)

E_{ref}= Reflected irradiance (W/cm^2)

$E_{r,burn}$= Retinal burn threshold (W/cm^2)

$E_{r,flash}$= Potential after-image threshold (W/cm^2)

E'= Irradiance of the reflecting surface (W/cm^2)

r= Distance between the eye and the source (m)

r_{obs}= Location of the observer (m)

x = Distance (m)

τ_V = Spectral coefficient of transmission

X_{obs} = Distance between the observer and the tower (m)

Z_{obs}= The tower height minus the height of the observer (m)

Heat stress

T = Dry-bulb temperature (ºC)

T_g= Black-globe temperature (ºC)

t_n= Time of exposure (min)

T_{nw}=Natural wet-bulb (static) temperature (ºC)

T_a =Air temperature (ºC)

RH = Humidity (%)

M = Metabolic rate (W)

vp = Vapor pressure (hPa)

v = Wind speed (m/s)

$WBGT_{out}$= Wet-bulb Globe Temperature with solar load (ºC)

$WBGT_{in}$= Wet-bulb Globe Temperature without solar load (ºC)

$WBGT_{avg}$= Wet-bulb Globe Temperature in mixed environments (ºC)

$WBGT_p$= Wet-bulb Globe Temperature productivity (ºC)

1. Basic concepts

1.1 Solar Radiation

The solar energy incident on Earth's surface can be classified in two parts. One of it is called direct solar radiation and corresponds to the fraction that reaches the Earth´s surface without being scattered or absorbed by the atmosphere. The other part that is scattered by the atmosphere, it is called diffuse solar radiation. The sum of both components is known as global radiation (Yunus, 2002). The radiation that reaches the surface of Earth can be subdivided, according to the wavelength, in Ultraviolet (UV), Visible (VL) and Infrared (IR) radiation (Polefka, et al., 2012; Amaro, et al., 2014). All of them are classified by its wavelength within the solar spectrum [Fig. 1].

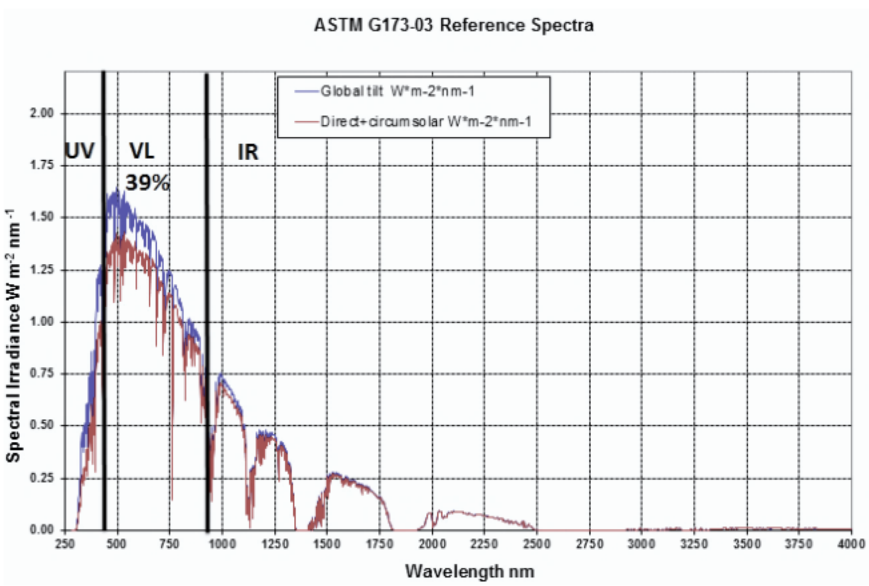

Fig. 1. Solar spectrum based on ASTMG173-03[15].

The solar spectrum is defined as a group of electromagnetic radiations (VL, UV and IR) emitted by the sun, named as well as non-ionizing radiations (NIR) (Knave, et al., 2001). VL is about half of the total irradiance distribution within the solar spectrum and it is the part of the NIR that can be perceived through the eyes. The rest of it cannot be

[15] ASTMG173-03 represents the standard terrestrial solar spectral irradiance distribution developed by American Society for Testing and Materials (ASTM).

perceived by any of the human senses unless the source has a high intensity so it can be perceived by feeling heat.

The radiant heat (thermal radiation), known as infrared radiation, is emitted by all objects with a temperature above zero. IR radiation conforms almost half of the solar radiation, and it is subdivided in IR-A, IR-B and the IR-C through the solar spectrum. The UV is a form of optical radiation of shorter wavelengths and photons (particles of radiation) more energetic than VL; subdivided into UV-A, UV-B and UV-C. Solar radiation classification differs somehow depending on the involved discipline [Fig. 2].

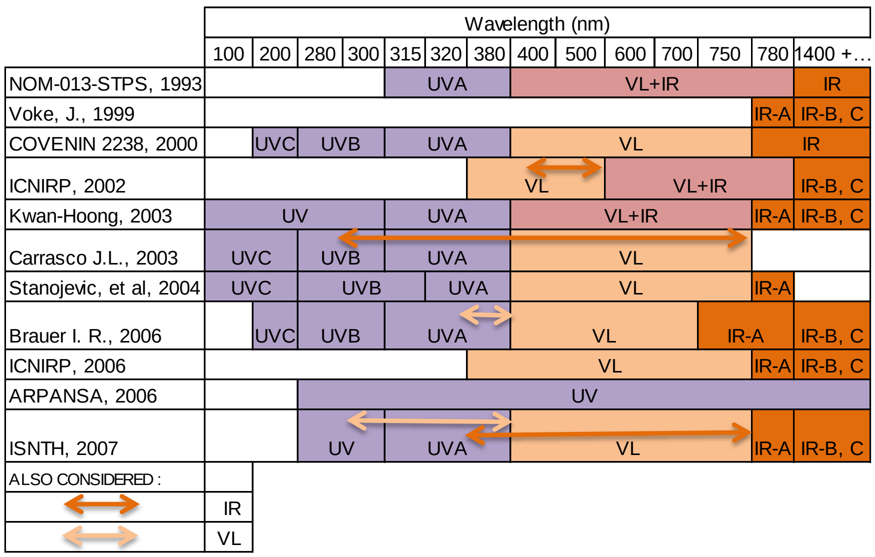

Fig. 2. Wavelength classifications. Literature adaptation.[16]

From a health perspective, wavelength components in the ultraviolet radiation region have particular relevance. In the area of environmental and dermatological photo-biology, UV radiation is usually classified in UV-A (from 400 to 320nm), UV-B (from 320 to 290nm) and UV-C (from 290 to 200nm). Fortunately, the UV-C, being the most energetic form of UV, does not reach the ground level because it is absorbed by the ozone layer (Amaro, et al., 2014; Knave B, 2001; Kwan-Hoong, 2003; Brauer, 2006;

[16] Kwan-Hoong, Ng., 2003; Brauer I. R., 2006; Carrasco J.L., 2003; Stanojević, M. R., et al. 2004; Voke, J., 1999; Segura, B. D., and Calvo, M. J. R., 2007; ICNIRP 2002; ACGIH 1993; CEN 2004; COVENIN 2238: 2000; ARPANSA 2006.

Carrasco, 2003; Hodder and Parsons, 2007; Polefka, et al., 2012; Mancebo and Wang, 2014; Yunus, 2002).

Brauer (2006) considers the part of UV that falls within the range between 200 and the 315 nm a concern in order to ensure human health and safety, while Kwan-Hoong (2003) believes that the biggest risks to the public are the ones coming from visible light and ultraviolet radiation or, in other words, natural light exposures. Natural light is present in solar thermal power plants in a daily basis.

1.2 Central receiver systems

One of the several types of solar thermal technology is based on the concept of the concentration of sunrays, known as the concentrated solar power (CSP) system. It uses the solar radiation as a renewable source for the electricity production through a thermodynamic cycle (Hamilton, 2011; IRENA, 2013). Among all the CSP technologies available in the late years, the one that uses central receiver system (CRS) is the type of technology moving to the forefront in market penetration (Behar, et al., 2013; Gauché, et al., 2017).

Basically, these systems concentrate the sunrays on the receiver by reflecting the sunlight through heliostats' surfaces (mirrors) (Kalogirou, 2009). The receiver absorbs the concentrated solar energy and transfers it to a circulating fluid. The heated fluid is pumped into storage tanks and passed across a heat-exchanger, where steam is produced. This steam is used in a turbine connected to a generator in order to produce electricity (Hamilton, 2011; IRENA, 2013; Kalogirou, 2004). The heliostat's surface is designed to focus the beams on the receiver where the reflected light will be scattered on a level that increases proportionally to the distance between the heliostat and the focal point.

These reflections can be classified in different human-interacting situations according to Franck et al. 2010; González, et al., 2015; Hamilton, 2011; Ho, et al., 2011; Kattke and Vant-Hull, 2012:

- The reflection aimed at the sky (potential risk for pilots),
- Non-concentrated reflection from one single heliostat (potential risk for a person standing in front of the mirror),
- Concentrated solar radiation from the heliostats field (potential risk for the workers located in the solar tower)
- The diffuse radiation from the receiver, Solar field and beyond (potential risks for people outside the heliostats field although nearby, i.e. roads, neighbors and pedestrians)
- The reflection from the mirrors when they are moving from the standby mode or stowed position and when they are not oriented towards the receiver
- Special manual cleaning care of the heliostats
- Extreme weather conditions vs physical activities

Each type of renewable energy production process (construction, operation, and maintenance) has its own occupational hazards (Schulte, et al., 2016). In the particular case of solar facilities, they usually use locations with high ultraviolet index (UVI) due to its requirements for power generation (Hamilton, 2011). Even though populations are adapted to their local climate (Kovats and Hajat, 2008), the ozone layer loss has been exceeding its natural restoration and a growing level of ultraviolet (UV) radiation reaches the surface of the Earth which means that the solar industry workers will be facing new risks (Ellwood, et al., 2014).

2. Skin exposures

Solar radiation interacts with the skin through absorption, reflection, and scattering mechanisms, which are determined largely by the layers of the skin and the physical characteristics of the type of radiation (Polefka, et al., 2012).

The two primary layers of the skin are the epidermis and dermis. The epidermis is the outermost layer and serves as the body's point of contact with the environment. The dermis underlies the epidermis and harbors cutaneous structures, immune cells, and fibroblasts, which actively participate in many skin physiologic responses.

The epidermis is a self-renewing tissue composed mainly by keratinocytes. The nascent epidermal keratinocytes formed as a result of cell division by keratinocyte stem cells in the stratum basale where keratinocytes move outward through the epidermis undergoing a programmed series of differentiation. In other words, they migrate outward toward the surface of the skin in order to form corneocytes which are linked to dead (but intact) cells that form the principal barrier of the outermost epidermal layer. Keratinocytes also receive melanin from melanocytes, where it is accumulated to function as a natural sunscreen against the incoming UV, so the amount and type of epidermal melanin is the main factor that determines skin complexion and UV sensitivity (D'Orazio, et al., 2013).

Skin sensitivity to UV is represented by using the Fitzpatrick classification [Table 2], with a six-level scale ranging from subjects who always tan and never burn to subjects who always burn during solar exposures (Gandini, et al., 2016).

Table 2. Fitzpatrick skin classification types

Skin type		Burns in the sun	Tans after sun exposures
I	Melano-compromised	Always	Seldom
I I		Usually	Sometimes
III	Melano-competent	Sometimes	Usually
I V		Seldom	Always
V	Melano-protected	Naturally brown skin	
VI		Naturally black skin	

Note: Reproduced from WHO (2002) *based on Fitzpatrick TB, et al., reported in TB Fitzpatrick and JL Bolognia, Human melanin pigmentation: Role in pathogenesis of cutaneous melanoma. In: Zeise L, Chedekel MR, Fitzpatrick TB (eds.) Melanin: Its role in human photoprotection. Overland Park, KS,Valdenmar Publishing Company, 1995:177-82.*

The ozone layer protects life on Earth from the UV radiation harmful effects by filtering almost all the UV-C radiation and nearly 95% of UV-B radiation emitted by the sun.

However, it only minimally filters UV-A radiation, ending in more than 95% reaching the surface of the Earth. In theory, around 5% of UV-B and 95% of UV-A of UV radiation, impinges upon the skin's surface (Polefka, et al., 2012; Mancebo and Wang, 2014).

Although the UV-B it is characterized by greater energy than UV-A, it has more difficulty to penetrate the skin; when the energy carried by each photon decreases (e.g. UV-B to UV-A to VL to IR), the ability to penetrate the biological tissue increases (Polefka, et al., 2012). From this relationship it can be then concluded: the UV-C never reaches the surface of the skin, the UV-B is susceptible to penetrate the outermost layer of the skin (which is the epidermis), and the UV-A can penetrate deeper, reaching the dermis (Polefka, et al., 2012; Amaro, et al., 2014; D'Orazio, et al., 2013; Grigalavicius, et al., 2016) [Fig. 3].

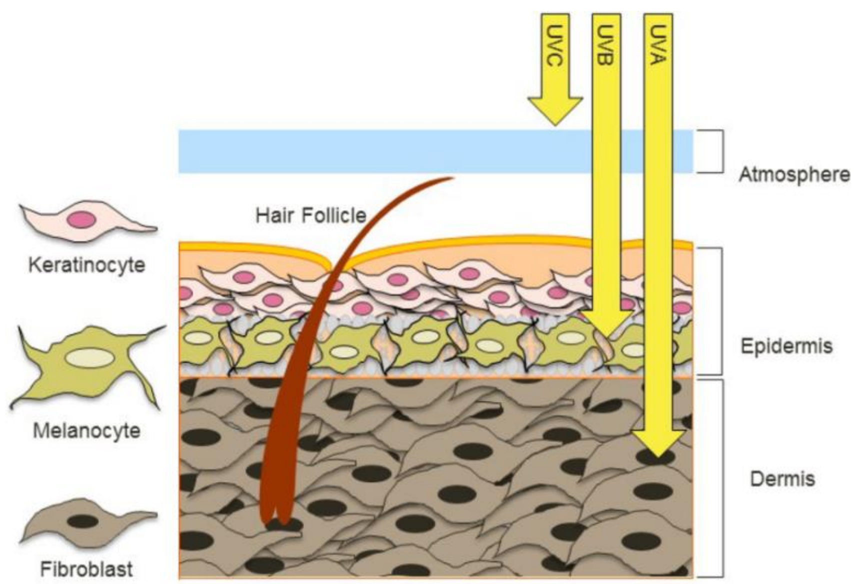

Fig. 3. UV light outcomes. Taken from Amaro, et al., 2014.

The skin has an adaptation process to solar radiation in order to provide protection through natural mechanisms. The pigmentation of the skin, noticeable within a day or two after sun exposure, is known as tanning. Indeed, a tanned skin does confer an increased degree of protection, which seems to be no more than a 2-3 sun protection factor (SPF) in the absence of skin thickening. The SPF is defined by McGregor and

Young (1996) as the ratio of the minimum erythemal dose of simulated sunlight on protected skin compared with unprotected skin.

On the other hand, skin thickening is a significant component of a mild sunburn reaction and single moderate exposure to UV-B can result in up to three-fold thickening of the outermost layer of the epidermis within one to three weeks (Vecchia, et al., 2007). Multiple exposures every, one or two days for more than seven weeks will thicken the epidermis in three to five folds (Vecchia, et al., 2007). Skin thickness returns to the normal state in one or two months after ceasing the exposures to radiation. This can increase the protection against UV by an SPF of five or even higher. An adapted skin to solar radiation infers at least three weeks of exposure to solar irradiance without presenting sunburn.The best-established beneficial effect of solar UV radiation, on the skin, is the synthesis of vitamin D. Vitamin D is known to be essential for the body's proper uptake of calcium, which is important for bone and musculoskeletal health. The Vitamin D synthesis begins when solar radiation, in the UV-B wavelength, photochemically converts dehydrocholesterol in the epidermis to pre-vitamin D3, which is converted later into vitamin D3. Due to the photo-instability of pre-vitamin D3, repeated short exposures to sunlight are more beneficial than rare but extended exposure. It is acquired right before there is a danger of acute effect to the skin called erythema (Vecchia, et al., 2007).

2.1 Health effects on skin

Skin cancer

Chronic UV irradiation leads to deregulation of biological mechanisms which promote abnormal proliferation of cells with DNA damage. Exposure to UV-B induces direct damage to DNA. Besides, DNA damaged due to UV-A exposure is mediated by reactive oxygen species (ROS), resulting in the formation of oxidative products. If the lesion occurs in one or more genes involved in regulating growth and proliferation, or tumor suppression, the cell must rapidly repair the damage. Incomplete repair of the DNA and removal of these mutagenic photo-products result in an uncontrolled proliferation of the cells, leading to the development of skin cancer (Polefka, et al., 2012; Mancebo and Wang, 2014; Vecchia, et al., 2007). People who spend working-periods outside are chronically exposing themselves to solar radiation. Cumulative exposures to UV radiation are responsible for Basal Cell Cancer (BCC) and Squamous Cell Cancer (SCC) (Vecchia, et al., 2007). SCC results mainly from chronic exposure and BCC are predominantly related to intermittent and acute UV exposure (Milon et al., 2014). Cutaneous Melanoma (CM) is also associated with UV exposure, but the responsible mechanisms and wavelengths are unclear (Grigalavicius, et al., 2016). Even though the recognition of skin cancer as occupational hazard remains scarce, it is still the most frequent carcinogenic agent in many countries (Milon et al., 2014).

Photo-aging

Solar radiation (UV-A, VL and IR) has an oxidative stress on the skin by triggering the ROS which can inappropriately activate cellular pathways causing damage. The resulting ROS affect the expression of several key transcription factors which enhance the breakdown of collagen and also down-regulates its synthesis. Photo-aged skin is described with clinical signs such as deep wrinkles, dryness, dilatation of blood vessels, multiple dark spots on the sun-exposed skin, sallowness, telangiectasia, significant laxity, pre-cancerous lesions, and a leathery skin appearance (Polefka, et al., 2012; Sklar, et al., 2013).

Pigmentation

The ultraviolet radiation causes a skin pigmentation reaction, which is an immediate change in skin color followed by delayed tanning with a new pigmentation formation. These two processes are known as pigment darkening and delayed tanning.

-Pigment darkening

There are two types of pigment darkening: immediate pigment darkening (IPD) and persistent pigment darkening (PPD). These two reversible processes result from oxidation and redistribution of pre-existing melanin and occur in less than 24 hours sun exposure. The first one results from exposure to low dose UV-A (1–5 J/cm^2) causing gray skin pigmentation, which disappears within minutes. On the other side, PPD results from exposure to higher doses of UV-A radiation (> 10 J/cm^2) causing brown skin pigmentation that can persist for more than 24 hours (Mahmoud, et al., 2008; Mancebo and Wang, 2014; Sklar, et al., 2013). The duration time, skin type and possible side-effects of the pigment darkening process, according to the wavelength of radiation, are shown in Table 3.

Table 3 .Radiation-induced pigmentation

UV-A	Induces immediate pigment darkening that fades within 2 h Delayed tanning appears within 3–5 days after exposure, may persist for months
UV-A I	Induces immediate pigmentation and delayed pigmentation in all skin types
UV-A II	In skin types I and II erythema precedes pigmentation In skin types III and IV induces immediate pigmentation with no visible erythema
UV-B	Pigmentation occurs when preceded by erythema
Narrowband UV-B	Peaks between 3–6 days, pigmentation returns to baseline at 1 month
Broadband UV-B	Peaks between 4–7 days, pigmentation returns to baseline at 3 months
Visible Light	Immediate pigment darkening and delayed tanning in skin types IV–VI, pigmentation may last for 2 weeks
IR	None

Reproduced from Sklar, et al., 2013.

Delayed tanning

In contrast, to IPD and PPD, delayed tanning (DT) is related to the synthesis of new melanin, resulting from both UV-A and UV-B radiation exposure. However, DT induced by UV-A is preceded by IPD and PPD without noticeable redness on skin, while that one induced by UV-B is more efficient in inducing erythema. Clinically, DT causes changes in pigmentation that can only be seen three days after sun exposure. The color changes on skin fade as the surface layer of the skin is shed (Mahmoud, et al., 2008; Mancebo and Wang, 2014).

Erythema (sunburn)

The most recognizable acute clinical effect of UV exposure on the skin is erythema, well known as sunburn. It is defined by Sklar et al. (2013) as a cutaneous inflammatory reaction that can be accompanied by warmth and tenderness. Erythema, depending on the UV wavelength, is caused due to direct damage to DNA or an indirect oxidative damage. As a consequence of the DNA damage, Cytokines (proteins secreted by specific cells of the immune system) and inflammatory mediators are synthesized and released into the skin. These substances regulate the adhesion of molecules on blood vessels and keratinocytes. As a result, recruitment and activation of inflammatory cells cause vasodilation and inflammation (Mancebo and Wang, 2014; D'Orazio, et al., 2013).

The solar spectrum is shaped by three types of wavelength, as discussed earlier. VL comprises almost 39%. VL at high doses, and depending on the skin type, can cause erythema (Mahmoud, et al., 2008; Mancebo and Wang, 2014). VL induces erythema surrounding the IPD response on skin types IV–VI, but erythema response fades within 2h. For these skin types, the degree of erythema increases with increasing doses of VL.

Mancebo and Wang (2014), in their review of the erythema response to VL, UV and IR, found that other skin types (II-IV) could develop an erythema due to a greater output of UV contained in the VL source and also thermal effects. The severity of erythema formation depends on environmental and host factors. In the case of the host, the main factors are the skin color, age, and anatomic site. Individuals with darker skin pigmentation require up to 30 times more UV exposure to induce erythema compared to individuals with fair skin. In the case of the environmental factors: latitude, altitude, and time of day may affect erythema formation (Mancebo and Wang, 2014; Vecchia, et al., 2007).

The duration, skin type, and side-effects, according to radiation wavelength, appear in Table 4.

Table 4. Radiation-induced erythema

UV-A	Biphasic: peaks immediately to 4 h and then 6–24 h Induces erythema in skin type I; in individuals with higher skin phototypes, it requires significantly high doses to do so.
UV-B	In lighter skin types, fades within 1–2 weeks In darker skin types, fades within 1–3 days
Narrowband UV-B	Milder and shorter than BB-UV-B
Broadband UV-B	Abrupt increase at 12 h and peaks at 6–24 h Immediate erythema only in skin types I and II
Visible Light	Immediate, fades within 2 h
IR	Lasts less than 1h

Reproduced from Sklar, et al., 2013.

2.2 Method for the assessment

2.2.1 Ultraviolet index (UVI)

Anthropogenic activities have contributed to the loss of stratospheric ozone and its destruction has been exceeding its natural formation, resulting in UV radiation increment reaching the Earth's surface (Polefka, et al., 2012; Lim and Cooper, 1999). Among other factors influencing the amount of UV radiation that reaches the Earth´s surface are atmospheric and environmental conditions, time of day, altitude, season, and most importantly, latitude (Polefka, et al., 2012).

The Global Solar UV Index (UVI) describes the level of solar UV radiation at the Earth's surface (WHO, 2002). It was formulated by the World Health Organization (WHO), the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) to communicate the general level of risk regarding the UV exposure conditions during the day. The UVI may be used to plan outdoor activities since it indicates the risk of sunburn at a given meteorological conditions (weather and sun position) (Vecchia, et al., 2007; ICNIRP, 2010).

The exposure category of the UVI ranges from 1 to 11 and over [Fig. 4]. The values 1-2 (green) are classified as low risk, 3-5 (yellow) moderate, 6-7 (orange) high, 8-10 (red) very high, and 11+ (pink) as extreme risk.

Fig. 4. UVI exposure category. Taken from Sklar, et al., 2013.

There are some organizations around the world reporting the solar UV by providing data to the public in the form of the UVI exposure values in category scale. The reporting values of UVI, provided by local forecasts are available as a single value rounded to the nearest number in the exposure UVI category. The values in Fig. 4 are attached to a suggested level of protection against the outside conditions. Also, the forecast report, at least, the daily maximum UVI value and the unsafe sun exposure period of the day. When necessary, the forecast includes the effect of cloud on UV radiation transmission through the atmosphere as a range of values. Otherwise, it should be interpreted as clear sky conditions (WHO, 2002).

Zaratti et al. (2014) published the time of exposure (in minutes) before skin damage is noticeable in each skin type in the Fitzpatrick skin scale [Fig. 5] The classification is weighted in 1 MED (Minimal Erythema Dose) as a function of the UVI and skin type.

The MED is the required UV dose to produce a noticeable impact (erythema) on the human skin that has been exposed to solar radiation. The MED is equivalent to a radiant exposure of 200 J/m^2, equivalent to 2 SED. The SED is defined as the amount of UV radiation reaching the skin surface and its unitary value is equivalent to an erythemal effective radiant exposure of 100 J/m^2. This indicates that the MED is the minimum dose to produce a notorious impact in the skin 24h after being exposed to the sun. In other words, MED represents a sunburn limit (WHO, 2002; Vecchia, et al., 2007; ICNIRP, 2010; Webb, et al., 2011; Moore, et al., 2013; Heisler and Grant, 2000; CEN, 2006; 2008; ICNIRP, 2004; Lucas, et al., 2006). The Fig. 5 shows the duration of the exposure in time as a function of 1 MED / 200 J/m^2 according to the skin type. The exposure time for Fair skin (type I-II) corresponds to 7-17 minutes which varies from skin type VI (melano-protected) that corresponds to a period between 40-100 minutes in the same UVI levels of 10+.

Time for 1 MED as a function of UVI and skin type

Skin type	I	II	III	IV	V	VI
Example	Celtic	Pale	Caucasian	Mediterranean	South American	Negro
Sensitivity	Always burns	Easily burns	May burn	Rarely burns	Rarely burns	Rarely burns
SED/MED*	2.5	3.0	4.0	5.0	8.0	15.0
UVI	Minutes of unprotected exposure before perceptible skin damage					
1	167	200	267	334	534	1001
2	83	100	133	167	267	500
3	56	67	89	111	178	334
4	42	50	67	83	133	250
5	33	40	53	67	107	200
6	28	33	44	56	89	167
7	24	29	38	48	76	143
8	21	25	33	42	67	125
9	19	22	30	37	59	111
10	17	20	27	33	53	100
11	15	18	24	30	49	91
12	14	17	22	28	44	83
13	13	15	21	26	41	77
14	12	14	19	24	38	71
15	11	13	18	22	36	67
16	10	13	17	21	33	63
17	10	12	16	20	31	59
18	9	11	15	19	30	56
19	9	11	14	18	28	53
20	8	10	13	17	27	50
21	8	10	13	16	25	48
22	8	9	12	15	24	45
23	7	9	12	15	23	44
24	7	8	11	14	22	42
25	7	8	11	13	21	40

Fig. 5. UVI Time of Exposure. Taken from Sklar, et al., 2013.

According to Lucas et al. (2006), a daily exposure of 6-10% of the body surface (one arm, one lower leg, or face and hands) to 1 MED should be sufficient to avoid disease load due to vitamin D deficiency. In terms of acute skin effects from solar exposure, it is equivalent to approximately 1.0 –1.3 SED (Standard Erythema Dose) (Vecchia, et al., 2007; ICNIRP, 2010).

The suggested safe SED, per day, in an experimental solar central receiver institution, is around 200 J/m^2 a day (2 SED/day), according to Azizi and Kudish (as cited in Franck, et al., 2009). Even though, the exact energy equivalent to 2 SED differs upon the individual sunburn sensibility. The ICNIRP standard 14 published in 2007 the skin dose for adapted and non-adapted skin to solar radiation [Table 5].

Table 5. Skin type dose

Skin type	MED without adaptation	MED with adaptation
I -II	2 SED	6 SED
III- IV	7 SED	10 SED
V	10 SED	60 SED
VI	15 SED	80 SED

The knowledge about the UVI can be a useful tool in educating the workforce. Training and awareness of workers is the key to achieving the goal of reduction of health issues due to UV exposures. The UVI could guide enterprises in the way of changing the level of overhead UV radiation exposure and the level of protective measures for outdoor workers (Vecchia, et al., 2007; ICNIRP, 2010). Encouraging people to reduce or expose wisely to the sun. If the objective is successfully achieved it can decrease harmful health effects and significantly reduce health care costs (WHO, 2002).

2.2.2 The skin exposure factor

The climatological factors and personal factors (sensitivity, sunburn history, and adaptation) to UV radiation significantly influence in the magnitude of the risk for the skin (ICNIRP, 2010). The skin exposure factor (**F_{es}**) is an indicator used for the assessment of the impact of the environmental conditions on skin (WHO, 2002; ICNIRP, 2010).

Six factors (f_n), related with the environmental conditions of a particular location, are involved in the result of **F_{es}**: f_1- geographical latitude and season (spring & summer (4, 7 and 9); autumn & spring (0.3, 1.5 and 5), f_2- cloud cover (clear sky = 1, partial cloudy =0.7, overcast sky = 0.2), f_3- duration of the exposure (all day = 1, one or two hours in midday = 0.5, early morning or late afternoon = 0.2), f_4- ground reflectance (fresh snow = 1.8, dry sand = 1.2, all the others = 1), f_5- clothing (unprotected = 1, arms and legs exposed = 0.5, hands and face exposed = 0.02), f_6- shade (no shade = 1, partial shade = 0.3, good shade= 0.02) (Vecchia, et al., 2007).

The skin exposure factor

$$\mathbf{F_{es}} = f_1 * f_2 * f_3 * f_4 * f_5 * f_6 \qquad (1)$$

According to the ICNIRP 14/2007 (Vecchia, et al., 2007), the levels shown in **Table 3.5.** Minimum level of protection required for the workplace should be used as categories of the exposure based on the minimum level of protection for a workplace.

Table 6. Minimum level of protection required for the workplace

Exposure factor	**Required skin protection**
<1	None
>1 but < 3	Shirt, brimmed hat
>3 but < 5	Long-sleeved shirt, trousers, brimmed hat and SPF 15+ sunscreen
> 5	Modify work environment and practices. Shade, long-sleeved shirt, trousers, brimmed hat and SPF 15+ sunscreen

Reproduced from Vecchia, et al., 2007.

In 2013, Wolska proposed a $\mathbf{F_{es}}$ modified method for the skin hazard assessment due to UV radiation exposure. It consisted in including the Solar UVI from a particular day and geographical place (maximum value to clear sky conditions) in the formula for the calculations of the $\mathbf{F_{es}}$. As skin tumors related to UV radiation are often found on the neck and head, and on the torso and arms, includes three additional values for the clothing factor (0.40 for the arms, head and neck exposed, 0.35 for the arms and neck exposed, and 0.07 for the head and neck exposed), plus the cloudiness condition (0.5).

The $\mathbf{F_{es}}$ *applied in the situation of facing the risk with no protective measures.*

$$\mathbf{F_{es}} = UVI * F_2 * F_4; \qquad (2)$$

$F_{es} \leq 1$ low risk, no additional preventive measures needed.

$F_{es} > 1$ preventive measures are necessary

where

F_2= cloud cover; F_4= ground reflectance.

If $\mathbf{F_{es}}$ is greater than 1, preventive measures are needed and the corrected Skin exposure factor ($\mathbf{F_{es}*}$) should be calculated as:

The corrected Skin exposure factor

$$\mathbf{F_{es}}* = (F_{es})*(F_3)*(F_5)*(F_6) \quad (3)$$

where

F_3= duration of the exposure;

F_5=clothing factor

F_6= shade factor

2.2.3 Cumulative exposures

People who spend working-periods outside are exposing themselves to solar radiation almost every day. Cumulative exposures to UV radiation are responsible for some forms of melanoma (MM) (ICNIRP, 2010; Moore, et al., 2013; Blazejczyk, et al. 2014). Blazejczyk et al. believe that it is still the most frequent carcinogenic agent in many countries and, in 2014, developed a method to estimate the incidence of SCC, where basically the anatomical exposures to solar UV are assessed by simulating the exposures with the Sim UVEx (Simulating UV Exposure).

The model predicts the dose and the anatomical distribution of radiation received on the basis of ground irradiance and morphological data (Blazejczyk, et al., 2014; Vernez, et al., 2015). After the ambient UV data is estimated through simulation, and/or measured with radiometers, the estimation of SCC risk is expressed as a function of age and cumulative exposure UV dose by:

The SCC risk

$$SCC_{risk} = Risk\ \alpha\ (age)^{\alpha} \times (UV_{tot})^{\beta} \quad (4)$$

where:

α = age dependent factor
β=biological amplification factor
UV_{tot}= cumulative UV exposure dose received

The cumulative UV dose is expressed as a sum of the exposures during the work (UV_{occ}) and lunch (UV_{lunch}) during ***n*** years of occupational activity and recreational (UV_{recr}) time from 0 to ***n***:

Cumulative UV exposure dose received

$$\sum_0^n UV_{tot} = \sum_{n1}^{n2}(UV_{occ} + UV_{lunch}) + \sum_0^n UV_{recr} \quad (5)$$

The UV_{occ}, and UV_{lunch} are obtained from SimUVEx model, and UV_{recr} from a survey.

Note that some factors are not taken into consideration, e.g. the access to shaded spots, indoor working periods, taking lunch outside, absences at work or clothing. Besides, the model assumes a constant for the annual exposure without any variation (long periods outside, no protective clothing and no shade) therefore the results should be considered as upper values (Blazejczyk, et al., 2014; Vernez, et al., 2015).

2.2.4 Time of the exposure

According to the ICNIRP standards (14/2007, 2004 and 2010) the way to find the effective irradiance of a broadband source, weighted against the peak of the spectral effectiveness curve (270nm), is given by the following weighting formula:

Effective irradiance

$$E_{eff} = \sum(E_\lambda)(S(\lambda))(\Delta_\lambda) \quad (6)$$

where
E_{eff}= effective irradiance in W/m^2 normalized to a monochromatic source 270nm
E_λ= spectral irradiance from measurements in W/m^2
$S(\lambda)$= relative spectral effectiveness (unitless) [Table 7]. Note that the values for wavelengths that are not listed in [Table 7] may be interpolated.
Δ_λ= measurement intervals

Table 7. Values of $S(\lambda)$ for wavelengths

λ[a] (nm)	EL[d] (J/m²)	EL[d] (mJ/cm²)	S(λ)[b]	λ[a] (nm)	EL[d] (J/m²)	EL[d] (mJ/cm²)	S(λ)[b]
180	2,500	250	0.012	310	2,000	200	0.015
190	1,600	160	0.019	313 [c]	5,000	500	0.006
200	1,000	100	0.030	315	1.0×10^4	1.0×10^3	0.003
205	590	59	0.051	316	1.3×10^4	1.3×10^3	0.0024
210	400	40	0.075	317	1.5×10^4	1.5×10^3	0.0020
215	320	32	0.095	318	1.9×10^4	1.9×10^3	0.0016
220	250	25	0.120	319	2.5×10^4	2.5×10^3	0.0012
225	200	20	0.150	320	2.9×10^4	2.9×10^3	0.0010
230	160	16	0.190	322	4.5×10^4	4.5×10^3	0.00067
235	130	13	0.240	323	5.6×10^4	5.6×10^3	0.00054
240	100	10	0.300	325	6.0×10^4	6.0×10^3	0.00050
245	83	8.3	0.360	328	6.8×10^4	6.8×10^3	0.00044
250	70	7	0.430	330	7.3×10^4	7.3×10^3	0.00041
254 [c]	60	6	0.500	333	8.0×10^4	8.0×10^3	0.00037
255	58	5.8	0.520	335	8.8×10^4	8.8×10^3	0.00034
260	46	4.6	0.650	340	1.1×10^5	1.1×10^4	0.00028
265	37	3.7	0.810	345	1.3×10^5	1.3×10^4	0.00024
270	30	3.0	1.000	350	1.5×10^5	1.5×10^4	0.00020
275	31	3.1	0.960	355	1.9×10^5	1.9×10^4	0.00016
280 [c]	34	3.4	0.880	360	2.3×10^5	2.3×10^4	0.00013
285	39	3.9	0.770	365 [c]	2.7×10^5	2.7×10^4	0.00011
290	47	4.7	0.640	370	3.2×10^5	3.2×10^4	0.000093
295	56	5.6	0.540	375	3.9×10^5	3.9×10^4	0.000077
297 [c]	65	6.5	0.460	380	4.7×10^5	4.7×10^4	0.000064
300	100	10	0.400	385	5.7×10^5	5.7×10^4	0.000053
303 [c]	250	25	0.120	390	6.8×10^5	6.8×10^4	0.000044
305	500	50	0.060	395	8.3×10^5	8.3×10^4	0.000036
308	1,200	100	0.026	400	1.0×10^6	1.0×10^5	0.000030

Reproduced from ICNIRP, 20014.

[a] Wavelengths chosen are representative; other values should be interpolated
[b] Relative spectral effectiveness.
[c] Emission lines of a mercury discharge spectrum.
[d] EL for a monochromatic source, but also limited by a dose-rate of 10 kW m^2 (1 W cm^2) for periods greater than 1s as well in order to preclude thermal effects.

The product of the E_{eff} (in W/cm^2) and the duration of the exposure (t, in seconds) results in the effective exposure dose (H_{eff} in J/cm^2) (Vecchia, et al., 2007):

Effective exposure dose

$$H_{eff} = (E_{eff})(t) \tag{7}$$

Permissible UV exposure time (t_{max} in seconds) for constant incident irradiance upon unprotected skin is found by dividing 30 J/m^2 by the value of E_{eff} in W/m^2 as it shown in (Vecchia, et al., 2007):

Permissible UV exposure time

$$t_{max} = \frac{30}{E_{eff}} \tag{8}$$

The exposure duration, $t_{erythema}$, necessary to achieve a minimum erythemal dose (MED) in an individual would be the MED for that individual in summer with that type of skin I, e.g., 220 J/m^2 divided by the irradiance $E_{erythema}$.

The exposure duration to achieve a minimum erythemal dose (MED).

$$t_{erythema} = \frac{MED}{E_{erythema}} \tag{9}$$

2.2.5 Limit of the skin exposure

The ICNIRP (2004) provided the exposure limits for working population and general public showed in Table 8, which presents the representative time of exposure corresponding to effective irradiances.

Table 8. Maximum limit of exposure

Time of the exposure per day	*Effective irradiance E_{eff} (W/m^2)*
8 h	0.001
4 h	0.002
2 h	0.004
1 h	0.008
30 min	0.017
15 min	0.033
10 min	0.05
5 min	0.1
1 min	0.5
30 s	1.0
10 s	3.0
1 s	30
0.5 s	60
0.1 s	300

In terms of acute skin effects from solar exposure, the ICNIRP 14 standard (Vecchia, et al., 2007) described the maximum limit of efficient radiant skin exposure as 30 J/m^2 (3 mJ/cm^2) which it is equivalent to approximately 1.0–1.3 SED or approximately one-half of an MED for fair skin (ICNIRP, 2004; 2010).

The ICNIRP (2010) classified this limit as a desirable goal limit for skin exposure to minimize the long-term risk. Besides, it must be recognized that this limit has its difficulties for being achieved in sunlight and some judgment must be used in its practical application. Many workers have not experience sunburn, meaning that their skin has adapted to solar exposure.

Even though, the accumulation of solar UV radiation exposures on skin may still have implication for the induction of skin cancer in the future. Minimizing the exposures to UV radiation in outdoor workers is clearly challenging.

3. Ocular exposures

The human eye has the natural aversion response against bright light sources. This response protects it from getting injured by viewing bright sources like the sun. Since this aversion limits, the duration of exposure lasts a fraction of a second (around 0.15 s) (Ho, et al., 2011). It means that the eye will naturally avoid the bright source by blinking or/ and the person will instinctively shift his view from the bright source in order to minimize incident visible light (Franck et al., 2010). In solar radiation exposures, the variation in eyelids opening plays a major role in terms of impact. The eyelids control the amount of light that enters into the eye. For example, the lids are more open during cloudy days as the irradiance is reduced due to the cloud cover. Ocular exposure is affected by the geometry of exposure, which means that sun irradiance reaching the eye is near limited to the indirect radiation that has been diffusely scattered by the atmosphere and reflected from all the surfaces (Vecchia, et al., 2007).

Besides, the unforeseen incidence of flash light on a visual scene naturally attracts the attention which could distract someone from his/her ongoing task and/ or produce a shock and panic reaction (Toet, et al., 2013).

Even though the avoidance instinct of the eye, the intensity of the bright light source, time of exposure, the incidence of the exposure and flickering pattern of light might cause temporary and permanent effects (Toet, et al., 2013; Ho, 2011). The visual disturbances could appear as a result of the neural processing in the retina after the light has been absorbed by the photoreceptors (Toet, et al., 2013).

There are several effects (physiological and psychological) that could represent a temporary impact or a permanent damage according to the type of wavelengths that define light intensity absorbed by the retina of the eye.

3.1 Ocular health effects

Glare is the temporary incapability to see details in the area around a bright light (visual field). Sometimes is called dazzle, being known as the first eye reaction to bright light (Franck et al., 2010). It is not classified as biological damage because it lasts only as long as the bright light exists within the individual's visual field (Toet, et al., 2013). Glare, relative to the ambient lighting, is defined as a result of the exposure to a source of continues excessive brightness while glint is attributed to a momentary flash of light (Ho, et al., 2011).

Disability glare

The moment that glare impact vision is called disability glare, which is caused by the diffractions and scattering of light inside the eye. It is also called physiological glare and it reduces the visual performance (Osterhaus, 2005). The light that is scattered overlays the retinal image and, consequently, reduces the visual contrast. The result of the overlaying scattered light distribution is usually called veiling luminance.

Veiling luminance is the decrement of contrast in the scene in the human eye (Toet, et al., 2013). Workers under the presence of disability glare immediately notice the reduction in their ability to see and/or to perform a visual task (Osterhaus, 2005).

Discomfort glare

Discomfort glare, also called psychological glare, does not necessarily affect the visual performance but it produces discomfort. An individual under discomfort glare might not notice any negative impact on his work performance but can experience side effects after a period of time, such as headache (Osterhaus, 2005).

Flash blindness

The retina adapts physiologically to light and when the light is more intense than that amount at which the retina is adapted at that moment, a temporary and immediate loss of vision is produced. Flash blindness is produced by the bleaching of the retinal visual (light-sensitive) pigments caused by bright light exposures (Toet, et al., 2013; Ho, et al., 2009; Franck, et al., 2010). Most of the people have experienced flash blindness after viewing a flashlight from a camera (Ho, et al., 2009). Dazzle and the “after-image” effects are the physiological responses to flash blindness (Franck, et al., 2010)

After-image

The after-image is a temporary scotoma (blind spot), or a lasting image, after looking directly at a bright source as the sun. It is caused by the visual impression which lasts after the image has disappeared. The after-image effect persists from several seconds to several minutes in the visual field in which target spots are partly and/or completely buried. These blind spots are stuck and move with the eyesight. The time to blind spots fade depends on the intensity and duration of light exposures, among other factors, such as target contrast, color, size, observer age, and the total adaptation state of the visual system (Franck et al., 2010; Toet et al., 2013).

Effects such as after-image, flash blindness, and veiling can be the result of experiencing disability glare caused by solar glare. Meanwhile, retinal burn can occur with exposure to concentrated sunlight and solar retinitis with associated scotoma results from staring at the sun (Sliney, 1994).

The prolonged exposures to some of these effects, such as discomfort glare and disability glare, can lead to side effects like headaches and/or other physiological impacts, and reduction of the visual performance (Ho et al., 2014). Glare and flash blindness might be followed by irreversible impairments such as thermal lesions (Toet, et al., 2013).

The recovery time, strongly dependent on the brightness of the projected image, ranges from 0.8 to 2.7 seconds, for approximately 1–3 W/m^2 of solar irradiance at the eye (Saur and Dobrash, 1969; Franck et al., 2010).

For the evaluation of the repercussion effects on a viewer located in the installations of a solar power facility, it is necessary to take into consideration that the effects are directly related to the ambient and background light conditions. In daylight conditions flash blindness is not considered to be a problem since the locations usually have bright surroundings and high global and diffuse radiation (Franck et al., 2010).

3.1.1 Permanent damages

Exposures to solar radiation, mostly UV radiation, are associated with a variety of impairments on cornea, lens, and retina. The health disorder depends on the amount and wavelength of radiation that reaches the internal structure of the eye (ICNIRP, 2010; Vecchia, et al., 2007; Diffey, 1991). For example, viewing intense VL radiation can be potentially risky for the retina and intense UV can be hazardous for the cornea and lens (Sliney, 2001).

The principal hazard resulting from looking directly at the sun is photoretinitis (solar retinitis with scotoma) which is a retinal damage. Intense exposure to short-wavelength of light can cause thermal lesions, which are burns of the retinal tissue that result in permanent scotomas (Sliney, 1994; 2001; Toet, et al., 2013).

Even though the retina is sufficiently protected by the cornea and crystalline lens against health effects (less than 1% of UV-A is available to reach the retina), solar retinitis is the consequence of a photochemical injury mechanism subsequent to the exposure of the retina to shorter wavelengths in the visible spectrum (Sliney, 1994; 2001; ICNIRP, 2004). Photoretinitis may result from viewing an extremely bright light for a short period of time or it could be the result of looking at a lesser bright light source for longer periods of exposure (Sliney, 2001).

Studying the physiology of the retina, light damage and the renewal process of the retina had been the concern between the adverse impacts to UV-A, and blue light upon the retina (Sliney, 2001).

On the other hand, the cornea does not pass through an adaptation process (increment in the capacity of protection) due to repeated exposures; therefore it is equally vulnerable day after day to the same amount of radiation (ICNIRP, 2010; Vecchia, et al., 2007; Knave, et al., 2001).

Acute effects such as photokeratitis and photokeratoconjunctivitis are produced by an inflammatory reaction in the cornea and the conjunctiva, respectively, and both can be very painful but don’t result in a permanent damage. They appear a few hours after the exposure and last one or two days (Knave, et al., 2001). Another effect upon unprotected eyes exposures to the sun is fibrous ingrowth of the cornea´s tissue (pterygium). Other effects could be attributed to a nonmalignant tumor in the conjunctiva (pingueculum) and cataracts (opacity of the lens). Usually, cataracts that eventually lead to blind eye appearance in individuals depend on the age and sun exposure (mostly UV-B exposures) (Diffey, 1991; WHO, 2002; Vecchia, et al., 2007).

Risks from glint and glare from bright sources within concentrating solar power plants include the potential of permanent damage in the eye and also temporary effects. Those effects could impact in people within the facility and also in the surroundings (working nearby, pilots flying overhead or motorist driving alongside the site). Assess the potential hazards coming from the glint and glare in concentrating solar power plants is an important requirement to ensure public safety (Ho, et al., 2011).

3.2 Method for the assessment

Ho et al. (2009) and Brumleve (1984) proposed short-term exposure parameters in order to assess the bright light sources in CSP installations. In those studies two variables were defined as necessary for the ocular impact assessment:

iii) The retinal irradiance (E_r);

iv) The subtended angle (size) of the glare source (ω)

The retinal irradiance can be calculated from the total power entering the pupil and the retinal image area, as follows:

Subtended angle of the glare source

$$\omega = d_s / r \tag{10}$$

Diameter of the image projected onto the retina

$$d_r = f\omega \tag{11}$$

where $d_r = f\omega \mathrm{d_r} = \mathrm{f\omega}$, is the product of focal length of the eye (f =0.017 m) by the subtended angle (ω, in radians) (Sliney and Freasier, 1973); d_s is the source size, and r refers to the distance between the eye and the source (Ho et al., 2009) [Fig. 6].

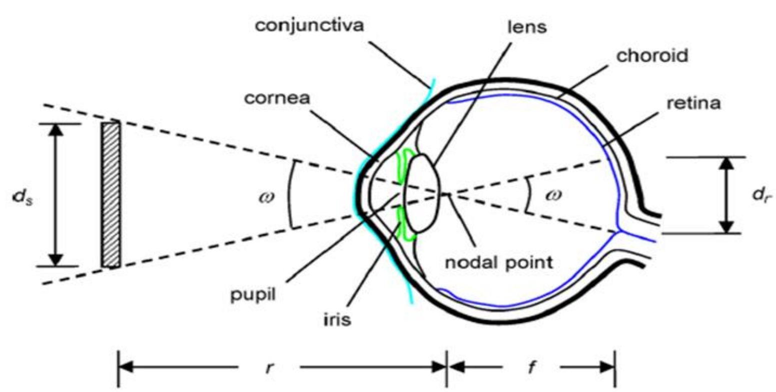

Fig. 6. Image projected onto the retina of the eye. Taken from Ho, et al., 2011.

The power entering to the pupil (E_r, retinal irradiance) is calculated as the product of the irradiance in the frontal plane of the cornea, E_c (W/m^2), and the pupil area (d_p). The power in the retina is divided by the retinal image area (d_r) and multiplied by the transmission coefficient (τ~0.5, as indicated by Brumleve, 1984), i.e.:

Power entering to the pupil.

$$E_r = E_c\left(\frac{dp^2}{dr^2}\right)\tau \qquad (12)$$

where d_p is the daylight adjusted pupil diameter (~2mm) (Brumleve, 1984).

By substituting the Equation 13 into Equation 14 gives:

Retinal Irradiance

$$E_r = E_c\left(\frac{dp^2}{f^2\omega^2}\right)\tau \qquad (13)$$

The calculated irradiances and thresholds for the determination of the ocular impacts are based on the solar spectral distribution (ASTM G 173-03) within the visible spectrum (from 380 to 800 nm, according to Ho et al., 2011). A potential risk to the eye scenery resides in the moment when ω increases and the safe threshold for E_r proportionally decreases. In other words, the permanent eye damage might occur when the delivery of power into the retina occurs in a larger amount. This happens because a larger subtended angle of a source ends in a larger retinal image, so it ends delivering an amount of power that the retina cannot easily dissipate.

The threshold for the burn in the retina can be represented by $E_{r,burn}$ (W/cm^2) and, according to Brumleve (1984), should be delimited by the threshold limit:

Threshold for the burn in the retina (permanent damage maximum limit of exposure)

$$E_{r,burn} = \frac{0.118}{\omega}\ for\,\omega < 0.118rad\ ;\ E_{r,burn} = 1\ for\,\omega \geq 0.118rad \qquad (14)$$

As the burns in the retina, the temporary blindness, caused by a flash (after-image effect), depends also on the size of the subtended angle of the source but differs on the severity of the impact. For instance, for a given irradiance, lesser or greater source ends in smaller/bigger after-image effect. Several authors (e.g., Brumleve, 1984; Ho, et al.,

2009) affirm that the size of the after-image and the impact is minor with small angles (ω). The potential threshold of after- image ($E_{r,flash}$) (W/cm^2) can be calculated as indicated in:

After- image effect threshold (temporary effect maximum limit of exposure)

$$E_{r,\,flash} = \frac{3.59x10^{-5}}{\omega^{1.77}} \tag{15}$$

The potential impacts in the eye for short-term exposures are resumed in Fig. 7, where three potential risks of impact regions are defined:

- The risk of permanent damage to the eye or retinal burn in 0.15 seconds (typical average time of blink response)
- Potential for a temporary after-image effect
- Low potential to produce after-image effect.

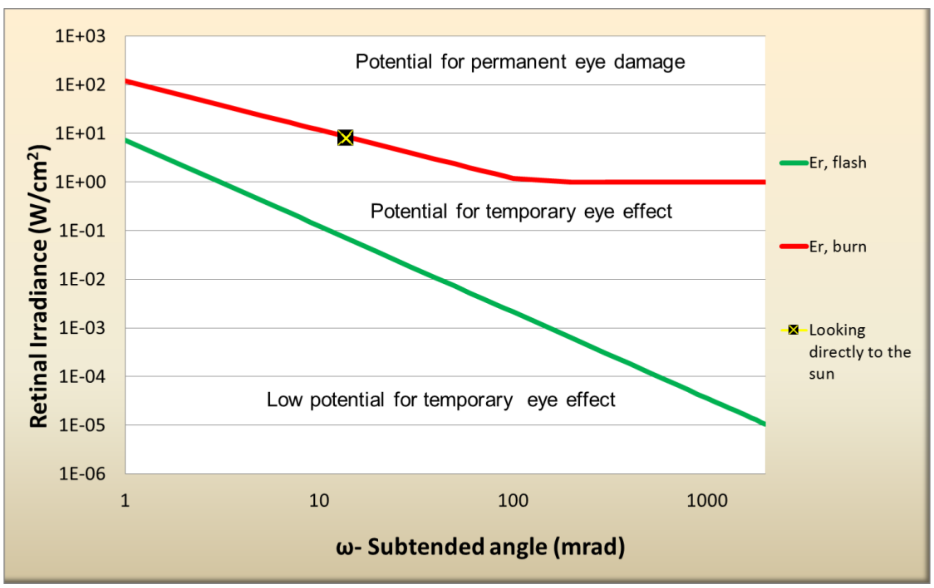

Fig. 7. Potential impacts represented as a function of the subtended angle. Adapted from Ho et al., 2011.

The retinal irradiance, E_r, caused by the action of looking directly to the sun (~8 W/cm^2), in Fig. 7, is settled up as a situation of reference and is delimited by the parameters: β= 9.4 mrad, ω =0.0094 rad, , d_p= 0.002 m, f= 0.017m, τ=0.5 and a direct normal irradiance of 1000 W/m^2 (E_{DNI}=0.1 W/cm^2). It is important to notice the fact that the quantified metrics and retinal irradiance estimations do not consider all the factors and situations, e.g., the situation of a person is wearing sunglasses, other human factors and behaviors, and also multiple beams from adjacent receiver(s) (Brumleve, 1984).

3.2.1 Specular reflections from the surface of the heliostats

Situations where the surface of the mirrors is in a position that allows the reflection of the sun to locations other than the receiver may occur. Those situations can lead to glint and glare hazards. In order to evaluate the situations under the conditions to produce the largest beam irradiance, some assumptions should be made, according to Ho et al., (2011).

Such assumptions will be considered for the calculations of the beam irradiance (E_{beam}), expressed in W/cm^2, as given in **Equation 18**, which is defined as the irradiance outside the eye based on the reflection coefficient, or mirror reflectivity, (ρ), and the area of concentration ratio (C) [**Equation 19**].

Beam Irradiance

$$E_{beam} = \rho E_{DNI} C \tag{16}$$

The area concentration ratio

$$C = \left(\frac{x\beta}{D_h} + \left| \frac{x}{b} - 1 \right| \right)^{-2} \tag{17}$$

In **Equation 18**, E_{DNI} is the direct normal irradiance at the Earth´s surface (W/cm^2) (Ho., et al., 2011); ρ is assumed equal to 0.92 (Ho., et al., 2011). Additionally, b is the focal length (set as $b = \infty$ for a flat mirror), x is the distance between the mirror and the observer, being β the total beam divergence angle (assumed as 9.4 mrad, according to Ho et al., 2011), and D_h is the effective diameter of the mirror (calculated from the total reflective surface of the mirror).

The size of the sun image that is reflected on the surface of the heliostats is different from the one observed by the individual (Ho et al., 2011). Therefore it is necessary to calculate the size of the reflected sun image in the mirror that is being observed, in order to determine the retinal irradiance (E_r) and the subtended angle of the source (ω).

It is necessary to take into consideration the spot size of the image, proportional to the measured irradiance ($E_{beam} = E_c$), which is projected on the surface and observed by a person at a given distance (x). The concentration ratio "C", is proportional to the area of the reflected spot image (A_{spot}) on the flat mirror viewed by the observer (Ho et al., 2011). Therefore, C is also equivalent to the square of the diameter´s ratio of the reflected area on the mirror (d_{spot}).

Concentration ratio

$$C = \frac{A_{spot}}{A_{spot,flat}} = \left(\frac{d_{spot}}{d_{spot,flat}}\right)^2 = \left(\frac{x\omega_{spot}}{x\beta}\right)^2 \quad (18)$$

where ω_{spot} is the subtended angle of the reflected image on a mirror, as observed from a given distance, and ($x\beta$) is the diameter of the reflected sun image observed at a x distance away from an infinitely large flat mirror. The subtended angle, of the reflected image on a mirror as observed from a given distance, it is express by:

The subtended angle

$$\omega_{spot} = \beta\sqrt{\frac{E_{beam}}{\rho E_{DNI}}}; \quad (19)$$

where: $E_{beam} = E_c$

The retinal irradiance[17] (from specular reflections), in Equation 22, is obtained from using the Equation 21 in Equation 12, Equation 13 and Equation 14.

The retinal irradiance from specular reflections

$$E_r = \frac{\rho E_{DNI} d_p^{\ 2} \tau}{f^2 \beta^2} \tag{20}$$

In the application of the methodology for the evaluation of ocular impacts, the equations Equation 12, Equation 13, and Equation 14 are used to convert E_c into E_r; where ω is represented by the ω_{spot} (Equation 21). The Equation 22 can be used for comparisons to the safe retinal irradiance levels in Fig. 7.

3.2.2 Diffuse reflections from the receiver

The receiver, located on the top of the tower, is designed to absorb the solar radiation coming from the heliostats field (Brumleve, 1984) and in order to assess the action of seeing the reflection of bright light coming from it and its impact on the eyes, the receiver surface can be interpreted as a diffuse source. Samaniego, et al., 2012, proposed a way to evaluate the reflected irradiance coming from diffuse sources based on the methodology proposed by Ho et al. (2011). The angular size of the source is determined by the effective area reflected on the receiver surface which is seen by the observer [Fig. 8].

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[17] *"The retinal irradiance does not depend on distance from the source (neglecting atmospheric attenuation). As the distance increases, both the power entering into the pupil and the retinal image area (which is proportional to the square of the subtended source angle) decrease at the same rate. Therefore, the retinal irradiance, which is equal to the power entering to the pupil divided by the retinal image area, is independent of distance (*Ho, et al. 2011) *"*

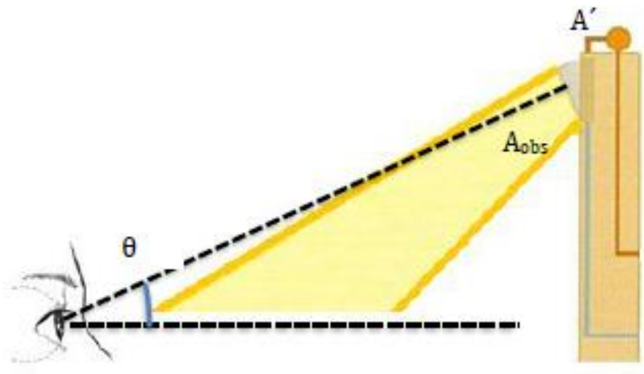

Fig. 8. Observer interaction with the receiver. Taken from Samaniego, et al., 2012.

The effective area seen by the observer (A_{obs}) can be calculated using Equation 23, where the angle between the tower and the observer depends on the distance between them and the tower height.

Effective area seen by the observer

$$A_{obs} = A' \cos\theta \qquad (21)$$

being A_{obs} the area seen by the observer, θ the angle, and A' the area of the reflecting surface.

Once the total illuminated area is known, the reflected irradiance (E_{ref}) can be calculated by multiplying it by the reflection coefficient ρρ (0.8 to 0.2) and the amount of irradiance seen by the observer (E'):

Reflected irradiance

$$E_{ref} = \rho E' \qquad (22)$$

However, there is a difference between the total reflected radiation and the total amount of radiation outside the eye (E_c in W/cm^2). The main reason is the distance and the angle in which the observer is located with respect to the receiver. The irradiance outside of the cornea is defined by:

Irradiance outside the cornea

$$E_c = I_{ref} A' \frac{X_{obs}}{\left(z_{obs}{}^2 + X_{obs}{}^2\right)^{\frac{3}{2}}} \tag{23}$$

where $I_{ref} = \frac{E_{ref}}{\pi}$, due to the circular shape of the image; Z_{obs} is the tower height minus the height of the observer; X_{obs} is the distance between the observer and the tower.

On the other hand, the quantity of irradiance (per cm^2) that enters through the pupil (E_r) is equal to the multiplication of energy that is outside of the cornea by the area of the pupil (A_p) for a certain distance "r_{obs}" (location of the eyes of the observer) divided by the area seen by the observer.

The quantity of irradiance (per cm^2) that enters through the pupil

$$E_r = \frac{E_C A_p \tau \, r_{obs}{}^2}{A_{obs} f^2} \tag{24}$$

Here the transmission coefficient (τ) is equal to 0.5 and the focal distance of the eye (f) is equal 0.017m (Ho et al., 2011).

Equation 26 refers to the amount of radiation on the retina produced by a single heliostat. Therefore, the amount of reflected irradiance coming from **n** heliostats in the field and reaching the retina is determined by an equivalent area (A_{equiv}) for an equivalent irradiance (E_{equiv}) as follows:

Equivalent area

$$A_{equiv} = \sum_{i=1}^{n} \frac{nA'_{i-n} nE'_{i-n}}{nE'_{i-n}} \tag{25}$$

The equivalent irradiance, E_{equiv}, is represented by the sum of the amounts of reflected irradiance coming from the heliostats. As it can be seen in:

Equivalent irradiance

$$E_{equiv} = \sum_{i=1}^{n} nE'_{i-n} \quad (26)$$

4. Heat exposures

All objects with a temperature above zero emit thermal radiation and the rate of its emissions increase with increasing temperature. Temperature is the measure of the intensity of energy transitions of molecules, atoms, and electrons of substance from those activities, the electromagnetic radiation emitted as a result is thermal radiation. Thermal radiation includes an only portion of the UV radiation and the entire VL, IR radiation (Givoni 1976 cited by Hodder and Parsons 2007; Kwan-Hoong, 2003; Yunus, 2002).

Through radiation, the body exchanges heat with its surroundings. When a body surface is exposed to such incident irradiance, scatters a part of it and absorbs the other portion. The body that is exposed to solar radiation will raise its temperature by absorbing part of the radiation ending the process in a heat exchange. Depending on the intensity of the source, the absorbed fraction of the radiation will induce physiological, biochemical or behavioral changes in the organism (Kwan-Hoong, 2003; Brauer, 2006; Carrasco, 2003; Stanojević, et al., 2004; Yunus, 2002). The human body is physiological regulated, which means that the human body system tends to maintain the internal stability when environmental conditions change. This internal stability depends on the rate at which metabolic heat produced is balanced by the rate at which heat is externally lost. If the internal heat in the body is dissipated really fast, the body will experience cold. Otherwise, if the loss happens slowly, the body experiences heat (Brauer, 2006). There are different ways of losing heat into the environment [Fig. 9]: through convection, conduction, respiration, and evaporation (sweat) (Blazejczyk, et al., 2014).

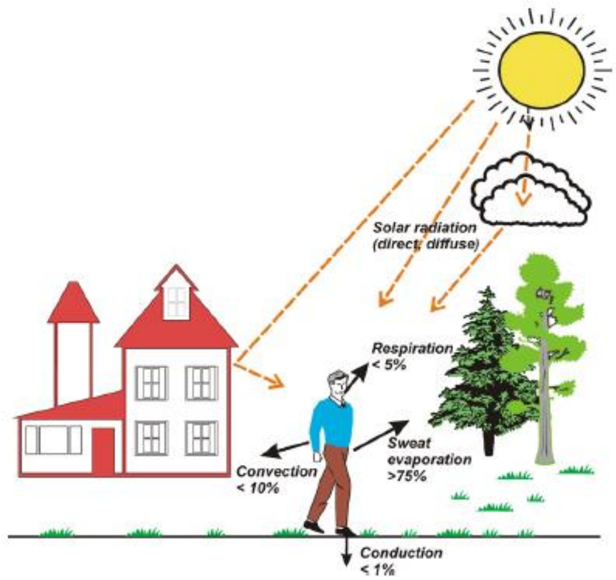

Fig. 9. Heat loss into the environment. Taken from Blazejczyk, et al., 2014.

When subjected to heat stress conditions, in hot weather, the body protects itself through thermoregulation by losing heat. The body, with the purpose of conserving its normal function, has the crucial requirement of maintaining, within ±1 ºC, the acceptable core temperature of 37 ºC. Achieving this equilibrium in body temperature (heat balance) depends on the heat exchange between the body and the environment. The human body will promote heat dissipation through sweat evaporation in order to achieve the equilibrium; 75% of the total of heat losses happens through evaporation.

Sweat will vaporize in order to cool down the surface of the body, but the process depends on the saturation of water in the air. If the heat persists, the cooldown process leads into abundant sweating and, in such state, the body is susceptible to dehydration by water and salt depletion. Eventually, when the skin is completely wet, the sweat glands present an inflammation which induces a reduction in sweating (hidromeiosis).

The decrements in sweating allow the rapid rise of the deep-body temperature, ending the process in a whole system collapse. The life-threatening result occurs in a body-temperature above 40 ºC. The nervous system collapse or heat stroke happens due to the absence of thermal equilibrium between the body and the environment due to a thermoregulatory failure (Blazejczyk, et al., 2014; Bouchama and Knochel 2002; Epstein and Moran 2006; Kjellstrom, et al., 2009b; Lemke and Kjellstrom, 2012; NIOSH, 2016; No and Kwak, 2016;Parsons, 2009 ; Yunus, 2002).

At this level of core temperature, the presence of mental confusion, behavioral changes, decrements in sweating and the failure in the central nervous thermoregulation could eventually end in the death of the individual (Parsons, 2009). At a lower heat exposure and before this serious health effect occurs, the mental task ability reduces and the risk of accident increases leading to a reduction in work capacity which negatively impact in productivity (Kjellstrom, et al., 2009b).

In the following sections, the physiological responses due to heat exposures are explained more in detail by addressing acute and chronic heat–related impairments, the physiological ability to regulate the temperature and how global warming could interfere with heat-related occupational safety and health.

4.1 Physiological response to heat

Kovats and Hajat in 2008 classified the heat as an environmental and occupational hazard with its physiological effects due to high-temperature exposures. Stress due to heat might happen when the exposure to hot environmental conditions brings to the individual discomfort and physiological strain.

The level of heat stress is influenced by the metabolic heat production of the body, which increases with the level of activity. In other words, physical work could accelerate the perception of the symptoms of heat. It also depends on the ability of the body to lose heat. If the body is available to cold down, the heat stored in the body will not raise the core temperature to unacceptable levels (Bouchama and Knochel 2002; Parsons, 2009).

Heat stress can be defined as the total heat load on a worker exposed to combined contributions of heat exchange between the body and the environment (metabolic heat,

heat gained from the exterior minus the body heat losses to the environment) that can result in an increase in heat storage in the body (Kjellstrom, et al., 2016; NIOSH, 2016).

The human body's response to heat stress is called heat strain and the National Institute for Occupational Safety and Health (NIOSH) (2016) defined it as:

> *"Physiological response to the heat load (external or internal) experienced by a person, in whom the body attempts to increase heat loss to the environment in order to maintain a stable body temperature".*

Heat strain is derived into some physiological responses to promote heat transfer from the body back to the environment in order to maintain core body temperature. The increased heart rate, blood flow and prominent sweating could possibly end in dehydration (Parsons, 2009; Kjellstrom, et al., 2016). Once the compensatory mechanism of the human body is no longer capable to maintain the inner temperature of the body at the required level, these physiological responses end with heat-related clinical diseases/ illnesses and health impairments (clinical damage to organ function, physical activity capacity reduction and heat stroke) (Kjellstrom, et al., 2016; Parsons, 2009; NIOSH, 2016). The severe heat-related health impairments that could cause permanent damage to a person's organs, such as the heart, kidneys, and liver, are called chronic heat–related disorder (NIOSH, 2016).

Besides chronic heat–related disorders, other occupational health effects due to exposures to hot environments have been reported (Kjellstrom, et al., 2016) and they are classified by the NIOSH as acute heat–related disorders:

Heat fatigue

Heat fatigue is a behavioral disorder due to heat exposures and it can be classified as transient or chronic. Transient heat fatigue decreases the performance of sensory and motor functions of the worker, as well as mental performance, during the development of tasks in heat due to discomfort and physiologic strain. Chronic heat fatigue reduces the performance capacity due to inability to concentrate and social behavior under psychosocial stress that may involve hormonal imbalance (Brauer, 2006; Parsons, 2009).

Heat rash

Heat rash (prickly heat /miliaria rubra) is characterized by small eruptions (red vesicles/ papules) on skin giving a prickly sensation due to constant exposure to humid heat. The skin persistently wet with unevaporated sweat will obstruct sweat gland ducts with retention of sweat ending in an inflammatory reaction.

Another skin disorder (miliaria crystallina) appears in areas in skin previously injured or sunburned areas. These areas start to sweat, but the damage prevents the escape of sweat ending in the development of small to large watery vesicles, which rapidly diminish once the mechanism of sweating stops.

The Anhydrotic heat exhaustion (miliaria profunda) appears in areas of the skin which don’t sweat during heating loads because the sweat ducts are clogged below the skin surface. Sweat retention deep in the skin, reduced evaporative cooling causing heat intolerance. This type of heat rash might also occur in previous skin injury. The skin presents goose-flesh appearance and pale elevations during the exposure. Mostly these heat rashes subside with the return to a cool environment.

Even though heat rashes are not dangerous themselves, each one could influence in thermoregulation due to the reduction in sweating that reduces evaporative heat loss back to the environment (Brauer, 2006; NIOSH, 2016; Parsons, 2009).

Heat syncope

Heat syncope is a collapse and/or loss of consciousness (fainting) as a result of heat exposure. It usually occurs without an increase in body temperature or cessation of sweating, in prolonged standing or sudden rising from a sitting or supine position. The redistribution of blood to peripheral tissue decreases the flow of blood to the brain inducing the faint in workers.

Heat syncope could be the result of dehydration and/or lack of acclimatization, and its symptoms include light-headedness, dizziness, and fainting (Brauer, 2006; NIOSH, 2016).

Heat cramps

Heat cramps are a heat-induced illness characterized by spasms/ spastic contractions in the muscles in arms, hands, legs, feet or abdominal area (during or after working hours). Heat cramps are usually associated with salt depletion due to sweating.

The body in profuse sweating presents no significant body dehydration because it is accompanied by abundant water intake (without salt replacement), where it dilutes electrolytes and water enters to the muscles causing the spasms (Brauer, 2006; NIOSH, 2016; Parsons, 2009).

Rhabdomyolysis

Rhabdomyolysis is a medical condition related to heat stress and prolonged physical action resulting in the death of most or all of the cells in muscle tissue. After the breakdown of muscle and its necrosis, electrolytes, mainly potassium, and large proteins are released into the blood. Besides large muscle proteins can damage the kidneys filtration system, high potassium levels might be the reason for irregular and dangerous heart rhythms and seizures.

Although symptoms can vary between individuals, NIOSH defined them as:

- Muscle pain, cramping, swelling, weakness, dark or tea-colored urine and decreased range of motion of joints.
- Some experiencing nonspecific symptoms such as fatigue, exercise intolerance abdominal pain, back pain, nausea or vomiting, and confusion.

Sometimes, the presence of muscle cramps and dark urine, after physical work with heat load, may be the only symptom and rhabdomyolysis may be misdiagnosed for another heat-related disorder and dehydration (NIOSH, 2016).

Heat exhaustion

Heat-related moderate illness resulting from water and salt losses due to hot environmental exposures. It is characterized by a failure to replace water and it is usually considered forerunner of heat stroke (NIOSH, 2016). Symptoms are described by Bouchama and Knochel 2002; Brauer, 2006; NIOSH, 2016; OSHA, n.d.; Parsons 2009 as:

- Heavy sweating, intense thirst, weakness, discomfort, anxiety, dizziness, nausea, vertigo, and headache.
- Clammy and moist skin, complexion pale and muddy or hectic flush behavior.
- Fainting, rapid thready pulse, and low blood pressure.
- Decreased urine output.
- Core temperature could be normal, below normal or slightly elevated (38 or 39 ºC). Oral temperature normal or low, but rectal temperature usually elevated (>34 but < 40 ºC)

Heat stroke

A heat-related severe illness characterized by central nervous system abnormalities resulting from exposure to environmental heat. It starts with a core temperature abnormally high (above 40 ºC) caused by a thermoregulatory failure in the body´s system. This failure of the central drive for sweating lead to loss of evaporative cooling and ends in an uncontrolled increment in the temperature (NIOSH, 2016). Some signs and symptoms described by Bouchama and Knochel (2002), Brauer (2006), NIOSH (2016) and OSHA (n.d.), are:

- Confusion and altered mental status, slurred speech and delirium, seizures or convulsions, lack of sweating, very high core temperature, loss of consciousness (coma) and death. Heat stroke is frequently fatal and those who persist may sustain irreversible neurological damage.

The occupational heat–related health effects previously described are interrelated and each has its unique clinical characteristics and differs in severity (Bouchama and Knochel 2002; NIOSH, 2016). Even though it is not known whether radiation energy (with different wavelength characteristics) will have different effects on human perception of thermal sensation and whether people are sufficiently sensitive to react physiologically, visible radiation has a very high intensity of energy. Therefore, climatic health hazards need to be placed on a developing relationship between climate and its effects on occupational health. A combination of the internal body heat production from physical activity and some factors involved in the ability to lose and gain heat (number of working hours, season, clothing, etc.) can cause health issues in workers, ranging from heat stress to heat stroke leading to death (Blazejczyk, et al., 2014; Hodder and Parsons, 2007; Kjellstrom, et al., 2016).

Heat strain could end in heat stroke due to the existence of a thermoregulatory failure, exaggeration of the acute-phase response, and alteration in the expression of heat-shock proteins. This fatal acute disorder (heat stroke) is a preventable illness and thorough awareness and administrative and engineering controls could be detectable by monitoring and control the heat stress level in workers (Bouchama and Knochel 2002; NIOSH, 2016).

4.1.1 Acclimatization

The level of heat stress at which heat strain will result in heat-related impairments on a worker depends on the physiological ability of the worker to tolerate heat. One of the many physical responses to heat exposure is that the body attempts to regulate its temperature and appropriate repetitive exposures causes a sequence of physiologic adaptations, known as acclimatization (NIOSH, 2016).

The NIOSH defines acclimatization as:

> *"The physiological changes that occur in response to a succession of days of exposure to environmental heat stress and reduce the strain caused by the heat stress of the environment; and enable a person to work with greater effectiveness and with less chance of heat injury".*

In most workers, appropriate increments in the level of work performed and repeated exposures to hot environments eventually allow the workers to perform their tasks under safety at levels of heat that were previously intolerable. Under acclimatization, the body becomes more efficient in dealing with heat loads. An individual that has been passing through this process should tolerate a greater heat stress levels before a harmful level of heat strain occurs.

The process of acclimatization to hot environments might take several weeks, but after continuous heat exposure, from 7 to 14 days, workers perform their tasks with a lower core temperature. Acclimatization in workers also involves the increase in the capacity to secrete sweat and the stabilization of the circulation by the improvement of cardiovascular performance (Bouchama and Knochel 2002; NIOSH, 2016).

In order to achieve the full heat acclimatization, unacclimatized workers should pass through brief daily exposures to heat and gradually increase the time exposure. The minimum heat time exposure for a worker to develop acclimatization is at least two hours per day; which may be broken into 1-hour exposures. The rest periods of time break the continues-heat-exposures and contribute to the acclimatization process and workers safety; opposite to long rest periods e.g. 24hr of rest after long time heat exposures at work. Excessive exposures could result harmful to workers without heat acclimatization because it is difficult for those individuals to replace all of the water loss in sweat. The level of acclimatization will depend on the initial level of physical capability and the amount of heat stress experienced by the worker (DOD 2003, cited by NIOSH, 2016).

Even though most healthy workers will be available to accomplish the acclimatization process, some of them will not be able to sustain heat. The workers whose temperature will start rising prior, and at a higher rate, than those others under the same conditions, could be heat intolerant. Heat intolerance may be associated with many factors, such as low physical fitness, lack of acclimatization, low work efficiency, reduced skin area to body mass ratio, sweat gland dysfunction, dehydration, infectious disease, x-ray irradiation, previous heat stroke, large scarred burns, and/or drugs. Especially after an episode of heat exhaustion or exertional heat stroke, a test can be used for the evaluation of individual's tolerance (Epstein et al. cited in NIOSH, 2016; Moran et al. 2007).

The multi-center health research and prevention program Hothaps is used to calculate the degree of the heath impact or adaptation in workers to heat exposure while working. Also, the program evaluates how climate change may increase heat-related effects on workers. This kind of program leads to future heat-related occupational safety and health regulations by documenting the emerging heat-related events (NIOSH, 2016).

4.2 Method for the heat stress assessment

According to the American Industrial Hygiene Association (AIHA), workers and supervisors should be aware of the basics of thermoregulation and control exposure. Therefore, agencies such as the International Standards Organization (ISO), the American Conference of Governmental Industrial Hygienists (ACGIH), OSHA and NIOSH have been overviewing exposure limits available, time-weighted averages, recommendations, etc., in order to protect workers from heat stress due to hot environmental exposures (NIOSH, 2016).

The standards are directed for unacclimatized and acclimatized workers exposed to heat. Most of them use the "Wet-bulb Globe Temperature" (WBGT) index, which is, by far, widely used to estimate the level of heat stress in outdoor conditions with solar load (Abdel, et al., 2014; Blazejczyk, et al., 2014; Epstein and Moran, 2006; Kjellstrom, et al., 2009b). Also, it is the heat index used for workplace assessments due to its recommendations about resting/work schedules at different WBGT levels and work intensity (Lemke and Kjellstrom, 2012).

The factors affecting human heat stress level can be classified as environmental factors and physiological factors. The amount of heat experienced by a worker is represented by measuring the temperature of the air, humidity (water vapor pressure), air velocity and radiant energy. Besides, the body metabolic heat generation rate also impact the level of heat stress and it depends on different factors such as personal activity, sex, age, ethnicity and type of clothing. Therefore, these factors vary between individuals (Abdel, et al., 2014).

The WBGT index, described by the ISO 7243, resides in the variable weighting of the dry-bulb temperature (T), natural wet-bulb (static) temperature (T_nw) and black–globe temperature (T_g) in the following equations (Blazejczyk, et al., 2014; Brauer, 2006; Epstein and Moran, 2006; Kjellstrom, et al., 2009a; NIOSH, 2016):

WBGT index (with solar load)

$$WBGT_{out} = 0.7\,T_{nw} + 0.2T_g + 0.1T \tag{27}$$

WBGT index (without solar load)

$$WBGT_{in} = 0.7\,T_{nw} + 0.3T_g \tag{28}$$

In the case of a worker being exposed to different thermal environments during a work shift, an average value of WBGT, based on the time of the exposure (t_n) (min), is suggested (Brauer, 2006):

WBGT average value

$$WBGT_{avg} = \frac{(WBGT_1 \times t_1) + (WBGT_2 \times t_2) + \cdots + (WBGT_n \times t_n)}{t_1 + t_2 + \cdots + t_n} \tag{29}$$

The WBGT index evaluates the effect of air movement (v in m/s) and humidity (RH in %) in T_{nw}. The combination of air temperature (T_a) and radiation is evaluated by the black–globe temperature (T_g) and the air temperature is measured by the dry-bulb temperature (T) (NIOSH, 2016).

In general, the components necessary for the WBGT calculation result from measurements with particular equipment (Blazejczyk, et al., 2014; NIOSH, 2016). The measuring instruments give T_{nw}, T_g and Ta separately or as combined WBGT readouts (NIOSH, 2016). The equipment required to perform the measurements is a black globe thermometer, a natural (static) wet-bulb thermometer, and a dry-bulb thermometer (OSHA, 1999). The thermometers could be suspended over a stand, in order to avoid the shade around the globe thermometer, and allow the free air flow around the bulbs and the wet-bulb. Also, placing the thermometers the measurements would be illustrative of the employee's working or resting areas. The range of the dry and the natural wet-bulb thermometers should be -5°C to +50°C, with an accuracy of ±0.5°C. On the other hand, the range of globe thermometer should be from -5°C to +100°C with an accuracy of ±0.5°C.

The globe thermometer should be exposed between 10-25 minutes before its reading, and its bulb sensor must be fixed in the center of the sphere. In the case of the dry bulb thermometer, it must be protected from the sun or radiant surfaces without interfering with the airflow. Further, the wick of the natural wet bulb thermometer needs to be clean and wetted with distilled water for at least one-half hour before the temperature readings are performed (OSHA, 1999).

The measurements of environmental factors used to determine the degree of heat stress on a worker should be performed at, or as close as possible, to the work area where the worker is usually exposed. If the task performed is not a continuous task in one spot (the worker develops the task in different working areas), and/or if the heat varies at one single hot area, the measurements should be carried on each working spot under a continuous heat level of exposure. The data should be gathered at least each hour, during the hottest period of the work shift and during the hottest season of the year (NIOSH, 2016).

The resulting WBGT index values obtained by applying the previous formulas can be compared to the WBGT ranges [Table 9] in order to follow the recommendations for outdoor exposures with heat load. Under climate change conditions, relative humidity is expected to remain constant so the WBGT- based occupational exposure limits are suggested to remain unaffected (Ingram cited by NIOSH, 2016).

Table 9. Recommendations for WBGT values in outdoor activity.

WBGT (ºC)	Recommendations
<18	Unlimited
18-23	Keep alert for possible increases in the index and for symptoms of heat stress
23-28	Active exercise for non-acclimatized person should be curtailed
28-30	Active exercise for all except the well-acclimatized should be curtailed
> 30	All physical activities should be stopped
Source: WBGT index 1991 (Blazejczyk, et al., 2011; 2014)	

Besides estimating the level of heat stress, occupational heat exposure guidelines, such as the NIOSH and ISO 7243, define the maximum level of exposure in relation to the work intensity (in watts) (Kjellstrom, et al., 2009a). Table 10 shows the reference values of WBGT levels of exposure corresponding to different work intensity levels. The ISO 7243 suggests reducing heat stress if any of those levels are exceeded.

Table 10. Reference values for WBGT (ºC) at corresponding work intensity

Work intensity	Resting	Light work	Moderate work	Heavy work	Very heavy work
Metabolic heat Kcal/h	100	200	300	400	500
M (Watts)	M<117 W	117< M< 234 W	234< M< 360 W	360< M< 468 W	M>468 W
WBGT (ºC)	33	30	28	26 - 25	25 - 23
(ºF)	91.4	86	82.4	78.8 -77	77- 73.4
Source: ISO 7243 (Kjellstrom, et al., 2009a; NIOSH, 2016)					

These WBGT values are set to avoid overheating (> 38 ºC) in a standard human with light clothing. This means that if the worker is sensitive to heat, or is not using light clothing, the levels need to be adjusted below the present levels suggested in Table 10 (Kjellstrom, et al., 2009a).

The NIOSH (2016) compared the recommended WBGT reference values from some institutions, among them AIHA, ISO, ACGIH and the OSHA, and concluded that there exists a slight variation between values recommended, but they are basically equivalent.

4.2.1 Working and resting periods

Depending on the WBGT level and work intensity, the worker will need to rest periods of time in order to maintain the core temperature under 38 ºC. The Table 11, shows the proportion of total work (100%) that can be performed under a body core temperature below 38 ºC; for the remaining proportion of time the worker is assumed to be resting (Kjellstrom, et al., 2009a; 2009b; NIOSH, 2016).

Table 11. WBGT exposed levels in ºC at different work intensities and rest/ work periods for an average worker with light clothing

Acclimatized worker					
Work demands	**Resting periods/ hour**	**Light work WBGT (ºC)**	**Moderate work WBGT (ºC)**	**Heavy work WBGT (ºC)**	**Very heavy work WBGT (ºC)**
100% work; 0% rest	0 min	31	28	27	25.5
75% work; 25% rest/ hour	15 min	31.5	29	27.5	26.5
50% work; 50% rest/ hour	30 min	32	30.5	29.5	28
25% work; 75% rest/ hour	45 min	32.5	32	31.5	31
0% work; 100% rest/ hour	60 min	39	37	36	34
Source: Kjellstrom, et al., 2009a					

Table 11, also, shows the work/resting periods for an acclimatized worker, WBGT levels that require continued work and those that require stopping work activities. It can be noticed that heavy work intensity at higher WBGT levels will need longer periods of rest.

Kjellstrom et al. (2009a) suggest that these recommendations are limited to clothing as it slows down the rate of heat exchange between the body and the environment (Brauer, 2006); heavier clothes will be required, also, longer resting periods. The ACGIH suggests the permissible heat exposure Threshold Limit Values (TLV) for heat stress conditions. Basically, TLV's suggested the levels under which acclimatized and unacclimatized workers could be continuously exposed without harm and those conditions under the worker have to take a rest from the job activity [Table 12] (Blazejczyk, et al., 2011; 2014; Brauer, 2006; Epstein and Moran 2006).

Table 12. American Conference of Governmental Industrial Hygienists (ACGIH) WBGT- based heat load levels in ºC

Acclimatized worker				
Work demands	**Light work**	**Moderate work**	**Heavy work**	**Very heavy work**
100% work	29.5	27.5	26.0	-
75% work; 25% rest	30.5	28.0	27.5	-
50% work; 50% rest	31.5	29.5	28.5	27.5
25% work; 75% rest	32.5	31.0	30.0	29.5
Unacclimatized worker				
Work demands	**Light work**	**Moderate work**	**Heavy work**	**Very heavy work**
100% work	27.5	25.0	22.5	-
75% work; 25% rest	29	26.5	24.5	-
50% work; 50% rest	30.0	28.0	26.5	25.0
25% work; 75% rest	31.0	29.0	28.0	26.5
Source: adapted from Epstein and Moran, 2006				

4.2.2 Limits of heat exposure

The NIOSH specifies the level of exposure at which workers should not be expected to perform the ongoing tasks (Kjellstrom, et al., 2009b). The levels, called Recommended Alert Limits (RALs) and Recommended Exposure Limits (RELs), aim to protect the workers with no health impairments, who are exposed to internal or external heat, from developing heat-related health effects. The exposure limits are determined by the following equations (NIOSH, 2016):

Recommended Alert Limits (RALs)

$$RAL[°C - WBGT] = 59.9 - 14.1\, log_{10} M \tag{30}$$

Recommended Exposure Limits (RELs)

$$REL\ [°C - WBGT] = 56.7 - 11.5\, log_{10} M \tag{31}$$

where

M is the metabolic rate in Watts (W)

The RALs were developed by NIOSH for the protection of unacclimatized workers who are exposed to environmental and metabolic heat and the RELs for workers who are acclimatized to the same conditions (NIOSH, 2016). These limits suggest work/rest schedules based on the concept that workers are able to work for short intervals of time at higher temperatures without showing heat-related health effects.

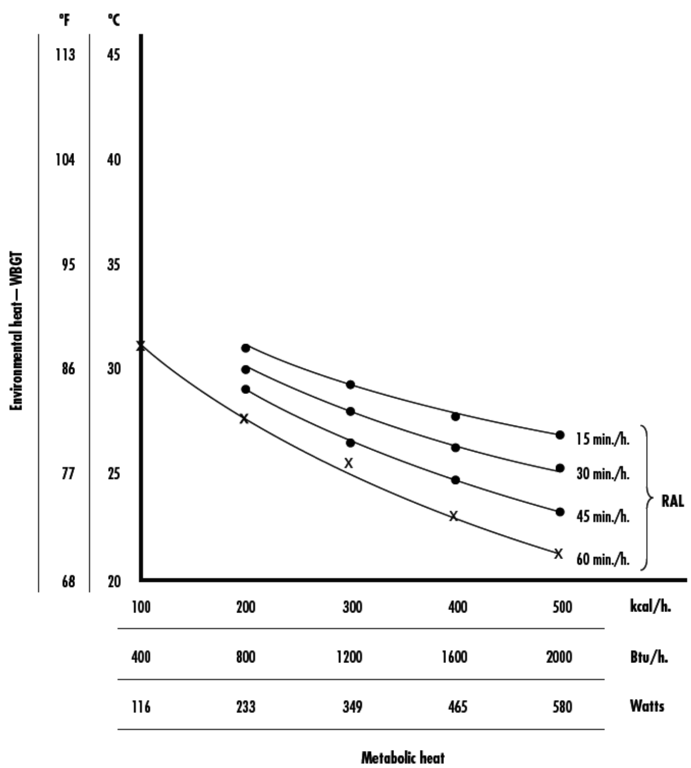

Fig. 10. Recommended heat stress alert limits (RALs) for unacclimatized workers. Taken from NIOSH, 2016, pp.94.

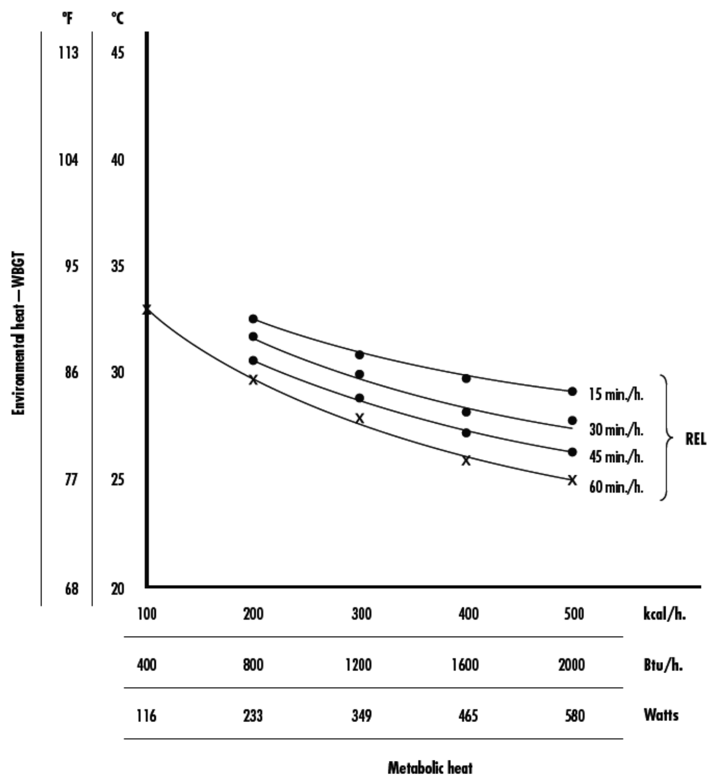

Fig. 11. Recommended heat stress exposure limits (RELs) for acclimatized workers. Taken from NIOSH, 2016, pp.95.

In Fig. 10 and Fig. 11, resting time periods of 60, 45, 30, and 15 minutes for work/rest schedules are shown. The NIOSH (2016) supports that shorter periods of time and rest breaks allow the workers to dissipate the heat accumulation in the body. Workers will be protected from developing heat-related health impairments if they maintain the expositions to environmental and metabolic heat below the appropriate NIOSH RALs or RELs.

The RALs and RELs are based on the concept of a "standard man" (70 kg body weight and 1.8 m^2 body surface) in order to normalize the data (NIOSH, 2016). Even though in some studies the men and women are considered with a similar ability to tolerate and adapt well to heat (NIOSH, 2016), Lundgren et al. (2013) affirm that women are more prone to heat loss and tolerate humid heat, but have higher core temperature.

4.2.3 Work capacity

The percentage of a working hour where the worker is available to perform the planned work is seen as work capacity (Kjellstrom, et al., 2009a). If the thermal conditions and the working load allowed to work during the entire hour continuously, the work capacity will represent 100%. If the worker needs to rest 45 minutes of an hour, due to thermal conditions or/ and physical activity, then the work capacity will be 25%. Based on the ISO and NIOSH standards for acclimatized workers, Kjellstrom et al. (2009b) provide, in Fig. 12**,** information about the percentage of an hour that a worker should be engaged performing the work task depending on thermal conditions and work intensity.

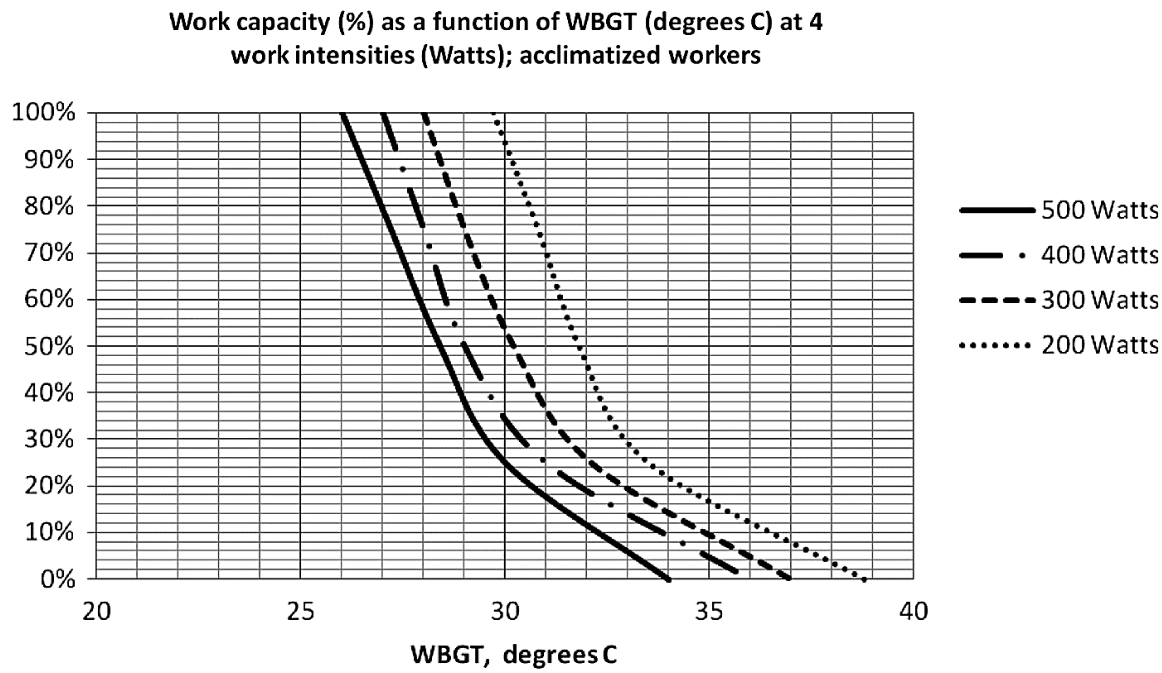

Fig. 12. Work capacity as a function of WBGT. Taken from Kjellstrom, 2009b, pp.7.

Australian Bureau of Meteorology (ABM) has published on its website (Kjellstrom, et al., 2009b; Lemke and Kjellstrom, 2012) a simple method which requires only the values of water vapor pressure (vp) and air temperature (T_a) for the calculation of the WBGT.

Kjellstrom et al. (2009b) used the following equations for the assessment WBGT levels and its potential impact on productivity:

WBGT productivity

$$WBGT_p = 0.567\,T_a + 0.393\,vp + 3.94 \quad (32)$$

Water vapor pressure

$$vp = \left(\frac{RH}{100}\right) \times 6.105\ \times exp\left(\frac{17.27T_a}{(237.7 + T_a)}\right) \quad (33)$$

where

T_a = 24-hour average shaded dry bulb air temperature (°C); vp = 24-hour average absolute humidity (water vapor pressure in hPa); RH= 24-hour average relative humidity (in %). The constant (3.94) represents the impact of WBGT from heat irradiated from the sun in outdoor work in calm wind conditions.

In the next section, a case of study is designed and, following the WBGT method for heat stress assessment in outdoor working population, it is intended to evaluate the impact of thermal conditions in health, work capacity and productivity. The results obtained are discussed at the end of the section.

5. Measurements

The energy coming from the sun incident on Earth's surface is composed of diffuse and direct components. The part of the solar radiation that is available to reach the surface of the Earth without being scattered or absorbed, called direct solar radiation, can be measured by calculating the Irradiance. The irradiance represents the amount of energy incident on the area of a surface, per period of time, with units W/m^2.

In addition, when some flux of irradiance hits the area of a surface, some part of it is reflected and some part is absorbed; if there is any remaining part, it is transmitted. The amount of energy that can be transferred from one system to another as a result of differences in temperature is heat. All the bodies at a temperature above zero emit this form of thermal radiation.

Temperature is the measure of the intensity of energy transitions of molecules, atoms, and electrons of a substance, in other words, temperature is how thermal radiation is measured (Yunus, 2002). The WBGT is a relevant descriptor of the influence of the level of heat experienced by a worker due to exposures to hot environments. It is an empirical index which is a representative measure of a combination of different environmental factors that represent the level of heat stress at which an individual is exposed. The WBGT index is based calculated in measurements that are easily to determine in an industrial environment (ISO 7243).

5.1 Equipment

Different parameters of radiation are needed for the design, sizing, performance, evaluation, and research of solar energy applications. Some of them are the total solar radiation, direct (beam) radiation, diffuse radiation, and sunshine duration. There exist basically two types of instruments to measure solar radiation. The first one is the pyranometer that is used to measure the total radiation (direct plus diffuse) within its hemispherical field of view (Kalogirou, 2009). The other instrument is called pyrheliometer and is mainly used to measure direct solar irradiance. Direct or beam radiation is the portion of solar radiation that reaches the surface of Earth from the sun without any scattering. The level of radiation is calculated by this instrument on direct solar radiation, taking into account all heat losses (Iqbal, 1983). This sensor consists of a copper thermopile with 9 mm diameter; the measurements can be easily made with a digital voltmeter. This instrument allows tracking the sun at its diurnal motion. In order to evaluate the level of heat experienced by a worker when the humidity is combined with temperature, air movement, and radiant heat, WBGT meters are used to record data. Basically, these instruments are made for the analysis of WBGT index in the presence or in absence of solar radiation. Some instruments are provided with three inputs for probes with SICRAM module; the SICRAM module interface between the instrument and sensor connected and communicate the sensor parameters and calibration data to the instrument. The measurements of the WBGT meters, consider the effects of temperature, humidity, and direct or radiant sunlight, where the Black Globe

Temperature monitors the effects of direct solar radiation on an exposed surface. A climate data logger could be used to record the air temperature and relative humidity of the environmental conditions in the facility.

5.2 Software

The National Renewable Energy Laboratory (NREL) provides on its website the SolTrace software tool developed to model concentrating solar power (CSP) systems and analyze their optical performance within the entire system. This tool utilizes Monte Carlo ray-tracing methodology and the user can select a number of rays to be traced. Such software can be used to model the flux of radiation in lineal concentration and punctual concentration collectors. It also allows to model optical geometries in different stages including shape, contour, and optical quality. Besides the NREL website, Wendelin and Dobos (2013) provide information about how to define each state during the simulation process in their technical report entitled " SolTrace: A Ray-Tracing Code for Complex Solar Optical Systems ".

6. Occupational safety practices for outdoor solar workers in central receiver systems

In order to ensure the occupational and safety at work, all the personnel in the solar facility must attend the following instructions. It is assumed that the combination of the recommendation should address the safety issue under the concept of prevention.

6.1 Sun avoidance

Individuals must avoid sun exposures around noon hours with clear sky conditions. Due to the highest levels of solar radiation recorded, it is strongly recommended the avoidance of outside periods during noon (10 am to 1 pm, when it might be required till 3 pm). Even though the UV intensities are at the highest under clear-sky condition, the days with thin clouds could transmit a sense of awareness comfort while the level of UV is still high and give rise to people going outside unprotected. In cases with sky cloudiness conditions, the workers must stay aware and follow the recommendations. During the warmest season of the year, it is recommended to schedule moderate-very heavy working tasks for early morning or afternoon. Workers could use the UVI to be aware of the level of ambient solar UV in the field. Its usage will allow the worker to avoid the outside when the UVI levels are above 7 and use protection when the levels are above 3. UVI describes the level of solar UV radiation at the Earth's surface. It could be monitored by using the UVI local forecast. Individuals must avoid staring at bright surfaces within the solar installation. Prolonging the period of time of eye staring before the blinking effect (avoiding reaction of the eye) will bring effects and side effects to human health.

6.2 Shade spots

In order to reduce the health effects in the skin and eyes due to solar exposure, the presence of shading structures can significantly reduce the total UV exposure. The workers are encouraged to fallow the shadow rule which is about the necessity of seeking a sheltered spot when the shadow of themselves is no longer than their height. In the moment that the skyline sight is blocked the ocular exposure reduces significantly. Also, implementing shade spots could transform continuous exposures into intermittent exposures. If shade spot structure is made only to block the direct solar radiation exposure, probably the individuals might experience an impact on the skin due to the diffuse solar radiation (ICNIRP, 2010). It is highly suggested that the sheltered spot is made of materials that will absorb the UV radiation. Moving Structures (E.g. Shelters, sunshade, canopies…etc.) on the field can provide substantial protection or partial shade in solar environments. These small shade structures provide protection for short periods of time (1-2 hours or less) due to it may leave large amounts of sky visible, but still enough for those workers who may develop a short task under near maximum limits of exposure (Vecchia, et al., 2007).

6.3 Ocular protection

Sunglasses are frequently used to glare by decreasing the luminance of visible radiation reaching the eye. Even though eye protection attenuates the UV radiation, the degree of attenuation is not apparent by visual inspection of the lenses (Vecchia, et al., 2007). The style of sunglasses wrap-around with side panels is relevant for the reduction of the amount of scattered and reflected solar UV radiation reaching the eyes (ARPANSA, 2006). The action of seeing directly to the sun (8 W/m^2) should be avoided due to it has sufficient potential to cause a permanent damage to the eye. The action of looking directly at the reflected irradiance from a heliostat's surface should also be avoided. Even though this situation is classified as a temporary risk situation, it is near the threshold limit of an eye permanent damage. The UNE-EN 172 suggest the designation on the proper solar filters for lenses [Table 13] in order to ensure the protection of the eye to excessive solar radiation exposures, as well as, increase the comfort and visual perception in workers. The main purpose of solar filter designation is to protect the organ that provides the vision against direct, scattered and reflected solar radiation. It is expected that a filter on lenses protects the eye against the UV spectral region by absorbing the visible radiation. The scale represents the protection level of the filters based on the spectral coefficient of transmission. The spectral transmission coefficient (τ_V) for the type of radiation comprehend between 315 and 380nm is maximum 0, 5τ_V.

Table 13. UNE-EN 172 Individual protection of the eye.

Scale	Range of values of the transmission coefficient in the visible radiation spectral band (in %) from 100%	Application	Designation
5-3, 1 6-3,1	17, 8 – 8,0	To observe the sky, snowed surfaces, sand, bright water surfaces. The 6-3,1 filter absorb the IR radiation	Dark range
5-4,1 6-4,1	8,0 – 3, 0	Intense radiation. The 6-4,1 filter absorb the IR radiation	Extreme dark
Note: The suggested filters do not bring protection against the direct observation of the sun, neither the direct observation of the surface of a heliostat. Those situations must be avoid.			

6.4 Sunscreen

It is recommended applying sunscreen, with both UV-B and UV-A protection and SPF of 15, 30 or 50, over the parts of the skin exposed in locations with a UVI of 3+. The sunscreen must be applied to dry skin and let it be absorbed between 15-30 minutes before the exposition. Sometimes due to high temperatures, the skin sweats so the skin must be cleaned and the sunscreen has to be applied all over again. If the skin makes contact with water it may be reapplied over that zone that made contact. Sunscreens should be repeatedly and constantly applied in abundant quantities in periods of 30 min-2hours depending on the skin type. The worker must know that an individual would get sunburn as a consequence of the inconsistent application of sunscreen. Applying sunscreen at approximately half the required thickness will reduce the effectiveness of its protection by achieving only near to half of the sunscreen rating (ARPANSA, 2006).

6.5 Clothing

It is recommended the use of clothing designed to provide a high-level protection from solar radiation and hats that provide shade to the face and neck. Hats with wide brims and a flap of fabric for covering the neck provide the particularly effective for protection (Vecchia, et al., 2007). It is important to address that clothing will work as a barrier between the skin and the environment to protect against normal environmental elements of heat, cold, moisture, and abrasion. In addition, clothing also alter the rate and amount of heat exchange between the skin and the ambient air by convection, conduction, radiation, and sweat evaporation. The workers in solar facilities will require protective clothing that promotes the heat exchange or cooling. The NIOSH (2016) provides some information and suggestions about the usage of auxiliary clothing systems such as water-cooled garments, air-cooled garments, cooling vests, wetted over-garments and heat reflective suits, or simply applying frozen materials under the clothing. Those auxiliary cooling approaches should be used only and after inevitable working periods in extreme weather conditions. Water-cooled garments, air-cooled garments, cooling vests, and wetted over-garments are not actively engaged while developing tasks due to practicality (limitations for operation). The NIOSH also suggested Work/rest periods of times for those workers wearing normal clothing [Table 14]. It is important to notice that the temperature readings must be adjusted before comparing them with the temperature in the table.

*Table 14. Work/rest schedules for workers wearing normal work clothing**

Adjusted temperature (°C)	Adjusted temperature (°F)	Light work (minutes work/rest)	Moderate work (minutes work/rest)	Heavy work (minutes work/rest)
32	90	Normal	Normal	Normal
33	91	Normal	Normal	Normal
33	92	Normal	Normal	Normal
34	93	Normal	Normal	Normal
34	94	Normal	Normal	Normal
35	95	Normal	Normal	45/15
35	96	Normal	Normal	45/15
36	97	Normal	Normal	40/20
37	98	Normal	Normal	35/25
37	99	Normal	Normal	35/25
38	100	Normal	45/15	30/30
38	101	Normal	40/20	30/30
39	102	Normal	35/25	25/35
39	103	Normal	30/30	20/40
40	104	Normal	30/30	20/40
40	105	Normal	25/35	15/45
41	106	45/15	20/40	Caution[1]
42	107	40/20	15/45	Caution[1]
42	108	35/25	Caution[1]	Caution[1]
43	109	30/30	Caution[1]	Caution[1]
43	110	15/45	Caution[1]	Caution[1]
44	111	Caution[1]	Caution[1]	Caution[1]
44	112	Caution[1]	Caution[1]	Caution[1]

*With the assumption that workers are physically fit, well-rested, fully hydrated, under age 40, and have adequate water intake and that there is 30% RH and natural ventilation with perceptible air movement.

[1]High levels of heat stress; consider rescheduling activities.

Note: Adjust the temperature reading as follows before going to the temperature column in the table:

Full sun (no clouds): Add 13°F and then convert to °C

Partly cloudy/overcast: Add 7°F and then convert to °C

Per relative humidity:

10%: Subtract 8°F and then convert to °C; 20%: Subtract 4°F and then convert to °C

30%: No adjustment; 40%: Add 3° F and then convert to °C

6.6 Acclimatization heat program

In order to achieve the full heat acclimatization, unacclimatized workers should pass through brief daily exposures to heat and gradually increase the time exposure. A heat-acclimatization program will allow workers to increase the ability to develop activities in hot environments and will decrease the risk for unsafe acts.

Introduction into acclimatization is based on reducing the metabolic heat load and promoting the adequate exposure to hot environments. The NIOSH (2016) provides an introductory process for heat adaptation [Table 15].

Table 15. NIOSH recommendations for acclimatization process of new employees

Workers without acclimatization		
Days	Maximum % of work duration per day	Work shift (8 hours-100%) in split sessions
1	≤ 20%	< 2 h
2	≤ 40%	≤ 3 h
3	≤ 60%	≤ 5 h
4	≤ 80%	≤ 6 h
5	≤100%	≤ 8 h
Workers with acclimatization		
1	50%	4 h
2	60%	5 h
3	80%	6 h
4	100%	8 h
Note: the maximum increment of ≤ 20% of time each day for workers that have not passed through an acclimatization process before, means that there are workers that would require a lesser increment each day so the period of adaptation would be extended from 7–14 days		

Basically, it is recommended the short repeated exposures during 7 to 14 days that will allow the performance of work activity with a reduction in core temperature and thermoregulatory strain.

The minimum heat time exposure for a worker to develop acclimatization is at least two hours per day; which may be broken into 1-hour exposures. Resting periods break continues heat exposures and contributes to the acclimatization process and workers safety; opposite to long rest periods (24hr) after long time heat exposures at work. Excessive exposures could result harmful for workers without heat acclimatization because it is difficult for those individuals to replace all of the water loss in sweat. The level of acclimatization will depend on the initial level of physical capability and the amount of heat stress experienced by the worker (DOD 2003, cited by NIOSH, 2016).

The physical fitness of individuals is an important factor within the acclimatization process and those that are physically fit require 50% less time to develop acclimatization. The acclimatization also depends on other factors such as age, sex gender, body fat, drugs intake.

6.7 Work/rest schedules and water intake

Implementing work and rest schedules where the administration should control the time of exposure of the workers by the establishment of the amount of time that the workers are allowed to be developing tasks outside, see section **4.2.1. Working and resting periods**. The suggested amount of time for both work and resting periods are defined per hour. The reduction of the heat load in high temperatures and promoting the development of job activities in cooler periods of the day are highly suggested.

When an individual is developing a task under hot weather conditions, usually with physical work involved, the body will cool down through sweat. An excess of sweating could end in water loss and salt depletion. Water intake replaces the water and fluids that contain electrolytes lost during sweating. If the lost water and salt are not replaced, then body levels will progressively decrease ending in dehydration. The amount of sweat production depends on the state of hydration of the body so that progressive dehydration results in a lower sweat production that could increase in body temperature, which can lead to major health issues. Water lost in large quantities of sweat is often difficult to replace completely as the day's work earnings, every effort should be made to encourage individuals to drink water or other fluids that contain electrolytes and salty food to compensate the losses.

The replacement of water lost in sweating will improve the development of physiologic adaptation, therefore water intake [Table 16] and salty foods are highly suggested. Heat acclimatization increases the sweating rate; therefore workers will need to take water (and other fluids for salt and water replacement) during frequent intervals such as 236 ml every 15-20 min.

Table 16. Recommendations for fluid replacement during warm weather conditions

WBGT index		**Easy work (250 W)**		**Moderate work (425 W)**		**Hard work (600 W)**	
(°C)	**(°F)**	**Work/ Rest (min)**	**Water intake* ($L \cdot h^{-1}$)**	**Work/ Rest (min)**	**Water intake ($L \cdot h^{-1}$)**	**Work/ Rest (min)**	**Water intake ($L \cdot h^{-1}$)**
25-28	78–82	Unlimited	±0.5	Unlimited	0.70	40/20	0.70
28-29	82–85	Unlimited	±0.5	50/10	0.70	30/30	±1.0
29-31	85–88	Unlimited	0.70	40/20	0.70	30/30	±1.0
31-32	88–90	Unlimited	0.70	30/30	0.70	20/40	±1.0
32+	90+	50/10	±1.0	20/40	±1.0	10/50	±1.0

Source: adapted from NIOSH, 2016.

*Fluid needs can vary on the basis of individual differences (± 236 ml·h-1) and exposure to full sun or full shade (± 236 ml·h-1). Fluid intake should not exceed 1.42 L·h-1.

Note: Rest = sitting or standing, in the shade if possible.

6.8 Engineering controls

The establishment of engineering controls within the solar facility has preventive purposes of bringing the possible risk situations below the applicable maximum limits of exposure. In order words, this controls aims to ensure the safety exposures while developing activities at work.

Continuous monitoring of the solar radiation fluxes, the UVI and other environmental factors at the solar facility will provide data that would help workers to be aware in real-time about extreme values of exposure to solar radiation. Information about the UVI could be obtained through monitoring a local forecast. Besides, the information of solar radiation fluxes and temperature on the field, such as the direct solar radiation and WBGT temperature index, could be monitored by employing equipment that should be installed on the field. The information from those devices could be used to emit the alert whenever the data exceeds the safety limits of exposure.

The NIOSH (2016) suggest the development and implementations of a written Heat Alert Program whenever weather service forecasts ensure that a heat wave is likely to occur the following day or days. The daily maximum temperatures that are characteristically attributed to a heat wave are the levels exceeding 35°C (95°F) and beyond. During this period of time, the weather must be monitored all the time and the installation must under alert period. This means that the facility has to count with access to water and electrolyte fluids, air-conditioned shelter and all the personnel of the solar facility must follow all the work safety practices combined, as well as the following issues:

- Reschedule tasks that require high or very high work activity
- Rotation of the workers according to the work/ rest schedules
- Resting periods under the air conditioning shelter
- Reminders about the amount of water intake that has to be consumed
- Restraint the worker over-exposure on field
- Restraint work activities to employees with symptoms of dehydration

For the practical application of the alert program, it will be required the cooperation of the administrative staff, the maintenance and operative workforce.

6.9 Administrative controls

The present structure towards the occupational and health in CRS should be consider as a base for the establishment of administrative controls such as the modification or reduction of the time of exposure, improving heat tolerance and skin adaptation, the establishment of work demands, training, and periodic medical evaluations of workers. Also, the administration should implement protection policies and monitoring program. In order to control health hazards to outdoor exposure, the monitoring program should include information about:

- Global solar UV index (UVI)
- Self-protection and behavior
- Shelter in shades

6.9.1 Educational programs

The occupational health and safety training for employees that includes information about recognizing symptoms of heat-related illness; proper hydration; care and use of heat-protective clothing and equipment; effects of various factors (e.g., drugs, alcohol, obesity, etc.) on heat tolerance; and importance of acclimatization, reporting symptoms, and giving or receiving appropriate first aid. It should also be provided information about how to monitor weather; reports and weather warnings. The individuals developing work tasks in the solar facility requires to understanding the variability of the solar radiation fluxes during the day, as well as, the impact of cloud conditions. Breaks under cloud cover conditions don’t ensure safety exposures and could contribute significantly to the daily UV dose (ICNIRP, 2010).

The program should provide an introductory session. Through educational guidance, the workers will be aware of the environmental conditions at work and will help them pass through the transition of skin adaptation according to their own skin type. In particular those individuals with skin type I-II, who will need sun protection all over the year (ICNIRP, 2010; Vecchia, et al., 2007).

Supervisors should inform the solar facility workforce through:

- Fact sheets on solar exposure risks and safety measures
- Communication about the Ultraviolet index usage
- Visual information in the control room about safety behavior during work
- Introduction about clothing, sunscreen and adaptation process to solar environments (gradual exposures and water intake).
- Work and rest schedules
- Water and sunscreen cream dispensers should be installed at the work site.

The solar facilities should put sings on the near surroundings in order to spread the awareness of glare and glint to individuals or drivers passing by the solar installations. Those facilities which aren't physically materialized or they are on a project state level, It should be evaluated the setting of the facility near airports and main roads.

6.10 Solar radiation and its health effects

Wavelength (nm)	Affected area	Primary effects	Description	Secondary effects	Side effects
380-1400nm UVA-VL-IR	Ocular	Thermal eye lesions	Most of the useful vision is lost	Burns in the retinal tissue	
1400nm-3000nm-10 µm IRB, IRC	Ocular		Protein coagulation of the front and middle layers, and ulcers	Burns in the cornea	
315-400nm UVA; 780-3000nm IR	Ocular		Opacities in the lens	Cataracts	
180-400nm UV	Ocular		Inflammation on the cornea (the feeling of sand in the eye)	Keratitis	
400-700nm VL; 780-3000nm IR	Ocular		Vision loss in a portion of the visual field	Scotoma	
380-700nm UV-VL	Ocular		Inflammation of the retina of the eye	Retinitis	

400-780nm VL	Ocular	Glare disability	Veiling luminance (scattered light) in the human eye which reduces the contrast in the scene	Reduction of the visual performance, flash blindness, after image and retinal burns	Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Glare discomfort	Continues exposure to a bright source that reduces the ability to see details in the area of the visual field	Headaches	Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Afterimage	Blind spot in the visual field which persists from seconds to a few minutes after the light in no longer in the visual perimeter		Falls or other kind of accidents ended in injuries
400-780nm VL	Ocular	Flash blindness	Immediate and temporary vision loss produced when the retinal light-sensitive pigments are bleached by the intensity of light (usually the eye is exposed to higher intensities of those that it is adapted at that moment)		Falls or other kind of accidents ended in injuries

400-780nm VL	Ocular	Luminance flicker	Temporal intensity modulations of bright lights	Vertigo, disorientation, mild headaches, muscle spasm ended in convulsions and epileptic seizures	Falls or other kind of accidents ended in injuries
315-1400nm UVA-VL-IR	Skin	Photo-aging	The skin is marked by fine lines and a modest skin laxity.		
290-400nm UV	Skin	Photo-immunosupp ression	The immune skin system is not available to recognize and destroy the invading pathogens and/ or skin cancer cells	Skin cancer	
290-700nm UV-VL	Skin	Photo-sensitivity (Photo-dermatoses)	Continues exposures that produce a sensitization phase resulting in a delayed-type of hypersensitivity reaction	Photo-allergy and/ or Photo-toxicity	Solar urticaria, porphyrias, polymorphus, light eruption, hiroa vaciniforme, actinic, prurigo, chronic actinic, dermatitis and others
380-3000nm UVA-VL-IR	skin	Sunburns	Skin tissue injury caused by the exposure to solar radiation	Red appearance of the skin due to the increment in blood content near the sink surface	Erythema (180-400nm): skin redness, edema, pain and skin swelling Apoptosis: delayed cell killing

	Skin	Heat rash	Pricking sensations during heat exposure	Skin irritation due to the excessive seating during hot and humid weather conditions	
	Skin	Anhidrotic heat exhaustion	Extensive areas of skin with no sweating but with gooseflesh appearance	Skin trauma (heat rash, sunburn) causes sweat retention in skin and reduce evaporative cooling	Temporary heat intolerance
	Nervous system	Heat exhaustion	Dehydration (loss of water and salt) and depletion of circulation blood volume	Fatigue, nausea, headache and giddiness, skin clammy and moist, pale complexion, muddy or hectic flush, may faint on standing with rapid thready pulse and breathing, and low blood pressure	
	Nervous system	Heat syncope	Lack of acclimatization by a prolonged standing or sudden rising from a sitting or lying position and dehydration	Light- headedness, dizziness and fainting	
	Nervous system	Heat cramps	Loss of body salt in sweat, water intake dilutes electrolytes, water enters to muscles causing spasm	Painful spasms of muscles used during work activities such as arms, legs and/ or abdominal	Heat exhaustion

	Nervous system	Transient heat fatigue	Behavioral disorders	Discomfort and physiologic strain	Decrement in productivity
	Nervous system	Chronic heat fatigue	Behavioral disorders	Psychosocial stress produce by the hormonal imbalance	Decrement in productivity
	Nervous system	Heat stroke	The regulation temperature system of the body fails when the body temperature rises, the sweating mechanism fails and the body is unable to cool down itself	Confusion, consciousness loss, convulsions, lack of sweating, dry skin, very high body temperature and hallucinations	Death
The effects differs in severity or has a low capability of impact in human health depending of the intensity of the source and time of exposure. Some of impacts begin as reversible effects and end as irreversible effects due to continue exposures in time.					

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