

Ergonomic design interventions for ensuring OSH of the workers engaged in Floating Solar PV installation and maintenance

A thesis submitted

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

by

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Declaration

I hereby declare that the thesis titled “*Ergonomic design interventions for ensuring OSH of the workers engaged in Floating Solar PV installation and maintenance*” carried out under the guidance of Dr. Sougata Karmakar, Professor & Head, Department of Design, Indian Institute of Technology (IIT) Guwahati, Assam is a piece of original work. This thesis does not contain any material previously published in any form. Wherever work from other publications have been referred to, the authors of the said publications have been adequately cited and acknowledged. Credit has been given to all individuals/organizations/entities who have directly or indirectly assisted in the various stages of the present research. Highest standards of ethics and integrity were maintained throughout the research work and no data/information has been falsified or misrepresented in this thesis.

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Certificate

This is to certify that the work contained in this thesis entitled “Ergonomic design interventions for ensuring OSH of the workers engaged in Floating Solar PV installation and maintenance” has been carried out under my guidance and supervision and is a bonafide work of Abhijit Sen. This work, submitted for the degree of Doctor of Philosophy is original and contains no materials previously published or written by any other person for degree or diploma at IIT Guwahati or any other institute or university. All the requirements including mandatory coursework as per the rules and regulations as mentioned in the Ph.D. ordinance for submitting the thesis for Ph.D. degree of Indian Institute of Technology Guwahati have been fulfilled.

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This thesis is dedicated to my inspiration

Swami Vivekananda

&

My late father

Shri Ashim Kumar Sen



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Executive Summary

Climate change concerns have prompted a concerted global push towards generation of renewable energy. Within the ambit of the solar photovoltaic industry, floating solar photovoltaic (FSPV) projects are growing in number in India. As a result, a large population of fixed term workers with little or no experience or training are being engaged in jobs related to installation and maintenance. While working in these new kinds of workplaces, there are likely to be several human-machine mismatches giving rise to ergonomic issues. As a result, these workers are exposed to emerging occupational health and safety (OSH) risks that can have both short term and long-term health effects as well as direct & indirect costs. Immediate attention for mitigation of these risks must be an important priority for all stakeholders. Little or no research has been conducted covering these OSH dimensions in the FSPV sector. In this backdrop, a comprehensive literature review using the PRISMA method was carried out followed by formulation of research questions. They are as follows:

- RQ1: What are the various features of FSPV projects and reasons for the growth of the sector in recent years?
- RQ2: What are the different kinds of physical, chemical, environmental, psychosocial, and organization related risks and their effect on workers in the floating solar photovoltaic sector and workplaces/occupations similar to the work environment (aquatic) of an FSPV project?
- RQ3: Are training programs/modules and Occupational Safety & Health (OSH) standards available for the FSPV sector?
- RQ4: What are the existing design approaches in the solar PV industry (with emphasis on the FSPV sector) as prevention and or OSH risk mitigation strategy?
- RQ5: What is the OSH risk perception of safety managers and FSPV workers wrt FSPV projects?
- RQ6: What are the cross-cultural and socio-demographic differences in OSH risk perception of solar PV workers?
- RQ7: Which design concepts/interventions can be developed from an ergonomics perspective for risks falling in the very high & high categories requiring immediate attention in FSPV projects?
- RQ8: What would be the perceived effect of the design interventions on ability of risk mitigation, ability to address the ergonomics issues, usability, and productivity improvement?

Knowledge gaps and possible design opportunities were identified. The aim of the present study is to investigate and measure the specific nature of OSH risks faced by the workers engaged in FSPV projects and to design context specific solutions from an ergonomics design perspective for risk mitigation. Objectives were defined and field studies were undertaken after obtaining approval of the ethics committee, informed consent, and permission from participating organizations.

The objectives are the following:

1. To explore various features of FSPV projects and identify the emerging risks (occupational, environmental, psychosocial etc.) being faced by the workers engaged in FSPV installation and maintenance including existence of training modules and OSH standards.
2. To explore the existing design approaches for mitigation of OSH issues in FSPV installation and maintenance.
3. To investigate and measure the specific nature of problems being faced by the workers due to the risks through field studies.
4. To explore cross-cultural aspects of solar photovoltaics workers from an OSH and socio-demographic dimension.
5. To develop ergonomic design solutions/concepts to protect against the risks for which solutions do not exist using the product design life cycle.
6. To measure the effectiveness of the design interventions from the perspective of risk mitigation ability, ergonomics, usability, and productivity.

Based on the aim and objectives set out in this thesis, working hypotheses statements were formulated as follows:

Hypothesis 1: Context-specific design interventions addressing the prioritized risk factors would have the potential benefits towards improved safety and occupational health of floating solar PV workers engaged in installation and maintenance.

Hypothesis 2: Cross-cultural factors and sociodemographic traits significantly influence the perception of occupational risks by workers engaged in solar photovoltaic projects.

In accordance with the objectives, literature review and exploratory field studies in India were carried out. Twenty different OSH risks were identified and measured at two FSPV sites in India based on severity and vulnerability using a risk perception questionnaire developed during the research work. Stakeholders such as safety managers (n=30) and FSPV workers (n=53) participated in the studies. In addition, discomfort glare, socio-demographic and environmental parameters at both the sites were also measured. The top five risks identified include falling into water, heat stress, electrocution, solar radiation, and slips/falls on the floating platform. Discomfort glare was also identified as a severe risk factor.

In a collaborative study, cross-cultural studies on OSH risk perception and socio-demographic aspects (age, weight, height, income & work experience) were carried out amongst solar PV workers (n=135) engaged in Saudi Arabia and India. Findings indicated differential risk perceptions across the countries towards the same kind of risk and correlation of socio-demographic factors with risk factors. Hence, Hypothesis 2 of the present research is accepted. This part of the research work explores the dimensions of cultural ergonomics in reference to solar photovoltaics projects as a maiden effort.

In accordance with the risks identified in the very-high and high categories, design concepts were developed using three methodologies namely, hierarchy of controls, Codesign and bow-tie risk

analysis. Innovative and novel design concepts resulted from the three methods and CAD models were developed to address the contextual risks.

Discomfort glare was found to be a severe risk factor requiring immediate attention. A prototype of an anti-glare and anti-UV eye protector was developed to address the risk of discomfort glare. Hypotheses statements specific to the eye protector were formulated to validate the design. They include:

h1: Performance of a visually demanding task in FSPV projects will improve significantly with anti-glare and anti-UVR eye protector.

h2: Use of an anti-glare and anti-UVR eye protector designed for FSPV workers will reduce discomfort glare from various sources at the workplace and improve eye safety.

The eye protector named 'GlareSafe' was positively validated on the parameters of productivity in visual tasks, reduction in discomfort glare and usability through field studies.

Statistical (t-test) and other analyses involving FSPV workers and solar PV engineers resulted in positive validation of the product i.e., eye protector and acceptance of alternate hypotheses for h1 & h2. The eye protector can be used in any outdoor work under the hot sun. The design of the eye protector involves retrofitting a visor to a safety helmet. This is aimed at ensuring dual use of both the helmet and the visor for better PPE compliance. The product also addresses contextual requirements such as hydration, wiping of sweat and preventing PPE loss in water. Flowing from this design, a proposed framework of Compliance through Design (CtD) is an output of this research work.

Several other novel design concepts such as floating fence, redesigned floater, maintenance board and maintenance mirror were validated through a questionnaire where solar PV engineers compared the existing design/working condition with the proposed concept(s). Significant improvement was perceived in favor of the proposed design concepts. This improvement in safety & occupational health of the workers through the context-specific design interventions developed in this study results in the acceptance of Hypothesis 1 of this research. Most of the design concepts are low cost and can be adopted by the stakeholders to avoid direct and indirect costs related to negative OSH events. The findings of this maiden study add new knowledge in the identification of OSH risks in the FSPV sector, measurement of OSH risk perception, socio-demographic profiling of FSPV workers, development of novel design concepts and framework for implementation of a design strategy. Application of design as a risk mitigation strategy is a major dimension of this work and is ultimately expected to add to the safety quotient in FSPV projects.

This research is also aligned to the Sustainable Development Goals (3,8,7 & 13) of the UN. The various facets of this present research will certainly be beneficial to safety managers, FSPV project developers, workers, policy makers, industrial designers, ergonomists, and other related stakeholders.

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Chapter 1: Introduction



Abstract

Climate change concerns and commitment to sustainable development goals have resulted in a global growth of renewable energy installations. Within the solar PV industry, floating solar photovoltaics projects is being preferred because of its many advantages. To execute these new projects, many fixed term workers are being engaged in the work of installation and maintenance. The outdoor work involves several emerging occupational and safety risks which require immediate attention and appropriate mitigation measures. Little or no research has been carried out concerning these emerging OSH issues which is the focus area of this research.

This chapter discusses the growth of the renewable energy industry, evolution of the floating solar photovoltaic sector in India and the emerging OSH risks associated with installation and maintenance affecting the workers.

The research motivation, background of the research area, research gaps, research questions, problem statement and aim and objectives are discussed.

1. Introduction

Electricity is an important prerequisite for industrial and socio-economic growth. Although the process of power generation from water (hydropower) and wind was discovered in the late 1800s, it was coal fired power stations that formed a larger part of the energy mix and was an important catalyst for the industrial revolution. Sustainability and climate change concerns in recent years have emphasized the need for producing electricity from renewable energy sources. An important landmark event in this quest was the Paris Climate Change Agreement in the year 2015 where several countries have committed to reduce the average increase in global temperature by reducing the emission of greenhouse gases (GHGs) and move towards net zero emissions. Other key drivers for a rapid transition towards renewable energy include the UN Sustainable Development Goals (SDGs 7&13) and Convention on Biological Diversity 2021.

The energy from the Sun is infinite. Thirty minutes of sunlight falling on Earth will be able support the annual energy demand of the globe (Kumar et al., 2015). As a result of the abundance in the energy of the Sun, solar photovoltaic installations have seen an exponential growth. The global solar PV capacity has grown from 40.33 GW in 2010 to 710 GW in 2020 (IRENA, 2019). It is forecasted that the installed capacity of solar PV would be 8.4 terawatt (TW) in 2050 (DNV Report, 2021).

1.1 Employment in the solar PV industry

The global growth in solar PV installations has resulted in a large workforce being engaged in manufacturing, installation, maintenance, and decommissioning activities. A report estimates that 11.7 million jobs will be created in the solar PV industry by 2030 (IRENA, 2019). The workers engaged in this entire value chain are mostly from the unorganized/informal sector and are engaged for intermittent periods. These workers are exposed to new technologies, tools, work methods, materials, and job requirements. Such challenges in their day-to-day work result in a mismatch

between the worker and the job, exposing the workers to multiple hazards. These hazards, if not addressed, can have enormous socio-economic costs. The cost of injuries at the workplace was found to be between 2.9% to 10.2% of GDP in a study that covered five European Union countries (Tomba et al., 2021).

1.2 Renewable energy scenario in India

The renewable energy capacity of India in January 2023 is more than 168 GW, which is 40.7% of the total installed capacity (Ministry of Power, Government of India, 2023). India is a founding member of the International Solar Alliance (ISA), and the government has initiated several policies and programmes to increase the share of renewables with a special focus on solar PV installations. India's Intended Nationally Determined Contribution (INDC) commitment is to generate a cumulative electric power capacity of 50 per cent from non-fossil fuel-based energy resources by 2030 which is equivalent to a target of 500 GW. Figure 1.1 shows the growth in capacity of renewable energy sources in India from 2010 to 2022.

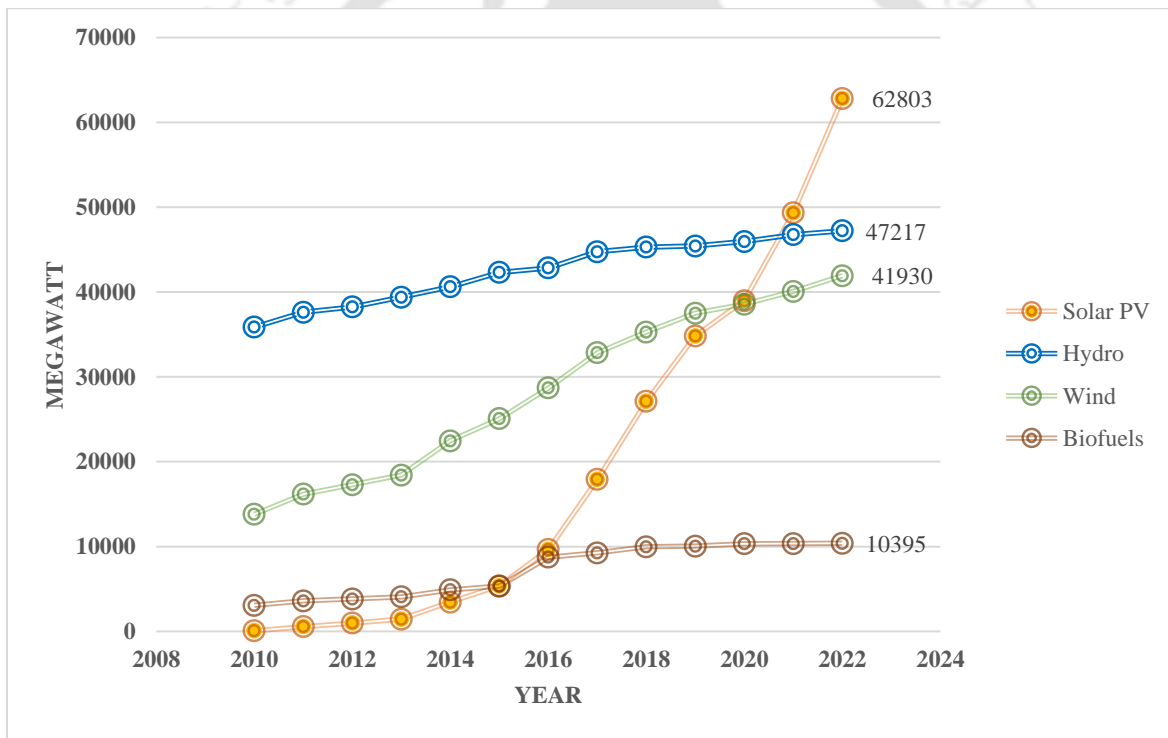


Figure 1.1. Growth of installed capacities (in MW) of different types of renewable energy sources in India between 2010 and 2022 (Compilation by authors based International Renewable Energy Agency data)

1.3 Emergence of floating Solar PV projects in India

In recent years, floating solar photovoltaic (FSPV) projects have seen exponential growth because of its distinct advantages over other types of solar photovoltaic installations and has been shown to have a global potential of 400 GWp (International Bank for Reconstruction and Development, 2019). These projects are installed on lakes, ponds, reservoirs of dams and thermal power plants, water basins, mine quarries, water treatment plants, and other water bodies. Floating

solar is still in nascent stages of development in India. A report by the Energy and Resources Institute (TERI,2019) estimates that about 18,000 km² water surface area is suitable for the installation of FSPV plants across States and Union Territories of India. Land is a sensitive socio-economic issue in India and project developers are increasingly moving towards solar PV installations over water. Some advantages of FSPV projects include a higher efficiency than other solar PV projects (Goswami et al., 2019), conservation of water (Azami et al.,2017), economic viability (Ferrer-Gisbert et al., 2013), can be combined with hydro plants (Cazzaniga et al., 2019) and ensures sustainability (Pringle et al., 2017).

1.4 Occupational Safety and Health (OSH) issues in the installation and maintenance of floating solar photovoltaic projects

Safe and comfortable work is an important objective for all stakeholders. However, several diverse kinds of OSH risks are emerging in relation to FSPV project execution. A major part of the installation and maintenance of FSPV projects involves manual work on both land and water. The risks especially while working on water are distinct and critical. The occupational risks on land and water associated with a typical floating solar photovoltaic project are depicted in Figure 1.2.

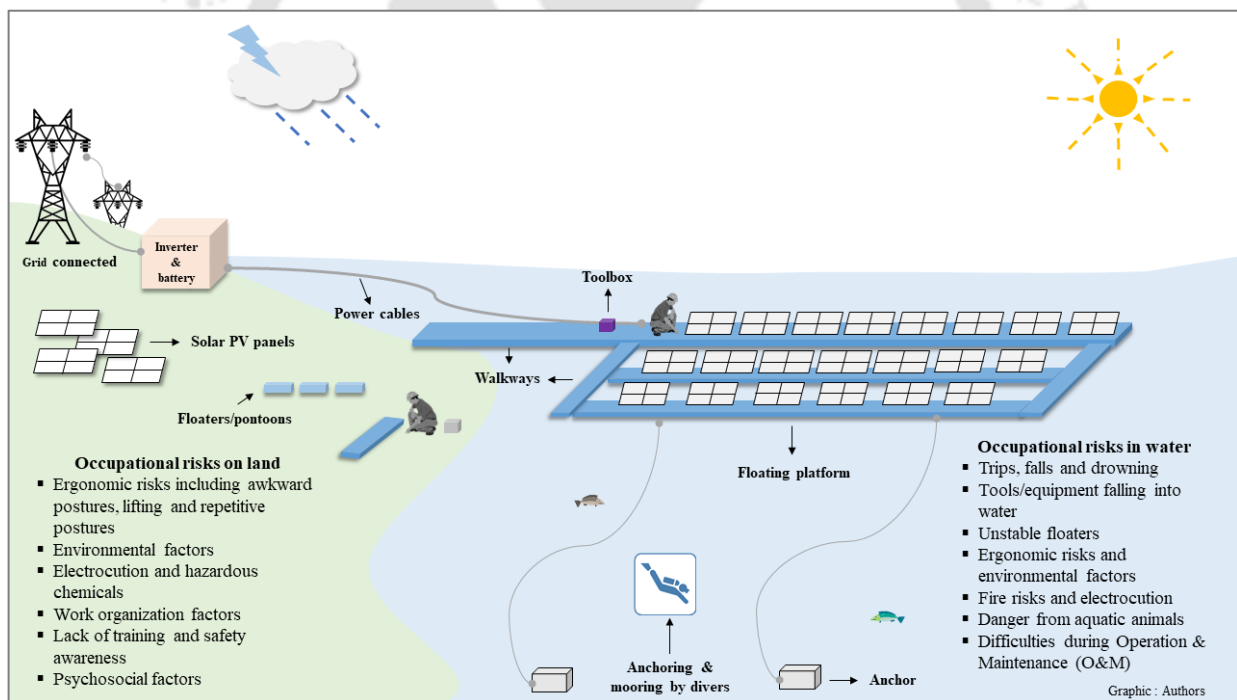


Figure 1.2. Occupational risks on land & water during installation and maintenance (Source: author)

The work in a FSPV project involves the unloading, carriage, and assembling of unwieldy and heavy solar photovoltaic panels, frames, bulky floats/pontoons, and electrical equipment. As a result, the workers are exposed to several occupational hazards such as repetitive work, bending for long duration, awkward postures, and handling load carriage. These are potential occupational risk factors for developing Work-related musculoskeletal disorders (Stack et al., 2016) which can lead to injuries to the tendons, nerves, cartilages, muscles, joints, ligaments, and other parts of the

body. Some examples of such disorders include neck injuries, carpal tunnel syndrome and epicondylitis (Bridger, 2018). Work-related musculoskeletal disorders (WMSDs) are linked to lost workdays, low productivity, and increased healthcare costs (Institute of Medicine, 2001). A labor survey in the UK has revealed that there is a prevalence of 1420 WMSDs per 100,000 workers in 2020/21. In the United Kingdom alone, 1.7 million workers were suffering from work related ill health in 2020/21 (Health & Safety Executive, 2021).

Requirements of work on a constantly moving floating platform and high wind speeds put postural challenges on the workers. Under these conditions, maintaining balance with no barrier against falls into water creates an unsafe condition. Figure 1.3 shows a worker slipping on the floating platform and falling into water during installation of a FSPV project.

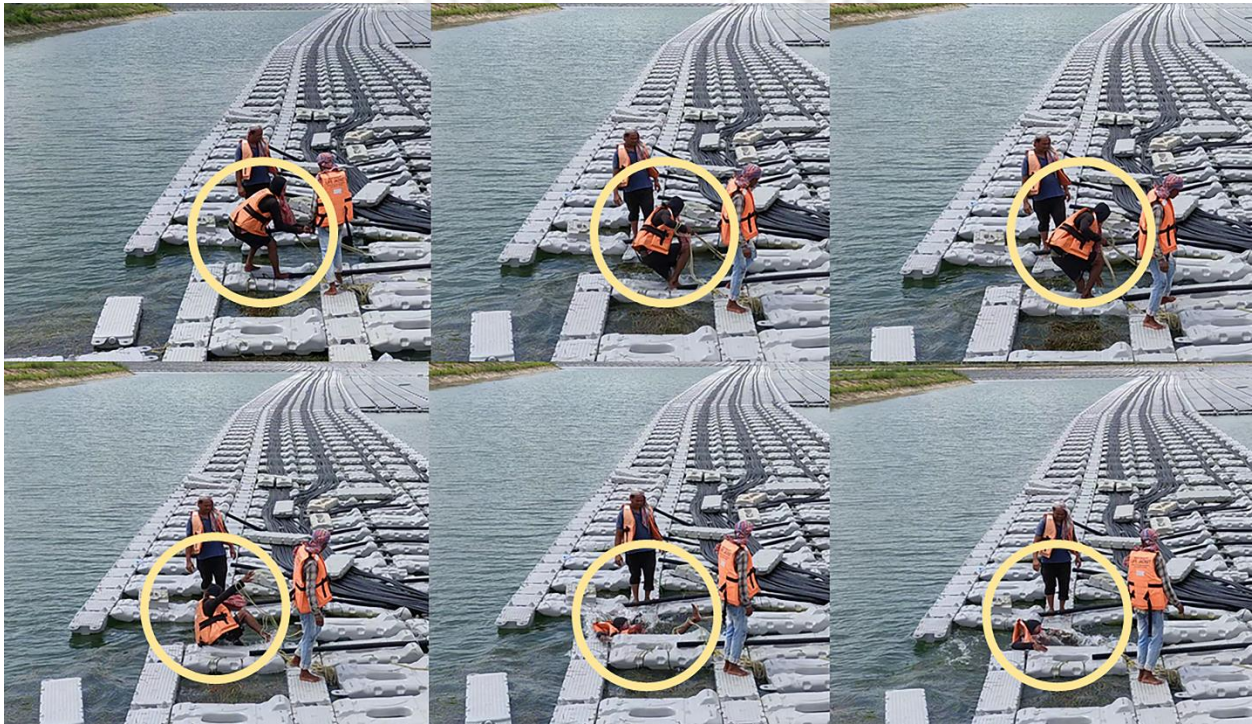


Figure 1.3. Workers are exposed to several OSH issues including falls into water (Image: author)

An aquatic working environment increases the chances of falling into water. Since water and electricity do not mix, a humid workplace increases the possibilities of electrocution. Use of power tools involves the risks of vibration which make FSPV workers prone to hand–arm vibration syndrome or Raynaud’s phenomenon (Bridger, 2018). Noise is also associated with the use of many power tools and unless such risks are controlled may lead to noise induced hearing loss.

A critical activity during installation is the anchoring and mooring of the FSPV system. For mooring (Figure 1.2), divers are engaged for diving into the depth/bed of the water body to fix concrete blocks to keep the FSPV installation in place. In such an environment, divers may suffer from hypothermia and may even drown. In relation to work on a floating platform, work requirements in confined spaces for reaching remotely located installation points results in awkward and non-neutral postures. This may lead to disorders of the bursae, tendon, muscles,

ligaments, and fascia. Lesions of the nerve may also be a serious consequence of working in such postures for prolonged periods. Injuries from sharp objects and non-chamfered edges are possibilities at the FSPV workplace. A typical FSPV layout has several gaps and crevices where feet can get stuck, and workers can fall over. Slips and trips are also a major risk due to the presence of water on the floating platform which is often invisible. The wires and electrical equipment also cause tripping hazards. Contact with electricity leading to electrocution is a major OSH risk factor. The consequence is often serious injury and even death. Solar photovoltaic projects are located in areas where the solar irradiation is on the higher side. This results in a microclimate which is hot and humid. Workers are engaged in such hot environments for prolonged periods which can lead to dehydration, heat hyperpyrexia, heat syncope and other heat illnesses. Solar radiation is a major source of risks affecting the skin and eyes of the workers. Deleterious health effects of solar radiation include cataract, melanoma (affecting the eye), pterygium, macular degeneration, and skin cancer (Modenese et al., 2018). Prolonged exposure to solar radiation, which may have adverse effects on the skin, eyes, and immune system (Modenese et al., 2018). Moreover, the workers can also experience glare from the solar panels' reflective surfaces and the surrounding water body. Glare may be direct or indirect and can degrade vision (Bridger, 2018). Glare can also affect productivity by making it difficult for workers to execute visually demanding tasks such as assembling electrical components and connectors to keep the floaters together. Some FSPV projects are also located on lakes/water bodies at high altitudes. Under such atmospheric conditions, there can be a decrease in the work capacity, and workers may suffer from the effects of cold stress (Bridger, 2018). As mentioned earlier, FSPV projects are new and emerging installations with very little capacity building in terms of skills of the workers and the supervisors. These skill gaps can lead to less productive work, errors, and even major procedural mistakes. Cleaning of solar panels is associated several repetitive tasks and prolonged working hours. These can cause fatigue and disorders of several body parts. Due to the design of the layout, the undersides of the panels are often unreachable and creates difficulties during preventive and predictive maintenance. Maintenance during conditions such as heavy rain, snowfall, work during the night, or under extreme heat can cause serious illnesses. FSPV projects are also exposed to hazards from inclement weather situations. On September 9, 2019, a fire broke out at the Chiba Yamakura Floating Mega Solar Plant of size 13.7-Megawatt in Japan after a severe typhoon (Bellini, 2019). The fire resulted in the destruction of hundreds of solar photovoltaic panels and allied structures. FSPV workers engaged in the repair after such adverse weather events are exposed to even more diverse and unknown occupational risks and surprises while removing and replacing damaged panels, floaters, and electrical equipment.

1.5 OSH aspects in FSPV and its relationship with Sustainable Development Goals (SDGs)

Several aspects of the FSPV installation and maintenance are closely related to the seventeen Sustainable Development Goals (SDGs) of the UN (UNDP, 2021). In addition, there is emphasis on “just transition” in the journey towards renewable energy projects. Just transition considers decent work and the needs of people and communities. Therefore, ensuring a safe and sustainable workplace is an important priority area for all stakeholders. Figure 1.4 represents the various SDGs linked to the installation and maintenance of floating solar projects. Goal 7 targets the availability of affordable and clean energy which is also a key trigger for rapid growth in the

solar photovoltaics industry. The SDGs related to the occupational health and safety aspects include Goal 3 (Good Health & Well Being) and Goal 8 (Decent Work and Economic Growth). Immediate attention should be on Goals 3 and 8 revolving around the safety and health of the workers.

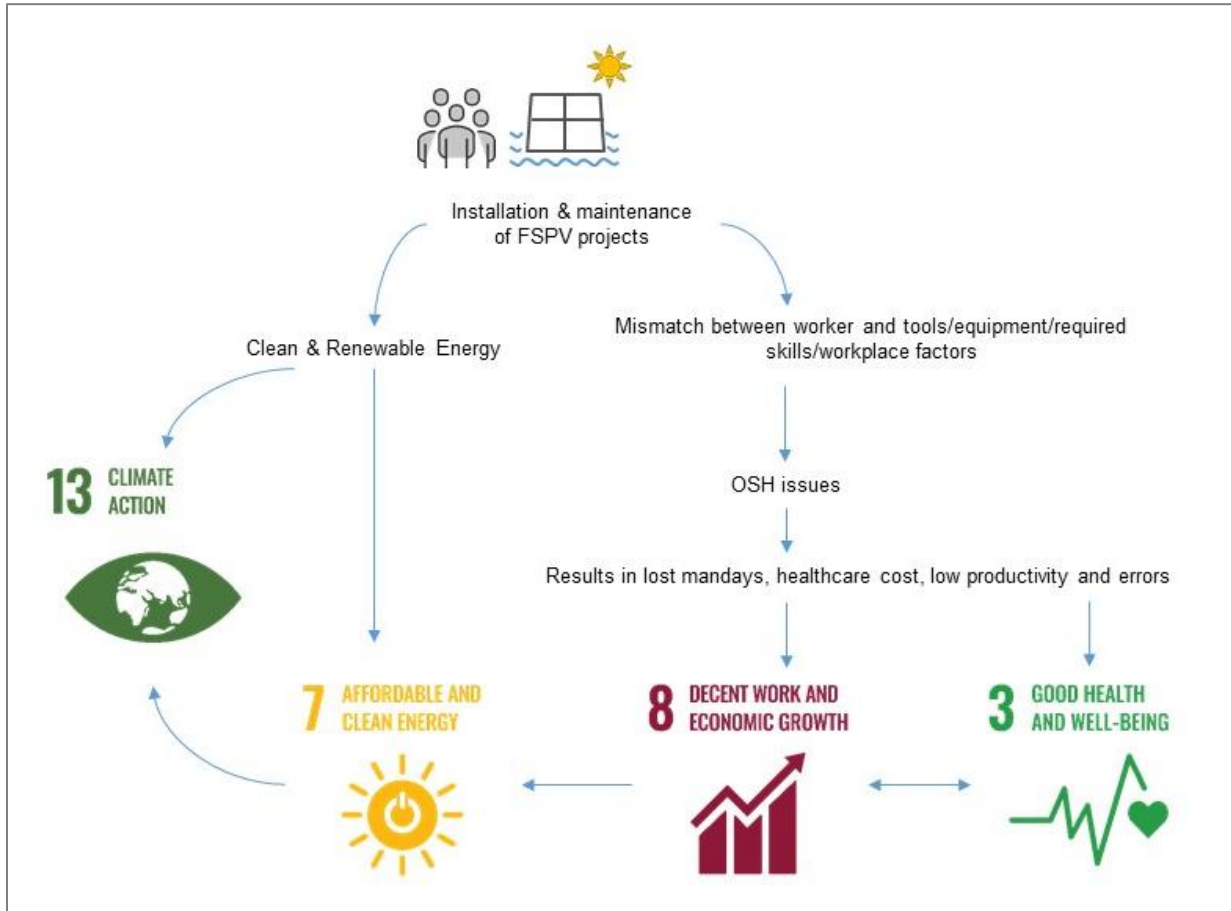


Figure 1.4. Interrelationships between OSH issues in installation and maintenance of FSPV projects and Sustainable Development Goals (SDGs) of the United Nations Development Programme (UNDP).

Unaddressed OSH issues will disrupt the goal of providing clean and affordable energy. This is mainly because of the losses in work hours (lower productivity) due to injury and accidents as well as health care costs. These factors have a direct effect on the sustainability and effective implementation of projects.

Past studies have shown a nexus between safety and sustainability. A study has shown that human benefit and business success can be achieved through a focus on safety aspects (Gilding et al., 2002). In another study in the manufacturing industry, a culture of safety was identified as a key performance indicator for achieving sustainable development (Hajmohammad & Vachon, 2014). A study by Nawaz et al. (2019) mentions a common thread connecting sustainability and safety based on financial, social, and environmental factors. Research has established a relation between safe workplace and knowledge of safety aspects with sustainable development (Jilcha and

Kitaw, 2017). These aspects reinforce the need for addressing the OSH concerns in the FSPV sector and the solar industry through design interventions keeping in mind contextual problems.

1.6 Research motivation

India is planning to develop 20 GW FSPV projects in the coming years. A study has estimated that 3358 person days is required for the installation and Operations and Maintenance of 1 MW solar PV project (IRENA, 2019). If applied to FSPV projects in India, this is equivalent to 66-million-person days for completion of 20 GW of floating solar. Occupational injuries suffered by workers are likely to have both direct and indirect costs to the industry. Moreover, most of these workers are contractual/fixed term workers with significant skill gaps and exposed to unknown OSH risks. Therefore, with rising employment in the Indian FSPV sector, ensuring proper OSH is critically important. The health of the workers is directly related to the efficient and effective completion and sustenance of the projects. The nature of FSPV installation and maintenance is such that automation is difficult and project layouts vary from location to location. This means that manual work will continue to be a significant component. Therefore, immediate attention needs to be attracted to the OSH issues in the early growing phase of the FSPV sector. Accordingly, it is important for the stakeholders in the FSPV industry to consider adaptation of design interventions for a safe and sustainable workplace.

Moreover, every new worksite may have its unique work organization, microclimate, and special skill sets requirements. This scenario gives rise to several concerns regarding the contextual occupational risks on account of the mismatch between human and machine. There is limited knowledge about the OSH aspects and existing ergonomics interventions in the fast-growing FSPV sector. Therefore, there is an urgent need to map the OSH aspects of the solar photovoltaic industry with a particular emphasis on the floating solar photovoltaic sector.

Need for interventions: OSH risks in the FSPV sector need to be addressed through a multitude of solutions especially from a socio-technical dimension. If they are not addressed properly, they can result in both direct and indirect social and economic costs by compromising with safety and health of the workforce. One dimension of solving the problems is to explore ergonomic design solutions to "*Fit the Job to the Human*". With the exponential growth in the FSPV sector, the number of workers engaged, and the lack of suitable interventions increases the magnitude of the problem. The risks for workers engaged in floating solar installations may also vary from type of installation, climatic conditions, safety culture/policies, worker related issues, work methods, and location of projects. Hence, the need for considering and developing context specific design interventions. Therefore, there is want of affirmative action from the scientific community to neutralize the risks through design interventions for a safe and sustainable FSPV sector.

1.7 Summary of the literature review

The emerging OSH issues in FSPV projects are complex and multidimensional. The existence of an aquatic environment adds to the risk factors. The existing literature is mostly concerned with OSH risks in rooftop and ground-mounted solar PV projects. The present design approaches for risk mitigation are limited to technical and commercial improvements. It is therefore imperative

to report the state-of-the-art in the FSPV sector from an occupational safety perspective and also similar risks in closely related occupations in order to identify future avenues for risk mitigation.

A comprehensive review of literature was carried out to shortlist existing research in the solar photovoltaic industry related to OSH issues with special focus on the floating solar sector. The detailed methodology and findings are mentioned in Chapter 2. The following sections summarize the findings to indicate the knowledge gaps.

1.7.1 Reasons for the emergence of FSPV projects

In recent years, research regarding FSPV projects have revealed several advantages over rooftop and ground mounted solar PV projects. Some of these features include efficiency (Liu et al, 2017, Goswami et al., 2019), land neutrality (Sahu et al., 2016), durability of system components (Sahu and Sudhakar, 2019), conservation of water (Azami et al. 2017, Mittal et al., 2017, Rosa-Clot et al., 2017), economic viability (Ferrer-Gisbert et al., 2013), combination with hydro projects for co-generation (Cazzaniga et al., 2019) and sustainability (Pringle et al., 2017, Trapani and Millar, 2013). These features have resulted in a fast growth of FSPV projects.

1.7.2 OSH risks in solar photovoltaics projects with reference to FSPV installations

The existing OSH risk factors include the presence of heat stress (Kamenopoulos and Tsoutsos, 2015, Samaniego-Rascón et al., 2019), electrocution (Wybo, 2013, White and Doherty, 2017), ergonomic risks (Bakhiyi et al., 2014), fire hazards (Dhere and Shiradkar, 2012, Falvo and Capparella, 2015), hazardous substances (Fthenakis and Moskowitz, 2000, Aman et al., 2015), psychosocial risks (Fernandez et al., 2017) and adverse weather conditions (Kamenopoulos and Tsoutsos, 2015).

1.7.3 Occupational risk factors in workplaces/ occupations similar to FSPV workplaces

Similar to workplace risks in FSPV projects, occupational risks in similar work settings include aquaculture where the risks include ergonomic, physical, biological, and other work-related risks (de Oliveira et al., 2017, Cavalli et al., 2019, Mitchell and Lystad, 2019, Ngajilo and Jeebhay, 2019). Shipyard workers face the risk of falling from heights, electrocution, fire, explosion, object-related injury, and drowning (Barlas and Izci, 2018). Port workers are exposed to occupational risks from toxic substances, noise, dust, extreme temperature, vibration, and ultraviolet radiation (Wang et al., 2017). The task of mooring in FSPV projects where boats are used is similar to work involved in jobs such as lobster hunting. Lobstermen in the northeast of the USA were found to be exposed to ergonomic risks such as force, awkward postures, and repetition, resulting in low back pain and discomfort in the hand and wrists (Fulmer et al., 2017). A study (Cha et al., 2019) on South Korean fishery divers revealed that 84.7% of them showed symptoms of decompression sickness (DCS). A study (Oldenburg et al., 2013) on seafarers in Germany showed the incidence of actinic keratosis as a result of occupational exposure to sunlight. A high exposure to solar UV radiation was found in a study (Modenese et al., 2019) on fishermen in North Italy engaged in three types of fishing activities.

1.7.4 Training programs and OSH standards/regulations for solar PV industry

Several studies have reported training need for installers, user training, training for technicians, capacity building programs, and the need for technically qualified installers (Mrohs, 1998, Middleton and McIntosh, 2011, Brooks and Urmee, 2014, Pavlova, 2019). Some available training programs include the Training of Photovoltaic Installers (PVTRIN), which is an accreditation and training scheme for some European countries for personnel engaged in small-scale PV systems (Tsoutsos et al., 2013). Lack of education and training has also been identified as a barrier in the renewable energy industry, resulting in a shortfall of qualified personnel in many countries (Lucas et al., 2018). Existing OSH standards include the National Standards on Health & Safety at solar PV power plant, formulated by the Skills Council for Green Jobs in India (Goel, 2016). Regulations of the Occupational Safety and Health Administration (OSHA) applicable to PV installations are covered in a) Occupational Safety and Health Standards (Part 1910) and b) Safety and Health Regulations for Construction (Part 1926). The Queensland Code of Practice is aimed at the safety and health of workers associated with the life cycle of solar farms (State of Queensland, 2019) which emphasizes the need to design safe solar farms by removing hazards at the planning and design stage. It recommends that design engineers associated with solar farms should acquire requisite competencies (such as health and safety rules, risk management, design standards, etc.) to minimize occupational safety and health risks. The Newport Beach Fire Department has specified standards for designing layouts and installing roof-top solar PV projects to ensure fire safety (City of Newport Beach, 2009). The Newport Beach Fire Department's guidelines recommend the provision of walkways and marking of PV components. The walkways along the solar PV installation-frames help the workers in safe and comfortable movement under various postures during installation and maintenance activities. Besides, these walkways also serve as escape routes for the evacuation of workers during exigencies.

1.7.5 Existing design approaches/studies in the solar PV industry

The present design approaches are primarily targeted at technical, efficiency improvements, aesthetics, and cost savings. Existing literature include focus areas such as improved operational performance (Dai et al., 2020), efficiency improvement (Spertino and Corona, 2013, Cazzaniga et al., 2018, Li et al., 2020), adaptability of solar panels (Bao et al., 2020), cost savings (Kim et al., 2017, Hernández- Callejo et al., 2019), usability (Hong, 2019), visual appearance (Bao et al., 2017), purchase preference (Balo and Şağbaşı, 2016), ecological factors (Scognamiglio, 2016) and durability (Lee et al., 2014). Evidently, most of these studies do not address the OSH issues in the solar PV industry. However, the review revealed two studies that address the OSH concerns. The first study (Ho et al., 2020) developed a Prevention through Design (PtD) protocol for small scale roof-top solar installations in the US. The second study (Bhang et al., 2018) which is specific to the FSPV installations. The design recommendation includes use of grounding electrodes for enhancing electrical safety.

1.7.6 Research Gaps

- There is paucity of research work/studies in the fast-growing FSPV sector from the perspective of OSH of the workers and other personnel engaged in installation and maintenance.
- Emerging OSH issues in FSPV projects have not been adequately identified and addressed in either the Indian or the global context.
- There are no studies in terms of measurement and prioritization of occupational risk factors (in the high and very-high categories that require immediate attention) associated with FSPV projects.
- No studies have captured the socio-demographic and cross-cultural aspects associated with solar PV workers.
- Existing design approaches do not comprehensively address the OSH issues in FSPV projects.
- No studies have attempted to validate design interventions based on parameters such as risk mitigation ability, productivity, ergonomics issues and usability.

The unexplored areas are represented in Figure 1.5.

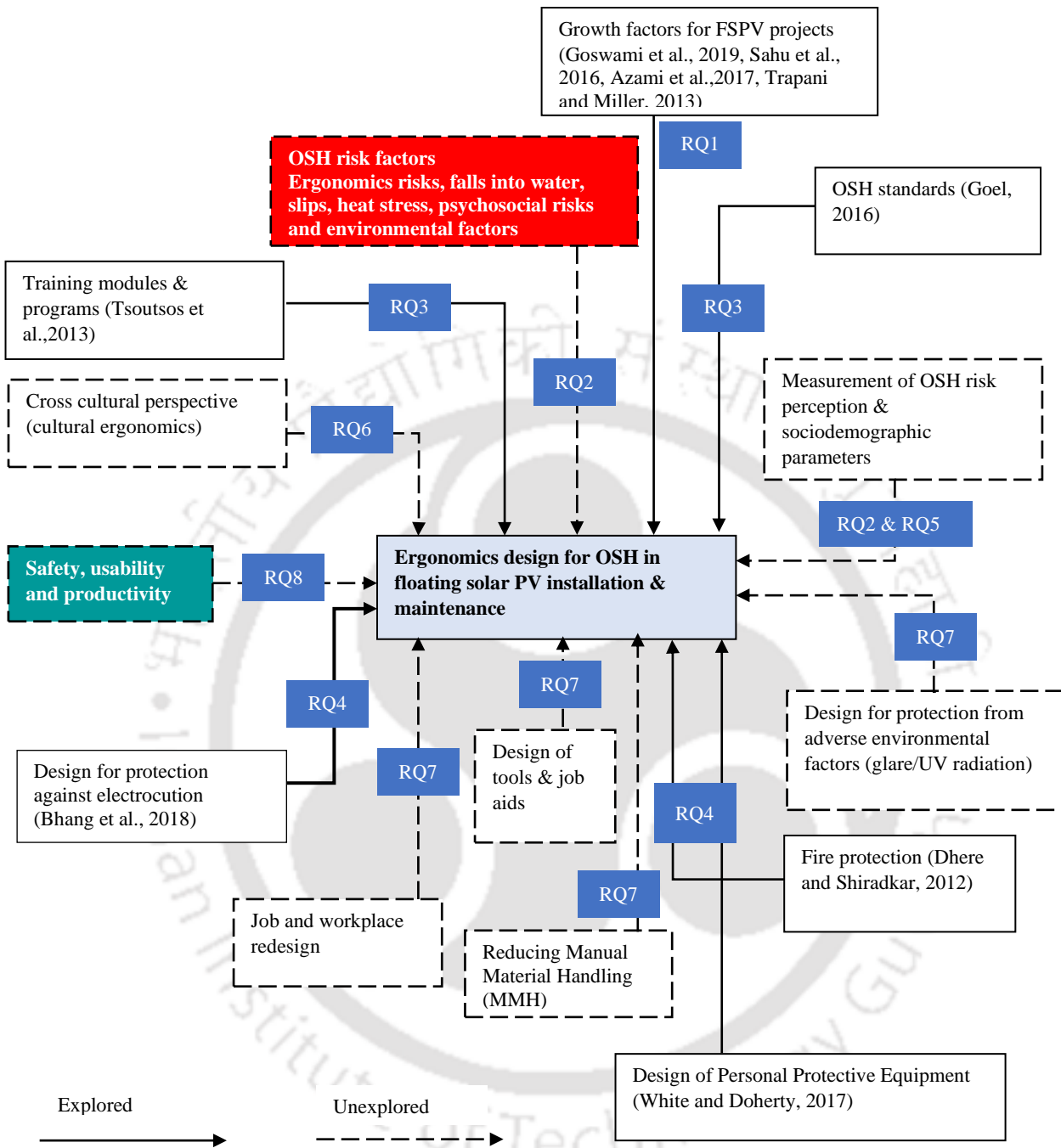


Figure 1.5. Identification of research gaps based on literature review

1.8 Research Questions

The Research Questions for the present research are the following:

- RQ1: What are the various features of FSPV projects and reasons for the growth of the sector in recent years?
- RQ2: What are the different kinds of physical, chemical, environmental, psychosocial, and organization related risks and their effect on workers in the floating solar photovoltaic sector and workplaces/occupations similar to the work environment (aquatic) of an FSPV project?
- RQ3: Are training programs/modules and Occupational Safety & Health (OSH) standards available for the FSPV sector?
- RQ4: What are the existing design approaches in the solar PV industry (with emphasis on the FSPV sector) as prevention and or OSH risk mitigation strategy?
- RQ5: What is the OSH risk perception of safety managers and FSPV workers with respect to FSPV projects?
- RQ6: What are the cross-cultural and socio-demographic differences in OSH risk perception of solar PV workers?
- RQ7: Which design concepts/interventions can be developed from an ergonomics perspective for risks falling in the very high and high categories requiring immediate attention in FSPV projects?
- RQ8: What would be the perceived effect of the design interventions on the ability of risk mitigation, ability to address the ergonomics issues, usability, and productivity improvement?

1.9 Problem Statement

Floating solar photovoltaic sites are new and emerging workplaces that are different from other kinds of solar photovoltaic installations but markedly different from industrial shop floors involving a combination of ergonomics factors (Figure 1.6). The workers engaged in the installation and maintenance of FSPV projects are facing several Occupational Safety & Health (OSH) risks that may lead to injuries, accidents and long-term health effects having both direct and indirect costs. In addition, they are engaged in repetitive manual work involving lifting, squatting, exposure to a hot and humid outdoor environment and working with electrical components. This situation is aggravated by awkward postures and the unstructured nature of work on a floating platform. In addition, there are no standard work procedures, training modules or tools/equipment's specifically designed for the FSPV sector. This mismatch in skills and constantly changing workplace layouts are making the work more challenging, giving rise to several OSH issues.

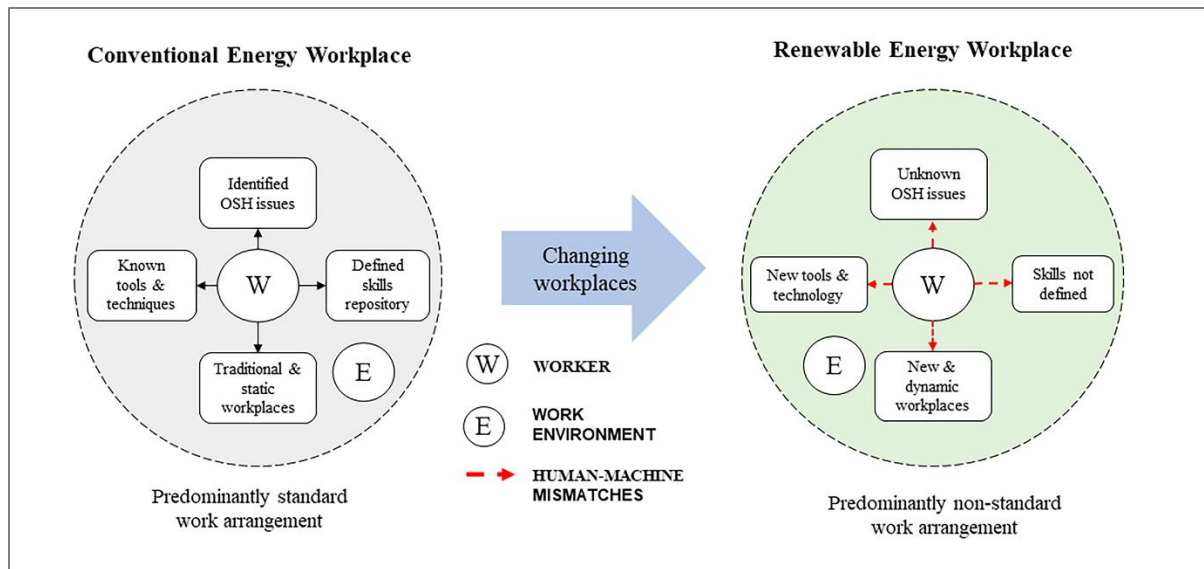


Figure 1.6. Workplace transition from conventional to renewable energy workplaces (graphic: author)

1.10 Aim & Objectives

Aim

The aim of the present study is to investigate and measure the specific nature of OSH risks faced by the workers engaged in FSPV projects and to design context specific solutions from an ergonomics design perspective for risk mitigation.

Objectives

1. To explore various features of FSPV projects and identify the emerging risks (occupational, environmental, psychosocial etc.) being faced by the workers engaged in FSPV installation and maintenance including existence of training modules and OSH standards.
2. To explore the existing design approaches for mitigation of OSH issues in FSPV installation and maintenance.
3. To investigate and measure the specific nature of problems being faced by the workers due to the risks through field studies.
4. To explore cross-cultural aspects of solar photovoltaics workers from an OSH and socio-demographic dimension.
5. To develop ergonomic design solutions/concepts to protect against the risks for which solutions do not exist using the product design life cycle.
6. To measure the effectiveness of the design interventions from the perspective of risk mitigation ability, ergonomics, usability, and productivity

1.11 Hypotheses

Hypothesis 1: Context-specific design interventions addressing the prioritized risk factors would have the potential benefits towards improved safety and occupational health of floating solar PV workers engaged in installation and maintenance.

Hypothesis 2: Cross-cultural factors and sociodemographic traits significantly influence the perception of occupational risks by workers engaged in solar photovoltaic projects.



1.12 Flow of the thesis

The flow of the thesis is represented at Figure 1.7

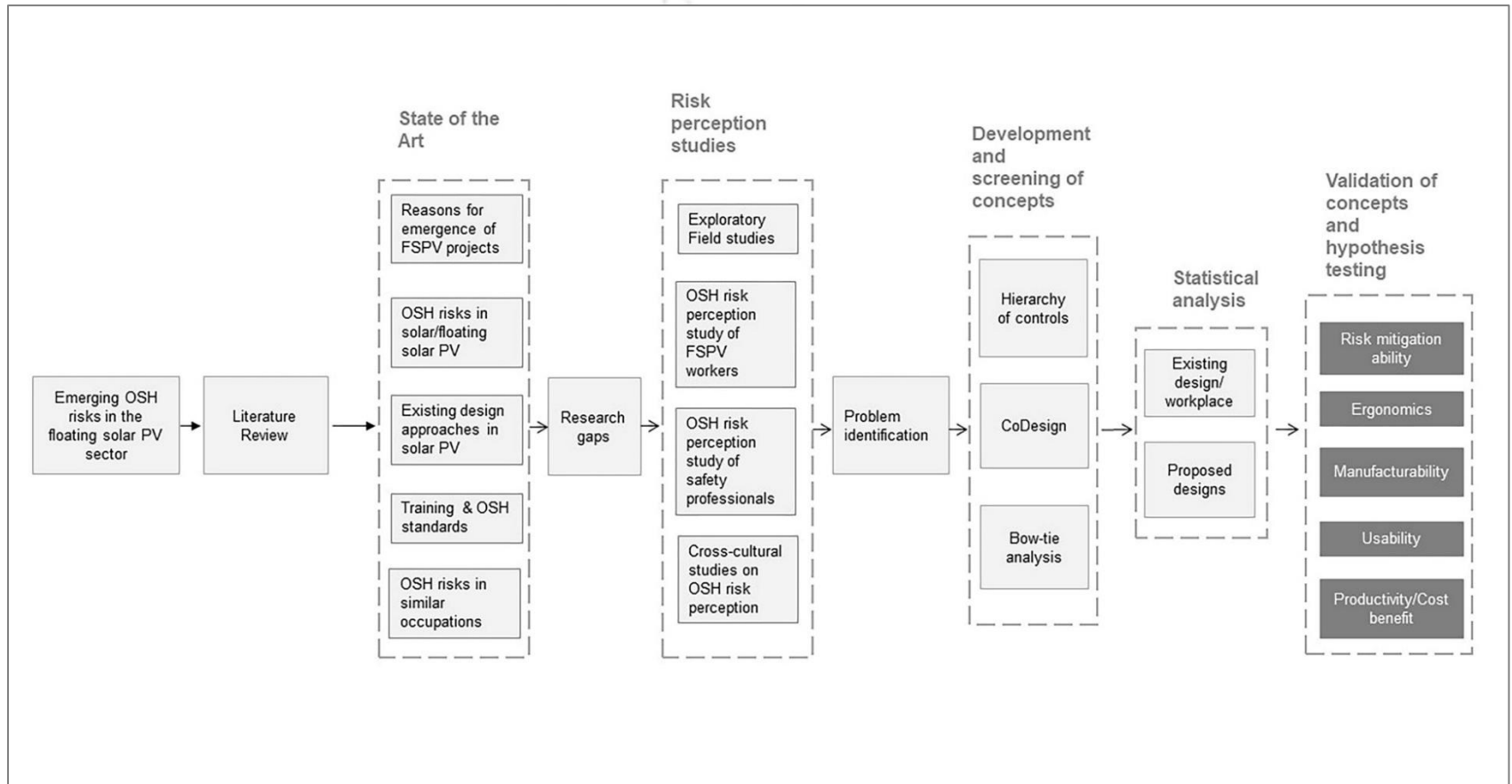


Figure 1.7. Flow of the thesis

1.13 This thesis is divided into seven chapters which cover various aspects of the study.

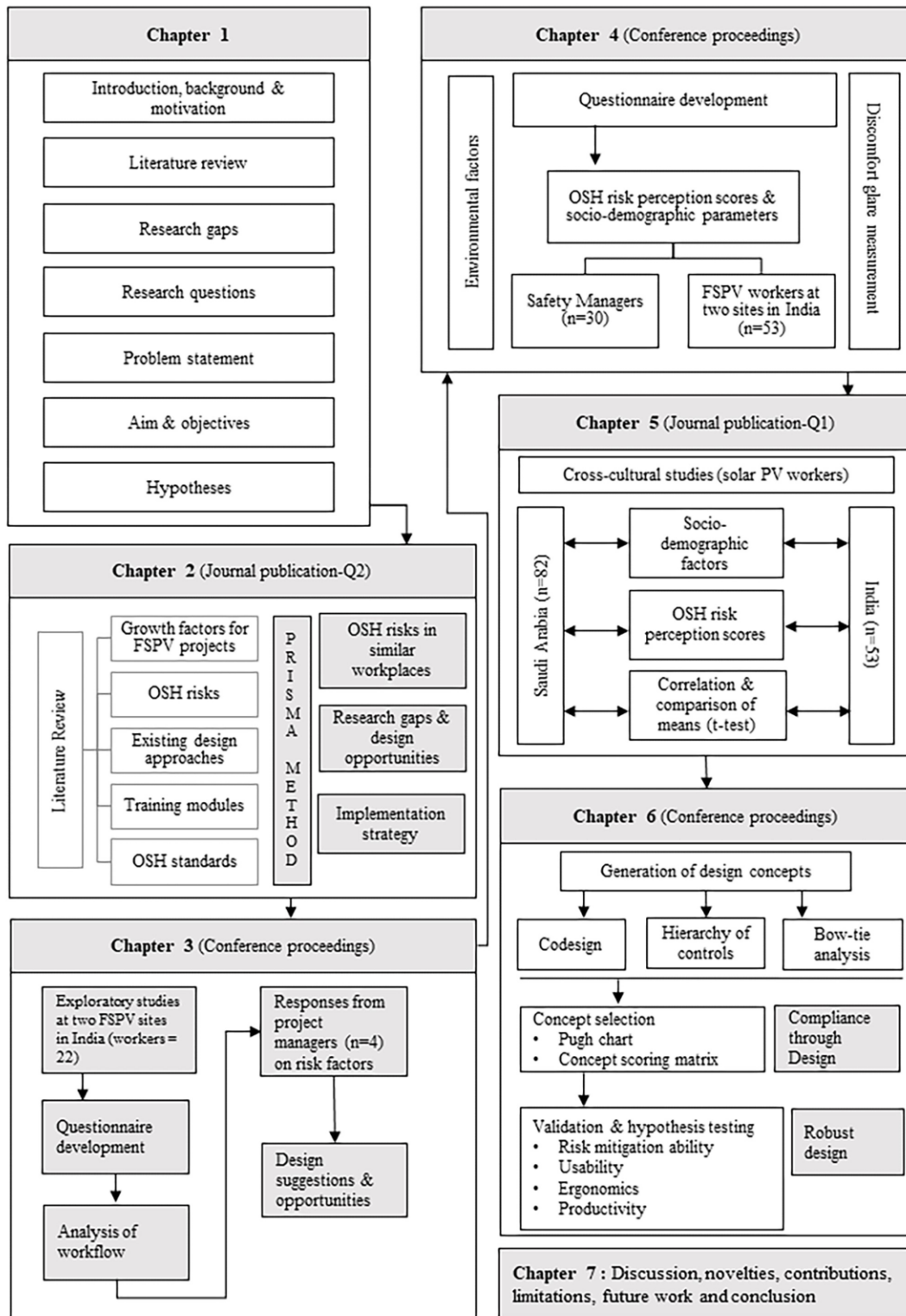


Figure 1.8. Arrangement of thesis chapters

Table 1.1 Research questions and objectives organized in various chapters and publications

Chapter	Research Questions	Objectives	Hypothesis statements	Publications	Contributions
2	<p>RQ1: What are the various features of FSPV projects and reasons for the growth of the sector in recent years?</p> <p>RQ2: What are the different kinds of physical, chemical, environmental, psychosocial, and organization related risks and their effect on workers in the floating solar photovoltaic sector and workplaces/occupations similar to the work environment (aquatic) of an FSPV project?</p> <p>RQ3: Are training programs/modules and Occupational Safety & Health (OSH) standards available for the FSPV sector?</p> <p>RQ4: What are the existing design approaches in the solar PV industry (with emphasis on the FSPV sector) as prevention and or OSH risk mitigation strategy?</p>	<p>Objective 1: To explore various features of FSPV projects and identify the emerging risks (occupational, environmental, psychosocial etc.) being faced by the workers engaged in FSPV installation and maintenance including existence of training modules and OSH standards.</p> <p>Objective 2: To explore the existing design approaches for mitigation of OSH issues in FSPV installation and maintenance.</p>	<p>Hypothesis 1: Context-specific design interventions addressing the prioritized risk factors would have the potential benefits towards improved safety and occupational health of floating solar PV workers engaged in installation and maintenance.</p>	<p>Sen, A., Mohankar, A. S., Khamaj, A., & Karmakar, S. (2021). Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals. <i>Risk Management and Healthcare Policy, Volume 14</i>(May), 1939–1957. https://doi.org/10.2147/RMHP.S304732 [SCIE & Scopus indexed; Q2 Journal]</p>	<p>I. Attracting attention to the emerging OSH issues in the FSPV sector, research gaps and relationship with SDGs.</p> <p>II. New OSH knowledge in the FSPV sector and design intervention implementation strategy for occupational practitioners/stakeholders.</p>

3 & 4	<p>RQ5: What is the OSH risk perception of safety managers and FSPV workers wrt FSPV projects?</p>	<p>Objective 3: To investigate and measure the specific nature of problems being faced by the workers due to the risks through field studies.</p>	<p>Sen, A., & Karmakar, S. (2021). Exploring the OSH Scenario in Floating Solar PV Projects in India and Opportunities for Ergonomics Design Interventions. In <i>Smart Innovation, Systems and Technologies</i> (Vol. 221, pp. 245–255).</p>	<p>III. Maiden effort to identify & measure OSH risks and sociodemographic parameters in FSPV projects</p>
			<p>https://doi.org/10.1007/978-981-16-0041-8_21</p>	
			<p>Sen, A., & Karmakar, S. (2022). OSH Risk Perception of Safety Managers and Scope for Ergonomics Design Interventions in Floating Solar Photovoltaic Projects. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) <i>Ergonomics for Design and Innovation</i>. HWWE 2021. Lecture Notes in Networks and Systems, vol 391. Springer, Cham.</p>	
			<p>https://doi.org/10.1007/978-3-030-94277-9_74</p>	

5	<p>RQ6: What are the cross-cultural and socio-demographic differences in OSH risk perception of solar PV workers?</p>	<p>Objective 4: To explore cross-cultural aspects of solar photovoltaics workers from an OSH and socio-demographic dimension.</p>	<p>Hypothesis 2: Cross-cultural factors and sociodemographic traits significantly influence the perception of occupational risks by workers engaged in solar photovoltaic projects.</p>	<p>Sen, A., Khamaj, A., Moosa, M., & Karmakar, S. (2022). Cross-Cultural Study on OSH Risk Perception of Solar PV Workers of Saudi Arabia and India: Risk Mitigation through PtD. <i>Energies</i>. https://www.mdpi.com/1996-1073/15/24/9614. [SCIE & Scopus indexed; Q1 Journal]</p>	<p>IV. Maiden effort to study the cross-cultural aspects with reference to OSH risk perception & socio-demographic factors in solar PV projects.</p>
6	<p>RQ7: Which design concepts/interventions can be developed from an ergonomics perspective for risks falling in the very high & high categories requiring immediate attention in FSPV projects?</p>	<p>Objective 5: To develop ergonomic design solutions/concepts to protect against the risks for which solutions do not exist using the product design life cycle.</p>	<p>Hypothesis 1: Context-specific design interventions addressing the prioritized risk factors would have the potential benefits towards improved safety and occupational health of floating solar PV workers engaged in installation and maintenance.</p>	<p>Sen, A., & Karmakar, S. (2023). OSH Risk Perception of Floating Solar PV Workers and Identifying Scope for Design Interventions: A Codesign Approach. In: Chakrabarti, A., Singh, V. (eds) <i>Design in the Era of Industry 4.0, Volume 1. ICORD 2023. Smart Innovation, Systems and Technologies</i>, vol 343, pp. 117–126). Springer, Singapore. https://doi.org/10.1007/978-981-99-0293-4_10</p>	<p>V. First of its kind study for development of comprehensive design interventions through co-design approach for addressing OSH issues in the FSPV sector.</p>
	<p>RQ8: What would be the perceived effect of the design interventions on ability of risk mitigation, ability to address the ergonomics issues, usability, and productivity improvement?</p>	<p>Objective 6: To measure the effectiveness of the design interventions from the perspective of risk mitigation ability, ergonomics, usability, and productivity.</p>		<p>Sen, A., Khamaj, A., & Karmakar, S. (2023). Understanding the concept and methodological benefits of co-design through live example from implementation of solar power-plant projects [communicated]</p>	

Chapter 1 introduces the background of the study and the emerging OSH concerns associated with floating solar photovoltaic projects. The motivation for the present research, problems and the need for a solution is discussed. Subsequently, the research questions and aims and objectives are formulated.

Chapter 2 covers a comprehensive literature review of the different aspects of the solar photovoltaic industry with a focus on the floating solar photovoltaic sector. The reasons for the growth of the sector, OSH risks associated with floating solar projects and existing design interventions in the FSPV, and closely related work environments are discussed. The outcome of the chapter includes identification of research gaps and establishes a rationale for using design interventions as a strategy for addressing different kinds of OSH risks.

Chapter 3 presents an overview of the exploratory field studies at two different FSPV project sites in India. Using a questionnaire, the workflow, specific nature of occupational problems and views of the project managers are captured. In addition, possible design solutions to address the hazards from the perspective of the project managers are presented.

Chapter 4 discusses the outcomes of the OSH risk perception studies carried out to gather responses from safety managers of ten organizations and FSPV workers engaged in two sites in India. Prioritization of the OSH risks based on the degree of perception, environmental aspects, socio-demographic features of the workers are also summarized. Intervention options at various levels are also summarized.

Chapter 5 is concerned with the findings of a collaborative cross-cultural study on the solar workers engaged in India compared to the solar workers engaged in Saudi Arabia. The chapter attracts attention to the need for considering population specific variations and nuances of cultural ergonomics while designing interventions to mitigate OSH risks.

Chapter 6 This chapter describes the development of design concepts following the methods of co-design, hierarchy of controls and bow-tie analysis. The contextual problems are defined, and problems desired to be addressed are described. This is followed by the screening and validation of the various concepts.

Chapter 7 This chapter summarizes the findings of the study. It discusses the main findings, fulfillment of objectives, novelty, future scope, contribution, strengths, and limitations of the research work.

Chapter 2: Literature review



Abstract

The emerging OSH issues of the floating solar projects have been rarely studied. This chapter presents a comprehensive literature review of the OSH aspects of the solar photovoltaic industry with reference to the floating solar photovoltaic sector. Following the PRISMA methodology, 49 papers were shortlisted based on search terms using the online bibliographic databases of Science Direct, Google Scholar, Web of Science, and Scopus. The papers were divided into headings such as reasons for growth of the FSPV sector, OSH risks, risks in similar workplaces, presence of training modules & OSH standards, existing design interventions/approaches, research gaps and future intervention opportunities. Use of design as a risk mitigation strategy is proposed and a framework for implementation of design interventions by stakeholders at various levels is discussed. This literature review is a maiden effort to identify and attract attention to the emerging OSH issues associated with installation and maintenance of floating solar photovoltaics projects.

2. Introduction

FSPV projects are new kinds of installations with projects coming up in large numbers only in the recent few years. Little research has been carried out in this sector especially from the perspective of occupational health and safety of the workers. Keeping this in mind and in accordance with the objectives of the study, the purpose was to carry out a comprehensive and holistic review of the existing body of knowledge in the FSPV sector. Adopting a structured approach, the review process started with developing some research questions to have a broad coverage of all possible aspects.

The research questions formulated for the review is as follows:

- Q1: What may be the various reasons for growth of FSPV projects in recent years?
- Q2: What are the various types of physical, chemical, environmental, psychosocial, and organization-related risks, and their effect on workers in the floating solar photovoltaic sector and occupations similar to the work environment (aquatic) of an FSPV installation?
- Q3: Do training programs/schemes and standards of Occupational Safety & Health (OSH) exist for the FSPV sector?
- Q4: What are the present design solutions/concepts in the solar photovoltaic industry and those specific to the FSPV sector for mitigation of risks?
- Q5: What may be the future scope for design interventions from an ergonomics perspective in the FSPV sector?

2.1 Methodology

At the outset, in alignment with the review questions, search terms were defined. A detailed literature review from the electronic databases of Science Direct, Google Scholar, Web of Science, and Scopus. The period of search was selected between the years 1965 to 2021, and only papers

published in the English language were included. The search terms and their different combinations used included solar photovoltaics, floating solar photovoltaics, psychosocial risks, environmental risks, OSH standards, training, green jobs, work organization, ergonomics design interventions, design, aquaculture, shipyard workers, and OSH risks. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (Moher et al., 2009) was used in the review process. The methodology followed is depicted at Figure 2.1.

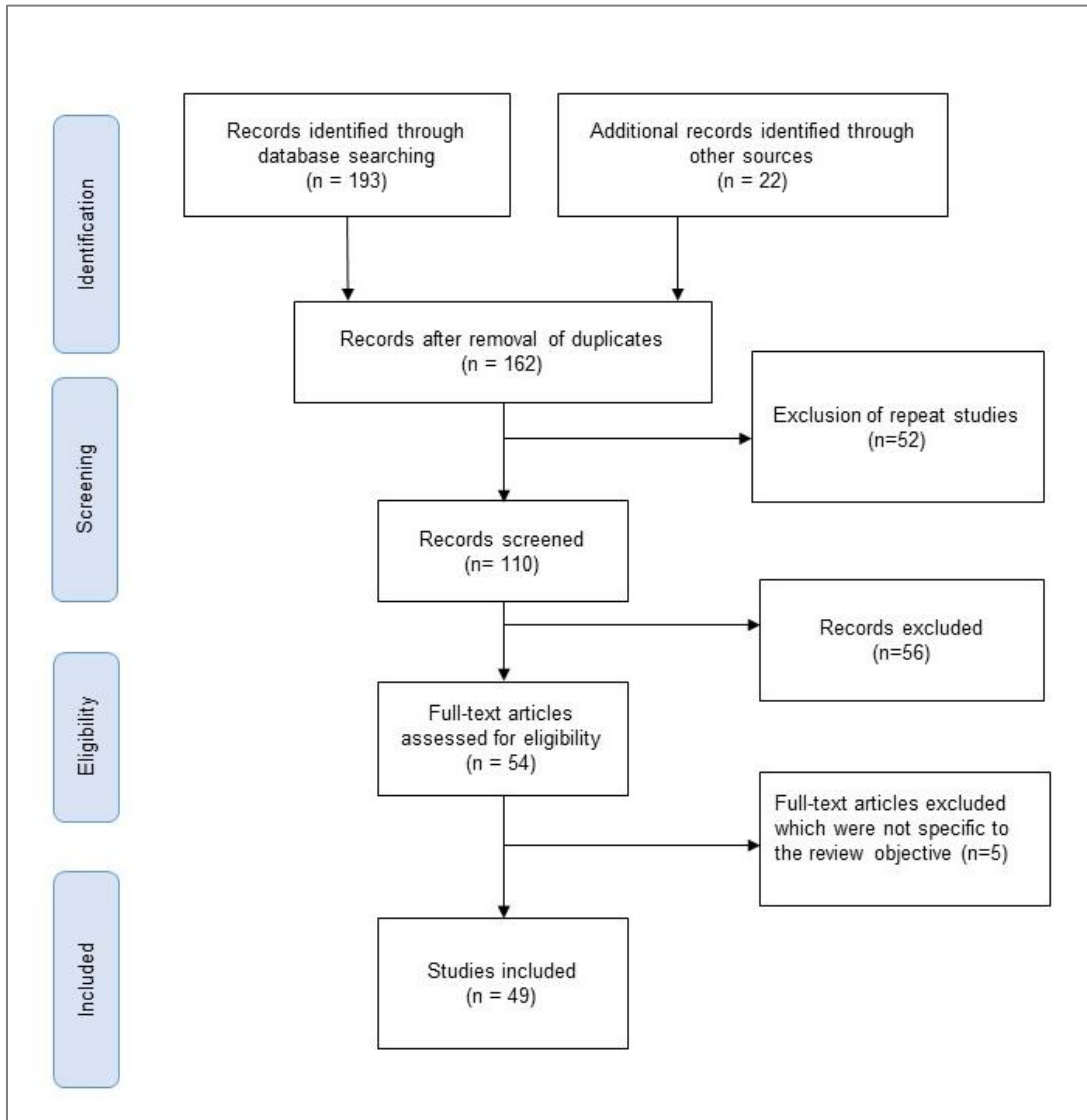


Figure 2.1. Flowchart showing the various steps in the review process using the PRISMA framework. PRISMA figure adapted from Moher et al. (2009).

The inclusion criteria for the online search using databases of Science Direct, Google Scholar, Web of Science, and Scopus was the presence of the search terms in the title, abstract, or the keywords. The list of references of the shortlisted papers was also analysed for related or relevant studies. The search resulted in the extraction of 193 studies. Another twenty-two additional studies/conference proceedings from other sources published by

stakeholders/researchers concerned with the solar photovoltaic industry and related OSH standards were also included. The shortlisted studies/resources were uploaded into a database manager, and duplicates were removed, resulting in 162 papers/resources. These records were further screened, and based on similar findings or repeat studies, 56 papers/resources were excluded. A total of 54 papers were found eligible within the scope of the study, and subsequently full texts were analysed. Further, some studies were not considered as they were not specific to the review scope. The comprehensive search resulted in the final shortlisting of 49 papers. The full papers were analysed and divided into five broad headings, namely a) overview of key reasons for the emergence of floating solar photovoltaic projects, b) occupational risks of workers engaged in the solar PV industry/FSPV sector, c) occupational risks in workplaces/occupations similar to floating solar photovoltaics projects, d) availability of training modules and occupational standards, and e) design interventions/approaches in the solar PV industry/floating photovoltaics sector. The future opportunities mentioned in each paper was also studied. Documentation, reports, texts, and online news matter relevant to the research area were also considered for including different aspects. The outcome of the review was compared to intervention approaches at various levels of hierarchy (Bridger, 2018) to determine the knowledge gaps and scope for ergonomics design interventions.

2.2 Results

The key findings of the literature review have been divided into various headings and discussed in detail in the following sections section.

2.2.1 Key reasons for the emergence of floating solar projects

To understand the key reasons for the emergence of the FSPV sector, a total of 11 studies specific to the FSPV sector were considered. The papers were reviewed and arranged according to the parameter, author, region of study, study type, and key findings. The findings/ highlights are represented in Table 2.1.

Table 2.1. A summary of key reasons for the emergence of floating solar photovoltaic projects

Parameter	Author	Region	Study type	Key findings
Efficiency	Goswami et al. (2019)	India	Techno-economic analysis	Higher generating capacity as compared to ground-mounted solar photovoltaics
	Liu et al. (2017)	China	Comparative study	Better efficiency due to reduced operating temperature as compared to ground-mounted solar photovoltaic projects
Land requirement	Sahu et al. (2016)	NA	Review Study	Land neutrality
Durability of components	Sahu and Sudhakar (2019)	NA	Technical study	Floating platforms (made of HDPE) are resistant to

				Ultraviolet exposure and can bear loads of panels/accessories.
Water conservation	Azami et al. (2017)	Iran	Theoretical analysis	Reduced evaporation & CO ₂ emission
	Mittal et al. (2017)	India	Numerical analysis	Annual water saving of 191 million liters for a 1 MW project
	Rosa-Clot et al. (2017)	Australia	Feasibility study	Saving of 15,000-25,000 cubic meters of water per MWp
Economic viability	Ferrer-Gisbert et al. (2013)	Spain	Feasibility Study	Feasible on agriculture reservoir
Hybrid energy system	Cazzaniga et al. (2019)	Global study	Data analysis	Large potential for energy production when coupled with Hydro Power Plants (HPPs)
Sustainability	Pringle et al. (2017)	NA	Feasibility study	FSPV combined with aquaculture can resolve food, energy and water problems
	Trapani and Millar (2013)	Malta	Techno-economic analysis	Carbon savings

Notes: NA: No specific mention of any particular region/country

Abbreviations: HDPE, high-density polyethylene; MW, megawatt; MWp, megawatt peak

2.2.2 OSH Risk Factors Associated with Solar/Floating Solar PV System

A total of 10 studies concerned with the identification of occupational risks in the solar PV industry with emphasis on FSPV projects) were reviewed. The information is summarised in under the headings occupational risk factors, authors, region, study type, findings, and future scope to mitigate the risks from an OSH perspective and represented in Table 2.2.

Table 2.2. Occupational risks of workers engaged in the solar PV industry/FSPV sector

Occupational risk factors	Author	Region	Study type/tool	Findings	Future Scope/Safety measures
Heat	Kamenopoulos and Tsoutsos (2015)	NA	Operational Risk Management tool	Heat is an OSH risk during operation & maintenance.	Safety measures, monitoring, and PPE

	Samaniego-Rascón et al. (2019)	Mexico	Wet-bulb Globe Temperature	Exposure exceeded recommended levels	Acclimatization, training on reporting of symptoms & work/rest schedule
Electrocution	White and Doherty (2017)	Canada	Hazard assessment	Shock and arc flash hazards	Use of insulated gloves and PPE
	Wybo (2013)	France	Focus Groups	Shock hazard during maintenance	Insulating gloves and covering of panels with light-proof film
Ergonomic risks	Bakhiyi et al. (2014)	NA	Review	Repetition, awkward postures, and sharp edges	Appropriate work methods
Fire	Falvo and Capparella (2015)	USA	Case studies	Blindspot in protection device was the cause of the fire	Use of many small inverters & inspection of failure modes
	Dhere and Shiradkar (2012)	NA	Case studies	Causes include open circuit, ground fault, and arcing	Proper installation, safety regulations, avoiding chimney effect, etc.
Hazardous substances	Fthenakis and Moskowitz (2000)	NA	Safety & Health study	Presence of chemicals in solar panels, batteries, and inverters are potential sources	Sustainable manufacturing, PPE, employee training, and safety procedures.
	Aman et al. (2015)	NA	Life Cycle Assessment	Presence of NH ₃ , acetone, As, Si, Pb, HNO ₃ , Cd, SF ₆ , PBBs, PBDEs, HCl, H ₂ , Cr-VI, Isopropanol, Toluene, Xylene	Substitution of dangerous materials, eco-friendly manufacturing, and safe disposal

				and 1,1,1-Trichloroethane	
Psychosocial	Fernandez et al. (2017)	USA	Data Analysis	Job insecurity and work-life imbalance in green jobs	Surveillance of occupational psychosocial risks, protective interventions, and company policies
Lighting, hail, typhoons, strong winds, and flora	Kamenopoulos and Tsoutsos (2015)	NA	Operational Risk Management tool	Work environment hazards	Design interventions to address the OSH risks

Notes: NA: No specific mention of any particular region/country

Abbreviations: PPE, personal protective equipment; NH₃, Ammonia; As, Arsenic; Si, Silicon; Pb, Lead; HNO₃, Nitric acid; Cd, Cadmium; SF₆, Sulphur hexafluoride; PBBs, Polybrominated biphenyls; PBDEs, Polybrominated diphenyl ethers; HCl, Hydrochloric acid; H₂, Hydrogen; Cr-VI, Hexavalent Chromium.

2.2.3 OSH risk factors in occupations similar to floating solar projects

The presence of water in the floating solar project work environment presents additional occupational risks. Seven studies in occupations such as aquaculture, shipping, lobstermen, and port workers were analysed to understand the risks in occupations where there is presence of water in the work environment. Workers engaged in aquaculture activities face several ergonomic, physical, biological, and other work-related risks (Cavalli et al., 2019, de Oliveira et al., 2017, Mitchell & Lystad, 2019, Ngajilo & Jeebhay, 2019). Shipyard workers run the risk of falling from heights, prone to electrocution, fire, explosion, object-related injury, and drowning (Barlas & Izci, 2018). Port workers are exposed to OSH risks from toxic substances, noise, dust, extreme temperature, vibration, and ultraviolet radiation (Wang et al., 2017). Boats are used in the work of mooring the FSPV installation to the ground/land. This is similar jobs such as lobster hunting. In the USA, lobstermen were found to be exposed to ergonomic risks such as force, awkward postures, and repetition, resulting in low back pain and discomfort in the hand and wrists. The researchers suggest the use of ergonomics interventions to assist in the handling of materials (Fulmer et al., 2017). Divers are engaged in the anchoring and load testing while installing the FSPV system. Working at significant depths is a work requirement for prolonged periods exposing the divers to several occupational risks. Prolonged outdoor work is a regular feature in FSPV installation and maintenance. This working condition exposes them to the risk of solar radiation which is significantly harmful. A study on German seafarers by Oldenburg et al. (2013) showed the occurrence of actinic keratosis due to the exposure to sunlight. Excessive exposure to solar

radiation was found in Italian fishermen engaged in several kinds of activities (Modenese et al., 2019).

2.2.4 Existing training modules and OSH standards in the solar PV industry/FSPV sector

A study of seven research papers and existing OSH standards reveal various dimensions of training and occupational standards in the solar PV industry. According to a study the requirement for filling the skill gaps for installers, imparting training to users and technicians, capacity building initiatives, and creating a pool of technically qualified installers are important considerations (Brooks & Urmee, 2014, Middleton & McIntosh, 2011, Mrohs,1998, Pavlova,2019). Universal training curriculum incorporating local needs was emphasized. Local availability of trained technicians will be key to the successful implementation of the project, particularly in rural areas. An important condition is that skill needs and training content for project users/ technicians may be different from project to project in terms of layout, technology used, design, and other location specific factors. Therefore, training of the local technically qualified workforce and users were found to be a critical factor in ensuring the success of rural solar photovoltaic projects (Brooks & Urmee, 2014). Existing training programs include the Training of Photovoltaic Installers (PVTRIN), which is a training and accreditation scheme for certain European countries for individuals engaged in small-scale photovoltaic systems (Tsoutsos et al., 2013). The gaps in training have also been identified as a critical barrier in the renewable energy industry, resulting in a shortfall of qualified workmen in several countries (Lucas et al., 2018).

During the review process, few occupational and safety standards were found. They include the National Standards on Health and Safety at solar photovoltaic power plant, developed by the Skills Council for Green Jobs in India (Goel,2016) and Occupational Safety and Health Administration (OSHA) regulations specific to PV installations which are covered under a) Occupational Safety and Health Standards (Part 1910) and b) Safety and Health Regulations for Construction (Part 1926). Another is the Queensland Code of Practice which covers the safety and health of workers associated with the life cycle of solar farms (State of Queensland, 2019). The Code of Practice emphasizes on designing safe solar farms by addressing potential hazards at the design and planning phase. In order to achieve this objective, it is recommended that engineers involved with design of solar farms should gain required skills and competencies in the areas of rules related to health and safety, management of risk and standards related to design. The fire department of the Newport Beach (City of Newport Beach, 2009) has formulated standards for layout design of roof-top solar photovoltaic installations with a focus on fire safety. The guidelines recommend the creation of walkways and labelling of photovoltaic equipment. The provision of walkways ensures sufficient clearance space for the movement of workers at different postures at various stages of installation as well as during maintenance. In addition, these walkways are important evacuation corridors during untoward eventualities such as fire, inclement weather, accidents etc.

2.2.5 Existing design interventions/approaches in the solar photovoltaic industry

This present research study aims to use design interventions as ways of addressing emerging OSH risks. To do so, existing approaches need to be mapped so that future opportunities can be identified. A total of 14 existing studies concerning design approaches in the solar photovoltaic industry were reviewed and summarized representing the author(s) of the study, region/location, type of solar photovoltaic project/product, type of study, scope of design, and design objective. The existing design approaches in the solar PV industry are shown in Table 2.3.

Table 2.3. Existing design approaches in the solar PV industry

Author	Region	Type of solar PV	Study type	Design scope	Design objective
Dai et al. (2020)	Singapore	FSPV	Analysis of performance	Efficiency, load-bearing ability, durability, and easy operation & maintenance	Better structural & operational performance
Ho et al. (2020)	USA	Roof-top PV	Case studies	Prevention-through Design (PtD) protocol & attributes	Workplace safety
Li et al. (2020)	Australia	Roof-top PV	Simulation	Roof design	Efficiency
Bao et al. (2020)	USA	Solar PV installations	Survey of stakeholders & homeowners	Human-Centered Design (HCD)	Adaptability of solar PV
Hernández-Callejo et al. (2019)	NA	Solar PV installations	Review	Design, operation & maintenance	Increased efficiency and lower costs
Hong (2019)	NA	Solar PV products	TRIZ innovation method	Design elements for better usability	Sustainable products
Cazzaniga et al. (2018)	Italy	FSPV	Performance analysis	Innovation in PV system design	Increased efficiency and lower costs
Bhang et al. (2018)	South Korea	FSPV	Predictive analysis	Use of grounding electrodes	Electrical safety
Bao et al. (2017)	USA	Roof-top PV	Consumer survey	Visual appearance of solar panels	Influencing the preference

					of solar panels
Kim et al. (2017)	South Korea	FSPV	Tech-commercial analysis	Design & construction of FSPV system	Cost-effectiveness
Balo and Şağbanşua (2016)	NA	Solar panel	AHP	Solar panel characteristics	Influence on purchase decision
Scognamiglio (2016)	NA	Ground PV	Ecological impact	Land-integrated photovoltaics	Ecological performance
Lee et al. (2014)	South Korea	FSPV	Performance analysis	The material of floating platform	Durability
Spertino and Corona (2013)	Turin, Italy	Roof-top & Ground PV	Techno-economic analysis	Design of guidelines for PV system, maintenance & installation	Energy Efficiency

Notes: NA: No specific mention of any particular region/country

Abbreviations: AHP, analytical hierarchy process; TRIZ, theory and inventive problem solving

2.3 Research gaps and scope for design interventions

The findings of the review and comparison with the intervention strategies at various hierarchical levels are shown in Figure 2.2. Different types of intervention approaches have been taken from Bridger (2018). Although there are some studies (indicated by blue lines in Figure 2.2) that have addressed a few OSH risks and issues, most of the OSH concerns are yet to be addressed (indicated by broken red lines in Figure 2.2). The review findings did not elicit any study that has addressed or plans to mitigate the OSH issues in the floating solar PV sector.

These findings present several opportunities for exploring and implementing design interventions at the early phase of growth of the floating solar sector. Accordingly, stakeholders will be able to adopt the interventions and ensure a safe and sustainable FSPV sector at the design phase itself.

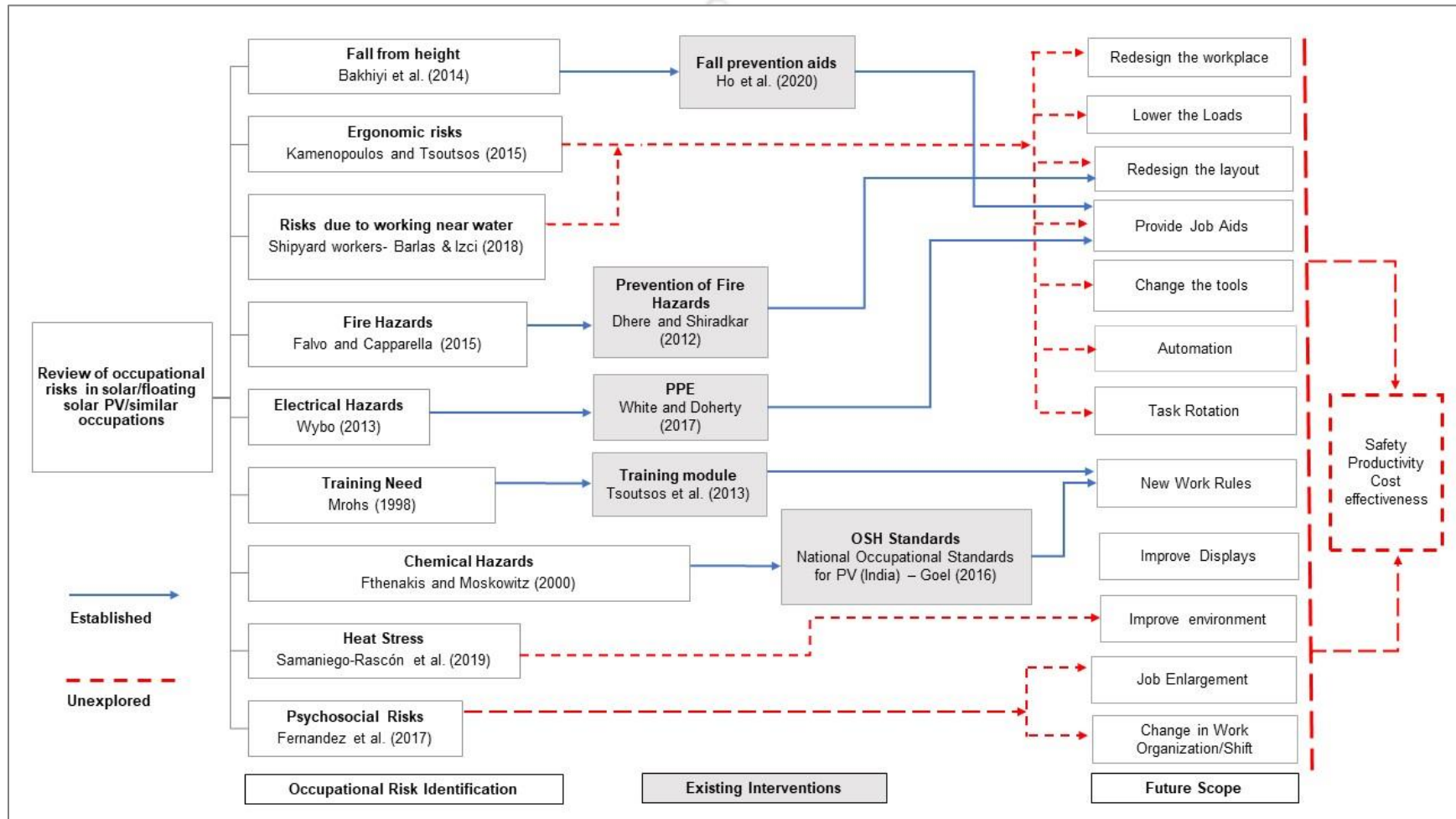


Figure 2.2. Risk identification, existing interventions, and opportunities for ergonomics design interventions at various levels as revealed from the review. (Studies and author names are indicative and not exhaustive).

The research gaps, indicated by red broken lines in Figure 2.2 are the unexplored interventions. They can be divided into bottom-up, top-down, and same-level interventions (Bridger, 2018)). They are follows:

Bottom-up interventions

- a) lowering of loads
- b) redesigning of layout
- c) provision of job aids, and
- d) changing tools

Top-down interventions

- a) automation
- b) task rotation
- c) job enlargement and,
- d) change in work organization

Same level interventions

- a) workplace redesign and,
- b) improvement in the work environment.

Important considerations for choosing the level(s) of intervention include project layout and design, duration, location, equipment type and materials utilized, work organization, financing, top management support, safety policies, statutory requirements, and priority towards OSH issues.

A significant part of the work on FSPV projects involve Manual Material Handling (MMH). The various activities include the repetitive carriage of solar PV panels and floaters, assembling of pontoons and PV panels, and construction of walkways. An outcome of such work requirements results in awkward postures, drudgery and performing work on a moving/swaying floating platform on water. Optimization of these work requirements can be achieved through bottom-up design interventions which are comparatively easier to implement and require limited investment. This assumes importance because the installation of floating solar projects involves short duration and can consist of a large workforce. Interventions in the top-down category like automation will require large investments, whilst task rotation and job enlargement will be complex to realize in unstructured work.

FSPV workplaces are located in outdoor environments. Addressing the risks in outdoor workplaces such as elevated temperatures and solar radiation are important priorities. Use of Personal Protective Equipment (PPE), construction of canopies/shelters, provision of drinking water, heat stress management, and discontinuing work during the hottest part of the day can be some of the control options. In addition, by the virtue of the work environment, solar radiation is a major risk factor. Some interventions that may be developed include products for protection of the eyes, skin, and head. Awareness and training programmes attracting attention towards the deleterious effects of solar radiation are important considerations. These are some of the design

opportunities, while a comprehensive list of concepts is discussed in Chapter 6. Human-machine interfaces, OSH risk factors and diseases, and proposed future opportunities from an ergonomics design perspective are summarised in Table 2.4.

Table 2.4. Human-machine interfaces in a FSPV workplace and design opportunities

FSPV System components	Occupational risk factors	Occupational diseases/conditions	Design/redesign scope
Solar PV panel	Awkward postures during installation & unwieldy equipment	Low Back Pain (LBP) & Musculoskeletal disorders (MSDs)	Lowering of loads and task rotation
Frames, clamps/nuts/bolts	Sharp edges and sub-optimal designs	Cuts, bruises, strains, and WMSDs	Layout redesign, lowering of loads
Water bodies, pontoons/surface of floating structures, and walkways	Unstable and slippery platform impedes balance and creates postural challenges during both standing and walking	Slips, trips, drowning, and even fatalities due to falls into water. Fatigue of the erector spinae, leg, abdominal, gluteal and iliopsoas muscles due to the additional strain for maintaining posture on an unstable platform apart from normal work requirements	Flotation devices, handrails, and walking aid. Workplace redesign, training, and Personal Protective Equipment (PPE)
Tools such as hammers, pliers, cutters, wire strippers, and manual cleaning equipment	Awkward & repetitive postures, noise, vibration, compression, and usability issues	Carpal tunnel syndrome, tendinitis, MSDs, cuts, bruises, and Hand Arm Vibration syndrome	Design/redesign of tools and/or PPE
Batteries, panels, and inverters	Toxic oxides and electrocution	Injury, burns, and even death from electrocution	Job aids/PPE
Cranes, connectors, wires & cables	Objects may fall, fall from height, slips, and electrocution	Head injuries and electrocution	PPE/Workplace redesign

Work environment	Heat, UV radiation, humidity, rain, snow, noise, dust, water etc.	Heat illnesses, tinnitus, slips, falls, respiratory diseases, Irritant Contact Dermatitis (ICD), immune system disorders, skin cancer, and diseases of the eyes	Improvement in the environment, design of PPE, skin protective clothing, head & eye protection products, sun-safety training/awareness programs, and health monitoring
Work organization	Psychosocial	Job stress and absenteeism	Training, job design, shift rotation & job enlargement

2.4 Discussion

This first-of-its-kind literature review was carried out to holistically cover the various aspects of the FSPV sector from an OSH dimension and for understanding the design opportunities. The following sections describe in detail the various aspects in an in-depth manner.

2.4.1 Growth of FSPV installations

A prime reason for the emergence of FSPV projects is the non-requirement of land (Sahu et al., 2016). This is a significant advantage in countries or locations where acquisition of land is a sensitive issue. Solar photovoltaic projects typically require land for a period of 25 years. In the Indian context and globally, there is a large number of small and large water reservoirs. Another advantage is the higher efficiency of FSPV projects over ground-mounted projects (Goswami et al., 2019). FSPV projects can be installed in combination with hydro power plants while reducing evaporation and safeguarding the aquatic environment (Cazzaniga et al., 2019). From a sustainability perspective, FSPV combined with aquaculture fulfills the objectives of a green economy and preserves the ecosystem effectively (Pringle et al., 2017).

In an indirect way floating solar can reduce environmental degradation by decreasing the use of fossil fuels for power generation such as coal. A study has shown that a large amount coal can be saved, and emissions of carbon dioxide can be reduced if a ten-megawatt FSPV project is installed (Goswami et al., 2019). These findings are important to attain the SDGs effectively.

A negative aspect of FSPV projects is that the cost of FSPV projects is higher as compared to ground-mounted projects. The higher investment is on account of the floaters/pontoons supporting the solar panels, mooring of the installation to the bed of the water body and anchoring to the land for keeping the project in position. However, FSPV projects are more efficient on account of the cooling effect of water and innovative designs (Ranjbaran et al., 2019). This neutralises the cost differential in the long term.

All project components go through the effects of entropy where materials and equipment degrade over time. From the durability perspective, HDPE (High-density polyethylene) is used in

the manufacture of floaters/pontoons. HDPE material has been found to be resistant to UV radiation and has significant load-bearing capacity (Sahu & Sudhakar,2019).

A report by International Bank for Reconstruction and Development (International Bank for Reconstruction and Development, 2019) indicates that some of the deleterious environmental effects of floating solar projects include water quality deterioration, negative effect on the aquatic animals, effect on avian habitat, decreased recreational value of water bodies and resultant waste products such as damaged panels, pontoons, wires, battery packs and other non-biodegradable materials.

2.4.2 OSH concerns associated with the FSPV Sector

Diverse kinds of OSH risks were elicited from the literature review. A key reason for the risks can be attributed to the mismatches between the abilities of the workers and the different factors at the workplace. The OSH risks include hazardous materials, ergonomics risks, fire, and electrocution (Fthenakis & Moskowitz, 2000, Bakhiyi et al., 2014, Aman et al., 2015, White & Doherty, 2017). Other risks include exposure to extreme temperatures for long hours and presence of inclement weather conditions such as hailstorms, typhoons, winds, etc. (Kamenopoulos & Tsoutsos, 2015, Samaniego-Rascón et al.,2019). Heat stress and its effect on workers is of concern in FSPV projects since solar photovoltaic projects are located in areas of high solar radiation. According to a report, heat stress may result in decrease in total hours of working by 2.2% in 2030 (ILO, 2019). A study (Samaniego-Rascón et al.,2019) on Mexican solar workers found that the effects of a hot environment was over and above the recommended exposure limits and the work capacity of acclimatized workers were more efficient than non-acclimatized solar workers. However, during a heatwave the work had to come to a stop. Some mitigation interventions suggested in this study include planning the heavy tasks at early morning hours and in the evening. Another Korean study (Kim and Lee, 2020) links the decrease in productivity (loss in work capacity) in fifty-two occupations with increase in Wet-bulb Globe Temperature (WBGT) as a result of global warming. Some risk management measures suggested are communicating information on a real time basis for them to understand the effects and causes of heat stress. The study also reports the existence of solar radiation as a risk factor. The degree of intensity is elevated due to reflection from the water surface and solar PV panels. This exposure over a prolonged period can affect the skin and the eyes (Modenese et al., 2018) and even be a causative factor in the long term for different types of cancer (Paulo et al., 2019).

Protection measures include provision of shelters, canopies, regular rest periods through work re-design, avoiding outdoor tasks during the hottest part of the day, training on sun-safety, eye protection with sunglasses, head coverings, use of sunscreens, reflective and sun-protective clothing and health camps for detecting signs of cancer (Modenese et al., 2018, Reinau et al., 2013). It is evident from the above paragraphs that solar radiation is a major risk in FSPV projects and outdoor work in general.

On account of a significant amount of manual work, human factors or ergonomics issues are associated with FSPV projects. These include ergonomic risks such as non-neutral postures and lifting of heavy loads according to a study by Bakhiyi et al. (2014) on the solar photovoltaic

industry. Risk factors from toxic chemicals, vibration from tools, sources of noise are also present in many project sites. The presence of water in the working environment is a significant contributor to many risk factors. Workers are exposed to a water interface not only during installation but also during maintenance work such as cleaning of solar PV panels. Some of the negative effects of working with water include skin disorders such as Irritant Contact Dermatitis (Behroozy & Keegel, 2014). As mentioned earlier, divers are engaged in FSPV projects. These personnel may suffer from decompression sickness (DCS) even with self-contained underwater breathing apparatus (SCUBA). The divers may also be exposed to a hypothermic and hyperbaric work environment (Francis & Mitchell, 2003).

A study reports the risks associated with installation and maintenance of solar photovoltaic panels (White and Doherty, 2017). The risks include electrocution, arc flash, solar heating, high winds, fire and, possibilities of falls from height. Moreover, solar panels can produce electricity in the presence of sunlight. Such unseen risks are difficult to detect and must be taken into account while designing signages, training modules and safety regulations. Leakage of electricity due to a humid environment (International Bank for Reconstruction and Development, 2019) in floating solar projects also creates additional OSH risks which may lead to possibilities of electrocution and also damage to electrical equipment in the long run.

A study (Kamenopoulos and Tsoutsos, 2015) has used the Operational Risk Management (ORM) methodology to figure out three categories of risks in maintenance and operation of solar photovoltaic systems. They include technological risks such as fire, electrocution, etc, risks due to natural factors such as winds and lightning, and other risk factors such as theft and vandalism. The same study identifies abnormal weather conditions such as hailstorms, lightning, and winds of high velocity. According to several reports (Bellini, 2019), adverse weather conditions can also affect the floating solar installation and its associated components. Some design interventions that may be adopted are storm shelters, personal protective equipment and restraining harnesses for protection of the FSPV workers. Consideration of weather forecast information while scheduling installation and/or maintenance activities and deployment of workers should be important priorities. Since workers are deployed on floating platforms far away from land, it will take significant time to come back to land during exigencies. Accordingly, mandatory training on evacuation procedures and safety aspects during bad weather conditions can be adopted. From a design perspective, many interventions can be adopted to protect the workers despite several challenges. Multiple hazardous materials and toxic substances are present in different components of a solar photovoltaic system (Aman et al., 2015). Presence of ammonia in modules can cause harm to the eyes and presence of arsenic can affect the lungs and other vital organs of the human body. Electrical components contain lead which has the ability to affect the nervous system. Some cancer-causing chemicals include cadmium (solar cells) and polybrominated biphenyls (used in inverters). Several other substances and their health effects are summarised in Table 2.2. Some of the measures to address OSH risks due to such substances include sustainable manufacturing, context specific personal protective equipment and secure disposal or decommissioning of different materials. Some psychosocial OSH factors identified in green-collar jobs are job insecurity and work-life imbalance (Fernandez et al., 2017). Some additional risk factors should also be considered while selecting workers. These risk factors that can cause musculoskeletal

diseases include injury history, age, socioeconomic background, compensation, and gender (Stack et al., 2016, Widanarko et al., 2011). In this literature review, no study could be traced that has measured or investigated occupational risks in the FSPV sector.

2.4.3 OSH risks in closely related workplaces/occupations

Many occupational risks are similar between FSPV workplaces and other occupations having an aquatic workplace. Such occupations include fishing, work at ports, aquaculture, and many others. The major risks include work with water over prolonged periods, human factors risk, unbearable temperatures, hazardous substances, noise, dust, falls from elevated areas, UV radiation, vibration, and possibilities of electric shocks. In FSPV projects additional risks may include possibilities of getting infected with water-borne diseases, threat from aquatic animals, unknown depth of water, changing levels of water in the water body and no prior experience of working over water. Some risk management options include safety training, close supervision, availability of rescue divers and deciphering pathways for the manifestation of contextual occupational diseases.

2.4.4 Requirements for standards of OSH and workforce skilling

No study was found that has mentioned training programs or OSH standards in the FSPV sector. Provision for such components is important for the workers who are exposed to unknown work procedures and ever-changing layouts. Occupational safety and training have to be shown to be related positively (Camuffo et al., 2017). Since safety from excessive sunlight is important, the training approach named “Sun Safety at Work Canada” can be adopted before commencement of work in all FSPV projects (Haynes et al., 2018). Future work can involve formulation of training programs with a focus on risk mitigation approaches. At the same time there should be an insistence from the stakeholders for development of OSH standards specific to the FSPV sector.

2.4.5 Design strategies in the solar photovoltaic industry

From the design perspective, the focus has mostly been on improving efficiency, overall performance, bettering cost-benefit of floating solar projects and long-term performance of pontoons/floaters (Bao et al., 2020, Dai et al., 2020, Hong, 2020, Kim et al., 2017, Spertino & Corona, 2013). Little research revolves around the occupational safety aspects. In terms of the shortlisted papers in this chapter, two studies have considered design approaches to neutralize OSH risks.

The first study recommends the grounding design of FSPV projects to protect against electrocution (Bhang et al., 2018) and contributes to electrical safety. This is especially critical since electrical OSH risks are unseen and more potent in an aquatic workplace.

The second study (Ho et al., 2020) adopts the Prevention through design (PtD) approach towards installation of small-scale roof-top solar installations. Contextual data and information were collected from several ongoing projects on PtD attributes (roof material, roof accessories, roof slope, the design layout of panels, fall protection system, solar panel lifting procedures etc.). Subsequently, a PtD protocol was developed after interaction with contractors. This can go a long way in addressing risks, but such protocols have to be customised for the floating solar sector.

Other design approaches include a study (Hong,2019) that explores the design of solar panels from an ergonomics perspective. The study recommends the inclusion of ergonomics factors, color aspects, functional aspects, interface considerations, material of the surface, and structural factors in the solar photovoltaic panel. Another study (Balo and Şağbaşıua, 2016) recommend that panels should be selected based on factors such as consumer satisfaction, cost, technical, financial, and environmental aspects. Some manuals related to the construction safety in roof-top solar installations such as the one developed by the Oregon Solar Industries Association (OSEIA) regarding construction safety can be useful but needs to be re-designed for FSPV projects. The Nigerian Energy Support Programme has designed a handbook (Isiolaotan et al., 2017) that deals with various dimensions of workplace safety in small solar installations. However, design solutions as a risk mitigation tool have not been considered. Future scope includes the extension of the design approach from roof-top projects to other types of solar projects.

2.4.6 Risk mitigation using a design strategy

Jobs associated with FSPV projects are categorized as green jobs as per the International Labour Organization (ILO, 2016). A study (Schulte et al., 2010) points out that even though the final product of such jobs are green or sustainable, the workmen engaged in such jobs are faced with several OSH issues. These risks factors may be neutralized using the approach of “designing out the hazards”. In this approach the worker should be involved during assessment of risk and consideration of factors related to the organization, cognitive and physical risks.

In another study (Hanson, 2013) regarding installation of solar photovoltaic panels, the need for design of workplaces and personal protective equipment has been emphasized. Figure 2.3 shows a suggested framework to implement design interventions/solutions in the FSPV sector. Concerned stakeholders can utilize the template to plan and implement design interventions using a participative approach. In addition, for greater job sustainability, a tool containing forty occupational health indicators for monitoring of green jobs based on the framework "Health indicators of sustainable jobs" of the World Health Organization (WHO) may also be utilized in the floating solar PV sector (Moreira et al., 2017).

2.5 Summary

This chapter has identified several intervention options such as ergonomically designed tools, job re-design, layout design from a safety perspective, automation, designing training programs, developing OSH standards, and preventing risks emanating from the aquatic environment. The review outcomes support the urgent need for interventions given the growing size of the FSPV sector and context-specific occupational risks associated with installation and maintenance. This review also highlights several research gaps/opportunities for addressing the risk factors from an ergonomics design perspective (Figure 2.2).

This chapter has summarized the literature review findings in a comprehensive way and outlined the state-of-the art knowledge in the floating solar sector. The research gaps will assist in identifying specific areas of research so that design interventions can appropriately address the contextual OSH risks.

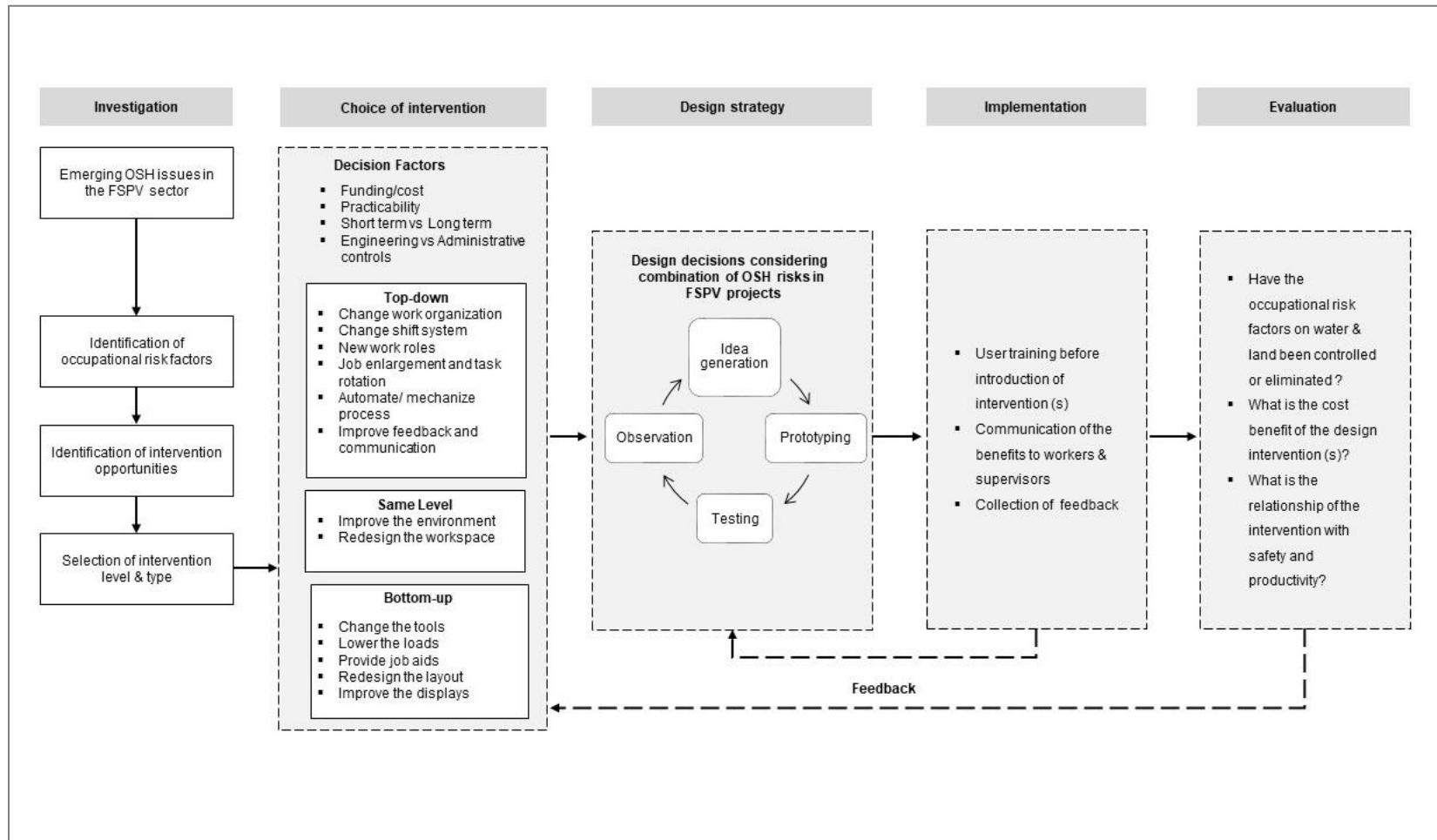


Figure 2.3. Proposed strategy for implementing design interventions in the FSPV sector.

Notes: Types and levels of interventions (under choice of intervention in the figure) data from Bridger (2018) and 'steps in the design process' (under design strategy in the figure) data from Norman (2013)

Chapter 3: Exploratory field studies



Abstract

To explore the ground scenario, field surveys were carried out to study the OSH concerns. The exploratory studies revealed that the workers are highly exposed to different occupational hazards during installation and maintenance due to heavy load handling, non-neutral postures, inappropriate tools, paucity of safety measures against the harsh working environment (hot sun, electrocution, drowning, etc.), lack of specific training and many others. Project managers agreed that immediate attention is required for the safety and better occupational health of the workers and felt the need for protecting the workers from the hazards especially through design interventions. This study is a maiden effort in understanding the OSH aspects in the emerging FSPV sector in India and establishes a knowledge gap, which is proposed to be addressed through suitable ergonomic design concepts.

This chapter describes the findings of preliminary exploratory field studies. The workflow, working conditions in two FSPV projects in India, contextual OSH risks and the safety concerns and recommendations of the site managers/engineers is elaborated.

3. Introduction

The first floating solar project in the world was installed by SPG Solar of Novato, California, and Thompson Technologies Industries (TTi) in 2007 at the Far Niente Winery in Napa Valley, located in California (Trapani et al., 2013). The size of the project was 175 kWp. The first project in India was installed in Kolkata, India in the year 2015. India is seeing a rapid growth in renewable energy projects in recent years on account of enabling policies, concerns over Climate Change and global commitments (Figure 3.1). In addition, attractive tariff, and availability of solar potential for a major part of the year are positive factors (Shukla et al., 2018). Within the solar photovoltaic industry, utility scale floating solar projects are gaining prominence on account of their land neutrality and other advantages which have been detailed in Chapters 1 and 2. More and more stakeholders are adopting the FSPV route for attaining renewable energy targets. According to a report, the size of water surface area that can be considered for installation of FSPV system is about 18,000 km². The highest potential estimated is 280 GW (TERI, 2019). Maharashtra State has the highest number of reservoirs. Other Indian States having good potential include Madhya Pradesh and Gujarat.

It has been established in Chapter 2 that there has been no research work or studies examining the emerging OSH issues in the FSPV sector. Since FSPV projects are new workplaces, it was decided to conduct preliminary exploratory studies to understand the ground realities.

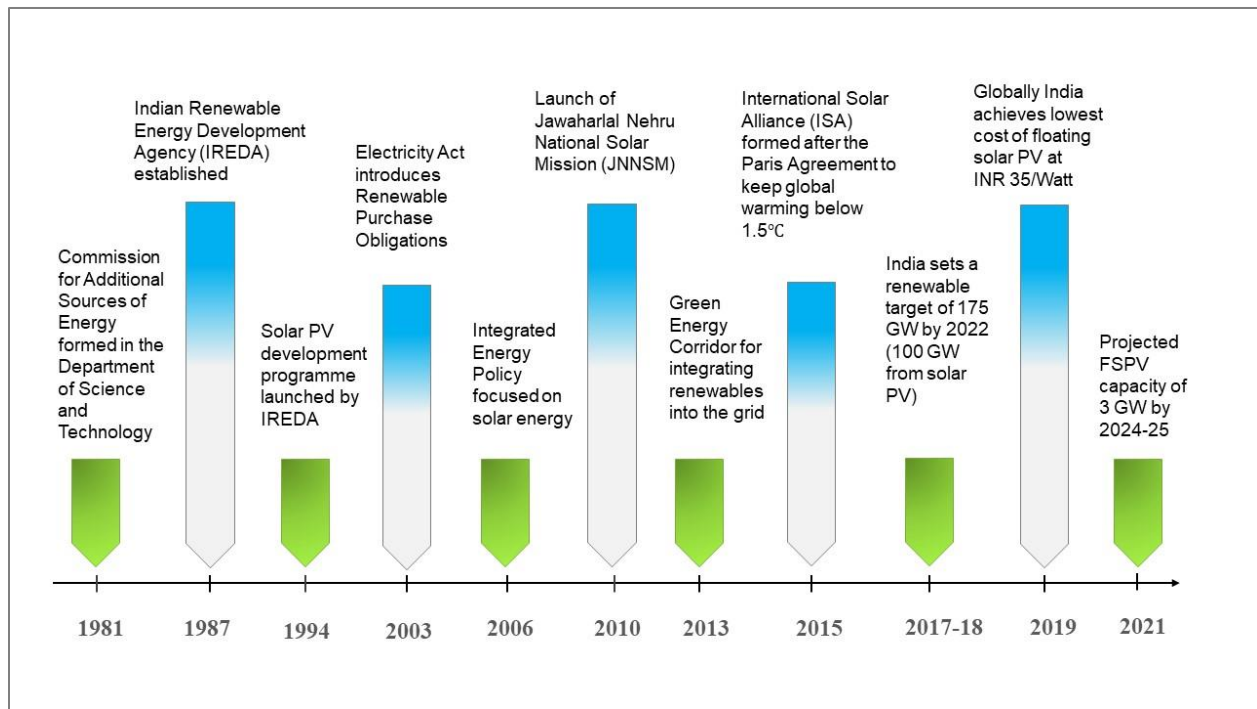


Figure 3.1. Significant milestones in the growth of Renewable Energy in India (Author compilation)

3.1 Methodology

For conducting the studies, two FSPV sites were selected. The research questions designed for the study were as follows:

- what are the occupational hazards that workers are exposed to during the installation and maintenance of floating solar PV projects? and,
- what context-specific tools, equipment, or other workplace aspects can be designed or redesigned to control the hazards for which existing solutions do not exist?

The aim of the exploratory study is to probe the ground scenario of OSH dimensions of the FSPV workers and understand/elicite innovative design interventions for mitigation of risks

The objectives are as follows:

- To identify the sources of hazards (occupational, environmental, psychosocial, skill gaps, etc.) regarding the workers engaged in FPV installation and maintenance.
- To study the existing occupational safety and health measures for the FPV sector.
- To identify the possibilities of design interventions from the OSH perspective.

3.1.1 Development of questionnaire:

A questionnaire was constructed based on the OSH risks identified in the literature review. A search was also conducted on the existence of safety checklists in the solar photovoltaic industry. Only one checklist related to safety and health in roof-top solar installations was found (EU-

OSHA, 2013). Based on some constructs of the checklist and varied risks identified earlier a questionnaire was constructed. The questionnaire contains eight sections, as follows:

- a) general information about location, type, and size of the project, type, and skill level of workers, etc.
- b) training, safety, and work organization aspects
- c) hazards of working on water, slips, and trips, falls, etc.
- d) use of Personal Protective Equipment (PPE)
- e) electricity-related hazards
- f) hazards that may lead to Musculoskeletal Disorders (MSDs)
- g) specific sources of OSH hazards and,
- h) suggestions for design/redesign of FSPV system components

The questionnaire is given in **Appendix-A**. Videography and photography were carried out at the project sites to understand the workflow and working of the floating solar system, especially those areas where there were human-machine interfaces. Tools and techniques used, worker facilities and other aspects were also studied. A total of 22 workers were working on the two projects surveyed. Four project managers/engineers responsible for installation and maintenance expressed their views through face-to-face interviews wherein they responded to the questionnaire about the safety aspects and various intervention opportunities from a design standpoint.

3.2 Results

The overview of the two sites considered for the study is summarized in Table 3.1. One of the projects is a 25 kW FSPV installation at the water reservoir of Mejia Thermal Power Station belonging to Damodar Valley Corporation (DVC). The other project is a 1 MW FSPV installation located at the Kawas Gas Power Station of National Thermal Power Corporation (NTPC).

Table 3.1. Overview of the FSPV sites considered for the study

Parameters	Mejia (DVC)	Kawas (NTPC)
Location	The water reservoir of a thermal power station	The water reservoir of a gas-based power station
Capacity	25 kWp	1 MW
Design of FPV	Floating structure type	All in one buoyancy type
Number of Workers engaged	06	16
Direct Normal Irradiation (DNI)*	1187 kWh/m ² per year	1614 kWh/m ² per year
Peak months*	March & April	March, April & May

Power Output for 1000 kWp*	1.297 GWh per year	1.478 GWh per year
----------------------------	--------------------	--------------------

*Source: Global Solar Atlas

3.2.1 Analysis of the workflow

After arrival of the materials at the site, the solar panels are fixed on the floaters/pontoons to form individual units (Figure 3.2). The individual units are assembled into an array consisting of about six to eight panels. These arrays are then deployed into water using a launching platform at the interface of land and water. These arrays are pulled by a boat to the installation point and further integrated to form a larger array of floating solar panels. Subsequently, wiring is completed, and electrical connections are established. The system is charged, and the power is evacuated through nearby transmission lines over land. The installation activities on land and over water are represented in Figures 3.2 and 3.3.



Figure 3.2. Installation activities on land (Image source: author)

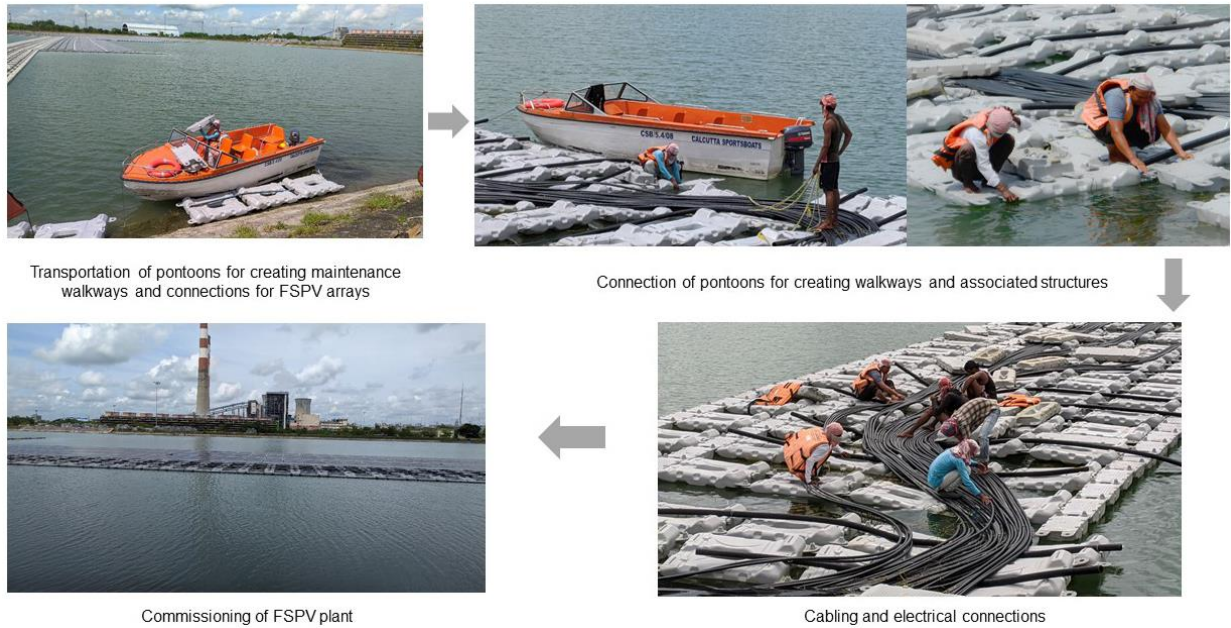


Figure 3.3. Installation activities on water (image source: author)

The installation workflow is shown in Figure 3.4.

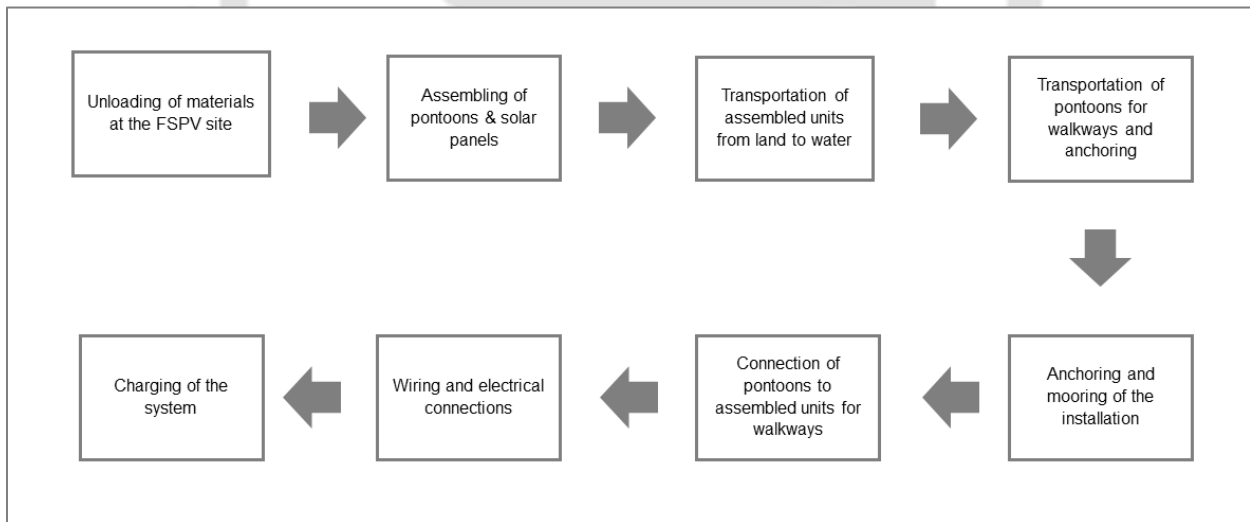


Figure 3.4. Workflow in a typical Floating solar PV plant

The different components of the main floater with solar modules fixed to it and the walkway floaters are shown in Figure 3.5. The different tools used in FSPV installation and maintenance is shown in Figure 3.6.

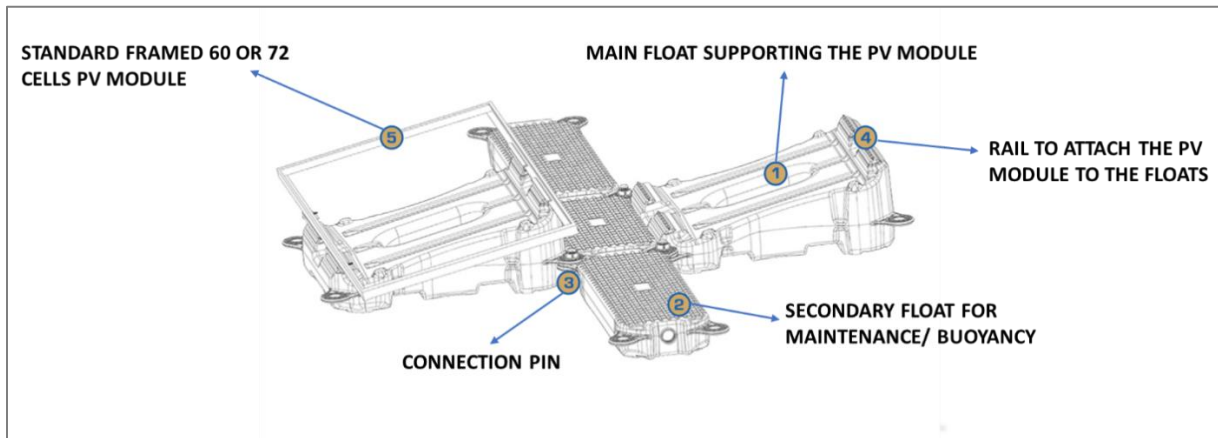


Figure 3.5. Different parts of a FSPV module (image source: Ciel et Terre)

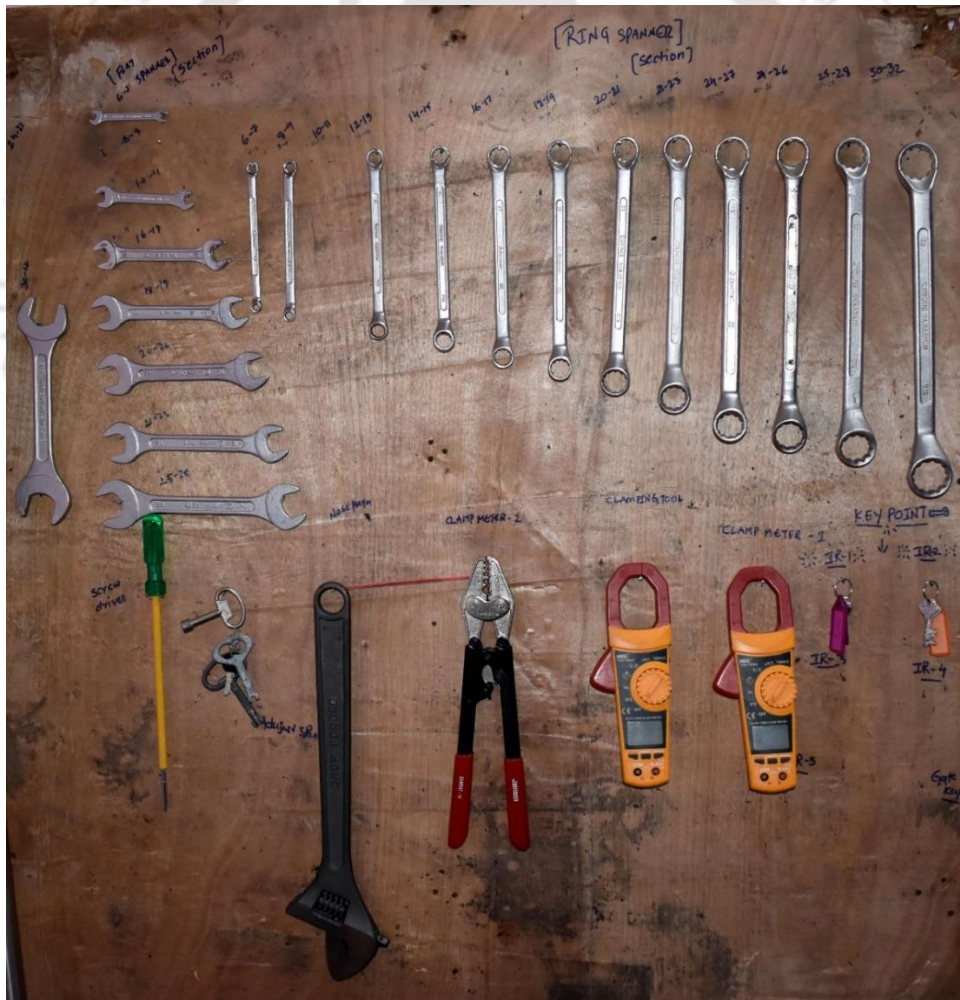


Figure 3.6. Array of tools used in FSPV projects (image source: author)

The project managers completed the questionnaires related to the two sites using online software during the period September-October 2019. The responses are summarized in Table 3.2.

Table 3.2. Summary of responses received from project managers

Parameters/queries	Site 1 (NTPC)	Site 2 (DVC)
Skill level of the workers	Semi-skilled	Semi-skilled
Mode of safety training	Lectures in local language	Demonstration
Cooperation, communication, occupational check-up and worker feedback for workplace safety	✓	✓
Consideration of needs of workers of different types, gender, and ages	✓	✓
Platforms/scaffolding/rails/barriers/safety nets for work near water	✓	✓
Inspection of all parts of the floating solar PV system	✓	✓
Type of tools used	Tools used in other solar PV projects	General hand tools
PPE (life jackets etc.) and life preservers	✓	✓
Safety signs, fire extinguishers, first aid, and emergency plan	✓	✓
Precautions to prevent electricity-related hazards such as grounding, dry inverter area, etc.	✓	✓
Design of work and layout to reduce Manual Material Handling and ergonomic hazards	✗	✗
Specific hazards from solar PV panels	Sharp edges, the weight of panels, and lack of proper grips	Sharp edges, lack of grips, electrical hazards, and difficulties in replacement
Specific sources of hazards from Floating structures/pontoons	Instability of the floating structure	Falls into water & gaps in the walkways
Specific sources of hazards from tools	Difficulty in use during installation	Difficulties in use during installation & tools may fall into the water

Specific sources of hazards from cables/inverters/batteries	Electrical shocks and carrying cables/wires	Electrical shocks, fire, and chemical hazards from batteries
Environmental hazards	Humidity & hailstorms	Rain and extreme sunlight
Design/redesign required	Scaffolds/walkways/shoes	Solar panels, floaters, Personal Protective Equipment, tools, and methods of work

3.2.2 Observations/concerns of project managers

- a) It was agreed that the risks in FSPV projects are different from risks in other types of solar photovoltaic projects.
- b) The unique risks include unstable floating platform and working on/near the water.
- c) FSPV workers were found to be casual regarding the use of PPE. This is frequently corrected by supervisors'/safety managers.
- d) Requirement for OSH standards/regulations for work process and skill levels were emphasized.
- e) High wind speeds and unstable floating platform presents several risks for the workers.
- f) Possibility of causing heat illnesses due to the harsh environment
- g) Need for OSH checklist/guidance and design standards.
- h) Training in installation & maintenance, safety consciousness, and error free work
- i) Protection against risks related to an aquatic environment.

Figure 3.7 (a to d) shows some of the OSH risks existing in FSPV projects.



Figure 3.7. (a) A multitude of ergonomic hazards during installation; (b) work near water exposes the workers to a combination of hazards; (c) sharp edges and presence of electricity are occupational hazards, and (d) work on unstable floaters presents additional hazards (image: author)

3.3 Discussion

This exploratory field study has provided important insights into the rapidly growing FSPV sector. The new kinds of risks and their combined effect on worker safety needs to be addressed immediately. In comparison to the existing design concepts already available (Chapter 2) several design opportunities have been identified. They are the following:

- a) Scaffolds/guarding around the walkways
- b) Redesign of walkway platform
- c) Redesign of solar panels and floaters
- d) Development of customized PPE
- e) Provision of special tools
- f) Design of anti-slip shoes/footwear
- g) Job redesign

Apart from this, design interventions towards ensuring requisite skilling, addressing the psychosocial factors and microclimatic factors can also be explored.



Figure 3.8. Some FSPV workers who participated in the exploratory study (Image: author)

3.4 Conclusion

Generation of power from clean sources is an important socio-economic objective. This objective is directed at reducing global warming and protecting the environment. At the same time, protecting the FSPV workers and other workmen in the renewable energy industry are equally important. To achieve objective, design intervention is proposed as a sustainable tool. The initial field study was undertaken for “problem defining” (Norman,2016) within the aims of the objectives of the present research and to understand the various contextual aspects.

The risks in FSPV projects are markedly varied from other types of solar photovoltaic installations. At one of the surveyed sites, a project engineer opined - *“Floating Solar Technology, still in an evolving stage, needs specific design of equipment, tools, and accessories suitable for Floating installation.”*

This chapter has identified some design opportunities interventions not identified earlier. Future scope will involve a detailed analysis of the OSH hazards using human factors/ergonomic assessments followed by the development of design solutions from the perspective of Human-Centred Design (HCD).

Chapter 4: OSH risk perception, sociodemographic studies, and work environment assessment



Abstract

Measurement and prioritization of occupational risk factors is an important step in the process of developing context specific risk mitigation interventions from a design perspective. Safety managers and FSPV workers engaged in FSPV projects are an important source for understanding the type and severity of the workplace risk factors. OSH perception scores, sociodemographic information, discomfort glare and environmental data were collected at two FSPV sites in India. OSH risk perception scores from safety managers (n=30) and FSPV workers (n=53) were collected. Risk factors in the very high- and high-risk categories include falling into water, heat stress, electrocution, solar radiation, slips and trips. Other risk factors include ergonomic risks, the threat from aquatic animals, hazardous materials, adverse weather conditions and skill gaps. Discomfort glare was found to be a severe risk factor.

This chapter discusses the development of an OSH risk perception questionnaire, measurement of the risks from the perspective of safety managers and FSPV workers and risk prioritization thereof. The outcomes of the assessment of environmental parameters and measurement of glare are also summarized.

4. Introduction

Some of the important stakeholders associated with FSPV projects involve workers, project managers/engineers, safety managers, project developers, policy makers and financiers. Understanding the OSH risk perception from the perspective of safety managers and the workers themselves can be important input for understanding the severity of the risks and can be a precursor for the development of specific design interventions.

Perception of risk consists of “subjective beliefs about potential harm or the possibility of a loss” (Turner & Gellman, 2020). Understanding of the characteristics of the risk and its severity are important components of the risk perception process. The research questions for this part of the study are as follows:

- a) What are the types and degree of risk that may be perceived by the safety managers with reference to FSPV projects?
- b) What according to safety managers can be the risk mitigation measures for the identified risks?

The aim of this part of the research is obtaining the perception of risks from safety managers. The objectives are a) collecting data on the types of risks faced by the workers as perceived by safety managers, b) obtaining the risk perception measures for the different kinds of risks and, c) obtaining opinions of the safety managers for mitigation of risks.

4.1 Methods & materials

An online search was conducted to understand whether a risk perception questionnaire exists in the solar photovoltaic industry. Since no such questionnaire could be found, it was decided to develop an OSH risk perception questionnaire for the FSPV sector. The different OSH risks

were obtained from a review of literature (Chapter 2) and related publications (Sen et al., 2021, Sen & Karmakar, 2021). A total of twenty risks were identified. The types of interventions were derived from the views expressed during the preliminary field surveys in FSPV projects (chapter 3). Participants also had the choice to opine about additional interventions while responding to the survey. For testing the reliability of the questionnaire, a pilot survey was carried out with a sample size of 10 safety managers and tested by applying the Cronbach's alpha test (Tavakol & Dennick, 2011). The value of alpha was found to be above 0.70, which is acceptable (Tavakol & Dennick, 2011).

The questionnaire consists of the following questions:

- a) General information such as organization, years of experience (especially in FSPV/solar PV projects),
- b) Perception of types of OSH risks faced by FSPV workers
- c) Perception of the degree of each risk on a five-point risk Likert perception scale based on severity, vulnerability, and frequency of exposure,
- d) Opinion of safety managers about OSH risk mitigation measures/intervention choices mentioned in the questionnaire,
- e) Additional areas of concern regarding OSH of the workers.

The questionnaire is provided as **Appendix-B**

Face to face and virtual interviews were carried out to obtain responses. Invites for the interviews were sent to forty-six safety managers working in organizations operating in India. The selection criteria for being a participant was that they had to be a professionally qualified safety professional with at least one year of experience. They should preferably be associated with the power industry and especially with those organizations executing solar photovoltaic projects. Finally, thirty managers completed the questionnaire. Safety managers from the following organizations participated in the study (figures in brackets indicate the number of participants from each organization).

- a) National Hydroelectric Power Corporation Ltd. (2)
- b) POWERGRID (3)
- c) Engie Solar (2)
- d) Tata Power Solar (3)
- e) Tata Consulting Engineers Ltd. (4)
- f) Cairn India (1)
- g) Damodar Valley Corporation (5)
- h) Bokaro Power Supply Corporation Ltd. (4)
- i) Sterling & Wilson (4)
- j) Quant Solar (2)

Pearson Coefficient of Correlation (Schober & Schwarte, 2018) was used as a tool to find out the correlation between OSH perception scores between the participating organizations.

4.2 Results/Observations

The minimum work experience of the respondents was 1 year, and the maximum was 32 years. Eight respondents had direct working experience in FSPV projects.

4.2.1 Identification of OSH risks

The percentage responses against each type of OSH risk faced by the workers are represented in Figure 4.1. Safety managers from the participating organizations had the choice of responding to more than one type of OSH risk when completing the questionnaire. For example, eighty percent of the participants felt that slips/trips on the floating platform was a critical occupational risk while working in FSPV projects.

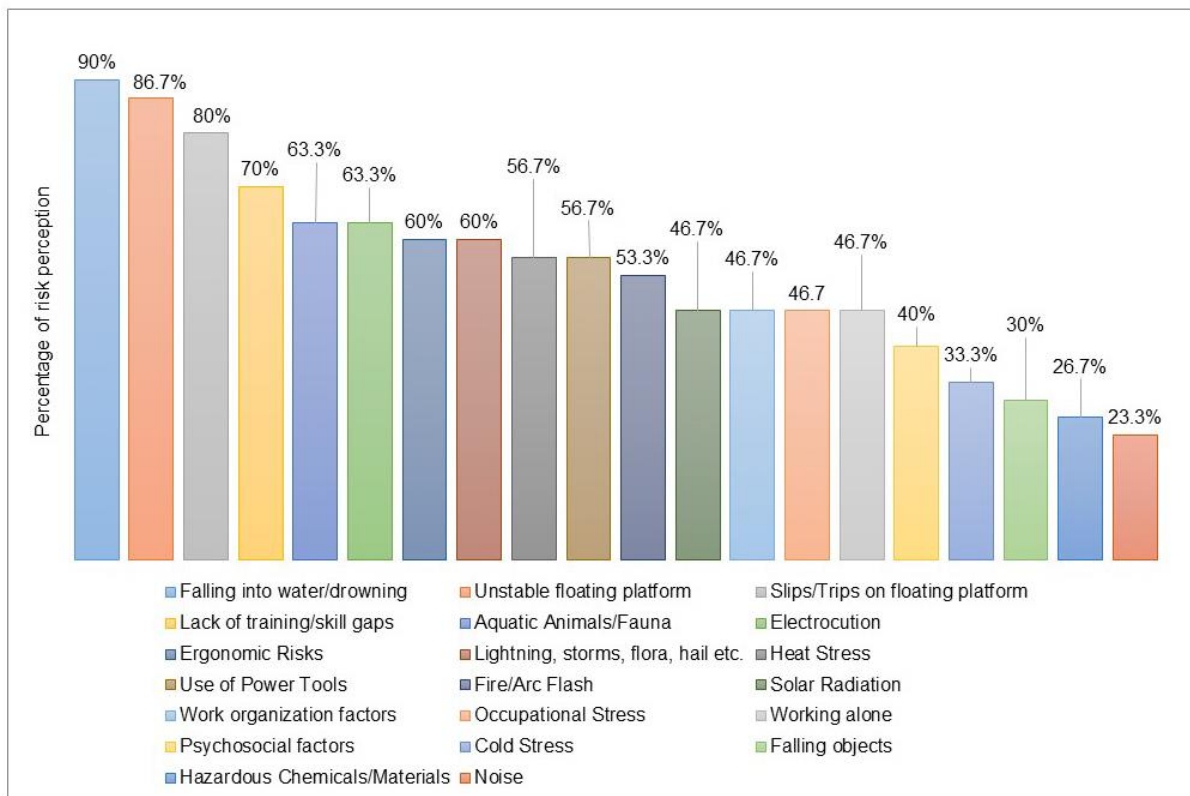


Figure 4.1. Types of OSH risks perceived by safety managers and percentage of responses against each risk.

4.2.2 Perception based on the degree of risks

Respondents completed a 5-point Likert type scale to respond to the degree of risk. The responses varied between “very low risk” to “very high risk” against each kind of risk. Table 4.1 shows the OSH risk perception summary for the different risk factors with the highest percentage of response against each. Since varied degree of risks could be perceived for a given risk, many risk factors have been rated as both very high and high and even low at the same time on account of same percentages.

Table 4.1. Degree of perceived risk based on highest responses against each OSH risk

S. No	OSH Risk	Degree of perceived risk	Percentage (%) of responses
1	Unstable floating platform	Very High	50
2	Slips and trips on the floating platform	Very High	46.42
3	Falling into water/drowning	Very High	44.82
4	Working alone	Very High/High	32*
5	Lack of training	Very High/High	29.62*
6	Psychosocial factors	Very High/High/Low	24*
7	Solar radiation	High	50
8	Electrocution	High	46.15
9	Fire/arc flash	High	42.30
10	Heat Stress	High/Medium	37.93*
11	Ergonomic risks	High	37.03
12	Use of power tools	High	37.03
13	Occupational stress	High	36
14	Lightning, storms, flora, hail, etc.	High/Medium	34.61*
15	Cold Stress	Medium	46.15
16	Aquatic animals/fauna	Medium	34.61
17	Hazardous chemicals/materials	Medium	33.33
18	Work organization factors	Medium	28
19	Falling objects	Medium	29.62
20	Noise	Low	24

* Similar percentage responses for different degrees of OSH risk

Pearson Coefficient of Correlation value (r) was computed for the risk perception scores obtained from the questionnaire outcomes. A number or quantitative value was assigned to each degree of risk (very high risk=5, high risk=4, medium risk=3, low risk=2, and very low risk=1). The average perception scores against each occupational risk factor were used for any two given organizations to arrive at the "r" value. Similarly, correlation values by comparing responses from participating organizations were calculated. The correlation values are summarized in Table 4.2.

Table 4.2. Comparison of Pearson Correlation Coefficient values (r) based on risk perception scores between participating organizations.

	ES	BPSCL	Cairn India	S&W	QS	TCE	PG	TPS	NHPC
DVC	0.33	- 0.12	- 0.17	0.49	- 0.16	0.36	0.43	0.19	0.25
ES		0.05	0.28	0.22	0.15	0.12	0.03	0.15	0.49
BPSCL			0.03	- 0.02	0.20	0.21	0.14	0.06	0.25
Cairn India				- 0.12	0.11	- 0.25	- 0.23	- 0.45	0.38
S&W					0.34	0.33	0.51	0.33	0.43
QS						0.23	0.09	0.42	0.37
TCE							0.47	0.67	0.35
PG								0.40	0.15
TPS									0.20
NHPC									

Note: S&W: Sterling & Wilson, DVC: Damodar Valley Corporation, QS: Quant Solar, BPSCL: Bokaro Power Supply Corporation, TCE: Tata Consulting Engineers Ltd., ES: Engie Solar, PG: POWERGRID, TPS: Tata Power Solar Ltd., NHPC: National Hydroelectric Power Corporation Ltd.

4.2.3 Interventions for OSH risk mitigation

A summary of the preference towards various interventions is summarized in Table 4.3.

Table 4.3. Interventions as opined by respondents for OSH risk mitigation in descending order

S.No	Type of intervention	Responses (n=30)	Percentage (%)
1	Safety training/behavioral change	29	96.7
2	Better supervision, oversight, and risk management	26	86.7
3	Design of Personal Protective Equipment (PPE)	24	80
4	Design and display of safety signage	21	70
5	Planned maintenance keeping in mind weather conditions	20	66.7
6	Better Safety Climate/OSH culture	19	63.3
7	Occupational Safety & Health Standards	18	60
8	Design of job aids	15	50
9	Improvement in Work Environment	14	46.7
10	Automation	14	46.7
11	Rest shelters	12	40
12	Redesign of workplace	11	36.7
13	Redesign of work-rest cycle/work organization	10	33.3
14	Lowering of loads/object weights	08	26.7
15	Better planning of the installation	01	3.3
16	Refreshment facilities	01	3.3
17	Better engineering controls	01	3.3
18	Environmental, Health & Safety (EHS)	01	3.3

4.2.4 Additional insights from the study

During the interviews, the participants expressed the following points of concern and suggestions in addition to the above:

Concerns:

- a) No provision for occupational health check-ups, hygiene factors not taken into account, and working conditions not suitable on many parameters
- b) Paucity of engineering controls for rigid structures
- c) No Standard Operating Procedures (SOPs)
- d) Changing water levels, flow characteristics, seasonal variations, and adverse weather conditions may have a bearing on the workers.

Suggestions:

- a) Skilling of the FSPV workforce, ensuring medical fitness of the workers, proper HSE Policy, and availability of rescue teams/medical aids at the FSPV site
- b) Redesign of the floaters/pontoons
- c) Consideration of long-term entropy and corrosion factors
- d) Compulsory earthing and grounding of the installation
- e) Reduction in repetitive and manual jobs to the extent possible
- f) Workers who are proficient in swimming to be allowed for work over water
- g) Provision of lifebuoys
- h) Development of OSH regulations/standards
- i) Urinals and shades/restrooms in the vicinity of the project
- j) Fair payment of wages and benefits
- k) Use of insulated gloves and tools for the electrical works
- l) Job evaluation from the safety perspective
- m) Emergency evacuation exercises and monitoring for near miss events etc.
- n) Design/redesign of safety aids for protection against heat, solar radiation, discomfort glare, and humidity

Protection against discomfort glare was one of the suggestions from the safety managers. The negative effects of glare include tiredness of the eyes and other medical conditions. The blinding effect of glare can lead to slips, trips, and falls. This is critically important in respect of FSPV projects where work on a floating platform is involved and workers may not be able to detect the edges of the FSPV project during installation and maintenance. This uncomfortable effect on vision at work can lead to falls into water and possibly fatalities. In addition, productivity of tasks involving dexterity such as connecting wires may be severely affected. Appropriate design intervention needs to be developed to neutralize this high category risk which is also connected to Research Question 7.

4.3 Discussion

As perceived by the safety managers, the most critical risks (the top 3) include:

- a) Falls into water
- b) Unstable floating platform, and,
- c) Slips/trips on the floating platform

The abovementioned risks were also identified in the “very high risk” category (Table 4.1). Evidently, immediate attention is needed to address these risks. Working alone and lack of training have been perceived in both the categories of “high risk” and “very high risk”. Risks from psychosocial sources are categorized as low, high, and very high risk.

The top three suggested interventions include:

- a) Safety training/behavioral change
- b) Close supervision and risk management, and,
- c) Provision of customized design of job aids and personal protective equipment

The part of the research aids in not only the prioritization of OSH risks but also captures the views of the safety managers who are an important part of the FSPV sector both during installation and maintenance. In addition, a diverse range of interventions have been elicited. These inputs will assist industrial designers to design and develop contextual solutions for addressing the problems being faced by the workers. It is evident from the insights that a system driven and integrated approach is necessary since many risk factors may work in combination and also independently and consideration of all dimensions of ergonomics such as cognitive, organizational and physical aspects must be considered.

As indicated by the values of the correlation coefficient at Table 4.2, there is largely a positive convergence in the views of the safety managers across the participating organizations with regard to OSH risk perception scores. However, the low positive correlation values indicate low strength and direction of relationship. This implies that more studies are required to establish the categorization of risks in terms of low, medium, high, and very high categories. This will allow more targeted design interventions. The next part of the study involves FSPV workers in an effort in that direction.

The findings emphasize the need for immediate attention from the stakeholders. As mentioned earlier, there are many stakeholders associated with the FSPV sector. These stakeholders may have various objectives while implementing interventions from a design dimension. The framework is shown in Figure 4.2.

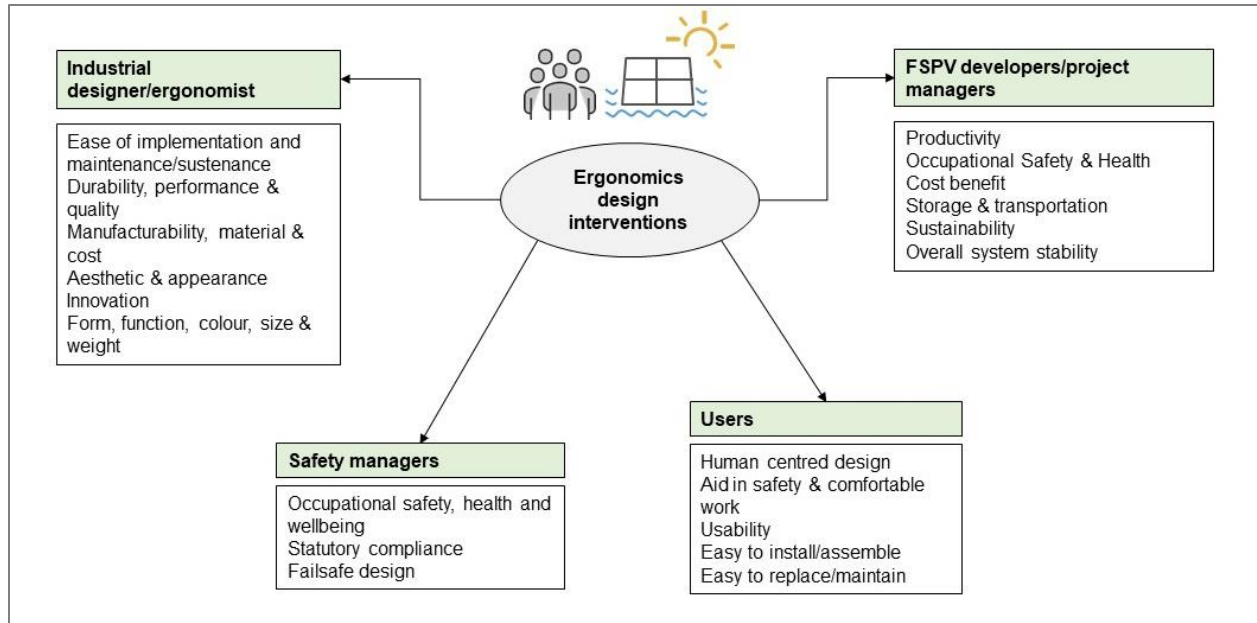


Figure 4.2. Objectives of different stakeholders for implementing ergonomics design interventions in FSPV project (Graphic: author)

Subsequent work involves collecting the risk perception scores of FSPV workers and comparing the outcomes with that expressed by safety managers.

OSH risk perception studies of FSPV workers

4.4 Introduction

FSPV workers are the most important stakeholders within the ambit of this research and understanding their risk perception towards the different kinds of OSH risks are critical inputs. In addition, the social background of the workers, their work experience, income, level of training (installation, maintenance, and safety aspects), physiological parameters etc. also need to be measured. This part of the chapter captures the various aspects of these workers.

The research questions formulated are as follows:

- What is the socio-demographic profiles of the workers engaged in floating solar installation and maintenance?
- What is the risk perception as per the FSPV workers towards the risk factors? and,
- What are the environmental/microclimate conditions to which FSPV workers are exposed to?

The aim of this section is to obtain the OSH risk perception scores across two FSPV projects located in India. The objectives include a) collecting data/information on the socio-demographic profiles of the workers, b) obtaining OSH risk perception scores using a questionnaire and, c) assessment of environmental parameters at the FSPV sites.

4.4.1 Methodology

Purposive sampling was used to determine the participants of the study. This approach was adopted since FSPV projects are very few and therefore FSPV workers are extremely difficult to get in large numbers from which samples may be drawn. Through a pilot study, the questionnaire used in the study on safety managers was used to collect responses from FSPV workers. It was found that the workers were finding it difficult to decipher and respond to the questions. Empathizing with practical issues, it was decided to convert the questions into visual constructs consisting of emoticons (Figures 4.3 & 4.4) on a five-point scale. This would allow the participants to easily comprehend the questions and respond accordingly. The visual questionnaire is provided at **Appendix-C**.

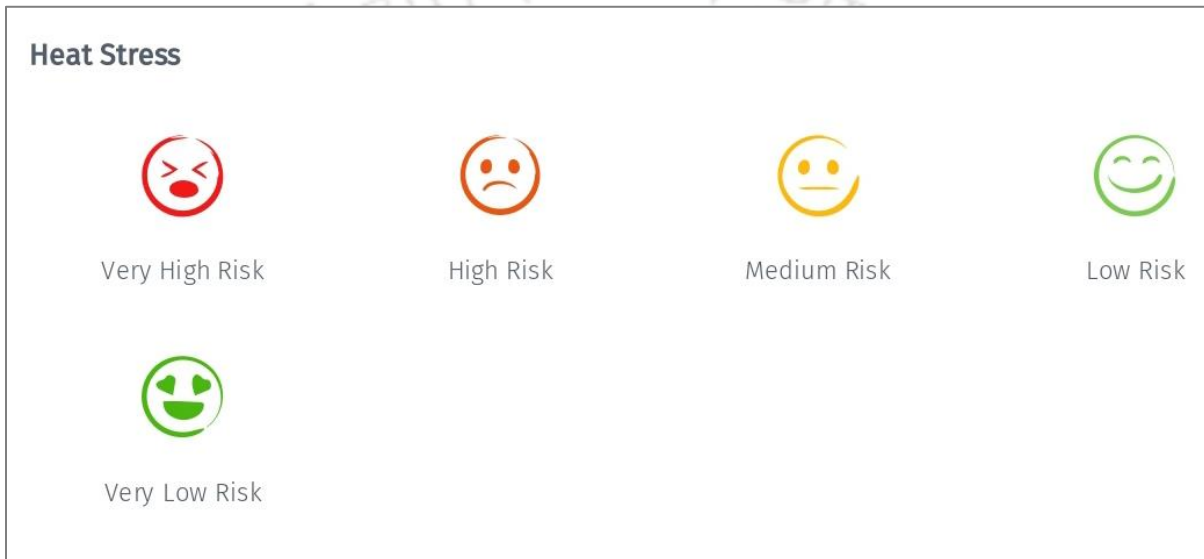


Figure 4.3. Sample question on Heat Stress

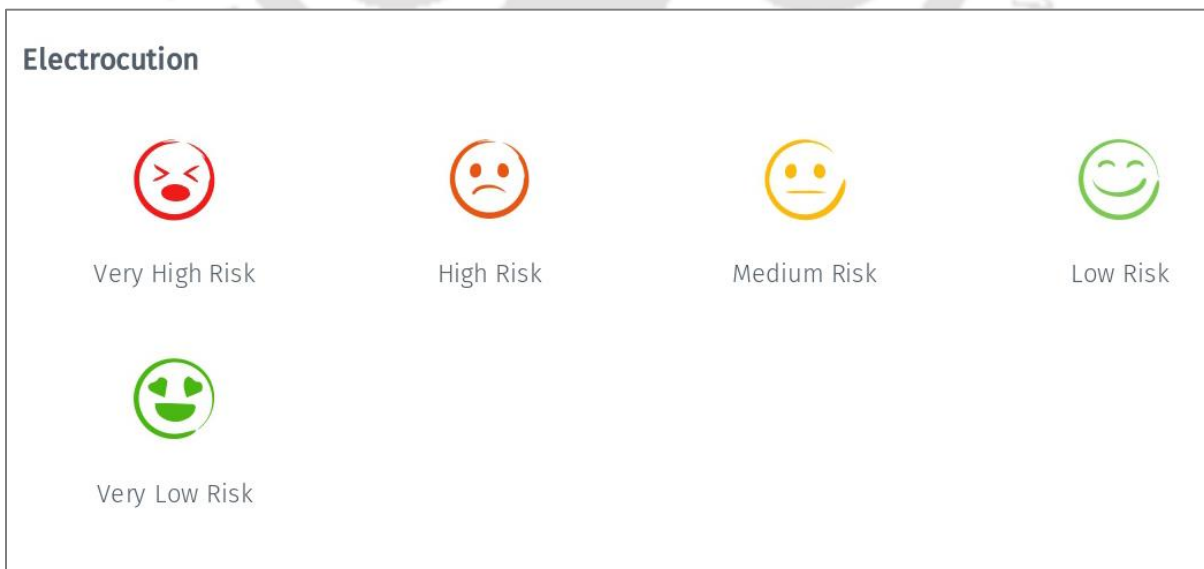


Figure 4.4. Sample question on Electrocutation

Two sites where installation of floating solar projects was underway were selected. Prior approval was obtained from the organizations for conducting field studies. The data collection was facilitated by supervisors at both sites in the presence of a medical personnel. Only medically fit workers were allowed to participate in the study. The data was collected during the period February to April 2021.

Ethical approval was obtained from the Institute Human Ethics Committee of IIT Guwahati (**Appendix-D**). Informed consent in local language was obtained from the workers prior to data collection. A format used to obtain consent is given at **Appendix-E**. Another questionnaire (**Appendix-F**) was constructed to obtain socio-demographic data/information. A total of fifty-three workers working at the two sites completed the questionnaire. Data on environmental parameters was collected using the observation checklist on Heat Stress developed by the Health & Safety Executive (HSE) of the U.K (**Appendix-G**), and Anemometer (Benetech make- GM 816) for measuring the wind velocity. Glare assessment was carried out using the de Boer's subjective rating tool (Jenkins et al., 2005).

4.4.2 Findings

A summary of the project sites considered for the study is given in Table 4.4. Electricity generation companies are using the surface of water reservoirs for installing FSPV projects of small sizes. These water reservoirs supply water for the generation of thermal power. These water bodies are also being used for power generation thus contributing to co-generation. The workers at both the sites were engaged in operation and maintenance. Both Direct Normal Irradiation and Power Output at site 2 is higher as compared to site 1.

Table 4.4. Overview of the FPV sites considered for the study

Parameters	Site 1 - Mejia (DVC)	Site 2- Simhadri (NTPC)
Location	The water reservoir of a thermal power station	Reservoir adjacent to a thermal power station
Period of data collection	February 2021	April 2021
Capacity	25 kWp	25 MW
Design of FSPV	Floating structure type	Floating structure type
Number of Workers engaged	30	23
Direct Normal Irradiation (DNI)*	1187 kWh/m ² per year	1298 kWh/m ² per year
Peak months*	March & April	March & April

Power Output for 1000 kWp*	1.297 GWh per year	1.41 GWh per year
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*Source: Global Solar Atlas

4.4.2.1 Socio-demographic information

Collection of socio-demographic data is important from the perspective of understanding the background of the workers, wage patterns, physiological status, literacy levels, prior work experience and training gaps. The information is summarised in Table 4.5. In the Indian context, skills levels (as indicated in table 4.5) are defined under the Payment of Wages Act, 1948 applicable in India. Unskilled workers are those “doing menial work, mainly applying physical force”. Semi-skilled workers are those who have a “defined set of instructions and responsible for the discharge of duties assigned and the work is limited to the performance of routine operations of limited scope”. Skilled and highly skilled workers are those who are required “to have a thorough knowledge of the trade and job process, taking up overall responsibilities, practising independent judgment, possess adequate over-viewing and reviewing skills and managing the lower-level workforce”. As the worker goes up the skill hierarchy, better is the ability to perceive risks based on prior work experience.

At site 1, the workers are a mix of locals and migrants while at site 2, all workers were locals.

Table 4.5. Overview of the socio-demographic data

	Site 1 (n=30)	Site 2 (n=23)	Combined (n=53)
	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	27.76 (5.87)	25.30 (4.34)	26.69 (5.35)
Height (cms)	169.46 (4.27)	170.15 (3.51)	169.76 (3.94)
Weight (kgs)	63.62 (7.14)	62.21 (2.74)	63.01 (5.67)
Monthly Income (INR)	15151 (1487.32)	15638 (3256.95)	15362.49 (2404.37)
Work experience (yrs.)	1.96 (0.55)	0.6 (2.27)	1.37 (0.8)

	Site 1 (n=30)			Site 2 (n=23)		
Background	Migrant (%)	Local (%)		Migrant (%)	Local (%)	
	13 (43%)	17 (57%)		-	23 (100%)	
Skill level	Unskilled	Semiskilled	Skilled/Highly skilled	Unskilled	Semiskilled	Skilled/Highly skilled
	19	7	4	-	15	8
Education level	Elementary	High School	Graduate	Elementary	High School	Graduate
	13	17	-	-	22	8

Occupational Safety & Health training (Nos.)	Yes	No	Yes	No
	1	29	-	23

4.4.2.2 Environmental data

The summary of environmental parameters is given in Table 4.6.

Table 4.6. Summary of environmental data

Parameter	Site 1	Site 2
Air velocity (metres/second)	0.9	1.8
Temperature (°C)	29.2	29.4
Humidity (%)	56	61.5

4.4.2.3 Heat Stress Assessment

The heat stress checklist of the Health & Safety Executive (HSE) was used in the field studies. The assessment tool covers different aspects to understand the level of heat stress. The aspects include air temperature, radiant temperature, air velocity, humidity, clothing worn and metabolic rate. Each of the parameters are rated by an assessor on a numeric scale. The scale ranges from - 3 to 6. As the score increases from 1 and beyond, the greater is the heat risk. If there are three (3) or more scores that are more than 1 then there may be a risk of heat stress. Physiological monitoring is required for a score greater than 5. The questionnaire may be referred to for assessment parameters and rating methodology (**Appendix-G**).

The findings at the two FSPV sites include the following:

- a) The air temperature was warm, and the source of heat stress was the sun.
- b) Warm air with moderate air speed with the air being very humid.
- c) The FSPV workers were wearing cotton overall with safety jackets as PPE.
- d) The work rate was moderate which included carrying, lifting, walking, and assembling equipment in an outdoor environment. Sometimes high work rate was also involved pulling and manual material handling on a floating platform. A typical workday consists of 8 hours of outdoor work with a lunch break of 1 hour. There was no shift work involved.
- e) The FSPV workers complained of feeling uncomfortable due to the heat and took regular breaks at short intervals.

For the FSPV sites considered for the study, the scores were higher than 1 for most parameters but for no parameter, the score crossed the value of 2. This indicates that the microclimate in both the FSPV project locations presents a risk of significant heat stress and needs immediate attention.

4.4.2.4 Risk perception scores

A total of fifty-three workers participated in the study. The OSH risk perception scores are summarised in Table 4.7. The mean risk perception score is arranged in descending order. Risks above the mean score of 4 (high risk and very high risk) include falling into water, heat stress, electrocution, solar radiation, slips/falls on the floating platform and fire/electric flash.

Table 4.7. OSH risk perception of FSPV workers (n = 53)

S. No	OSH Risk	Mean Risk Perception Score (On a scale of 1-5)
1	Falling into water	4.75
2	Heat Stress	4.73
3	Electrocution	4.47
4	Solar radiation	4.20
5	Slips/falls on floating platform	4.20
6	Fire/Electric Flash	4.16
7	Ergonomics risks	3.92
8	Lack of training/skill gaps	3.50
9	Lighting, storms, hail etc.	3.49
10	Use of power tools	3.39
11	Psychosocial factors	3.37
12	Work organization	3.18
13	Occupational stress	2.94
14	Unstable platform	2.64
15	Cold stress	1.51
16	Working Alone	1.33
17	Hazardous materials	1.24
18	Noise	1.19
19	Aquatic animals	1.17
20	Falling objects	1.15

4.4.2.5 Glare Assessment

Whether it is installation or maintenance, FSPV workers are engaged in outdoor work during a major part of the day. The outdoor workplace presents a problem of glare. As per ISO 9241-6, Glare is described as follows:

“Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution of range of luminance, or to extreme contrast”.

Glare is classified into two kinds namely discomfort glare and disability glare. The glare is caused due to two main sources. The first one being the reflection of the sunlight from the solar photovoltaic panels and the second source that compounds the OSH risk is the reflection from the surface of the water body surrounding the FSPV installation (reflective glare). There can be discomfort while walking or working on the floating platform. Glare can cause severe discomfort while doing work involving dexterity such as connecting wires, attaching panels to floaters, and detecting the peripheries of the project. The problem can lead to falls, human errors, decrease in productivity, problems in readability of signages/labels, use of equipment and both short term and long-term damage to eyesight. Therefore, the measurement and mitigation of glare in FSPV projects is an important area of intervention. Among many assessment methods to measure glare, the de Boer's subjective rating scale is widely accepted and used. The rating scale consists of verbal responses on a nine-point scale (Jenkins et al., 2005). The scale is represented in Table 4.8.

Table 4.8. de Boer's (1967) rating scale for evaluation of discomfort glare

1	Unbearable
2	
3	Disturbing
4	
5	Just Acceptable
6	
7	Satisfactory
8	
9	Unnoticeable

Assessment of glare was carried out at both the sites (Mejia & Simhadri) using the de Boer's scale. A total of forty (n=40) workers participated in the study. The collection of data was facilitated by the site supervisors. A summary of the observations is presented in Table 4.9. Most of the participants rated the glare as disturbing.

Table 4.9. Discomfort glare assessment scores

Rating scale	Score	% of responses
Unbearable	8	20%
Disturbing	26	65%
Just Acceptable	4	10%
Satisfactory	2	5%
Unnoticeable	nil	NA

4.4.3 Discussion

This is a first-of-its-kind study to collect data on the various kinds of OSH risks faced by the FSPV workers and the socio-demographic profiles of such workers. The workers are mostly from the local population living near the FSPV installation and belong to the unskilled and semi-skilled categories. The participants had received education up to the high school level while a few were graduates. The socio-demographic data obtained from this study are important inputs for design interventions from an OSH perspective since information on age, height, skill level, background, income, and others influence the type and scope of interventions. The top five OSH risks identified include falling into water, heat stress, electrocution, solar radiation, and slips/trips on the floating platform. Other identified risks include fire/electric flash, ergonomics risks, skill gaps, inclement weather etc.

A study of the environmental parameters revealed the existence of heat stress at both the sites. This is in accordance with the heat stress being perceived as a risk factor in the very high-risk and high category by safety managers and FSPV workers. Workers are protected against possible injuries/accidents due to electrocution as workers were wearing insulated gloves. Most of the participants (65%) found the outdoor glare in the disturbing category. The physiological effects of discomfort glare are severe and consist of both short term and long-term health effects. Some of the deleterious effects include eye pterygium, cataracts, macular degeneration, and ocular melanoma (Guénel et al., 2001, Modenese et al., 2018, Wright & Norval, 2021).

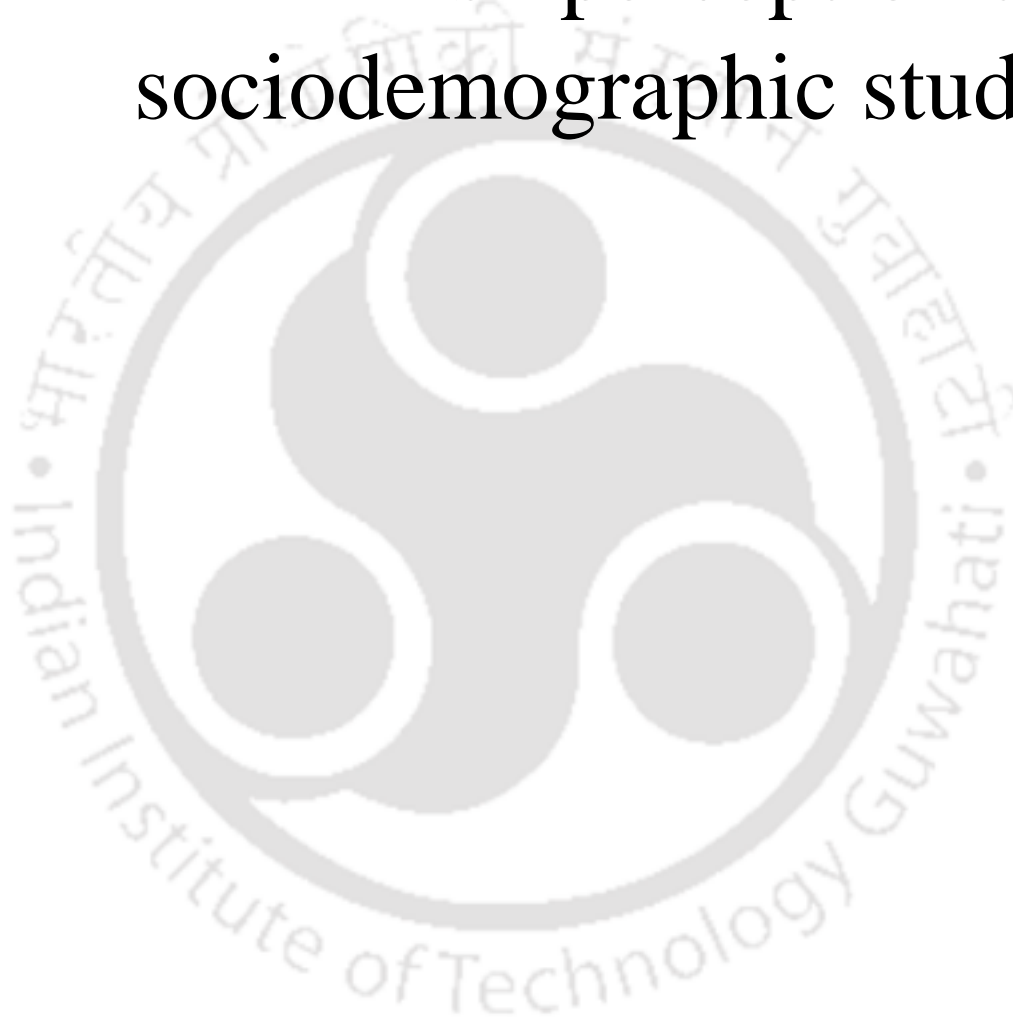
4.4.4 Conclusion

FSPV projects are new and emerging workplaces involving several mismatches between man, machine, and environment. There is a lack of studies covering the OSH aspects in this sector of the solar photovoltaic industry. The preliminary exploratory field studies were aimed at understanding the actual problem (s) and OSH risks being faced by the FSPV workers. The insights will be used for the development of design interventions for those risks in the high and very high-risk categories requiring immediate attention.



Figure 4.5. Photograph of data collection from FSPV workers in one of the sites (image: author)

Chapter 5: Cross-cultural OSH risk perception and sociodemographic studies



Abstract

The influence of cultural factors across different populations on risk perception and sociodemographic parameters is recorded in literature. However, there are no studies examining these dimensions in the solar photovoltaics industry. To understand these aspects and to explore the dimension of cultural ergonomics, a cross-cultural study was undertaken at two FSPV sites in India and one ground mounted solar PV site in Saudi Arabia. Solar PV workers from India (n=53) and Saudi Arabia (n=82) participated in the study. Interesting insights were obtained wherein varied risk perception scores were elicited towards the same risk factor across both countries. The findings of the correlation of socio-demographic factors with risk factors and its implications for design are discussed. Overall findings indicate the need for considering cultural, demographic and microclimate factors in developing design interventions. This study is a first-of-its-kind effort to map the OSH and sociodemographic aspects of workers engaged in the solar photovoltaics industry.

5.1 Introduction

Deployment of solar photovoltaic projects are spreading across diverse geographical regions across the globe. Comparative studies across countries from the perspective of OSH risk perception and socio-demographic factors concerning the solar PV industry are rarely explored. Cross-cultural aspects have an important bearing on the development of effective design solutions. A study was planned to compare the various aspects related to solar PV projects across two countries i.e., India and Saudi Arabia, both of which are implementing an ambitious renewable program. Insights into the cross-cultural aspects will finally help in determining the design strategy. The following paragraphs cover the need for the study, objectives, and outcomes. This chapter attempts to cover an important dimension from a design standpoint.

5.2 Cross-cultural aspects and socio-demographic factors

The profiles and background factors of the workers differ from country to country. These factors include customs being practiced, physiological status, psychology, languages spoken and anthropometric parameters (Chapanis,1974). Such factors have important significance and relationship with the development of good design interventions especially when they must be contextual and population specific. For instance, size, shape, color and material of PPE or safety equipment will have to be customized according to cultural choices of the project location for greater acceptability. These dimensions fall in the scope of cultural ergonomics (Kaplan,1995) where such factors have a mediating role influencing the interactions between the user and the system. The success of design interventions from an occupational safety perspective will largely depend upon how well cultural factors are incorporated in the design. Some aspects include design of clothing, language/dialect used in safety training and signages, design of work and workplace facility design. Customs and coping abilities should also be important considerations for design interventions. Many solar photovoltaic projects have a mix of both local and migrant factors. Accordingly, inclusion of diverse socio-cultural dimensions for any intervention are critical aspects. To the best knowledge and available literature, there is no study in the solar industry that

addresses these important aspects. This chapter attempts to explore the risk perception and other socio-demographic aspects across two countries.

Socio-demographic and work organization factors are known to have relationships with OSH risk factors. Studies have established relationships between individual factors (such as age, gender, and health) with propensity of risk, between work organization and Work-related Musculoskeletal Disorders (Liu lu et al., 2015) and between national income and fatal accidents at work (Kahraman et al., 2019) to mention some. The data on socio-demographic factors have implications for design of work, selection of workers, compensation patterns and training needs. Cultural factors also have relationships with risk perception and safety performance (Gharpurea et al., 2018, Håvold, 2007, Moosa & Oriet, 2022).

A literature review was conducted to find studies that have examined aspects related to the solar PV workers i.e., socio-demographic factors and OSH risk perception. No such study was found in the solar PV industry, indicating the need for immediate attention for identifying the degree of OSH risks and its prioritization for targeted interventions. In this backdrop, this study has been planned to address a knowledge gap existing in the solar PV industry. The outcomes will assist stakeholders for designing and developing mitigation measures for the safety and health of the solar PV workers.

The study has the following objectives:

- a) To obtain the socio-demographic data and OSH risk perception scores of solar PV workers of Saudi Arabia & India
- b) To compare the findings across various parameters between the two countries
- c) To examine relationships and associations between different socio-demographic variables with OSH risk perception scores

5.3 Methodology

Solar PV projects across two countries i.e., Saudi Arabia and India were selected for the study. Both Saudi Arabia and India plan to generate 50% of their energy from renewable sources of energy by 2030 are signatories to the Paris Agreement of 2015. Figure 5.1 shows the growth of installed capacity of solar PV projects in Saudi Arabia & India.

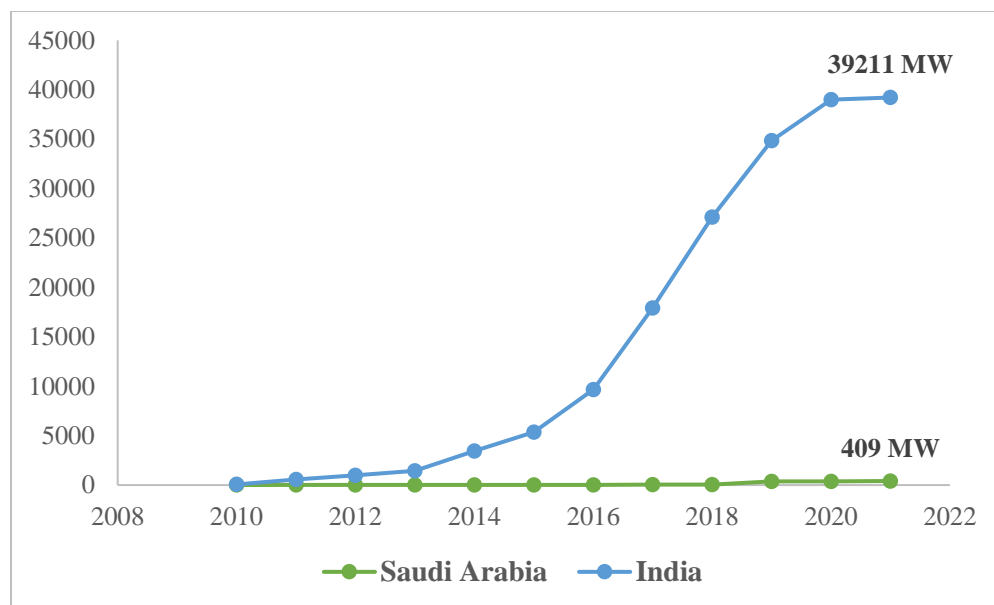


Figure 5.1. Growth of installed capacity in Megawatt of solar photovoltaics for the period 2010 to 2021

In Saudi Arabia, the workers were engaged at a solar farm (ground mounted solar) at Sakaka City. Purposive sampling was used to determine the participants of the study. In India, data were collected from two floating solar PV sites (refer to Chapter 4). The study protocol was approved by the Institute Human Ethics Committee, Indian Institute of Technology (IIT) Guwahati prior to collection of data/information. Prior permission was obtained from project developers for the site visits and for conducting data collection involving human subjects. The study at Saudi Arabia was conducted during the period December 2021 to February 2022. Workers were invited for voluntary participation in the study. Informed consent was taken from all the participants before collection of data/information (Annexure). A total of 82 workers in Saudi Arabia participated in the study. The data collected for workers in India (n=53) has been represented in Chapter 4 and has been used for comparative purposes in this chapter. The responses obtained using the visual questionnaire were converted into quantitative scores for statistical analysis where a) very low risk=1, b) low risk = 2, c) medium risk = 3, d) high risk= 4 and, e) very high risk = 5. Another questionnaire was developed to obtain information on socio-demographic parameters such as age, gender, weight, height, income, skill level, background, education level, working hours and work experience. In addition to data collection through questionnaires, photographs were taken of workers engaged at the sites. At the end of data collection, statistical analysis was carried out using SPSS v.20 to understand the relationships between the different sets of data.

5.4 Results

An overview of solar photovoltaic projects considered for the present study is given at Table 5.1. The sites are in diverse geographical areas considering workers engaged in two different kinds of solar installations i.e., ground-mounted, and floating solar. The solar radiation and power output at the solar PV site at Saudi Arabia is higher as compared to the two sites in India. A picture of the solar farm at Sakaka City and that of floating solar project at Simhadri is shown at Figure 5.2.

Table 5.1. Overview of the locations considered for the study.

Parameters	India		Saudi Arabia
Region	Site 1 – Mejia (West Bengal State)	Site 2- Simhadri (Andhra Pradesh State)	Sakaka City, Al Jouf Province
Location	The water reservoir of a thermal power station	The water reservoir of a thermal power station	Solar farm
Period of study	February 2021	April 2021	Dec 2021-Feb 2022
Capacity	25 kWp	25 MW	300 MW
Design of FSPV	Floating structure type	Floating structure type	Ground mounted
Number of Workers engaged	30	23	82
Direct Normal Irradiation (DNI)*	1187 kWh/m ² per year	1298 kWh/m ² per year	2270.03 kWh/m ² per year
Peak months*	March & April	March & April	March & July
Power Output for 1000 kWp*	1.297 GWh per year	1.41 GWh per year	1.89 GWh per year

*Source: Global Solar Atlas

Abbreviations: kWp, kilowatt peak; MW, Megawatt; kWh/m², kilowatt hour/metre square; GWh, Gigawatt hour



Figure 5.2. Workers (left) engaged in maintenance at the 300 MW solar farm at Saudi Arabia and FSPV workers (right) engaged in cleaning of solar panels at the 25 MW floating solar project in India. (Image source: authors)

The sociodemographic parameters of the workers are summarized in Table 5.2. A total of 135 workers participated in the study. The workers engaged in India were mostly from the local population while those in Saudi Arabia were mostly migrant workers.

Table 5.2. Summary of sociodemographic features of the workers

Demographic parameter	Saudi Arabia (n=82)		India (n=53)	
	Mean	SD	Mean	SD
Age (years)	35.25	8.99	26.69	5.35
Height (cm)	174.46	5.49	169.76	3.94
Weight (kg)	73.04	9.42	63.01	5.67
Monthly income (INR)	8298.78	2825.52	15362.49	2404.37
Work experience (years)	2.80	1.30	1.37	0.80

Abbreviations: cm: centimeter; kg: kilogram

To compare the means of two groups (between workers of Saudi Arabia and India) against each OSH risk, independent two tail t test was carried out. The mean scores for each risk factor (on a scale of five) and comparison are summarized in Table 5.3. Heat stress was perceived as a strenuous risk factor in both the sample populations and there was no statistical significance at $p < 0.05$ level indicating general agreement amongst the workers. Falling into water (mean score of 4.75 out of 5) was perceived as the most critical risk by the respondents in India owing to the fact that they are engaged in work on or near water. Other OSH risks falling into the very high- & high-risk categories include fire, electric flash, electrocution, solar radiation for workers engaged in Saudi Arabia. For the two sites in India, slips/trips on floating platform, electrocution, solar radiation, and electric flash/fire were perceived as risk factors in the very high and high-risk categories.

Table 5.3. Summary of the comparison of means between the two groups of workers

OSH risk parameter	Saudi Arabia		India		t value	at $p \leq 0.05$
	Mean	SD	Mean score	SD		
Heat stress	4.68	0.46	4.73	0.59	- 0.57	Not significant
Cold stress	3.66	0.76	1.51	0.58	17.62	Significant
Solar radiation	3.96	0.72	4.20	0.68	- 1.94	Not significant
Electrocution	4.46	0.63	4.47	0.91	- 0.06	Not significant
Fire/electric flash	4.47	0.61	4.16	1.03	2.15	Significant
Ergonomics risks	3.87	0.82	3.92	0.93	- 0.30	Not significant
Hazardous materials	3.78	0.77	1.24	0.61	20.13	Significant

Unstable platform/slope	1	0	2.64	1.66	- 8.94	Significant
Falling objects	3.12	0.71	1.15	0.53	17.30	Significant
Lighting, storms, hail etc.	2.36	0.88	3.49	1.95	- 4.54	Significant
Skill gaps	2.2	0.80	3.5	1.3	- 7.40	Significant
Psychosocial factors	2.62	0.81	3.37	0.88	- 5.10	Significant
Work Organization	3.31	0.96	3.18	0.76	0.81	Not significant
Noise	2.01	0.66	1.19	0.40	8.20	Significant
Use of power tools	1.74	0.71	3.39	0.88	- 11.91	Significant
Occupational Stress	1.80	0.69	2.94	1.44	- 6.12	Significant
Working Alone	1.75	0.71	1.33	0.99	2.82	Significant
Risk from animals	1	0	1.17	0.75	- 2.04	Significant

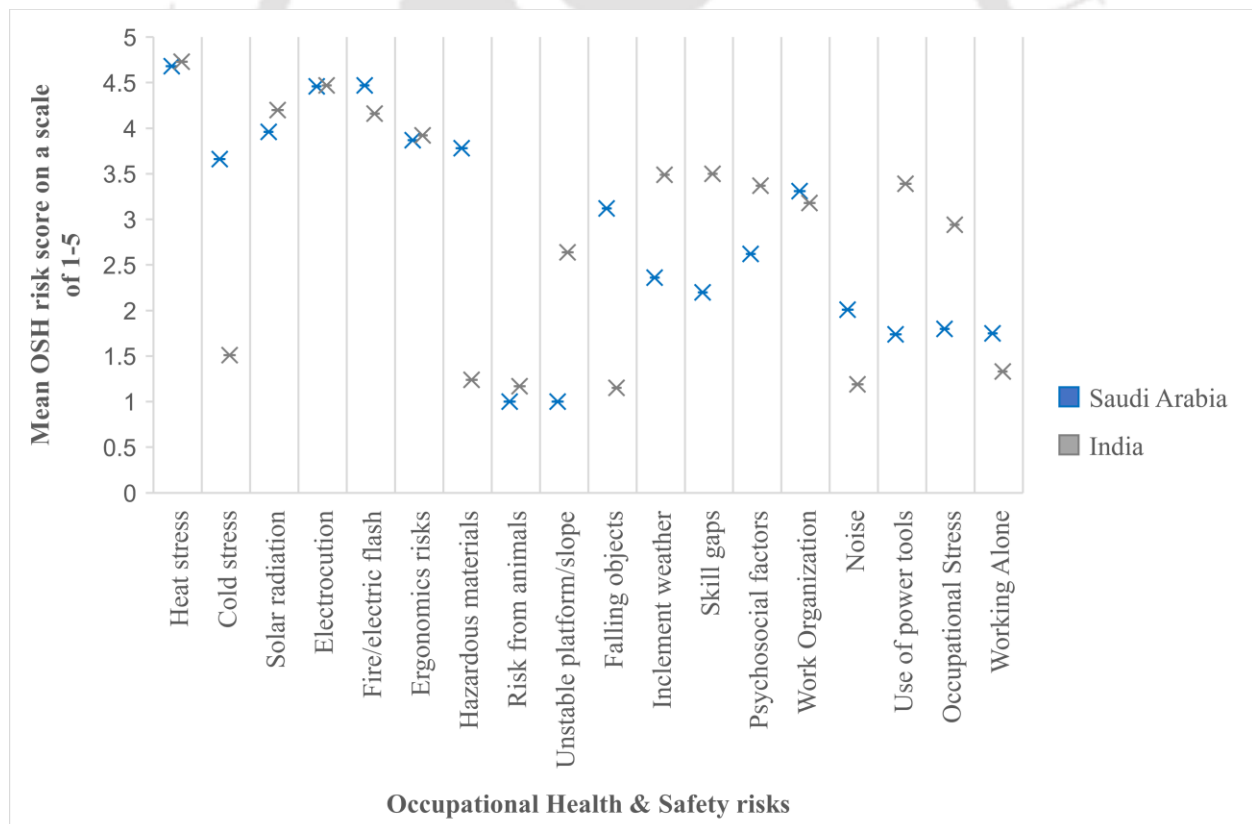


Figure 5.3. Mean scores for OSH risks for solar PV workers engaged in Saudi Arabia and India. The higher the score, the higher is the perceived risk.

Understanding the association (positive or negative) between the various risk factors and sociodemographic factors would assist in designing interventions for causative risk factors.

Pearson's correlation coefficient scores were calculated towards this objective. The scores are represented in Table 5.4. There is a positive correlation between age, height, and weight with heat stress for workers engaged in both countries while there is negative correlation between age and income with electrocution. For workers in Saudi Arabia, there is no correlation between the sociodemographic factors with risks from aquatic animals, slips on the floating platform, unstable platform and falling in water. Amongst FSPV workers in India, ergonomics risks have positive association with age, weight and work experience, and negative association with height and income.

Table 5.4. Correlation between OSH risks and socio-demographic factors for solar PV workers in two countries. Sample size for Indian workers is 53 and for workers in Saudi Arabia is 82 totaling 135 workers. Figures indicate Pearson's correlation coefficient scores.

OSH risk factor	Age		Height		Weight		Income		Work experience	
	IND	SA	IND	SA	IND	SA	IND	SA	IND	SA
Heat stress	0.017	0.034	0.019	0.034	0.030	0.121	-0.099	0.118	-0.250	0.160
Cold stress	0.144	-0.134	-0.125	-0.059	0.148	-0.278	0.219	-0.067	0.372	-0.093
Solar radiation	-0.233	-0.155	0.093	0.054	0.038	-0.034	-0.022	-0.028	-0.436	0.109
Electrocution	-0.053	-0.019	0.107	-0.070	0.124	-0.058	-0.492	-0.083	0.355	0.111
Fire/electric flash	0.249	-0.036	0.010	-0.085	0.051	-0.070	-0.127	-0.094	0.671	0.102
Ergonomics risks	0.294	0.271	-0.051	-0.069	0.079	-0.033	-0.125	0.191	0.623	0.299
Hazardous materials	-0.070	0.311	0.143	-0.066	-0.177	-0.033	0.175	0.271	-0.392	0.336
Aquatic animals	-0.225	nc	0.034	nc	-0.109	nc	0.230	nc	-0.222	nc
Slips/trips on floating platform	-0.229	nc	0.089	nc	0.094	nc	-0.141	nc	0.050	nc
Unstable platform	-0.217	nc	0.047	nc	-0.090	nc	-0.058	nc	-0.772	nc
Falling in water	-0.011	nc	0.093	nc	0.153	nc	-0.249	nc	0.373	nc
Falling objects	0.016	0.177	0.012	0.289	0.190	0.193	-0.056	0.067	0.190	0.026

Lighting, storms, hail etc.	0.212	-0.031	0.029	0.094	0.078	0.028	-0.095	-0.047	0.760	-0.012
Skill gaps	0.179	-0.012	-0.018	0.078	0.081	-0.091	-0.303	-0.050	0.678	0.011
Psychosocial factors	0.240	0.130	-0.151	0.358	0.083	0.154	0.242	0.126	0.630	0.197
Work Organization	0.076	0.070	-0.117	-0.002	0.022	-0.068	0.160	0.082	0.021	0.176
Noise	0.245	-0.044	-0.074	-0.063	0.102	0.022	-0.030	-0.012	0.320	-0.040
Use of power tools	0.237	0.014	0.022	0.009	0.094	0.245	-0.129	0.102	-0.262	0.038
Occupational Stress	0.152	-0.069	-0.050	0.193	0.049	0.139	0.028	-0.160	0.697	-0.151
Working Alone	-0.067	0.025	0.185	0.080	-0.174	0.000	0.026	0.084	-0.335	0.054

Abbreviations: Ind, India; SA, Saudi Arabia; nc, No Correlation

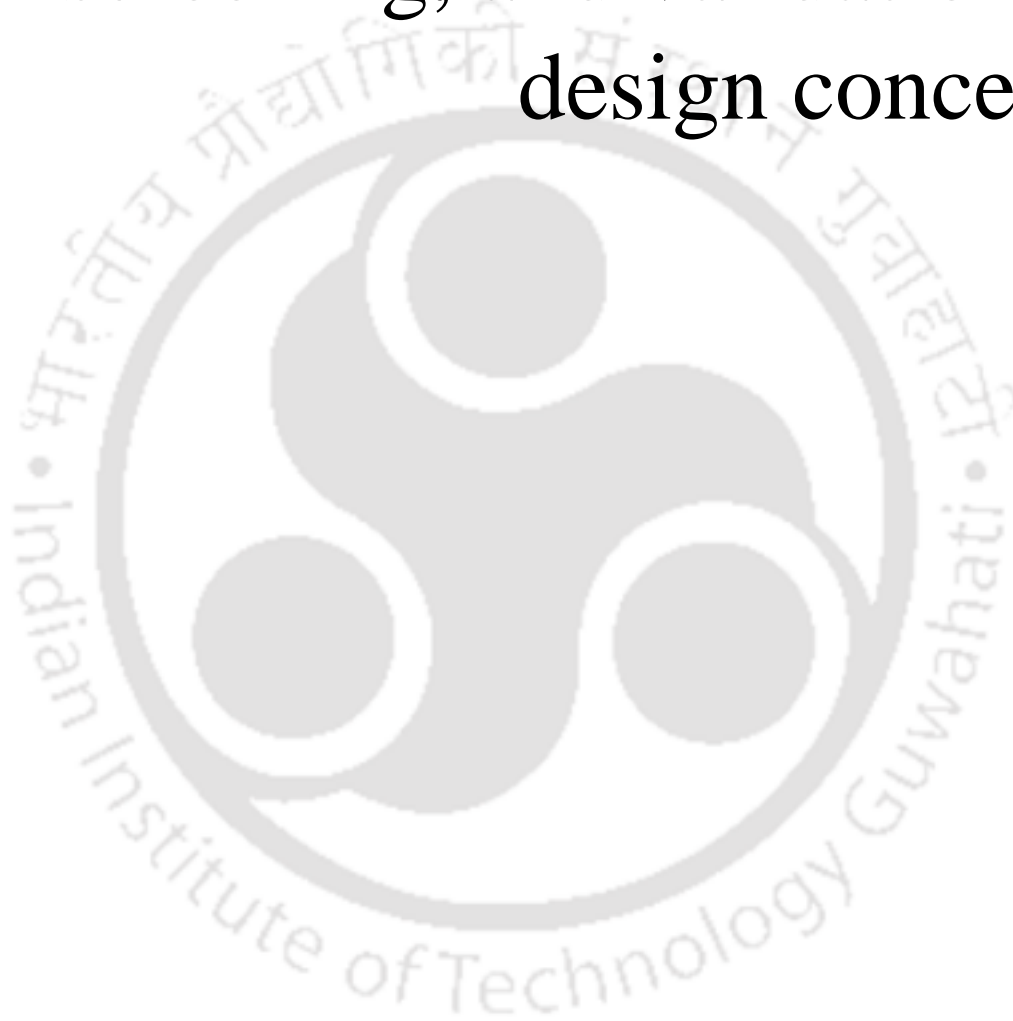
5.5 Discussion and Conclusion

A statistical analysis and synthesis of the risk perception scores (Table 5.3) between the two countries reveals that there is no significant difference in relation to heat stress, solar radiation, electrocution, ergonomics risks and work organization indicating agreement regarding severity of the risks. An analysis of data represented in Table 5.4 shows that there is a positive correlation between age, height and weight with heat stress and use of power tools for workers engaged in both countries while there is negative correlation between age and income with electrocution. Before considering deployment of workers to an outdoor work environment age, height and weight of the workers should be taken into consideration. A study has shown that whole body heat loss reduces with increase in age (McGinn et al., 2017). According to a report by the International Labour Organization, workers lose about fifty percent of their work capacity between 33°C to 44 °C which negatively affects labor productivity (ILO,2019). Therefore, PPE and administrative controls must be adopted to reduce unproductive work and prevent harm to workers' health. Psychosocial factors and work organization risk factors are positively correlated with income and work experience. Fair compensation, job design, social support, placement of aged workers in low-risk jobs and screening of psychosocial hazards can be some of the approaches in solar PV projects. Amongst FSPV workers in India, ergonomics risks have positive association with age, weight and work experience and negative association with height and income. Accordingly, ergonomics assessments and risk management considering the demographic parameters must be an integral part of the safety management practices during the installation and maintenance of solar projects. Since this is a first-of-its-kind study on socio-demographic factors related to solar PV workers, we have no way of collaborating these findings with previous studies.

From a cross-cultural perspective, risk perception of workers towards risk factors such as cold stress, adverse weather, harmful materials, work-related stress, lone working, lack of training were found to vary significantly (Table 5.3) when compared amongst responses from India and Saudi Arabia. For example, heat stress is an area of concern for workers engaged in India and not so much cold stress, but both heat and cold stress are risk factors of concern at the Saudi Arabian solar PV site. This is primarily due to the large variation in day time and night time temperatures in Saudi Arabia. From a design perspective, provision of light clothing (to combat heat stress) for workers in Saudi Arabia may not be suitable for work during the evening and night. Therefore, design of suitable clothing having features that can address both heat stress and cold stress may be developed. Variations in microclimate, coping ability of the workers and acclimatization history of exposure to hot outdoor environments will be important determining factors of how workers handle heat stress. All these factors will vary from country to country and thus a cross-cultural dimension should be an important consideration for good design. In India, a positive correlation was found between work-related stress and work experience. Stressed workers can lead to fatigue which may lead to errors and other downstream deleterious effects. Screening of relatively experienced workers for occupational stress should be considered. Lone working has been identified as an OSH risk factor in solar projects. This is due to the fact in large sized solar photovoltaic projects, workers are spread out across large areas and often individual workers carry out the installation and maintenance jobs alone for long periods. Being “out of sight” and “out of mind” presents several risks for the workers. Under various circumstances, workers may fall into water, fall ill, or get involved in accidents. Since supervision of every worker over a vast location is practically difficult, a system of buddy work may be introduced. Having its origins in the military, workers are divided into groups of two called buddies where each worker would be responsible for the other worker. This would help in continuous monitoring, faster response to injuries or accidents and quick response to incidents such as falls into water where time is of the essence. The buddy system also can aid in preventing loneliness at work which might induce boredom or affect productivity. Prior work experience in installation and maintenance of solar projects has several implications for safety at work. For example, electrocution/electric shock is a major OSH risk factor since there is no indication for a charged solar PV system and can be categorized as an invisible risk. Novice workers will thus be prone to injuries or accidents due to electrocution. Accordingly, deployment of experienced solar workers in riskier tasks, comprehensive safety training, designs that are fail safe and continuous monitoring of inexperienced workers is recommended. Factors associated work organization was found to be associated with compensation and work experience. Therefore, design of jobs should consider matching of prior work experience and skill level with complexity of work. Other factors to be under work organization that should be considered include rules of work, work-rest cycle, job roles, rotation of jobs, hygiene, and workplace facilities.

Some limitations of the cross-cultural study include difference in the worker sample from India & Saudi Arabia in terms of demographics and background, type of solar installation and environmental conditions. For FSPV installations, the major difference in risk profile is the presence of an aquatic environment which has its own set of risks such as unstable working platform, aquatic animals, work with water, depth of water and need for contextual skills to manage work on a floating structure.

Chapter 6: Development, screening, and validation of design concepts



Abstract

Several risk factors have been identified in Chapters 3 and 4 of this thesis. The risk factors in the very high- and high-risk categories need to be addressed through contextually relevant design interventions. This chapter describes the use of three design methodologies namely hierarchy of controls, codesign and bow-tie risk analysis were used to arrive at a comprehensive list of interventions. The design concepts were screened using the Pugh chart and concept scoring matrix. The design of an anti-glare and anti UV eye protector was developed to address the problem of discomfort glare. The design was validated using statistical tools based on performance of a visual task (to avoid wicked problems), glare assessment and usability studies involving users engaged in FSPV projects. Several other concepts were developed to address other risk factors associated with installation and maintenance followed by validation by solar PV engineers. The findings indicate the positive benefits of the proposed interventions. In addition, parameter diagrams for robust designs are proposed. This chapter also proposes a framework for addressing the problem of PPE avoidance. Named Compliance through Design (CtD), the model stresses on the need for adopting design thinking tenets to increase acceptance and use of PPE by the workers/personnel.

Development of design concepts

6.1 Introduction

The research gaps in the present research have been identified in Chapter 2 and the emerging OSH risks have been identified in Chapters 4 & 5. Identification of risk mitigation measures and concepts are the next important steps towards shortlisting design interventions to neutralize the identified risks. The potential users for the design interventions are primarily the users i.e., the FSPV workers and the supervisors/engineers engaged at the installation. Concept generation is not very expensive and involves not more than five percent of the budget and fifteen percent of the time involved in development (Ulrich and Eppinger, 2016).

Several ideation and problem solving methodologies are in practice. TRIZ (short form for theory of inventive problem solving) is a method used to generate concepts. The tool often involves creating a matrix to identify potential mismatches/problems in a design challenge and work towards their resolution. Other methods include creativity techniques (inventorying, associative, confrontational, provocative, and intuitive techniques), mind maps, brainstorming, synectics, functional analysis, morphological chart, storyboard, written scenario, biomimicry, and context mapping.

It is not known what process/methodology of idea generation was followed while designing the different kinds of equipment/parts/components presently being used in FSPV projects. As is evident from the research gaps indicated at Chapter 2, there are very few mitigation measures (especially from a design perspective) to address the OSH risks associated with the installation and maintenance especially from the perspective of workmen engaged in such projects. This chapter explains the multi-method approach towards development of concepts for ensuring safe installation and maintenance activities.

6.2 Aims & Objectives

The aim of this chapter is to develop design concepts (risk mitigation measures) using mixed methods.

This chapter has the following objectives:

1. To develop design concepts by following different methodologies for risk mitigation in FSPV projects at various intervention levels
2. To shortlist the concepts based on research gaps, novelty and innovation

6.3 Methods & Materials

Several design methods/approaches were considered to generate concepts. Among many, three approaches were adopted to arrive at design concepts to manage the risks. The approaches are codesign, hierarchy of controls for Prevention through Design (PtD) and bow-tie risk management analysis.

6.3.1 Codesign

The codesign approach was adopted in order to engage the stakeholders who are either working on such projects or part of a team designing and planning such projects. Participatory design practices have been used for many decades by designers from Europe and Collective Research Approach has been used by design practitioners from Denmark, Sweden, and Norway by involving workers in the development of better systems. Participatory design throughout the design process by involving the user, researcher and the designer is the core philosophy of codesign (Sanders & Stappers, 2008). In the codesign process, the design researcher facilitates the participants (who are one of the future users) in generating concepts which may also be called the ideation phase. It incorporates the knowledge and creativity of the users into the proposed design concepts.

Following the toolkit method, a questionnaire (**Appendix-H**) was designed seeking inputs from workers and project engineers. The questionnaire consists of two sections. The first section describes the OSH risks and the problem statement (derived from the OSH risk perception scores) and the second section contains a blank sheet for developing/sketching design solutions. FSPV workers and project engineers were invited to participate in the codesign process. Informed consent was obtained before starting the process. The authors of this present study facilitated the process by briefing about the context, problems arising out of OSH risks and the objectives of the study. Designs were developed using Google Sketchup and Blender software.

6.3.2 Hierarchy of Controls

The hierarchy of controls (NIOSH,2023) involves the formulation and implementation of risk controls which finally leads to the preventing risks by “designing out” the hazards. Prevention through Design is an initiative of the National Institute of Occupation Safety and Health. The hierarchy of controls (Figure 6.1) consists of several levels of addressing occupational risks which include personal protective equipment (PPE), administrative controls, engineering controls,

substitution, and elimination. PPE being the least effective control whilst elimination being the most effective. Prevention through Design (PtD) is being practiced in many industries and sectors. “Designing out risks” is the core philosophy of the PtD approach (Howard, 2008). The approach is closely linked to the hierarchy of controls approach which considers all dimensions for ensuring safety at work (Yuan et al., 2019). The benefits of applying PtD include reduced costs of operation, reduced risks, higher productivity, and avoidance of costly retrofitting (Manuele, 2008). The linkage of design and safety issues has been established in previous studies. In a study conducted in Australia for 210 workplace related deaths between the years 2000 and 2002, design aspects were found to be a significant contributor for as many as 77 deaths (Driscoll et al., 2008). For an organization making helicopters, it was found that ergonomics factors were responsible for 86% of the occupational injuries (Eherts, 2008). Successful PtD interventions have been reported in several industries in the US resulting in safer workplaces (Ertas, 2011). The approaches included containment of harmful chemicals, replacing manual work with automation, and implementing engineering controls. Application of PtD to address health effects in asphalt roofing resulted in several design solutions related to materials, tools, and equipment (Young-Corbett, 2014).

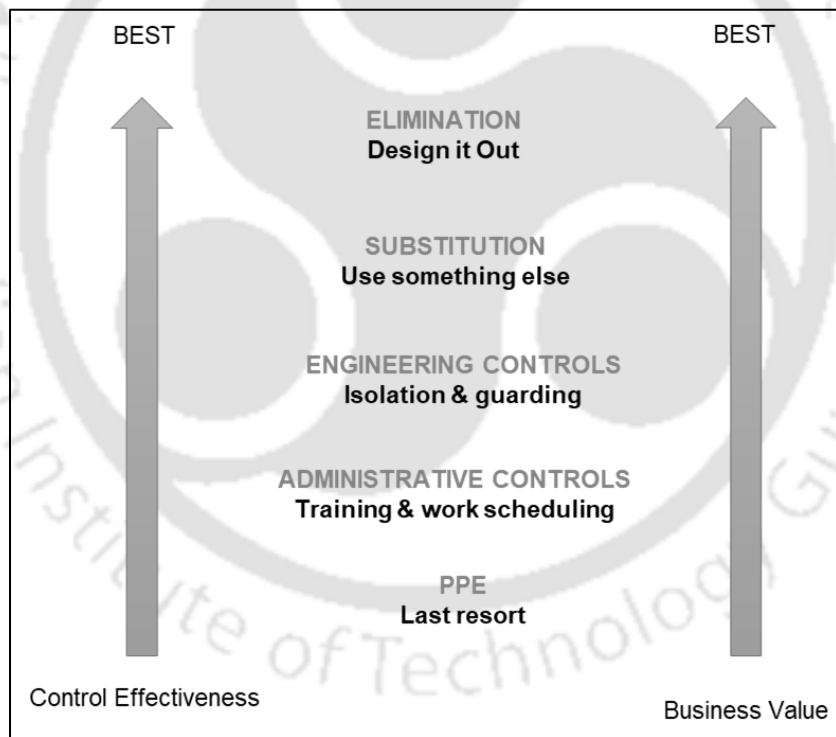


Figure 6.1. Prevention through Design using hierarchy of controls (NIOSH)

6.3.3 Bow-Tie Analysis

Bow-tie analysis belongs to the domain of safety and reliability has been used in several industries (Meland et al., 2019). A bow-tie diagram looks like a fault tree on the left-hand side and event tree on the right-hand side (Figure 6.2). The top event is represented at the centre, the threats are mapped at the left side and the consequences are mapped on the right side. A top event can result

into many threats which can lead to many consequences. The analysis is completed with the inclusion of prevention barriers (left side) and mitigation barriers (right side). Design concepts are derived from these barriers. Although bow-tie analysis is predominantly used as a risk analysis method, it can also be used as a tool for developing concepts for hazard control and risk management which is the approach adopted in this present study. Analysis for two top events namely *falls into water* and *electrocution* was carried out.

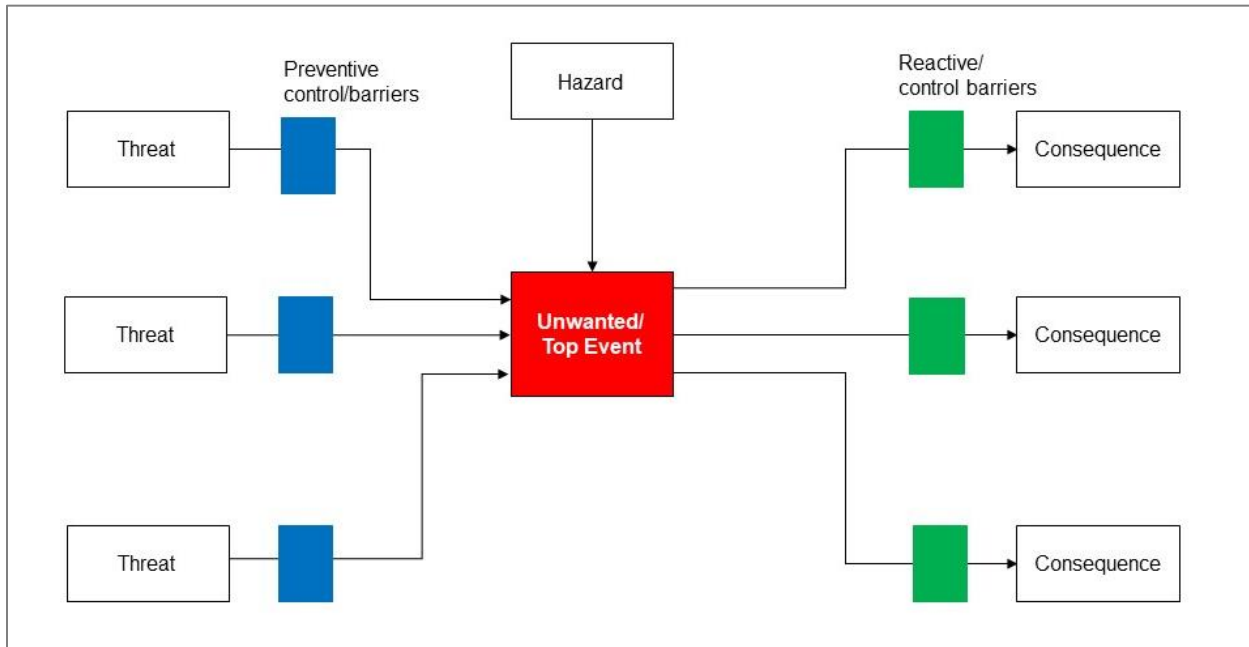


Figure 6.2. Components of a bow-tie diagram

6.4 Results

Several design concepts were elicited through the use of the three methodologies. The results are discussed in the following chapters.

6.4.1 Codesign outcomes

A total of sixteen participants consisting of project engineers (n=12) and FSPV workers (n=4) completed the questionnaire with regard to the top five risks. The participants expressed themselves through discrete sketches, written expressions, and verbal explanations of what they thought could mitigate the OSH risks. Figure 6.3 shows some participants completing the questionnaire.



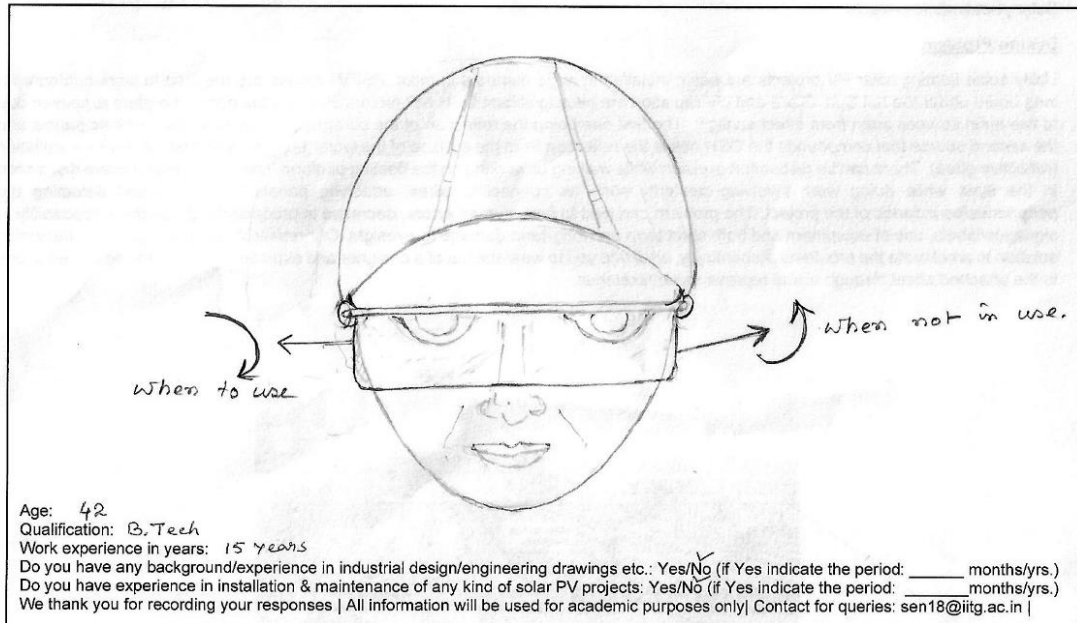
Figure 6.3. Participants completing the co-design questionnaire (image: author)

The following design concepts were elicited from the process:

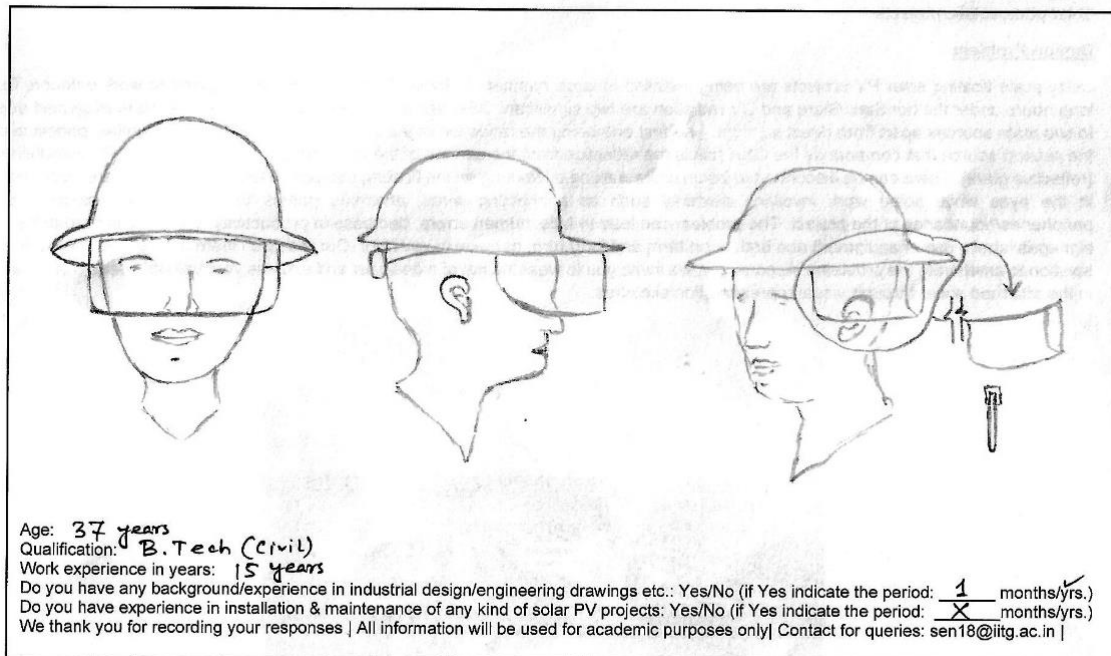
1. Redesign of the fixing system of the solar panel with the pontoon (floater)
2. Design of handrail (floating fence) along the fringes of the FSPV installation
3. Design of anti-glare eye shield
4. Redesign of work rest cycle avoiding work during the hottest part of the day
5. Anti-slip footwear
6. Light and reflective clothing to protect against solar radiation
7. Maintenance board for carrying out safe maintenance
8. Inspection mirror for inspecting the undersides of solar panels without adopting awkward postures

Sketches made by Codesign participants

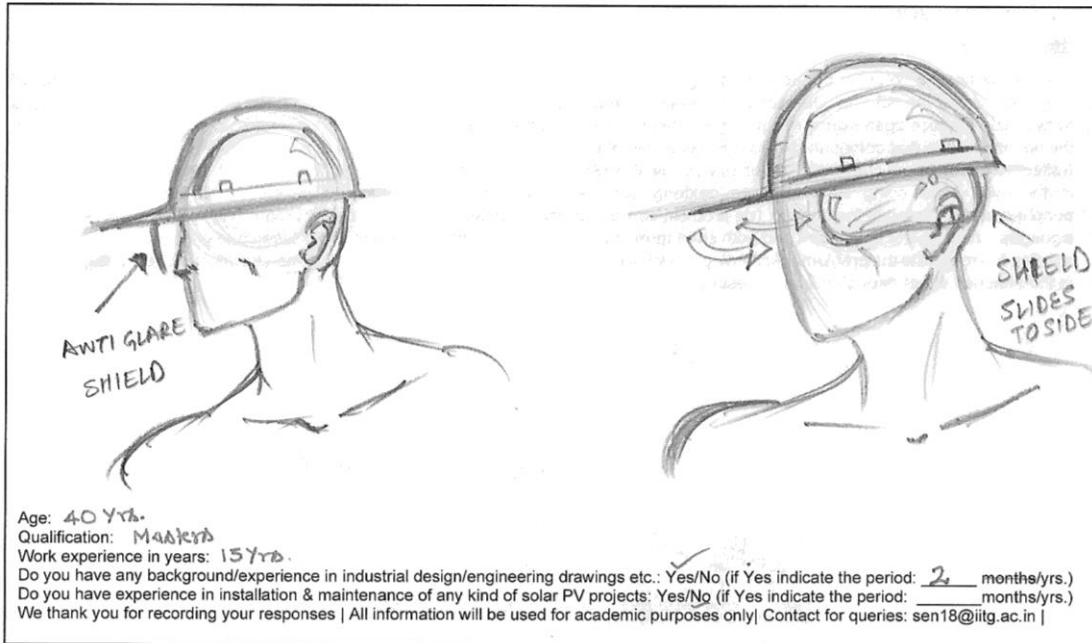
Your redesign/design solution (s) – you may choose to draw a sketch (preferred) or describe your solution in words. Multiple solutions may be provided.



Your redesign/design solution (s) – you may choose to draw a sketch (preferred) or describe your solution in words. Multiple solutions may be provided.



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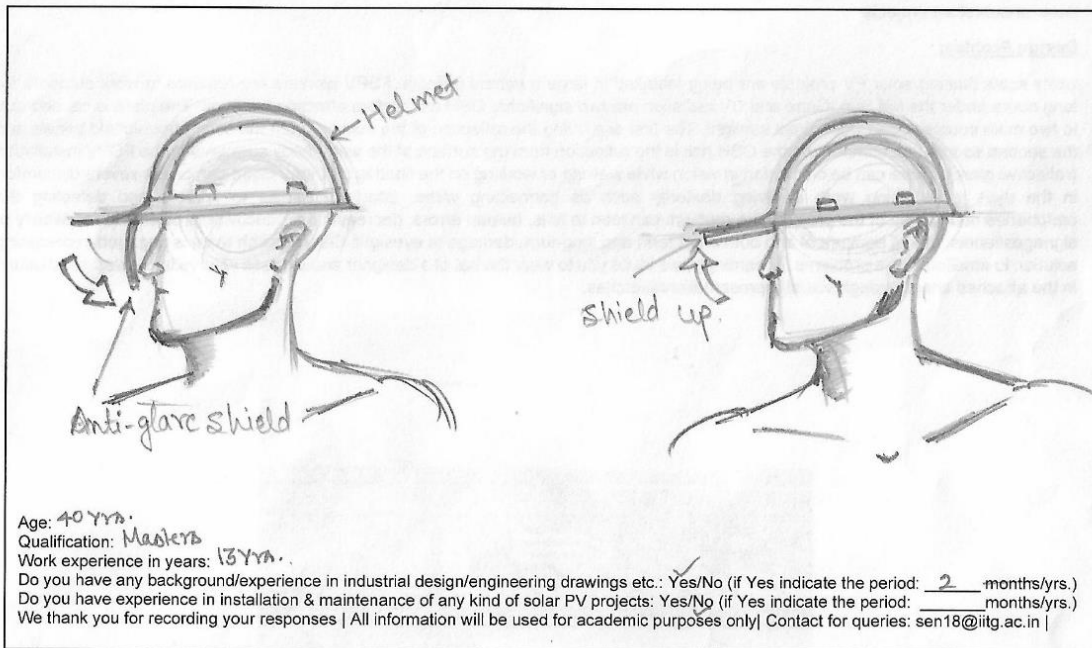


Figure 6.4. Design concepts elicited through the Codesign process – for protection against glare and solar radiation

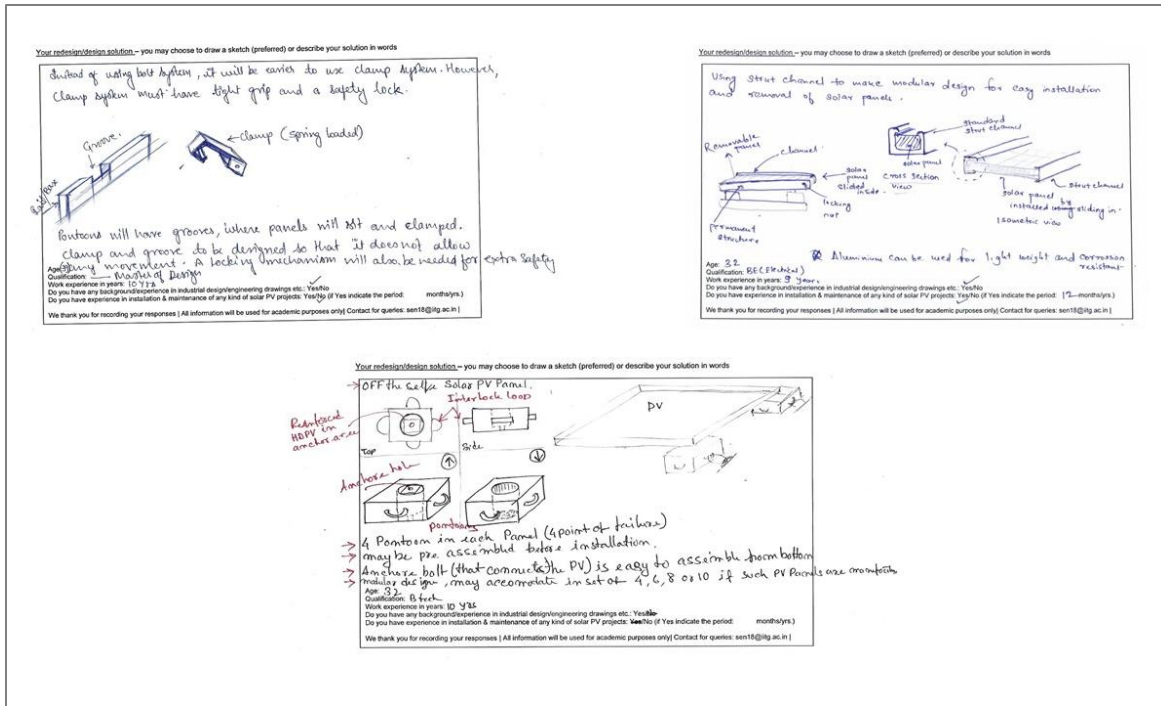


Figure 6.5. Design concepts elicited through the co-design process – redesign of the fixing system of solar panel with the pontoon to prevent awkward postures

6.4.2 Hierarchy of Controls

Following the concept of Prevention Through Design (PtD), a matrix of hierarchy of controls applicable for floating solar PV projects was created. The matrix is shown in Figure 6.6. The different levels of interventions are arranged under PPE, administrative controls, engineering controls, substitution, and elimination. One or more categories as well as types of interventions can be used to address a particular OSH risk. For example, to effectively combat heat stress, workers may be provided with light and reflective clothing and the work can be redesigned so that work rate is slowed down or avoided during the hottest part of the day. Similarly, slips on floaters can be avoided or reduced by designing anti-slip shoes and redesign on walkway floaters. The risk of electrocution can be neutralised through grounding/earthing of the system and use of insulated gloves by the workers. The choice of intervention must consider the cost benefit aspects as well as the practicability. The layout designs of FSPV projects are changing rapidly and interventions must have a certain aspect or flexibility.

OSH risk	PPE	Administrative controls	Engineering controls	Substitution	Elimination
Falling into water	<ul style="list-style-type: none"> - Life jackets - Lifebuoys 	<ul style="list-style-type: none"> - Discourage work near water - Safety signages/alerts 	<ul style="list-style-type: none"> - Guard rails (floating fence) - Portable toe/knee board 	<ul style="list-style-type: none"> - Workplace redesign 	<ul style="list-style-type: none"> - Fall prevention aids - Safety nets - Life lines
Heat stress	<ul style="list-style-type: none"> - Reflective and light clothing - Brimmed hat 	<ul style="list-style-type: none"> - Avoid work in the hottest part of the day - Job rotation - Oral rehydration - Heat acclimatization - Buddy system - Reduce work rate - Safety signages 	<ul style="list-style-type: none"> - Climate controlled rest shelter (cool spots) - Canopies 	<ul style="list-style-type: none"> - Mechanization of work 	<ul style="list-style-type: none"> - Cooling vests - Work during early morning & late evening
Electrocution	<ul style="list-style-type: none"> - Insulated gloves - Insulated mats 	<ul style="list-style-type: none"> - Toolbox training - Permit-to-work system - Lock Out Tag Out 	<ul style="list-style-type: none"> - Accessible emergency switches 	<ul style="list-style-type: none"> - Insulated tools 	<ul style="list-style-type: none"> - Grounding/earthing - Shock/fire proof wires
Solar radiation	<ul style="list-style-type: none"> - Protective clothing and caps - Anti-glare shields and sunglasses - Sunscreen creams 	<ul style="list-style-type: none"> - Screen workers for symptoms - Monitor health effects of UV radiation 	<ul style="list-style-type: none"> - Anti reflective coating on solar panels to prevent glare 	<ul style="list-style-type: none"> - Design and deployment of prefabricated systems 	<ul style="list-style-type: none"> - Canopy over the installation/working area
Slips on floaters	<ul style="list-style-type: none"> - Anti-slip shoes/soles - Walking aids 	<ul style="list-style-type: none"> - Training - Lowering of loads - Encourage safe walking 	<ul style="list-style-type: none"> - Redesign of walkway floaters with anti-slip features 	<ul style="list-style-type: none"> - Maximize installation work on land 	<ul style="list-style-type: none"> - Mechanization
Fire/electric flash	<ul style="list-style-type: none"> - Insulated gloves - Face/eye shield - Fire/flash resistant aprons 	<ul style="list-style-type: none"> - Fire protection system - Allow only trained personnel 	<ul style="list-style-type: none"> - Use of small inverters - Inspection of failure modes - Avoid chimney effect 	<ul style="list-style-type: none"> - Fire resistant materials 	<ul style="list-style-type: none"> - Redesign of wiring system with failsafe features

Figure 6.6. Design opportunities identified following the hierarchy of controls matrix



Figure 6.7. Photographs showing Lock Out Tag Out (LOTO) for electrical safety (image: author)

6.4.3 Bow-Tie Analysis

The analysis of two top events namely falls into water and electrocution resulted in several areas where design interventions can be contemplated. The analyses are represented in Figures 6.8 & 6.9.

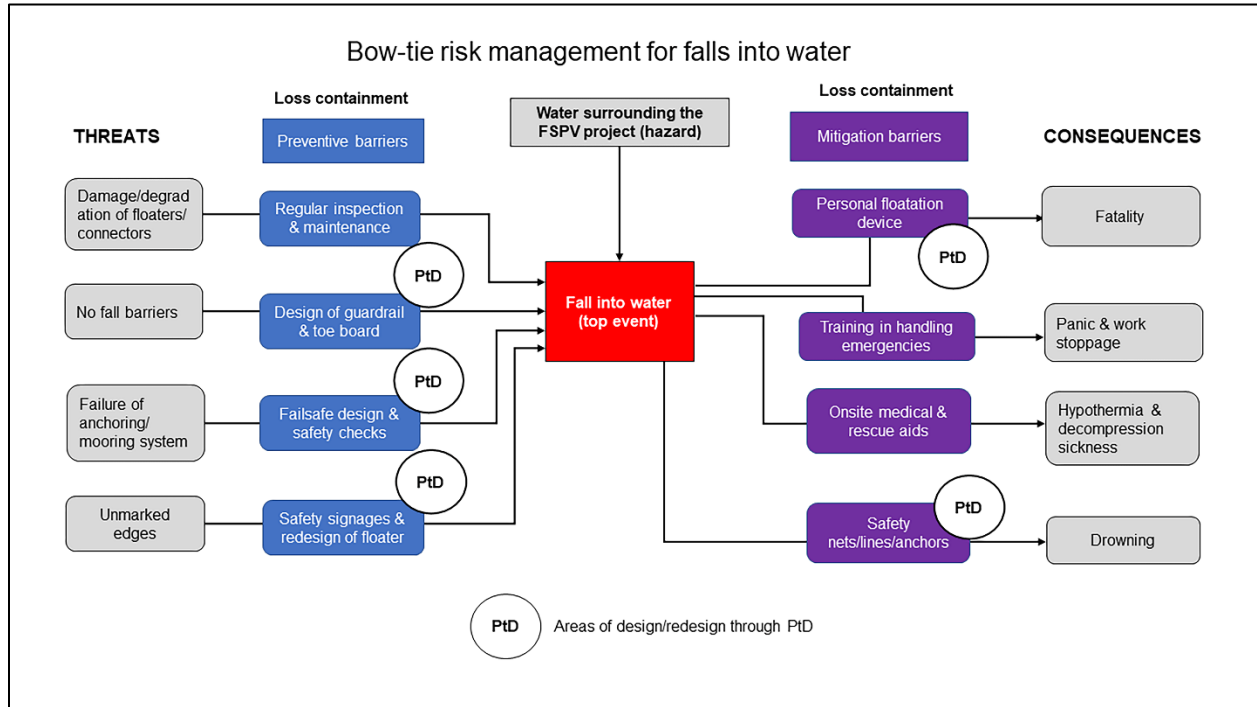


Figure 6.8. Bow-tie analysis for the top event “falls into water” showing possible areas of design interventions marked as PtD. (graphic: author)

The design opportunities derived from bow-tie analysis for **falls into water** are the following:

Preventive barriers

- a) Guardrail and toe board
- b) Safety checklist
- c) Floater redesign
- d) Safety signages

Mitigation barriers

- a) Personal floatation device
- b) Safety nets/lines
- c) Safety anchors

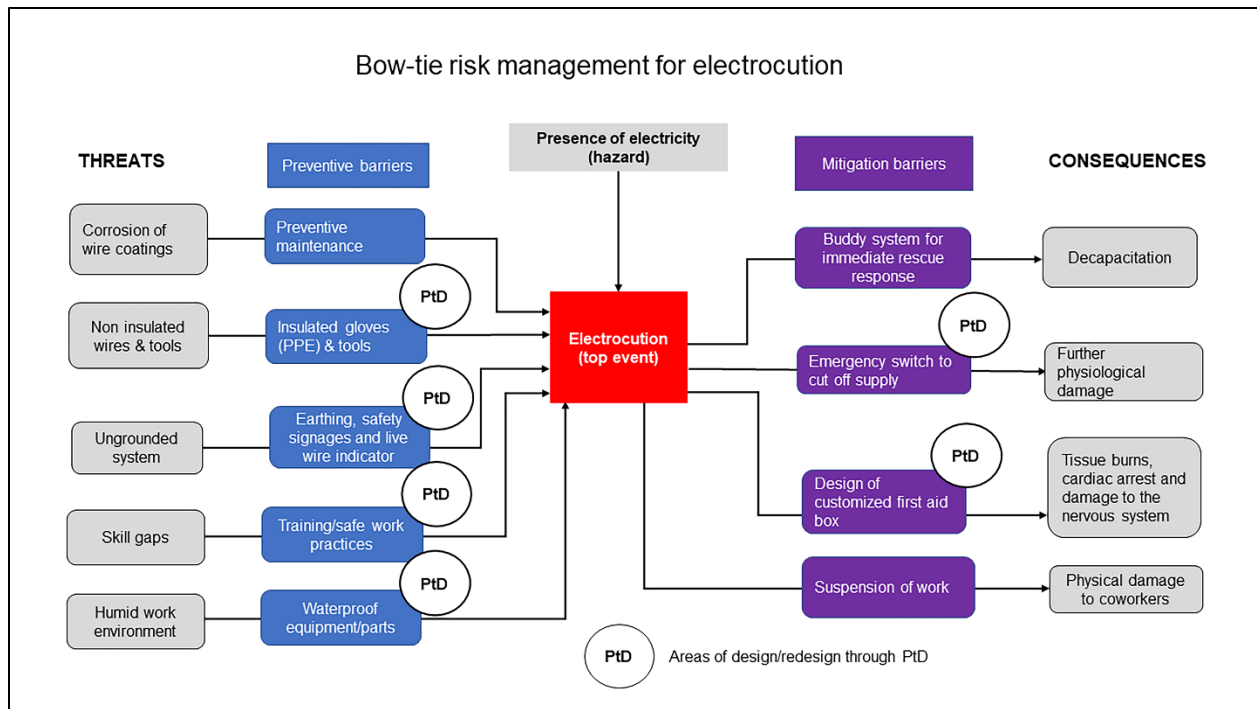


Figure 6.9. Bow-tie analysis for the top event “electrocution” showing possible areas of design interventions marked as PtD. (graphic: author)

The design opportunities derived from bow-tie analysis for **electrocution** are the following:

Preventive barriers

- a) Insulated gloves and tools
- b) Live wire indicator
- c) Earthing
- d) Safety signages
- e) Design of training modules
- f) Waterproof equipments (electricity and water do not mix)

Mitigation barriers

- a) Emergency switch within worker reach
- b) Customised first aid box

6.5 Specific problems, selection of concepts and validation

This section concerns the development of several concepts for addressing the various OSH risks and selection of the most suitable concept to address the contextual need. The best concept is selected on the basis of a concept-scoring matrix and Pugh chart (Ulrich & Eppinger, 2016).

6.5.1 Specific problem to be addressed

As discussed in Chapter 4, discomfort glare and UV radiation is a major OSH risk for FSPV workers exposed to the sun in outdoor work during installation and maintenance. Apart from the direct light from the sun, the reflectance (reflected glare) from solar panels and the water body surface are sources of glare. This discomfort glare can severely affect performance of visual tasks, affect vision resulting in slips, trips and falls which are major OSH risks in FSPV projects, tiredness in the eyes and associated problems (Bridger, 2018). The problem of glare is explained in Figure 6.10. Glare has been identified as an underestimated occupational risk factor (Sawicki & Wolska, 2022) influencing safety at work.

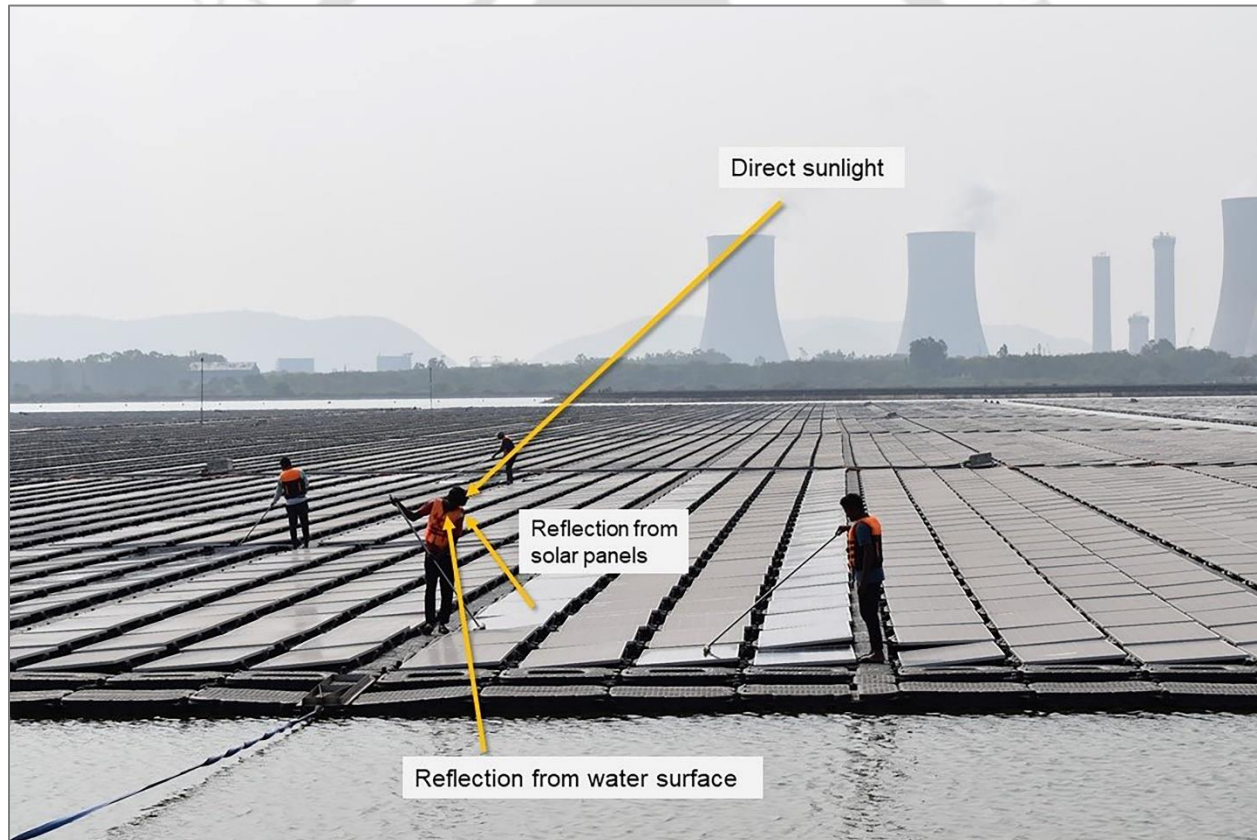


Figure 6.10. The problem of glare due to three sources (image source: author, location: NTPC Simhadri, India)

An analysis of fatality data related to the US construction industry by Occupational Safety and Health Administration (OSHA) during the period 1990-2007, found that the degree of illumination was responsible for 7.2% of the total deaths of 13511. Instances of workmen being blinded by the

effects of glare were pointed out in this report (Hinze & Teizer, 2011). The quantum of illumination has been associated with occupational illness and hence productivity (Badri et al., 2011).

6.5.2 Physiological and work-related effects of UV radiation and discomfort glare

UV radiation

The diseases due to exposure to UV radiation include eye pterygium (Figure 6.11), cataracts, and macular degeneration (Modenese et al., 2018, Wright & Norval, 2021). Others include ocular melanoma (Guénel et al., 2001), photoconjunctivitis (inflammation of the conjunctiva) and photokeratitis which is the inflammation of the cornea (Wright & Norval, 2021).

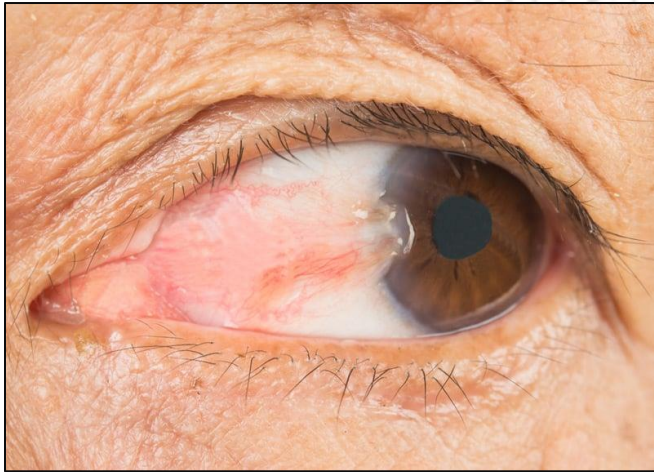


Figure 6.11: Eye Pterygium is a wing-like or triangular-shaped thickening of an area of conjunctiva tissue (Image source: clevelandclinic.org)

6.5.3 Discomfort glare

As per ISO 9241-6 discomfort glare is defined as a “Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution of range of luminance, or to extreme contrast”. The effects of glare include tiredness of the eyes and interferes with task performance. The blinding effect of glare can lead to slips, trips, and falls. This is critically important in respect of FSPV projects where work on a floating platform is involved and workers may not be able to detect the edges of the FSPV project during installation and maintenance. This uncomfortable effect on vision at work can lead to falls into water and possibly fatalities. In addition, productivity of tasks involving dexterity such as connecting wires may be severely affected.

In a broad sense, discomfort glare can cause both physiological effects and work-related challenges that are both direct and indirect.

6.6 Anti-glare & anti UVR eye protector

The following paragraphs discuss the rationale, existing design standards, concept development and screening for the final proposed design.

6.6.1 History of safety eyewear

The earliest efforts to design and patent an eye protector was made by Powell Johnson (U.S. patent no. 234,039). This product was intended at protecting the eyes of iron puddlers, furnace and firemen from glare. A chance discovery of cellulose nitrate in 1903 by Edouard Benedictus (French chemist) paved the way for the manufacture of safety glasses. Almost six years later, the American Optical company introduced safety goggles under the brand name “SANIGLAS”. It was not until 1979 that the American National Standards Institute (ANSI) introduced design standards for safety eye wear. Figure 6.12 traces the history of safety eyewear over time.

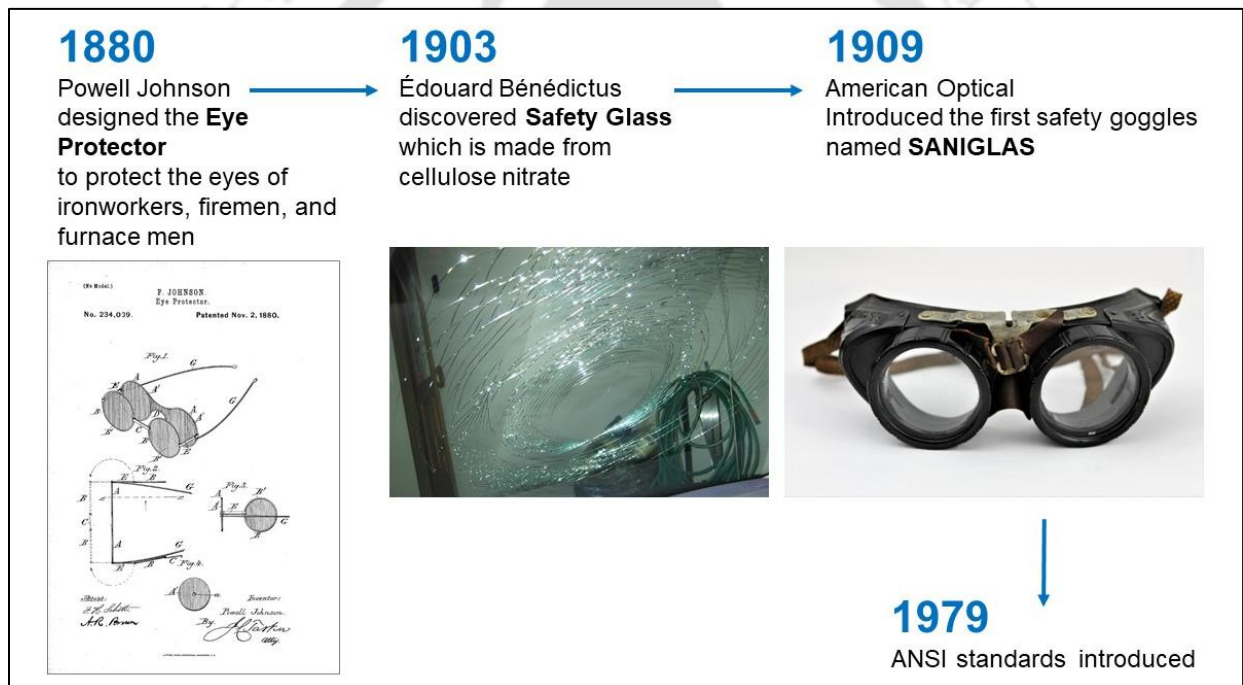


Figure 6.12. History of protective eyewear (source: <https://www.linkedin.com/pulse/history-protective-eyewear-delta-health-and-safety-equipment-/>)

6.6.2 Types of safety eyewear

As per the International Labour Organization (ILO), the different types of eye protection include common types of spectacles (with and without side shield), goggle type, face shield type and face protection for welders (Figure 6.13). An important aspect regarding the designs of the face protectors includes the context of use i.e., the OSH risks that need to be neutralized. This implies that there is no size fit for all as far as safety eyewear design is concerned.

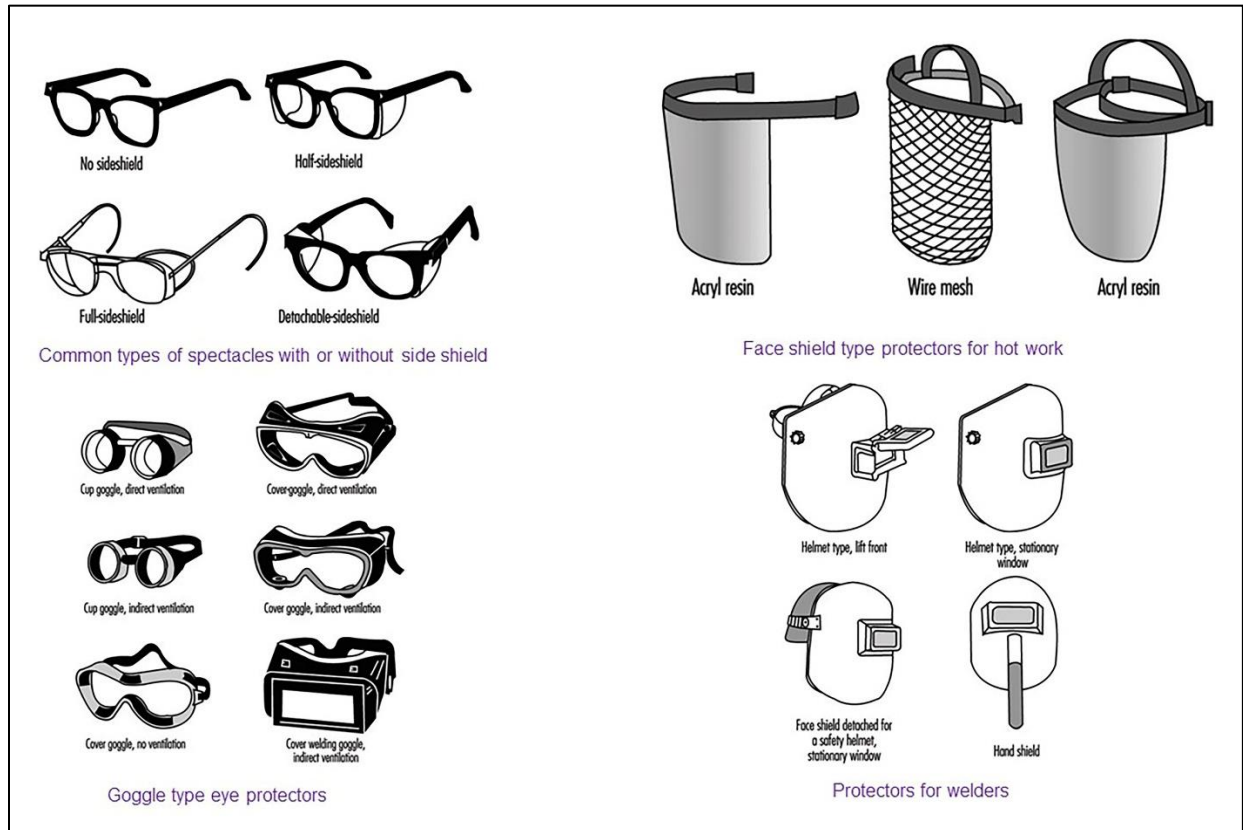


Figure 6.13. Types of eye protection as per International Labour Organization (ILO)

6.6.3 Contextual needs of FSPV workers

The main challenges in designing the eye shield include 1) providing protection against the combined glare from the reflection from the surface of the solar panels and the water body surrounding the workplace, 2) can be worn for long hours without discomfort in a hot and humid environment and, 3) should not restrict vision or intermittent activities such as drinking water and/or rehydration fluids.

Presently, the workers normally use two separate Personal Protective Equipment (PPE) for eye safety (eyewear) and head protection (hard hat/helmet). This presents a problem of managing two separate kinds of equipment. Moreover, storage of the PPE compounds the problem. The eyewear

being a smaller object than the safety helmet is even more difficult to store. Safe storage assumes even more importance in an aquatic environment. Figure 6.14 depicts the contextual problems.

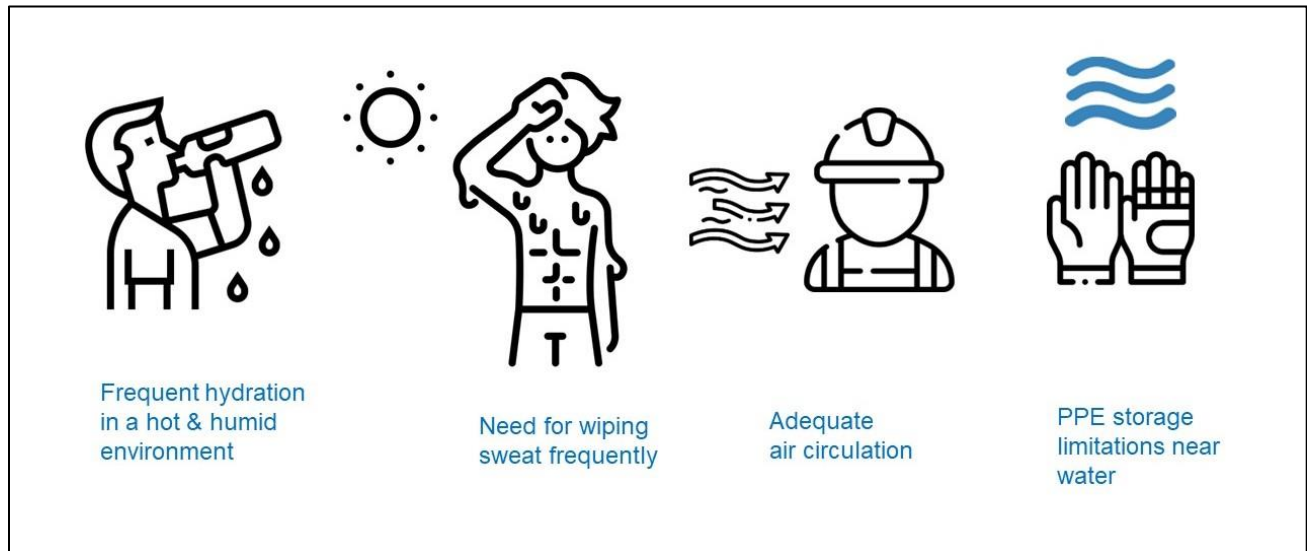


Figure 6.14. Contextual needs FSPV workers to be considered for the final design intervention (icon source: flaticon)

6.6.4 Design standards

The American National Standards Institute (ANSI) prescribe standards for design and manufacture of personal eye and face protection devices. The standards are named as ANSI/ISEA Z87.1-2020 (latest version). The Bureau of Indian Standards (BIS) applicable to safety eyewear is IS 5983:1980 (2018).

6.6.5 Concepts to address the specific problem

Concept 1

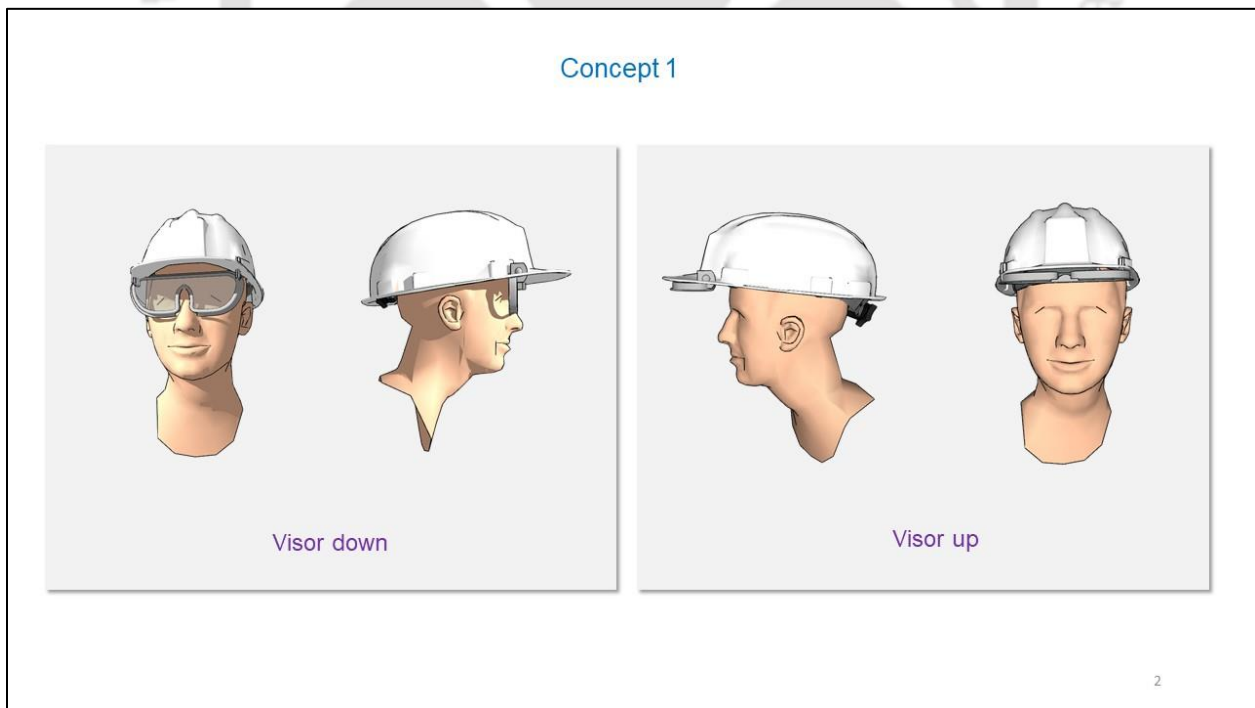
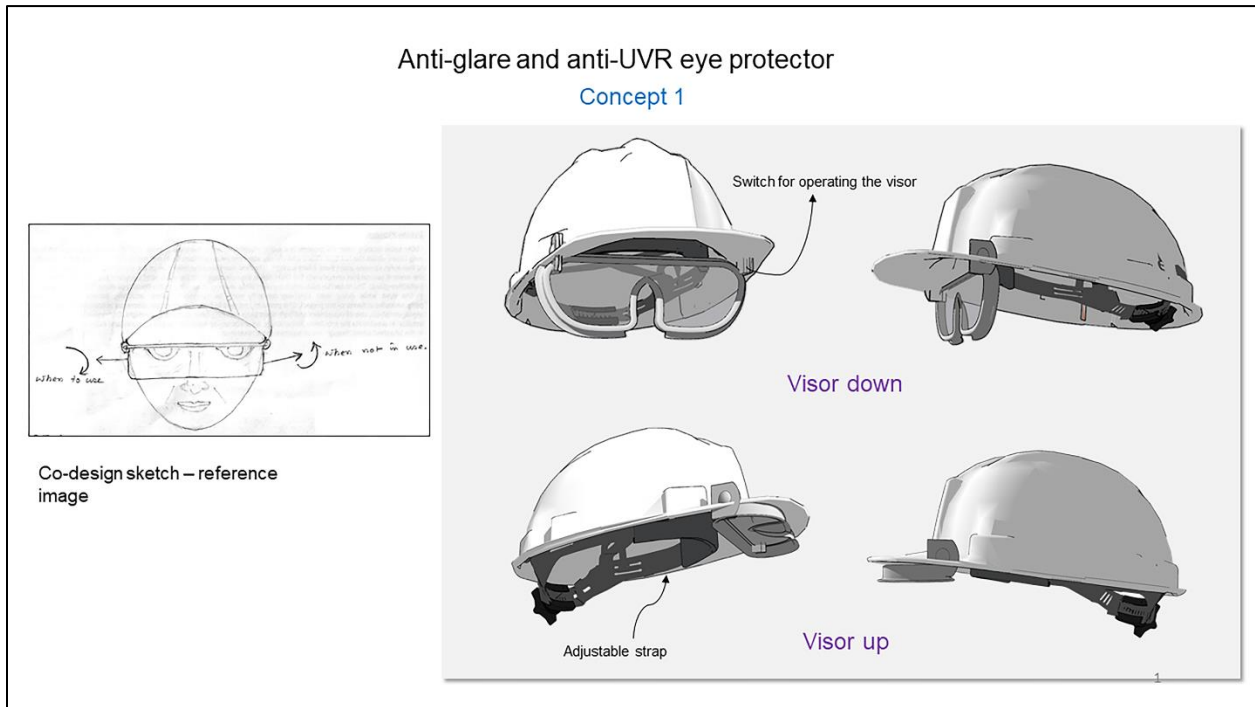


Figure 6.15. Design concept 1 for anti-glare eye glare and UV protector

Concept 2

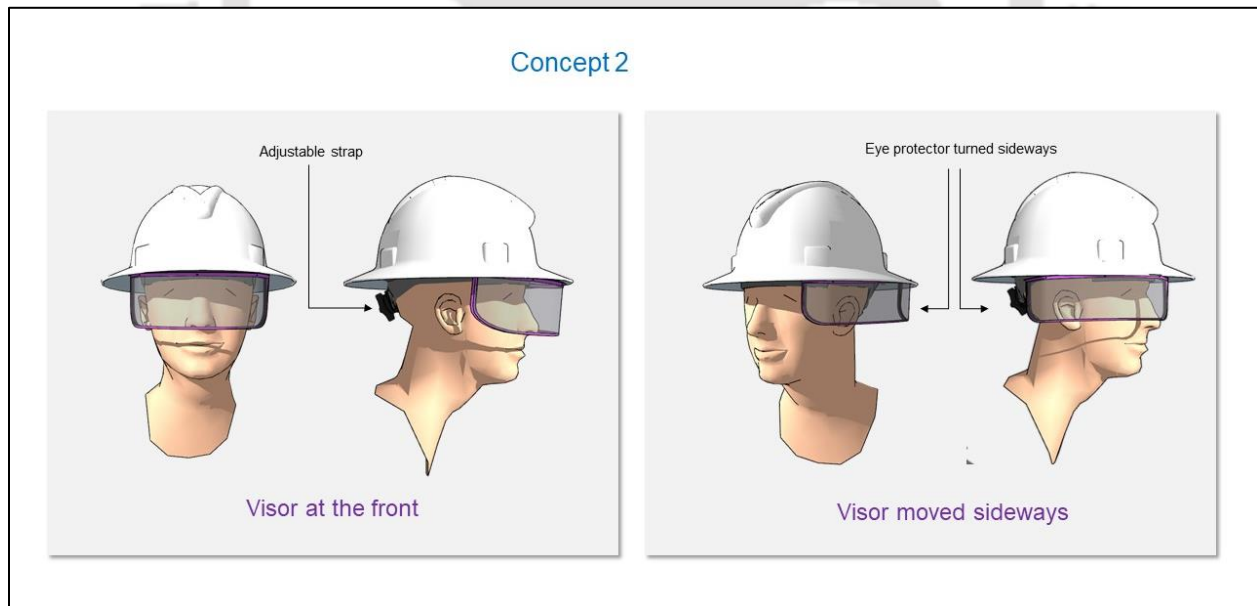
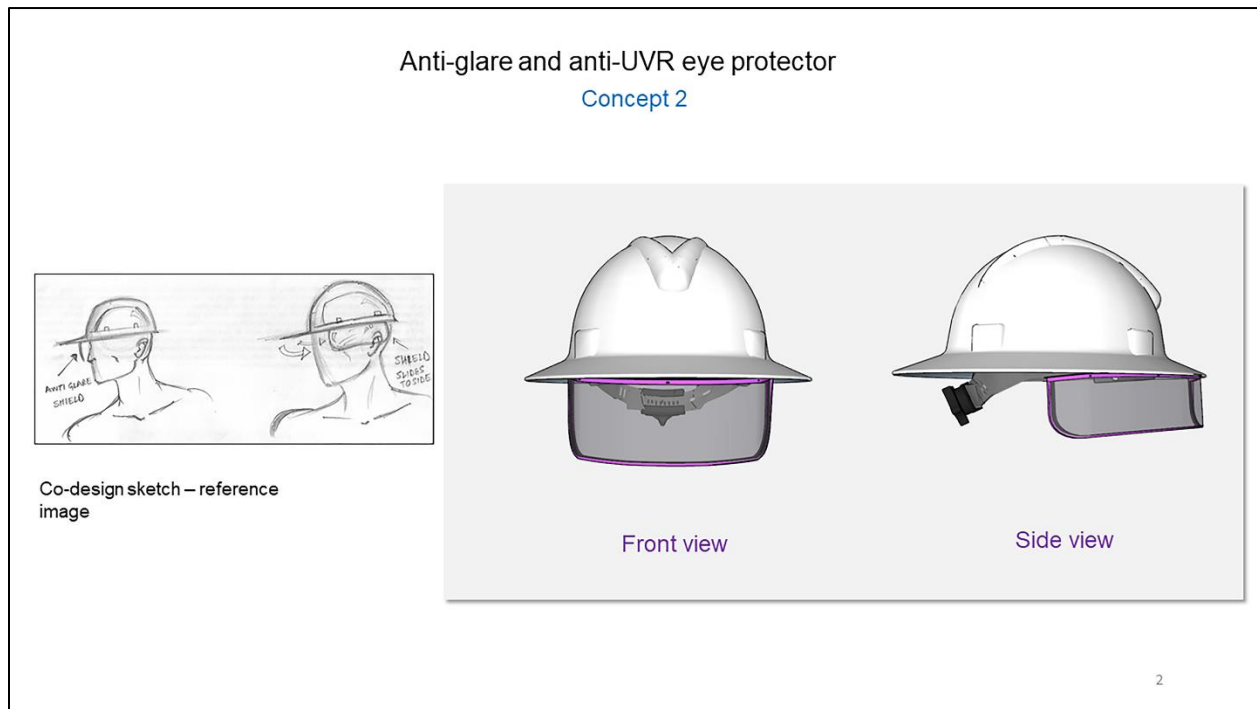

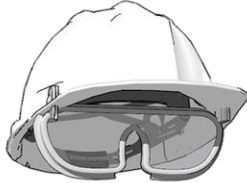



Figure 6.16. Design concept 2 for anti-glare eye glare and UV protector

6.5.6 Concept screening

The two concepts were screened using the Pugh chart.

Table 6.1. Pugh chart for selection of concepts

		Datum*	Concept 1	Concept 2	
					
Design criteria	Weight	D A T U M			
Effort required to operate	2		+	+	
Easy provision for drinking water, wiping sweat, ventilation etc.	3		+	+	
Ability to reduce glare & UVR	3		0	0	
Visual performance	2		0	0	
Easy to manufacture	2		-	+	
Cost	1		0	+	
Aesthetics	1		0	+	
sum of positives	+			2	5
sum of neutrals	0			4	2
sum of negatives	-		1	0	
Total Points			1 (rank 2)	5 (rank 1)	

*HSN Code: 90049090. Product Code: UD 91 GREY (IS 5983:1980 certified)

6.6.7 Final proposed concept

The proposed design can be universally used in all kinds of solar photovoltaic projects and in all occupations involving outdoor work. The design is represented at Figure 6.17. The design is being called as Glare Safe.

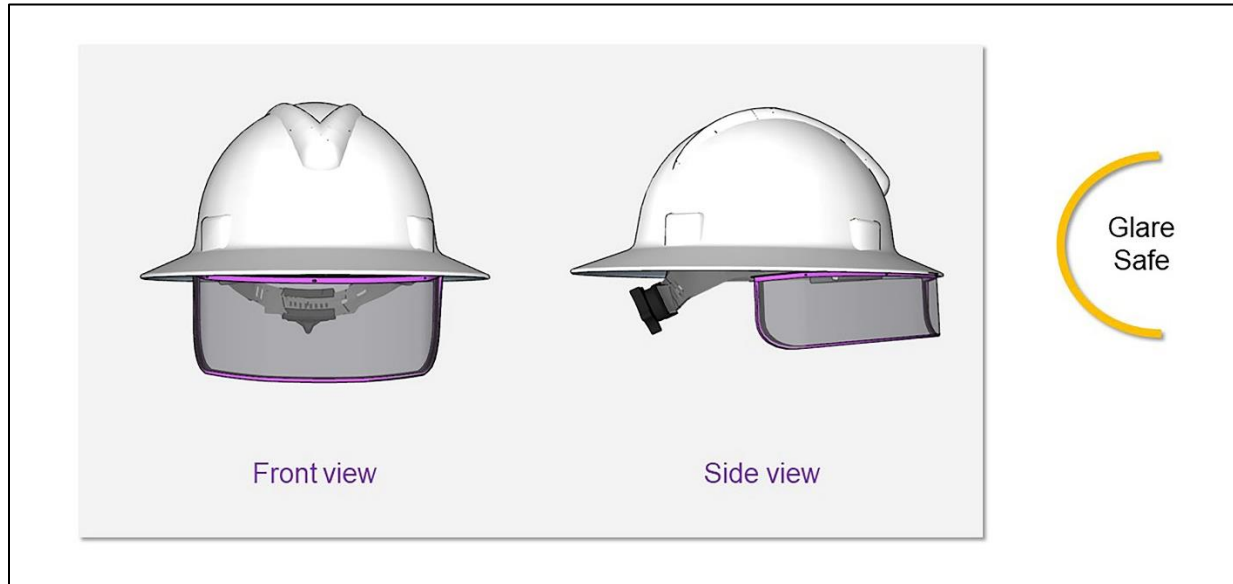


Figure 6.17. Final proposed design concept for the eye protector (image: author)

The eye protector (anti UV & anti-glare) is retrofitted onto the existing design of a round brimmed safety helmet. The eye protector can be moved sideways and brought back to its original position depending on task/contextual requirements. The mechanism is shown in Figure 6.18.



Figure 6.18. Mechanism of use of eye protector

6.6.8 Limitations of existing safety eyewear

An obvious question may arise in the minds of the readers and OSH professionals as to what may be the limitations of the existing safety eyewear available in the market. Figure 6.19 shows some of existing design of safety eye protectors being used for various kinds of workplaces.

	<p>ForceFlex™ Plus Safety Eyewear</p> <p>92235 — Gray lenses, glossy black frame</p> <ul style="list-style-type: none"> • Innovative combination of strength, comfort and performance, without sacrificing style • Flexible and resilient frames for a customizable fit • Soft rubber accents for all-day comfort • Multi-injection technology fuses lens to frame • Designed with the latest technology to keep vision clear, with impact-resistant lenses that absorb 99.9% UV • Anti-scratch lens coating • Includes microfiber storage bag and lanyard • Meets ANSI Z87.1-2010 standards
	<p>ForceFlex™ Flexible Safety Eyewear</p> <p>92232 — Clear lenses, glossy black frame</p> <p>90897 — Gray lenses, dark blue frame</p> <p>92231 — Gray lenses, glossy black frame</p> <ul style="list-style-type: none"> • Innovative flexible design and resilient frames • Multi-injection technology fuses lens to the frame • Soft features for a comfortable fit • Anti-scratch coating • Impact-resistant lenses absorb up to 99.9% UV • Includes microfiber storage bag and lanyard • Meets requirements of ANSI Z87.1-2003 (92231) • Meets requirements of ANSI Z87.1-2010 (92232, 90897)
	<p>Metallic Safety Eyewear</p> <p>90788 — Indoor/outdoor mirror lens, silver frame</p> <ul style="list-style-type: none"> • Single-lens design • Soft nosepiece • Anti-scratch coating • Includes microfiber storage bag and lanyard • Meets the requirements of ANSI Z87.1-2010 and CSA Z94.3-2007

Figure 6.19. Some kinds of available safety eyewear (image source: 3M)

The limitations include:

- a) Customization required in terms of anthropometric variabilities such as head size, nose bridge. Cannot be universally used.
- b) Over spec design need for those workers wearing spectacles
- c) Discomfort due to snug fit and sweating around safety glasses (fogging)
- d) Cost for purchase of different models for different users
- e) PPE avoidance
- f) PPE storage issues
- g) Wearing helmet and glasses together may be uncomfortable due to chin strap (Figure 6.20). Putting on and removing the eyewear several times a day involves dealing with the chin strap.



Figure 6.20. Negotiating the chin strap of the safety helmet is a major challenge in using safety eyewear (image: author)

6.7 Compliance through Design (CtD)

While there is a large body of research revolving around the design and development of appropriate PPE to neutralize various kinds of OSH risks, there has been little effort towards addressing the problem of PPE avoidance at the workplace. Use of PPE is a statutory and legal requirement in most countries and non-compliance can result in not only injuries and accidents but also direct and indirect costs for the concerned stakeholders. Also, an injury or accident brings a bad reputation to the project/workplace and creates a sense of fear amongst other workers engaged at the site. In terms of article 16 of the Occupational Safety and Health Convention, 1981 (No. 155) of the International Labour Organization employers are under obligation to provide PPE to their workers

for occupational health and safety. An extract of the article is reproduced below. S. No 3 of the relevant article is related to use of PPE.

Quote

Article 16

1. Employers shall be required to ensure that, so far as is reasonably practicable, the workplaces, machinery, equipment, and processes under their control are safe and without risk to health.
2. Employers shall be required to ensure that, so far as is reasonably practicable, the chemical, physical and biological substances and agents under their control are without risk to health when the appropriate measures of protection are taken.
3. *Employers shall be required to provide, where necessary, adequate protective clothing and protective equipment to prevent, so far as is reasonably practicable, risk of accidents or of adverse effects on health.*

Unquote

In a survey (Kimberly Clark, 2012) carried out amongst US safety professionals it was found that 82% of the respondents reported that workers did not use PPE at the workplace in the preceding twelve months. The survey found that reasons for PPE non-use included discomfort, heat, decrease in productivity, unavailability near work location, not having proper fit and lack of aesthetics. A study on construction workers in Egypt, found that 40% of them did not use PPE (Sehsah et al., 2021). The study also found that major reasons for non-use included discomfort, lack of knowledge of use, poor fit and discomfort due to heat. Worker age, education, category of job and prior training in safety had a significant association with safety use. In recent years, strategies to ensure compliance of PPE include use of deep learning (Shen et al., 2020, Nath et al., 2020) for detection of safety helmets and real-time monitoring using RFID technologies such as cyber-physical systems (Barro-Torres et al., 2012).

Existing efforts for better compliance include strategies for supervision and monitoring involving external methods often including an element of enforcement. However, it is important to delve deep into the actual reasons for non-use/avoidance of PPE by the users. Accordingly, a design driven approach is proposed for better compliance. The approach is proposed to be called Compliance through Design (CtD).

Proposed definition of CtD:

Design, redesign, rethinking and reorganization of products, processes, and interfaces considering usability, utility, behavioral, cultural, training and contextual needs of users so as ensure acceptability and usage of OSH resources in order to promote compliance of statutory and safety requirements. CtD is aimed at positive behavioural changes in users through good and acceptable design interventions. A framework of CtD is represented at Figure 6.21.

The concept of CtD is proposed in this study to ensure that not only a contextually relevant solution is arrived at, but also PPE or a combination of PPE (hybrid design) is accepted and used by the FSPV workers. Normally, separate PPE or safety resources are developed for different kinds of risks. A new design should not be a new addition to the existing safety tools/resources but preferably an integration or retrofit to the existing PPE or safety equipment. For example, a new PPE comes with issues related to fit, usage, storage and responsibility of preventing loss of safety equipment. Combination and recombination can result in new designs that makes PPE usage user driven rather than being enforced by the contractor or supervisor.

The concept proposed in this present study involves the integration of the eye protector with the safety helmet. The result is a hybrid design that addresses multifarious OSH risks such as falling objects, inclement weather (such as rain, extreme temperatures etc.), UV radiation and discomfort glare. The hybrid design not only protects the worker but also results in compliance. A relevant design indirectly enforces compliance.

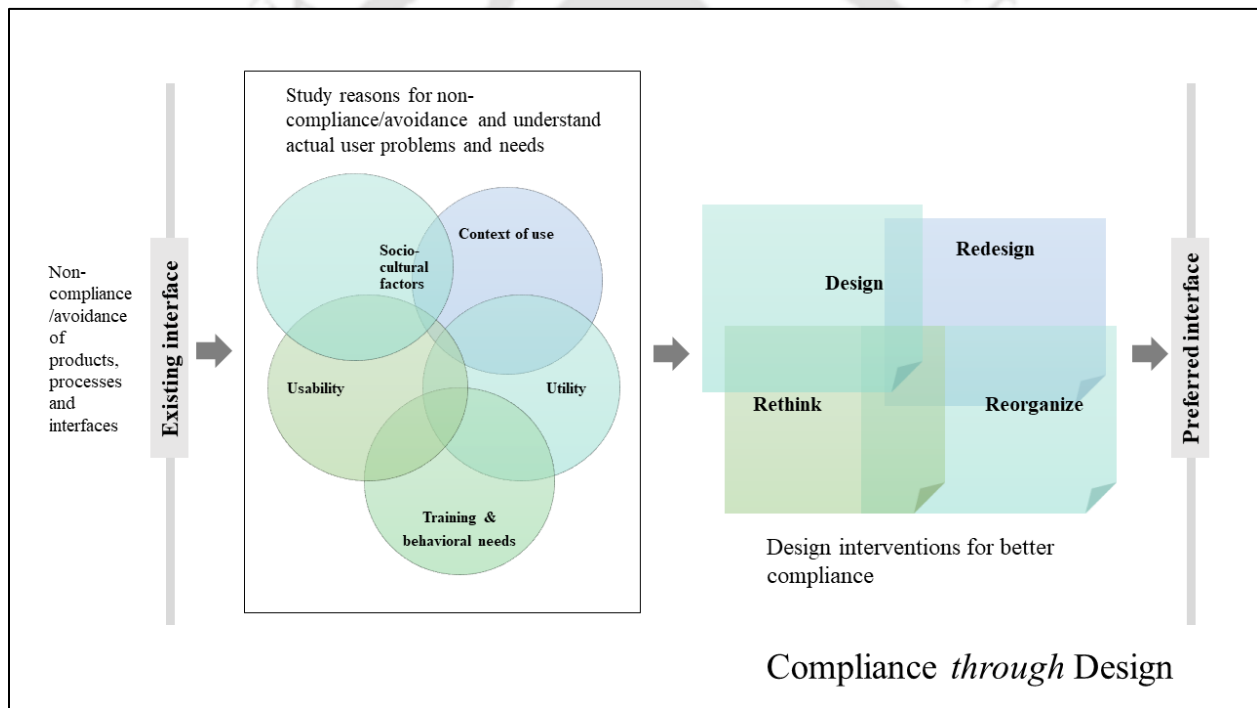


Figure 6.21. A framework for *Compliance through Design* (CtD) process. Interface refers to human-machine interfaces such as products, processes, and other interfaces. (graphic: author)

6.8 Robust design

Ensuring good performance under different or non-ideal conditions is an important objective of good design. For any given product or process, noise factors may affect the performance affecting the robustness of the design. “*Robust design* is the product development activity of improving the desired performance of the product while minimizing the effects of noise (Ulrich & Eppinger, 2016).”

A parameter or “p” diagram for a given design concept shows the control factors, noise factors and expected performance metrics. For the all the design concepts proposed in the present study, “p” diagrams have been constructed. The “p” diagram for the eye-protector is represented at Figure 6.22.

Robust design of eye protector

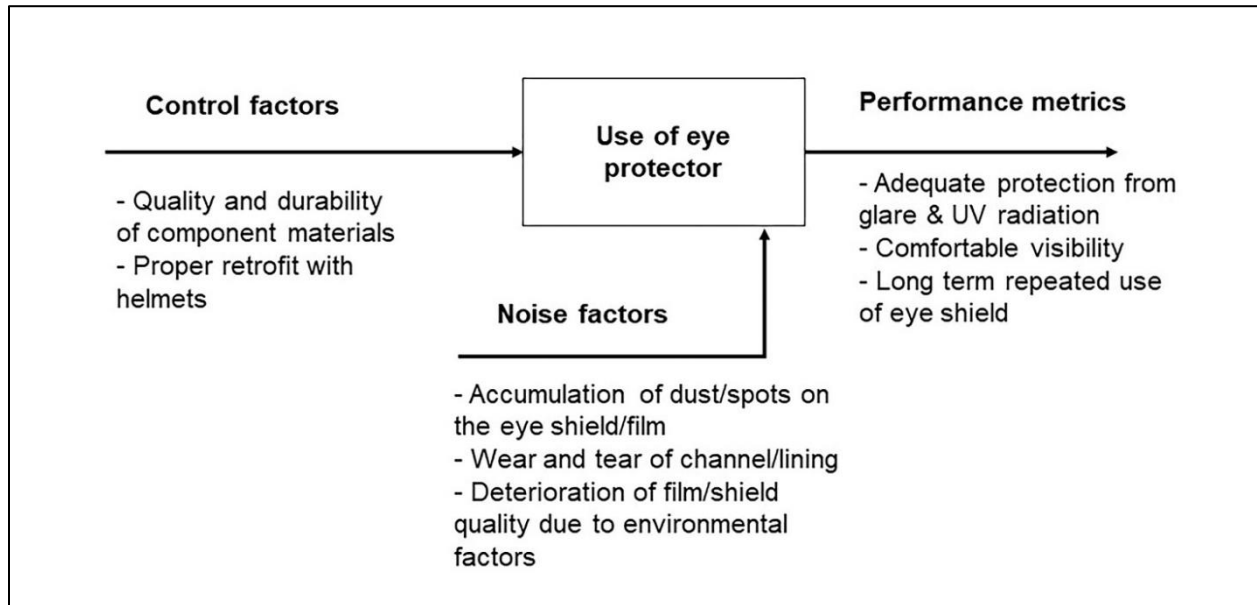


Figure 6.22. Parameter (p) diagram for robust design of eye protector (graphic: author)

6.9 Validation of Design concept - Eye protector (anti UV & anti-glare)

To understand the effectiveness of the proposed design intervention amongst the user group i.e., solar PV workers and site engineers/managers, validation of the design concept was planned.

6.9.1 Formulation of hypothesis statements

Within the scope of the study, the objectives of the intervention include risk mitigation at the primary level, ensuring that visual tasks are more comfortable at a secondary level (an intervention should not affect task performance) and use of the design is enforced or promoted as a tertiary benefit. The objective of the visual task is to ensure the avoidance of a new problem due to the introduction of a design solution which is typical of the “wicked problems” in design (Bayazit, 2014).

Keeping these aspects in mind, the following hypotheses statements were formulated:

h1: Performance of a visually demanding task in FSPV projects will improve significantly with anti-glare and anti-UVR eye protector.

Null hypothesis

h1₀: Performance of a visually demanding task in FSPV projects will deteriorate significantly with anti-glare and anti-UVR eye protector

Alternate hypothesis

h1_a: Performance of a visually demanding task in FSPV projects will improve significantly with anti-glare and anti-UVR eye protector

h2: Use of an anti-glare and anti-UVR eye protector designed for FSPV workers will reduce discomfort glare from various sources at the workplace and improve eye safety.

Null hypothesis

h2₀: Use of an anti-glare and anti-UVR eye protector will not reduce discomfort glare from various sources at the workplace

Alternate hypothesis

h2_a: Use of an anti-glare and anti-UVR eye protector designed for FSPV workers will reduce discomfort glare from various sources at the workplace

6.9.2 Methods, materials & design of experiment

The following methods/tools were used to understand how the participants rated the design concept:

- a) Performance of a visual task with and without the eye-protector
- b) Measurement of discomfort glare using the de Boer's scale
- c) System Usability Scale (SUS) for measuring the usability of the design

An experimental set up was established at a solar PV project with the sun as the source of glare and reflectance from solar PV panels (Figure 6.23). The experiment was conducted during the day during the month of December 2022 in India. Engineers, workers, and site managers associated with the solar photovoltaic industry in India were invited to participate in the study as subjects. Convenience sampling method was used in the study. Informed consent was taken from all participants (**Appendix-I**).

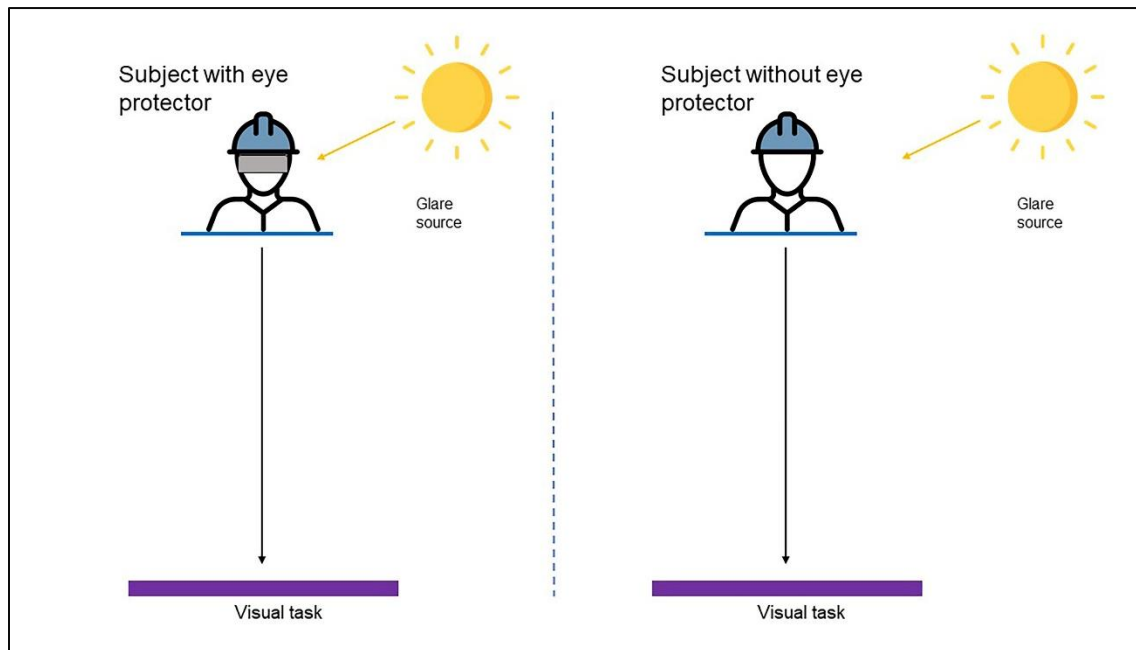


Figure 6.23. Experimental set up for assessing the effectiveness of the eye protector (graphic: author)

A questionnaire (**Appendix-J**) was constructed to record the time taken and satisfaction level for completion of the task. The subjective glare ratings using the de Boer's scale were also obtained. The subjects were also requested to complete the System Usability Scale (Lewis, 2018).

In a within group experimental design, the subjects had to perform a visual task, first without the eye protector and then with the eye protector. The visual task consisted of completing the tumbling "E" eye chart (Figure 6.24). The chart was placed ten feet away which is the protocol for using the eye chart. Subjects were asked to restrict reading up to the same row number "with" and "without" the eye protector to standardise the task under both conditions.

The tumbling "E" chart was used in the present study since it is an instrument to measure the visual acuity (Lai et al., 2011, Reich & Ekabutr, 2002) and can be used as a tool to measure visual performance.

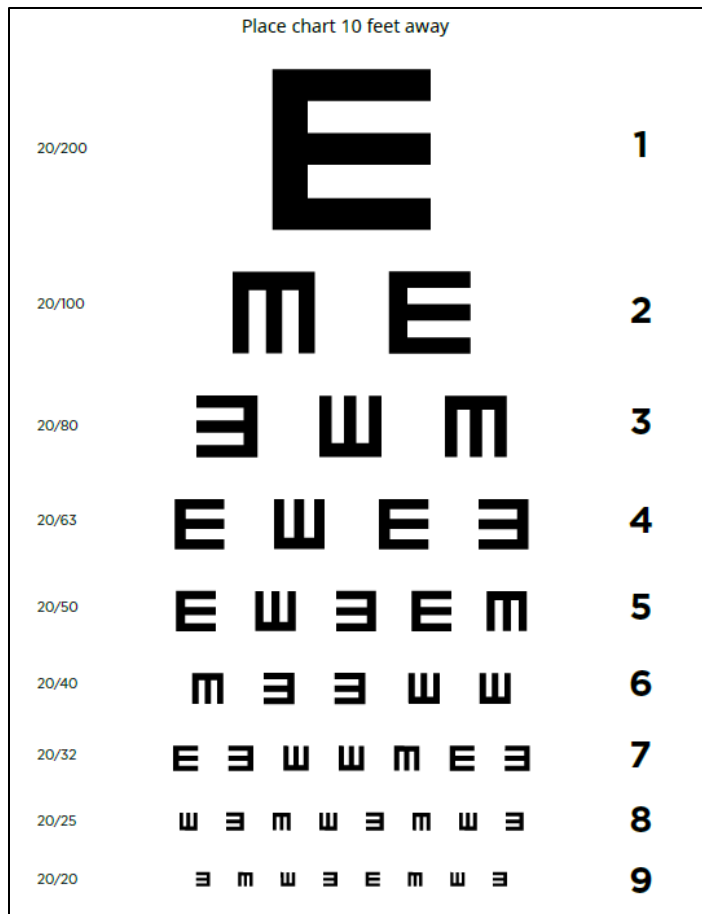


Figure 6.24. Tumbling “E” eye chart

In a pre-trial demonstration (PTD), the subjects were shown how to complete the task and questionnaires they had to fill-up (Figure 6.25). All clarifications from the participants were addressed during the pre-trial demonstration. A total of 49 subjects participated in the present study (Figure 6.26).

The aim was simulating the outdoor task at a FSPV location and measuring the effectiveness of the eye protector without compromising the visual demands at work. As mentioned earlier, discomfort glare needs to be neutralized and visual tasks to be made comfortable at the same time.

Statistical analysis was carried out to understand the significant difference if any in performance of the visual task. Performance was measured in terms of time for completion and satisfaction of the subject. To understand the satisfaction level or ease of performing the task, subjects had to rate the task on a five-point Likert scale ranging from very difficult (1), difficult (2), neutral (3), easy (4) and very easy (5) with and without the eye protector.



Figure 6.25. Pre-trial demonstration (PTD) of the experimental protocol (image: author)



Figure 6.26. A solar PV engineer wearing the eye protector participating in the study (image: author)

6.9.3 Results

The findings of the experiment are summarised in the following paragraphs.

The environmental conditions at the solar PV project are represented in the table below:

Table 6.2. Environmental conditions at the studied location

Temperature	25.8 °C
Air Velocity	2.3 metres/second
Illumination	65560 lux

Demographic profile of the subjects

The subjects consisted of solar photovoltaics engineers and workers having experience of both installation and maintenance of at least one solar PV project. All the subjects were males with a majority i.e., 56% belonged to the age group of 31 to 40 years while 44% subjects belonged to the age group of 41-50 years. The mean age was 40.39 years with a standard deviation of 5.91 years.

The solar PV engineers were graduates and the all the workers had studied up to the higher secondary level.

Performance of the visual task

Time taken and satisfaction (ease of completion) score to complete the task under two conditions is represented below. Two tailed dependent t-test was carried out between the scores “with” and “without” the eye protector to understand whether the design intervention was statistically significant or otherwise.

Table 6.3. Mean and standard deviation for time taken and satisfaction score with and without the design intervention

Parameter	WITHOUT EYE PROTECTOR		WITH EYE PROTECTOR	
	Mean	SD	Mean	SD
Time taken	19.12 seconds	8.47 seconds	15.09 seconds	6.32 seconds
Satisfaction score (on a scale of 1-5) *	3.36	0.63	4.36	0.75

*Higher the score, higher is the satisfaction level in performing the visual task

It is evident from the above table (6.3) that subjects (n=49) took less time with the eye protector to complete the visual task. Subjects also expressed a higher satisfaction score while performing the task wearing the helmet with the eye protector.

An interesting observation during the experiment was that many subjects while wearing the eye protector were able to read beyond the line number that they read without the eye protector. This indicates the improvement in vision and thus higher productivity while wearing the eye protector. The design intervention thus does not reduce vision but only improves it.

Statistical outcomes:

Time taken for task completion: The time taken for performing the task “with” and “without” the eye protector was recorded.

The results were significant at $p \leq 0.05$ (t value = - 6.37). This indicates the observed effect due to the design intervention by reducing the time taken for the visual task. Accordingly, the alternate hypotheses i.e., h_{1a} is accepted and null hypotheses h_{10} is rejected.

Satisfaction score: The satisfaction score for performing the task “with” and “without” the eye protector was recorded.

The results were significant at $p \leq 0.05$ (t value = 8.57). Accordingly, the alternate hypotheses i.e., h_{1a} is accepted and null hypotheses h_{10} is rejected.

Discomfort Glare measurement

The findings of the measurement of glare show that subjects who found the glare in the “disturbing” category (Table 6.4) without the eye protector was 49%. This reduced to 4% while wearing the eye protector. The glare in the “satisfactory” category without the eye protector was 12 %, which increased to 55% with the eye protector. This indicates the design of the eye protector has been able to reduce the discomfort glare experienced by the subjects.

Accordingly, the alternate hypotheses i.e., h_{2a} is accepted and null hypotheses h_{20} is rejected.

Table 6.4. Subjective rating of discomfort glare using the de Boer’s rating scale (n=49).

Rating scale	WITHOUT eye protector Figures indicate number of subjects	% of responses	WITH eye protector Figures indicate number of subjects	% of responses
Unbearable	2	4	0	0
Disturbing	24	49	2	4
Just Acceptable	17	35	15	31
Satisfactory	6	12	27	55
Unnoticeable	0	0	5	10

Usability measurement

The System Usability Scale (**Appendix-K**) was used to obtain the perceived usability of the eye protector. A total of fifty FSPV workers responded to the SUS questionnaire after using it for 5 days during working hours. The average SUS score came to 84.2.

Figure 6.27 represents the trend of SUS scores.

Figure 6.28 shows a solar PV engineer engaged in usability testing.

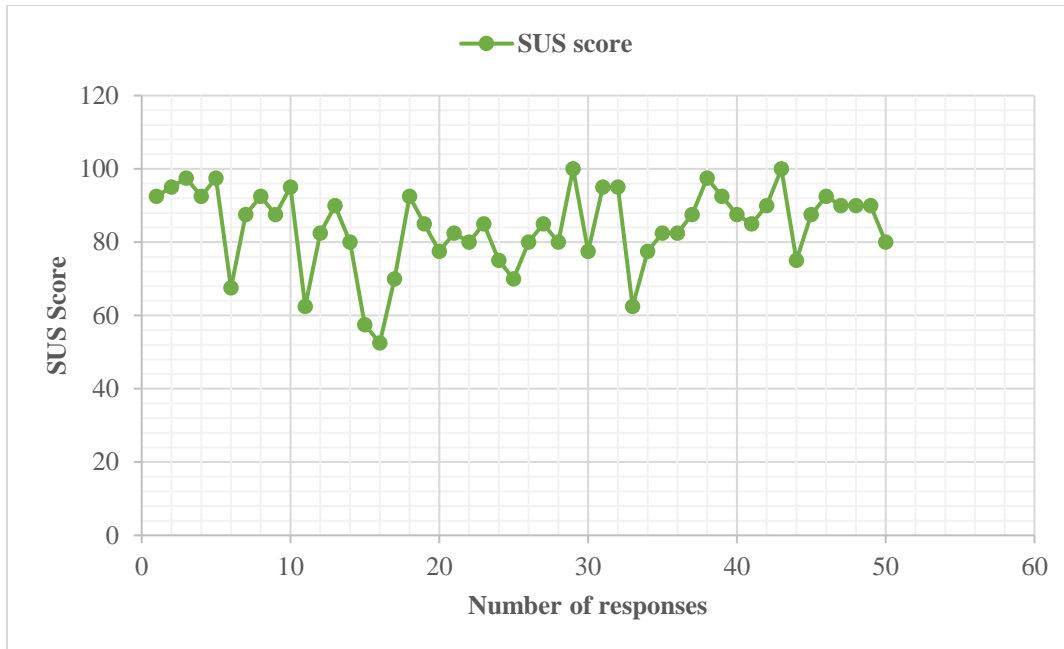


Figure 6.27. System Usability Score (SUS) after use of the anti-glare and anti-UVR eye protector by study participants

The product sheet for GlareSafe is provided at **Appendix-L**.



Figure 6.28. Usability testing of the anti-glare and anti-UVR eye protector (image: author)

6.10 Other concepts

In accordance with the research gaps and design opportunities, additional concepts were developed. The design concepts and the problems they are proposed to address are described below.

6.10.1 Concept 1

Maintenance board for preventing falls and reducing awkward postures

The maintenance of the FSPV equipment/plant is carried out by workers while positioned on the walkway floaters. In many layout designs, there is gap (vertical and horizontal) between the walkway floaters and the solar panels and associated components (Figure 6.29). As a result, the workers have to stretch themselves to reach confined places for working with components below the solar panels such as wires and connectors. Several concepts of a maintenance bridge are proposed as a job aid to assist the worker in several ways. The portable maintenance board can be fixed to the walkway floater to ensure stability and anchoring during use. The design is aimed at mitigating awkward postures, enabling better reach to confined equipment and to prevent falls into water.



Figure 6.29. Chances of falls in gaps in FSPV projects (image : author)

Carrying out maintenance in floating solar projects involves working on a constantly moving floating platform, handling loads (solar panels, floaters etc.), navigating gaps, reaching confined spaces and frequent squatting/kneeling. Non-neutral arm and hand postures and work in uncomfortable positions can lead to a host of work-related musculoskeletal disorders (WMSDs) such as neuritis, low back pain, impingement syndrome, bursitis, and repetitive strain injuries (Bridger, 2018). Moreover, there is also a need for storing of tools to prevent them from falling

into water. To resolve these issues, the design of a maintenance bridge is proposed. By placing the maintenance aid between two floaters, it acts as a bridge and assists the worker in reaching out to remotely located equipment, parts and undersides of solar panels aiding in convenient reach and visibility. The aid will also help in maintaining suitable postures while using power tools and prevent ulnar deviation. It provides a base for the worker for sitting/squatting/kneeling or lying down in a supine position (face upwards) when carrying out maintenance work. An added feature is the provision of a knee rest and handholds for supporting different postures. The design is expected to ease the drudgery and awkward postures involved in maintenance work. It will also aid in fall prevention and has a space for storing tools and first aid materials.

Selection of concepts: The concept scoring matrix (Ulrich & Eppinger, 2016) was used to shortlist the best concept of a maintenance board (Table 6.5). The concepts are shown at Figure 6.30.

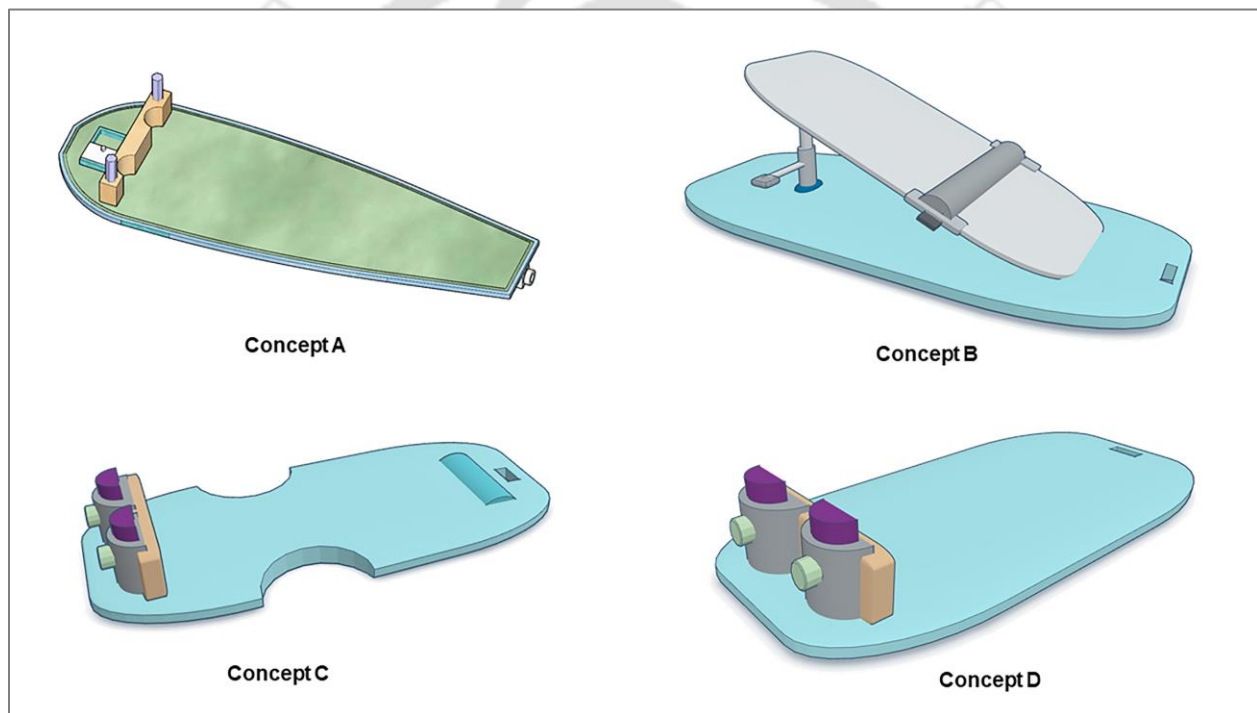


Figure 6.30. Concepts developed for maintenance board (image: author)

Selected concepts are shown at Figures 6.31 & 6.32.

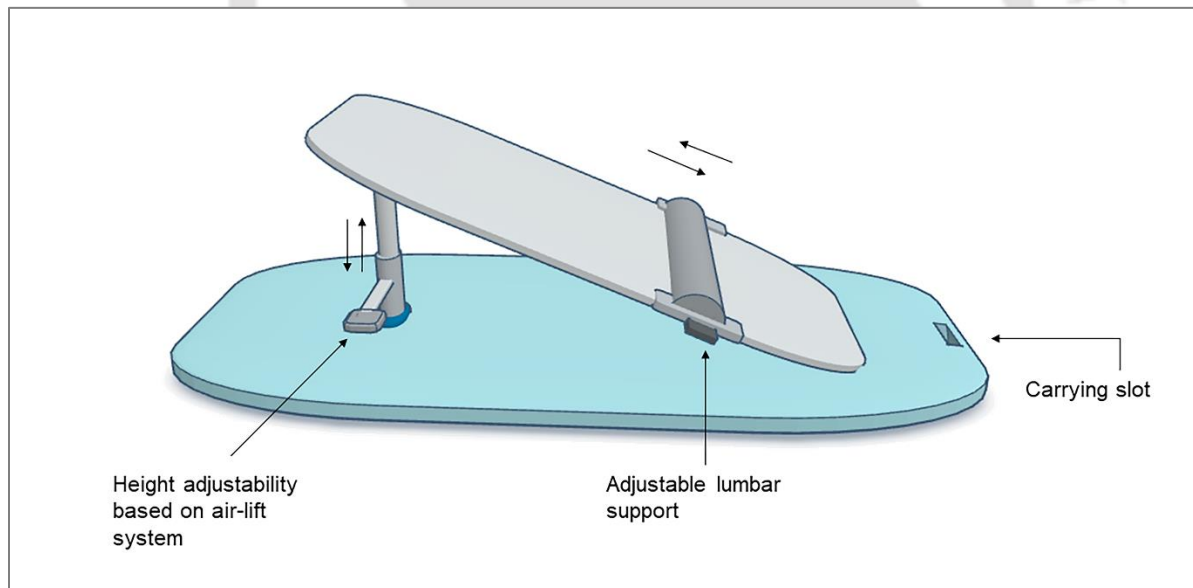
Table 6.5. Concept-Scoring Matrix (rating on a scale of 1-10) for Maintenance Board

		Concept A		Concept B		Concept C		Concept D	
<i>Selection Criteria</i>	<i>Weight</i>	<i>Rating</i>	<i>Weighted score</i>	<i>Rating</i>	<i>Weighted score</i>	<i>Rating</i>	<i>Weighted score</i>	<i>Rating</i>	<i>Weighted score</i>
Easy and Safe to Use (Usability)	20								
Lightweight	5	4	20	8	40	4	20	3	15
Portable	5	4	20	7	35	3	15	2	10
Comfortable grip/handling	5	2	10	6	30	2	10	3	15
Insulated	5	2	10	8	40	1	5	1	5
Ergonomics	30								
Not slippery when wet	5	3	15	8	40	3	15	3	15
Provision for lumbar support	5	1	5	10	50	1	5	1	5
Can be carried in one hand	5	2	10	2	10	2	10	4	20
Chamfered edges	5	1	5	7	35	2	10	2	10
Prevents non-neutral postures	10	2	20	7	70	3	30	1	10
Manufacturability	10								
Low-cost materials	5	4	20	8	40	8	40	2	10
Low complexity	5	3	15	8	40	5	25	3	15
Durability	10								
Material can withstand adverse weather	5	1	5	7	35	2	10	1	5
Ability to support weight of the worker	5	2	10	6	30	5	25	2	10
Added features	10								
Height adjustability	5	1	5	8	40	8	40	1	5
Elbow rest/lumbar support	5	1	5	9	45	10	50	2	5
Requires little maintenance	10								

Can be easily stored	5	3	15	5	25	2	10	5	25
Easy to clean	5	2	10	4	20	5	25	2	10
Aesthetics	10								
Looks	5	6	30	6	30	5	25	3	15
Colour	5	7	35	7	35	3	15	2	10
Total Score			265		680		385		215
Rank									

Concept 1-B

Concept 1-B provides a base for the worker for sitting/squatting/kneeling or lying down in a supine position (face upwards) when carrying out maintenance work. This concept has a lumbar support that can be moved along the base so as accommodate anthropometric as well as postural needs of various users. The base is adjustable with provision of an “air lift” mechanism which is expected to assist in height adjustability to enable workers in navigating vertical gaps. The design is expected to ease the drudgery and awkward postures involved in maintenance work.



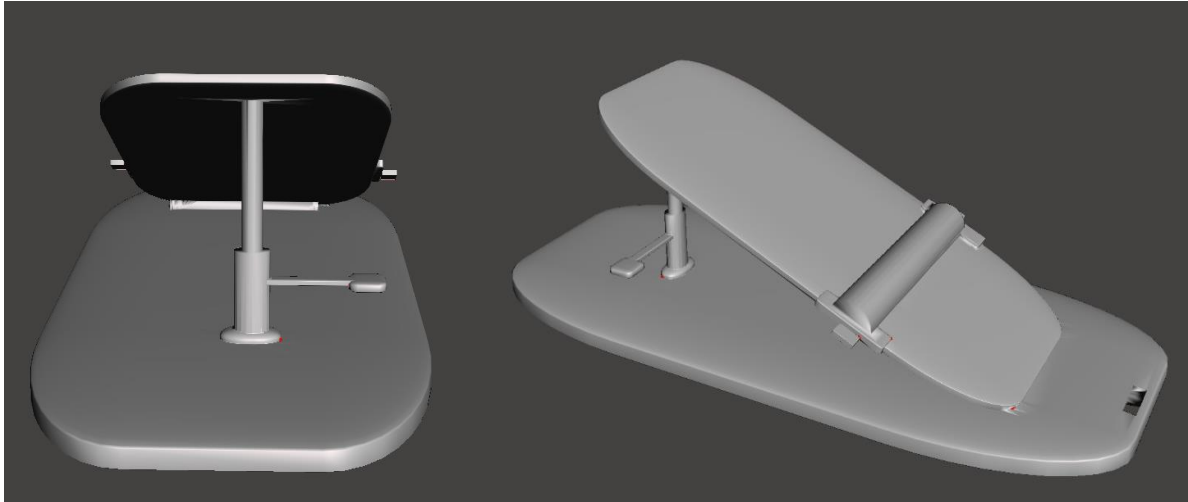


Figure 6.31. CAD models of maintenance board concept 1-B

Concept 1-C

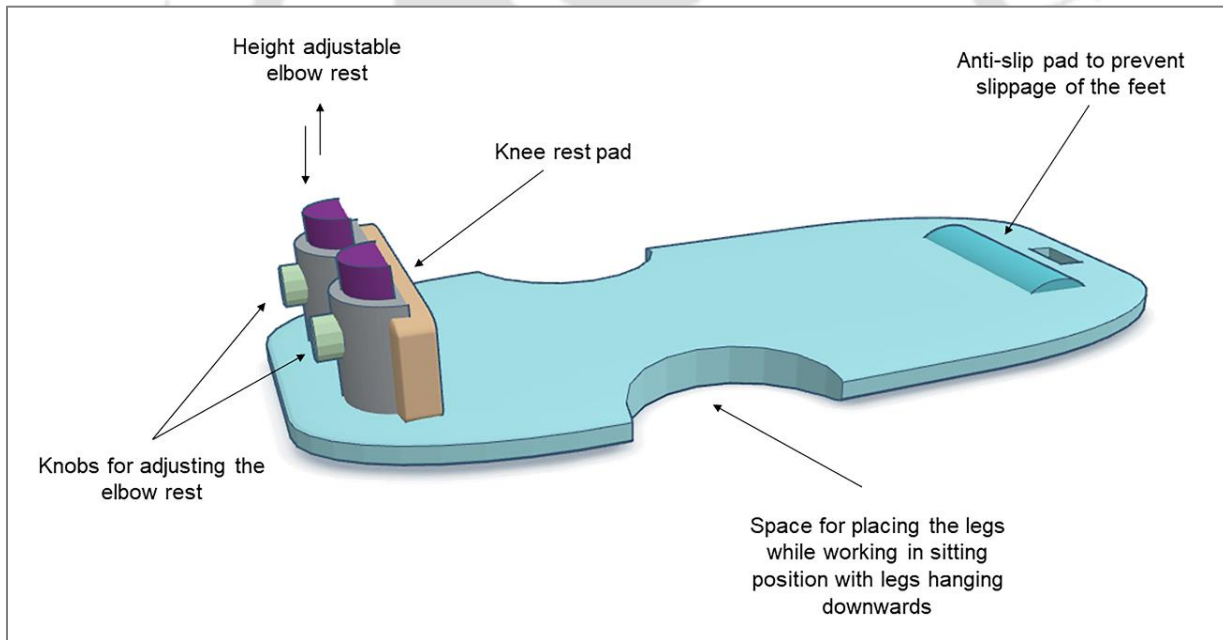


Figure 6.32. CAD model of maintenance board concept-1C (image: author)

The additional utilities of the board include a set of handholds for supporting awkward postures (while reaching out to remotely located spaces), a knee rest and a space for storing tools so that they do not fall into water.

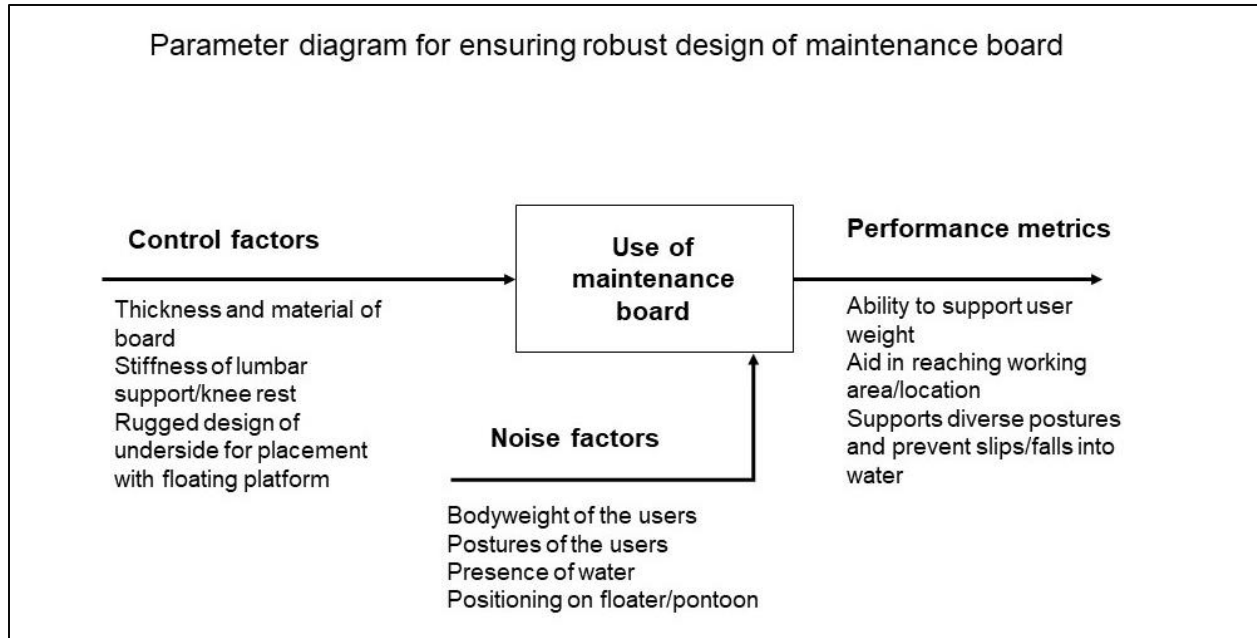


Figure 6.33. Parameter (p) diagram for ensuring robust design of maintenance board (graphic: author)

6.10.2 Concept 2

Handrails (floating fence) with resting area and tool storage slots

In the existing designs of FSPV layouts, the workers use walkways to install components and carry out maintenance work. The periphery of the FSPV project is unguarded and workers are prone to falls into the water body. Falls into water may result in hypothermia and even death due to drowning. The proposed design (Figure 6.34) involves design of a guardrail (floating fence) along the water interface and redesign of the walkway floaters to serve the dual purpose of toe/knee boards for fall prevention and prevent the loss of tools into water through the provision of tool slots. In addition, the provision of backrest is designed to serve as resting areas where workers can take short breaks. The floating fence is proposed to be made of High-Density Polyethylene (HDPE) material.

Selection of concepts: The concept scoring matrix (Ulrich & Eppinger, 2016) was used to shortlist the best concept of the floating fence (Table 6.6). The concepts are shown at Figure 6.34.

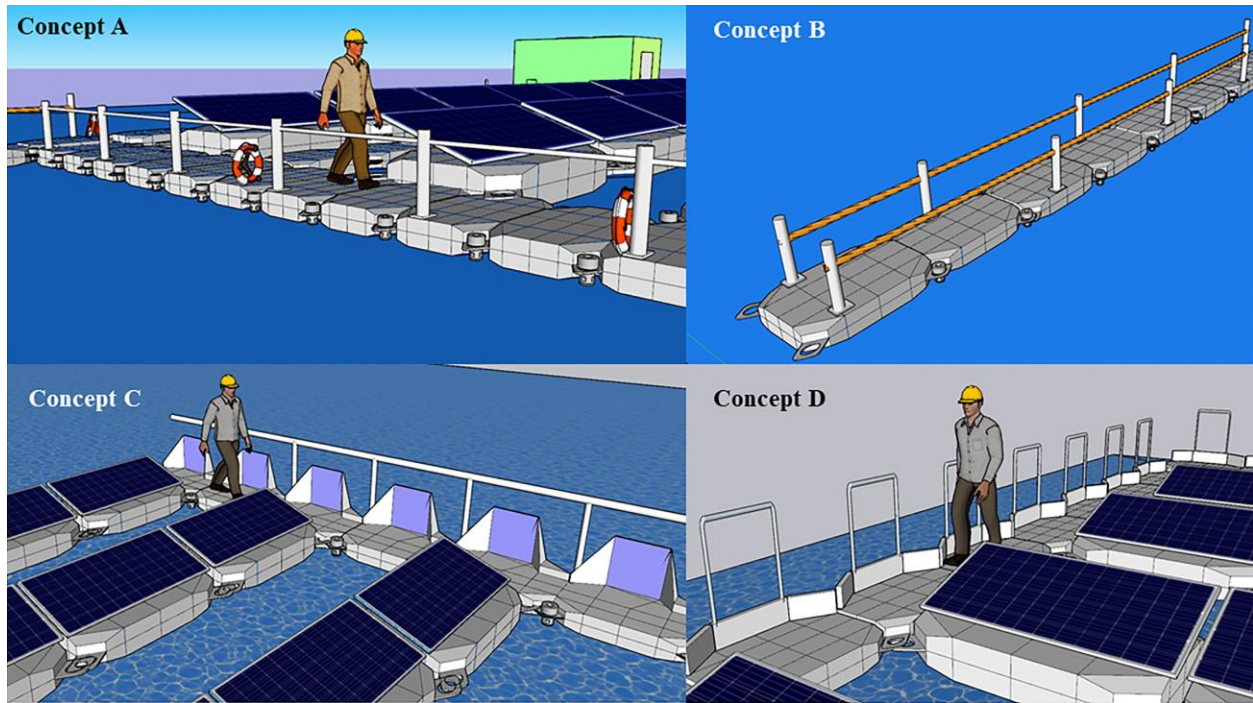


Figure 6.34. Concepts developed for floating fence (image: author)

Table 6.6. Concept-Scoring Matrix (rating on a scale of 1-10) - Floating Fence (Ulrich & Eppinger, 2016)

Selection Criteria	Weight	Concept A		Concept B		Concept C		Concept D	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Safe to Use (Safety & Usability)	25								
Comfortable grip	10	3	30	2	20	8	80	3	30
Insulated	5	2	10	2	10	6	30	2	10
Easy assembly	10	3	30	3	30	5	50	3	30
Ergonomics	30								
Back rest for sitting	10	1	10	5	50	10	100	1	10
Space for tool storage	5	1	05	2	10	7	35	2	10
Chamfered edges	5	5	25	7	25	8	40	5	25

Prevents falls	10	2	20	6	60	8	80	6	60
Manufacturability	10								
Low-cost materials	5	5	25	3	15	6	30	2	10
Low complexity	5	5	25	5	25	6	30	3	15
Durability	15								
Withstand adverse weather	5	8	40	5	25	8	25	5	25
Durable over many years	10	7	70	5	50	6	40	5	50
Requires little maintenance	10								
Easily to replace components	5	5	25	5	25	7	35	5	25
Easy to clean	5	3	15	4	20	8	40	3	15
Aesthetics	10								
Looks	5	5	25	6	30	9	45	5	25
Colour	5	5	25	4	20	6	30	3	15
Total Score			380		415		690		345
Rank									

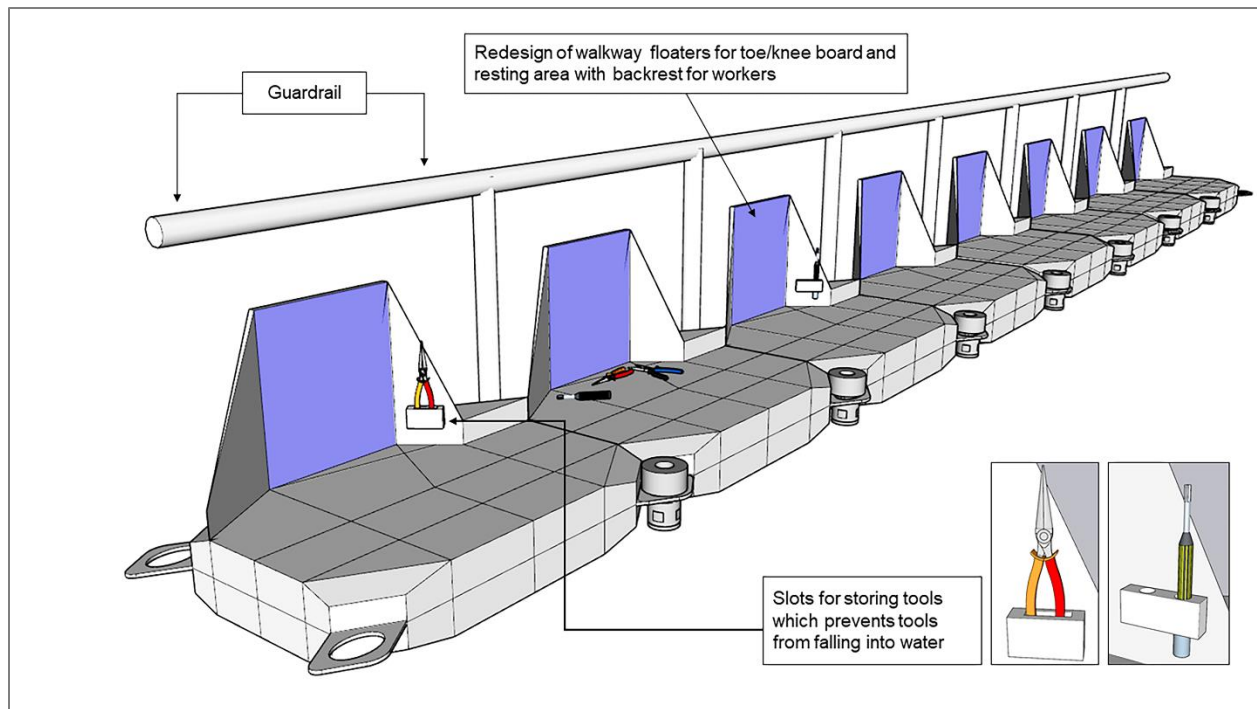


Figure 6.35. CAD model for concept (Concept C at Figure 6.34) of floating fence with provision of backrest and tool storage (image: author)

The guardrail or use of a floating fence (Figure 6.35 above) is designed to prevent falls into water. Existing knowledge in the specific areas of handrail design can be used as inputs for arriving at an optimum design. Durability of the handrail material must also be a significant consideration because of its exposure to the outdoor environment in order to prevent entropy and failure in the long term since these projects typically have a lifespan of 25 years. Falls into water can have serious consequences in terms of both direct and indirect cost and may even result in fatalities. Hypothermia is a possible health effect. Rescue and recovery should also be important considerations for mitigation if the event i.e., falls into water does take place. However, we argue that even if manufacturing cost would escalate on account of adding a floating fence, its cost benefit would far outpace the additional investment. Working on water also entails challenges such as tool loss (accidental dropping of tools into water) which adds to the cost of the project. An added feature of the guardrail design is the provision for tool slots which will address the challenge. Provision of tool lanyards (one end fixed with the body of the worker) will also prevent them from falling into water. Workers have to spend long hours in an outdoor environment on a FSPV project away from land. Adequate space for resting during the work rest cycle is essential. The proposed design provides a backrest for the workers. Suitable anthropometric and other design considerations must be incorporated for greater usability. Figure 6.36 shows a FSPV worker walking along the proposed floating fence.

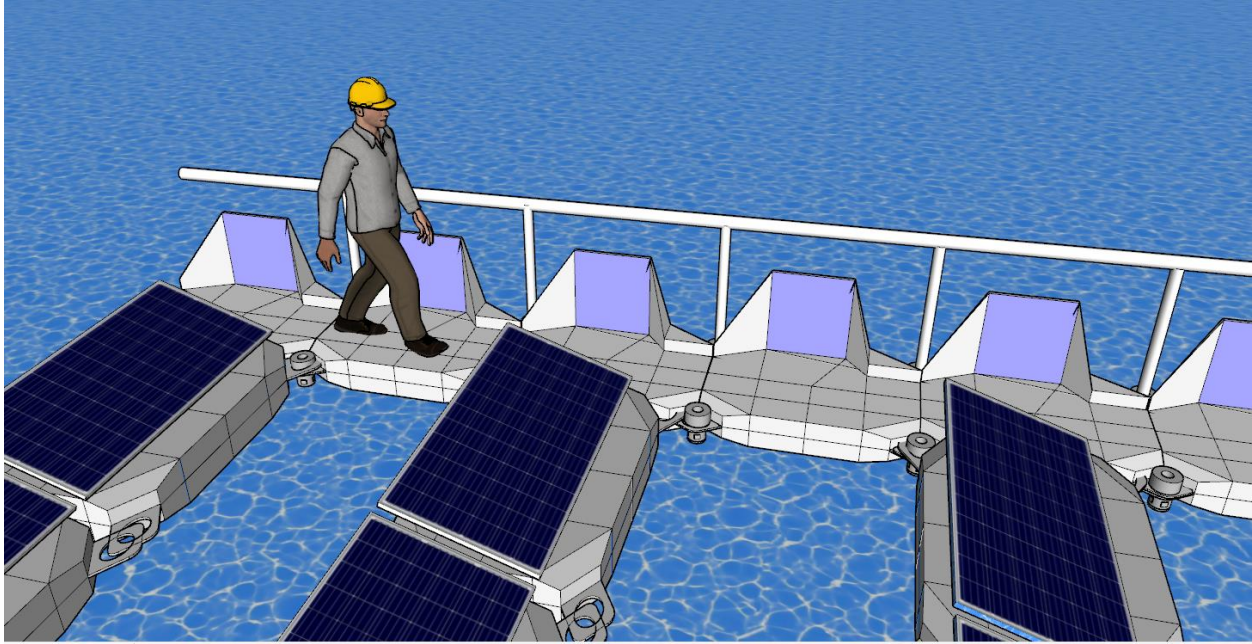


Figure 6.36. CAD model of a floating fence (image source: author)

The parameter diagram for the floating fence is shown at Figure 6.37.

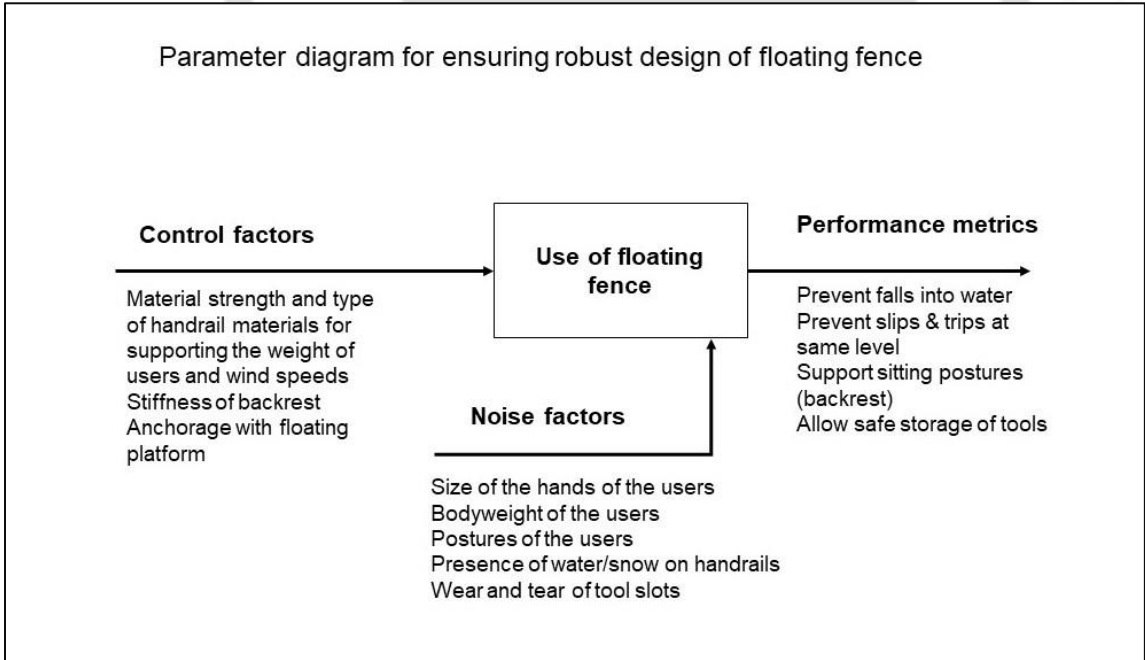


Figure 6.37. Parameter (p) diagram for ensuring robust design of the floating fence. (graphic: author)

6.10.3 Concept 3

Redesign of walkway floater surface for preventing slips, trips, and falls

FSPV workers are required to walk (often carrying heavy loads) on a floating platform (also known as pontoons) during installation and maintenance of FSPV projects. During walking (even running during emergency situations) they are faced with a dual challenge of maintaining stability (on a floating platform) and are prone to slipping and falling on the walkways, the surfaces of which are flat. In addition, the presence of water on the walking surface due to an aquatic environment adds to the unsafe situation. Sufficient Coefficient of Friction (CoF) during the gait cycle (Figure 6.38) is vital to prevent slips and falls, the prevention of which is an important design challenge. The design shown at Figure 6.40 proposes the redesign of the floater/pontoon surface so as to prevent slips by increasing the coefficient of friction and also ensure balance of the worker (with or without load carriage). The risers at both sides of the floaters forces the user(s) to walk along the central line and the treads along the walking surface provides the friction required to mitigate slip/fall events.

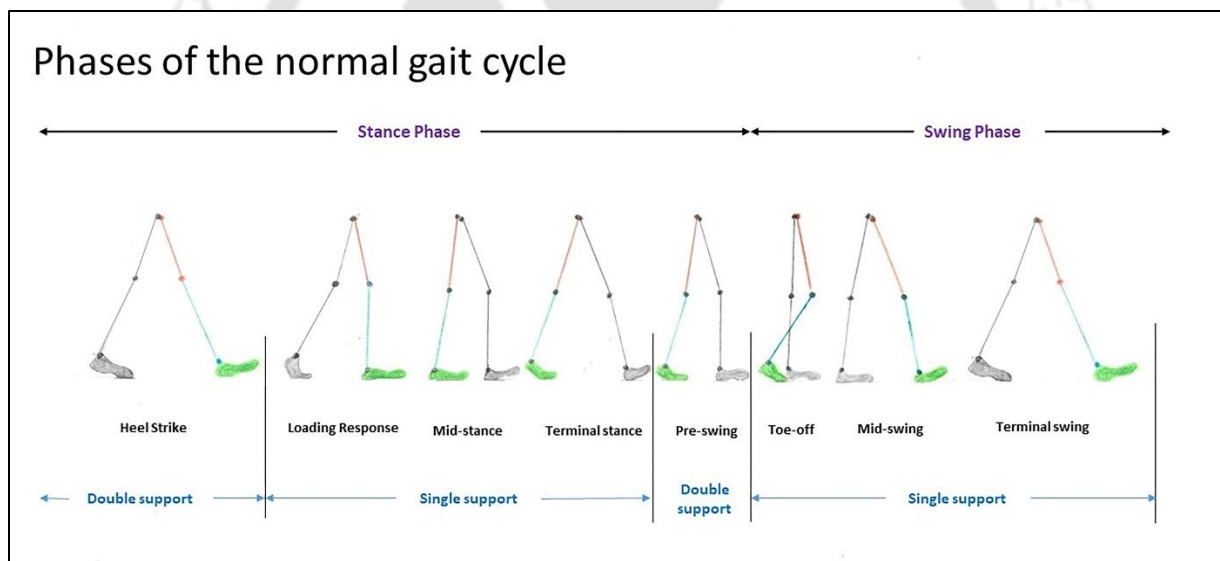


Figure 6.38. Phases of the normal gait cycle (Redrawn from Perry, 1992).

Selection of concepts: The concept scoring matrix (Ulrich & Eppinger, 2016) was used to shortlist the best concept of redesigned floater (Table 6.7). All developed concepts are shown at Figure 6.39.

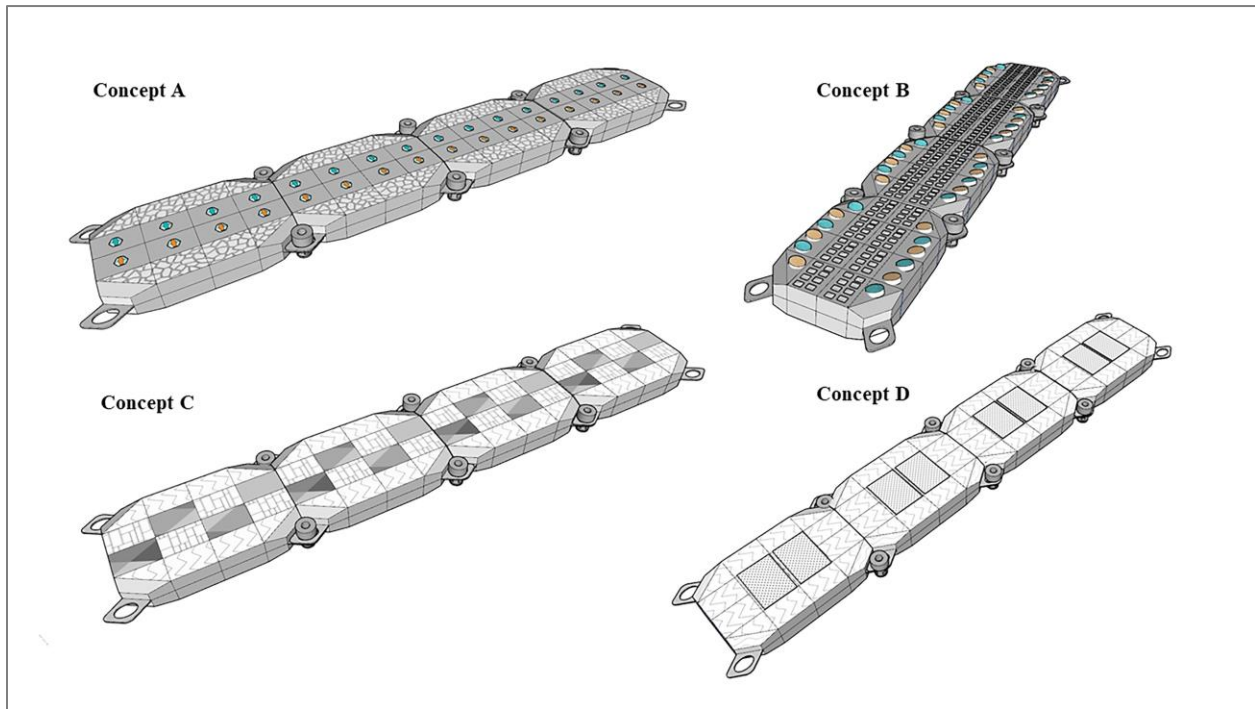


Figure 6.39. Concepts developed for floating fence (image: author)

Table 6.7. Concept-Scoring Matrix (rating on a scale of 1-10) - Floater Redesign (Ulrich & Eppinger, 2016)

Selection Criteria	Weight	Concept A		Concept B		Concept C		Concept D	
		Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Easy and Safe to Use (Safety & Usability)	30								
Easy to install	10	6	60	8	80	3	30	2	20
Enables better coefficient of friction	10	5	50	6	60	2	20	3	30
Easy store & transport	10	4	40	7	70	1	10	2	20

Ergonomics	30								
Compatible with human gait	20	4	80	6	120	3	60	1	20
Prevents non-neutral postures	10	3	30	8	80	2	20	2	20
Manufacturability	10								
Low-cost materials	5	7	35	7	35	5	25	2	10
Low complexity	5	7	35	8	40	3	15	3	15
Durability	10								
Withstand adverse weather	5	8	40	9	45	5	25	5	25
Low wear & tear	5	7	35	8	40	4	20	5	25
Requires little maintenance	10								
Easy to replace	5	5	25	5	25	5	25	5	25
Easy to clean	5	4	20	4	20	5	25	5	25
Aesthetics	10								
Looks	5	6	30	7	35	5	25	4	20
Colour	5	7	35	7	35	3	15	3	15
Total Score			515		685		315		270
Rank									

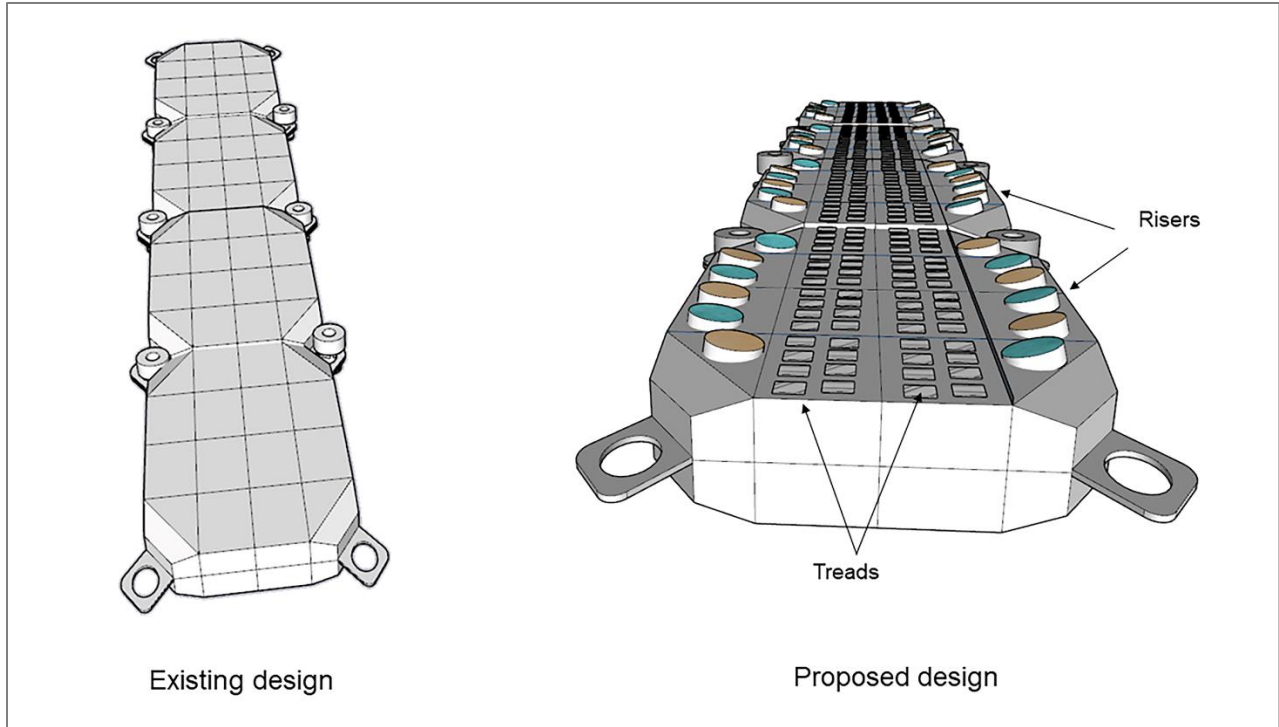


Figure 6.40. CAD models of existing and proposed design (Concept B of Table 6.7) of the floaters related to FSPV projects (image: author)

The “p” diagram for robust redesign of floaters is shown at Figure 6.41.

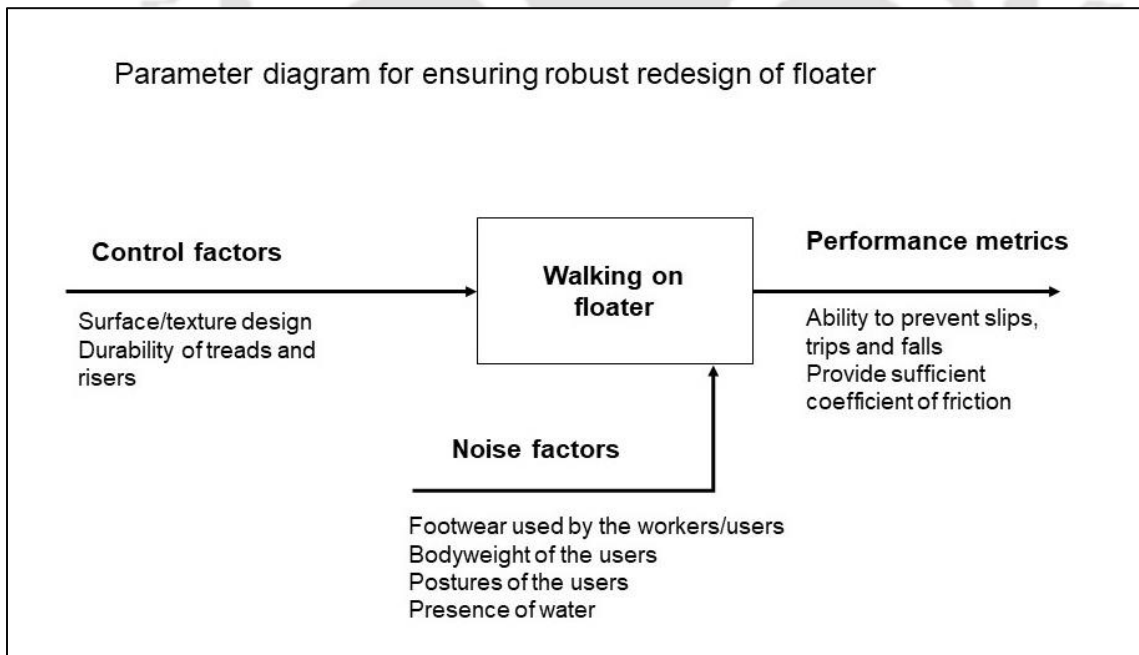


Figure 6.41. Parameter (p) diagram for ensuring robust design of the redesigned floater. (graphic: author)

6.10.4 Concept 4

Maintenance mirror

A key problem faced by the FSPV workers (also maintenance engineers) engaged in inspection and maintenance is the limitation of visibility of the undersides of the solar panels. Electrical connections, wiring, condition of solar panel frames and nuts/bolts are some of the aspects that need to be monitored as a part of preventive maintenance. To aid in visibility, workers have to resort to awkward postures which can not only lead to musculoskeletal disorders but also chances of falling into water. These postures are attained by the workers for prolonged periods which can specifically affect the neck and shoulders (Bridger,2018). Moreover, the inspection process is likely to affect the viewing angles and prevent comfortable vision even with constrained postures. Some of the postures are represented at Figure 6.42.

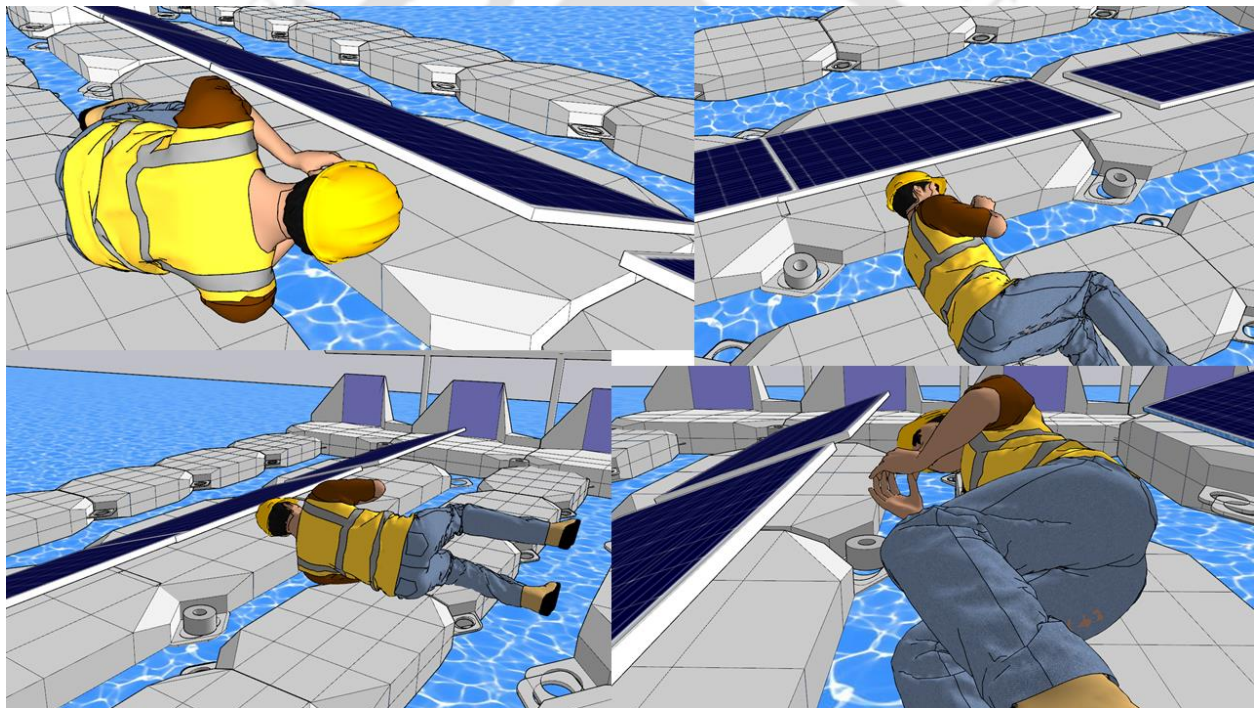


Figure 6.42. Maintenance work involves awkward postures and difficulties in reaching confined spaces. (graphic: author)

To mitigate these practical problems, the design of a maintenance mirror is proposed. The mirror would allow the inspection of the under sides of the solar panels in neutral postures and provide a wide range of viewing angles. Several concepts were developed. The most suitable concepts were selected based on the concept scoring matrix. The scoring matrix is represented below in Table 6.8.

The developed concepts are shown at Figure 6.43.



Figure 6.43. Concepts developed for maintenance mirror (image: author)

Table 6.8. Concept-Scoring Matrix (rating on a scale of 1-10) - Maintenance Mirror (Ulrich & Eppinger, 2016)

Selection Criteria	Concept A			Concept B	
	Weight	Rating	Weighted score	Rating	Weighted score
Easy and Safe to Use (Safety & Usability)	25				
Lightweight	5	8	40	2	10
Portable	5	7	35	2	10
Comfortable grip	5	7	35	3	15
Insulated	5	7	35	4	20
Easy storage	5	10	50	1	05

Ergonomics	30				
Inspection mirror allows viewing at all angles	10	8	80	5	50
Can be carried in one hand	5	6	30	2	10
Chamfered edges	5	7	35	7	35
Prevents non-neutral postures	10	9	90	6	60
Manufacturability	10				
Low-cost materials	5	7	35	7	35
Low complexity	5	7	35	2	10
Durability	15				
Withstand adverse weather	5	8	40	5	25
Rotating ball and mirror work for long periods	10	7	70	5	50
Requires little maintenance	10				
Easily available spare parts	5	5	25	5	25
Easy to clean	5	2	10	4	10
Aesthetics	10				
Looks	5	6	30	6	30
Colour	5	7	35	7	35
Total Score			710		435
Rank					

The proposed design concept and its mechanism of functioning is represented below at Figure 6.44.

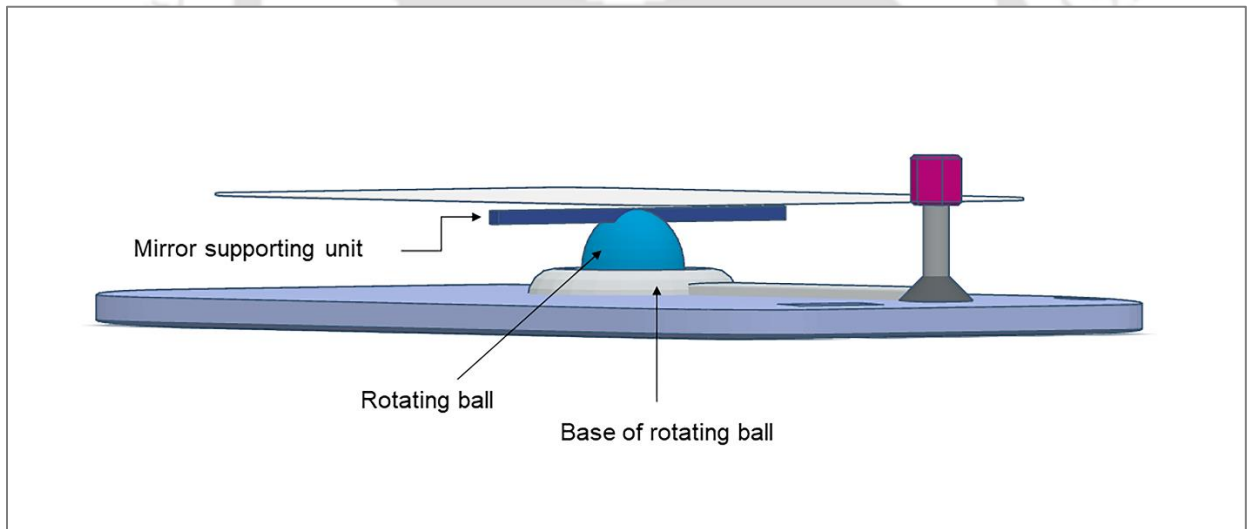
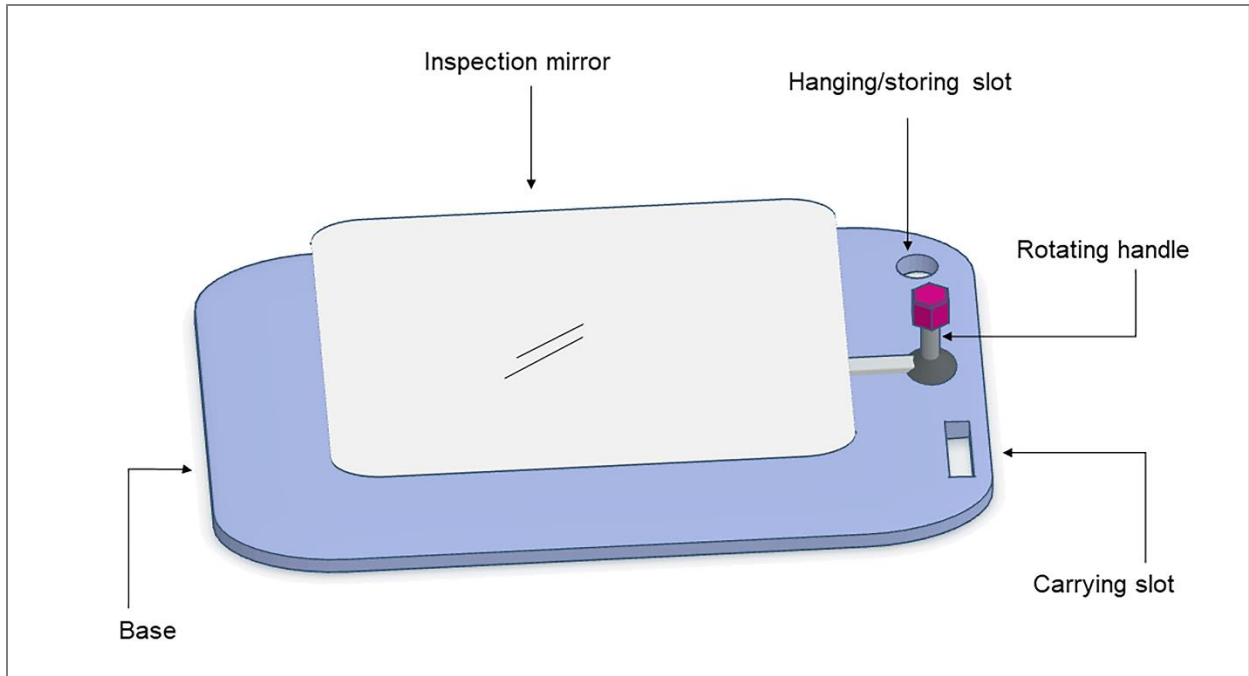


Figure 6.44. CAD models showing top and side view of maintenance mirror concept (Concept A of Table 6.8)

Robust design

The parameter “p” diagram for the maintenance mirror for an effective process of inspection is represented below:

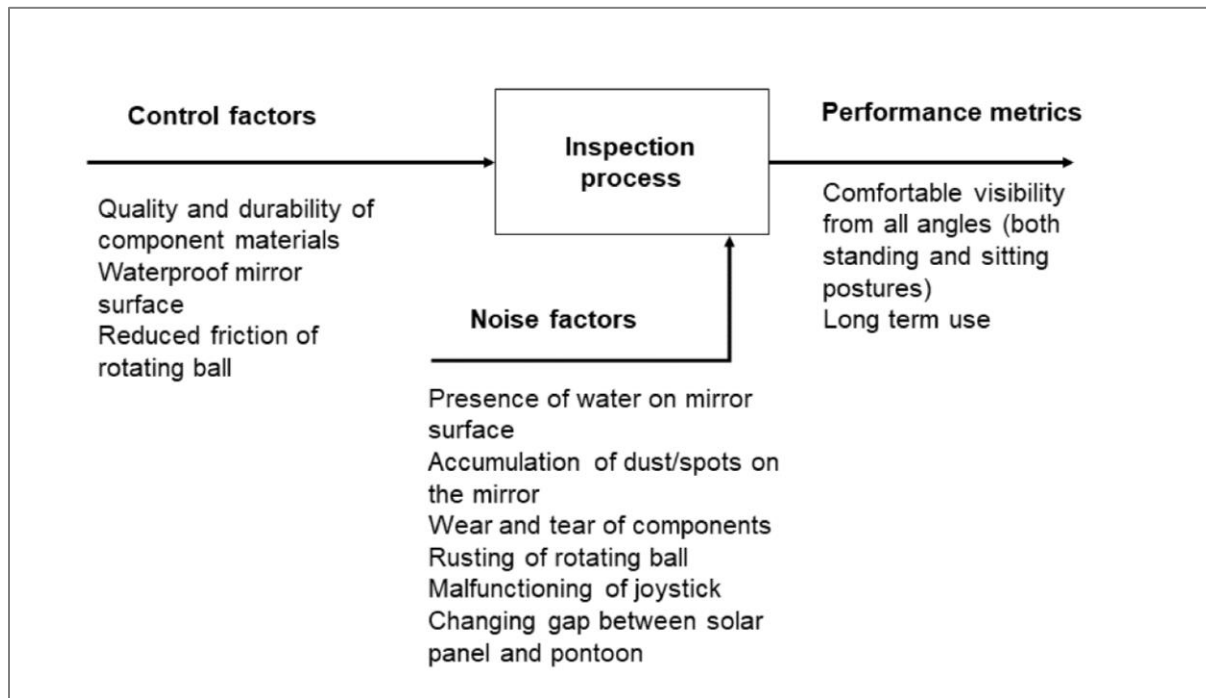


Figure 6.45. Parameter (p) diagram for ensuring robust design of the maintenance mirror

6.11 Validation of design concepts

For the validation of the proposed design concepts, a questionnaire (**Appendix-M**) was constructed to collect responses from engineers in the solar photovoltaic industry. The participants were requested to rate each design on the perceived benefits of the design concepts on certain parameters. The parameters and their importance in accordance with the present study and the FSPV workplace were explained to the participants before recording the responses.

The parameters include the following:

- a) Ability to mitigate the OSH risks
- b) Addresses ergonomics issues
- c) Manufacturability
- d) Cost benefits
- e) Improvement in productivity

Based on a Likert scale, responses were divided into five choices ranging from strongly agree to strongly disagree. The respondents were asked to compare the existing design/working situation with the proposed design intervention on the evaluation parameters. The qualitative responses were

converted into a quantitative scale where strongly agree = 5, agree = 4, neutral= 3, disagree = 2 and, strongly disagree = 1.

The questionnaire was sent to 125 engineers engaged in various organizations executing solar photovoltaic projects in India. A total of 73 engineers completed the questionnaire. The participants had a minimum diploma/degree in engineering. The average work experience is 15.56 years. Ninety-six percent of the participants are male while four percent are female.

Paired two-tailed test was carried at significant level of 0.05 using the scores related to the existing design and the proposed concepts/interventions. A summary of the statistical analysis (using SPSS v.20) is represented at Table 6.9.



Figure 6.46. A participant engaged in design validation exercise (image: authors)

Table 6.9. Summary of the statistical tests for various concepts based on evaluation parameters

(Significance level, $p \leq 0.05$). Figures indicate the t-value. $n = 73$.

Design concept	Risk mitigation ability	Addresses ergonomics issues	Manufacturability	Cost benefits	Improvement in productivity
Anti-glare and UVR eye protector	21.42*	14.98*	10.75*	15.08*	18.25*
Maintenance board	20.26*	13.97*	7.75*	15.55*	15.76*

Guardrail (floating fence)	16.68*	11.57*	4.27*	16.89*	11.12*
Redesign of walkway floaters	14.65*	10.48*	4.70*	13.73*	11.92*
Maintenance mirror	20.48*	14.21*	10.22*	12.79*	18.25*

*Significant differences between the existing work situation and the proposed designs were found as per the outcomes of the statistical analysis.

6.12 Discussion and conclusion

This chapter covered the different methods adopted to elicit design concepts for the safety and health of floating solar workers engaged in installation and maintenance. The use of codesign, hierarchy of controls (PtD) and bow-tie analysis resulted in several diverse design concepts which comprehensively covers different options that can be implemented in the FSPV sector. For each kind of OSH risk, the design concepts were further screened based on various parameters and some design concepts are proposed.

The OSH risk of discomfort glare which has the potential of damaging the vision of the workers was taken up as a specific area of intervention requiring immediate attention. Out of many concepts and considering the contextual requirements of the users, a design concept of an anti-glare and anti UV eye protector is proposed. The design was validated through several methods and significant differences were found between the existing situation and task performance with the use of the proposed design.

Several other design concepts are also proposed in this chapter. These designs were validated through a self-reporting questionnaire survey where responses from engineers in the solar photovoltaic industry were obtained. Proposed designed were preferred over existing designs/situations on various evaluation parameters.

Chapter 7: Discussion and Conclusion



Abstract

This chapter discusses and analyses the overall findings of the study in accordance with the research questions, aims and objectives.

The fulfillment of objectives, strengths, novelties, contribution to the existing body of knowledge, limitations, and future scope is outlined.

7. Discussion

This thesis revolves around identifying the emerging OSH issues in the Floating Solar PV sector within the renewable energy industry and developing design interventions from an ergonomics design perspective for risk mitigation for those risks that fall in the high and very high categories. The motivation for selecting this area of research includes recognising the OSH issues and addressing them in the early phase before the risks start having deleterious effects and become uncontrollable. This is important from the perspective of the huge growth potential of FSPV projects globally where a large number of workers (mostly fixed term and contractual) are being engaged. Risk mitigation is also critical to avoid direct, and indirect costs associated with workplace incidents, injuries, and accidents as well as to ensure that Sustainable Development Goals (SDGs) 3,7,8 and 13 are pursued in the right earnest. Since there is very little or no research in this area, this area was selected for the study.

7.1 Salient Findings

- Floating solar PV projects are seeing a fast growth on account of efficiency, land neutrality, durability of components, conservation of water, economic viability, can be combined with hydro projects for co-generation and promotes sustainability.
- Several OSH risk factors are associated with installation and maintenance of floating solar photovoltaics projects. Those in the very high and high categories include falling into water, heat stress, electrocution, solar radiation, and slips on the floating platform. Discomfort glare was also found to be a severe risk.
- Risk perceptions towards OSH risk factors vary from country to country and have a cross-cultural dimension.
- Users/future users such as FSPV workers and engineers can be an important source of novel design concepts (through the use of Co-design method) for risk mitigation.
- Ergonomic design interventions have a significant effect in reducing the deleterious effect of various occupational risks in FSPV projects.
- Compliance through Design (CtD) can be used as a framework for addressing the problem of PPE avoidance across several industries.

7.2 Addressing research gaps and fulfilment of objectives

Objective 1: *To explore various features of FSPV projects and identify the emerging risks (occupational, environmental, psychosocial etc.) being faced by the workers engaged in FSPV installation and maintenance including existence of training modules and OSH standards.*

Objective 2: *To explore the existing design approaches for mitigation of OSH issues in FSPV installation and maintenance.*

Literature review and state of the art

The research process began with a comprehensive literature review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology in accordance with the research questions RQ1, RQ2, RQ3 and RQ4. The findings of the literature are detailed in Chapter 2. Major findings of the literature review indicate that FSPV projects are new and emerging workplaces which are growing in number due to non-requirement of land (Sahu et al., 2016) and higher efficiency (Goswami et al., 2019) compared to ground-mounted solar PV projects. Other reasons including water savings (Mittal et al., 2017), reduction in evaporation (Azami et al., 2017), can be combined with hydro plants (Cazzaniga et al., 2019) and reduction in carbon footprint (Trapani and Millar, 2013).

Work in solar PV projects involve several kinds of diverse OSH risks. There is little or no studies in the FSPV sector to address these issues. The OSH risk factors identified in solar photovoltaic projects (roof-top & ground mounted) in the review include heat stress (Kamenopoulos and Tsoutsos, 2015, Samaniego- Rascón et al., 2019), electrocution (Wybo, 2013, White and Doherty, 2017), ergonomics risks (Bakhiyi et al., 2014), fire (Dhere and Shiradkar, 2012, Falvo and Capparella, 2015), hazardous substances (Fthenakis and Moskowitz, 2000, Aman et al., 2015), psychosocial risks (Fernandez et al, 2017) and adverse weather (Kamenopoulos and Tsoutsos, 2015). Significant skill gaps (Brooks and Urmee, 2016) and lack of OSH standards specific to FSPV projects were identified.

An important objective of this thesis is the development of interventions for risk mitigation from an ergonomics design perspective. Design as a strategy for addressing risks is well established in literature. The review process revealed that most design interventions and efforts revolved around improving technical efficiency (Kim et al., 2017, Dai et al., 2020), improved operation and maintenance (Hernández- Callejo et al., 2019), reducing manufacturing cost (Cazzaniga et al., 2018), roof slope design for roof-top solar installations (Li et al., 2020), ecological impact of solar installations (Scognamiglio, 2016), design guidelines for installation and maintenance (Spertino and Corona, 2013) and visual aesthetics of solar panels (Bao et al., 2017). Amongst the reviewed papers, two studies use a design approach for addressing risks. The first study on a FSPV project proposes use of grounding electrodes to protect against instances of electrocution (Bhang et al., 2018). The second study (Ho et al, 2020) developed a Prevention through Design (PtD) protocol for small scale roof-top solar installations. The output of the comprehensive literature review resulted in several research gaps that are proposed to be addressed through design interventions for safety in the FSPV sector. Chapter 2 also proposes a strategy to implement design interventions and design opportunities considering different man-machine interfaces.

The findings of the literature review have been published in a peer reviewed journal as follows:

Sen, A., Mohankar, A. S., Khamaj, A., & Karmakar, S. (2021). Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals. *Risk Management and Healthcare Policy*, Volume 14(May), 1939–1957. <https://doi.org/10.2147/RMHP.S304732> [SCIE & Scopus indexed; Q2 Journal]

Objective 3: *To investigate and measure the specific nature of problems being faced by the workers due to the risks through field studies.*

Exploratory studies

FSPV projects being new and emerging installations for the generation of electricity, preliminary exploratory studies were chosen as an approach to understanding the workflow, training history, OSH aspects and design opportunities from the perspectives of different stakeholders associated with FSPV projects. Exploratory studies at two locations (very few projects were under execution during 2019) in India where FSPV installation and/or maintenance were underway were carried out. Chapter 3 contains the findings of the exploratory studies. Project managers responded to an unstructured questionnaire and identified several contextual OSH risk factors such as instability of the floating structure, possibilities of falls in water, electrocution, adverse environmental conditions, and ergonomics risks. Suggested interventions include standards for work procedures, skilling programmes, design standards, handrails, redesign of walkway platform, ergonomics design of solar photovoltaic panels, customized PPE, tools, anti-skid footwear and changes in work organization. An important insight generated from the studies was that hazards in FSPV projects were distinctly different from other forms of solar PV projects. The exploratory studies helped in “defining the actual problems” associated with FSPV projects and is a maiden effort in the FSPV sector.

The findings of the field study have been published in conference proceedings as follows:

Sen, A., & Karmakar, S. (2021). Exploring the OSH Scenario in Floating Solar PV Projects in India and Opportunities for Ergonomics Design Interventions. In: A. Chakrabarti et al. (eds.), *Design for Tomorrow—Volume 1, Smart Innovation, Systems and Technologies*. International Conference on Research into Design, IIT Bombay, India, 7-10 January 2021, (Vol 221, pp. 245-255). Springer, Singapore. https://doi.org/10.1007/978-981-16-0041-8_21

Risk perception studies

In order to understand the risk perception towards various occupational risk factors, it was decided to seek responses from two important stakeholders associated with FSPV projects. These stakeholders include safety managers and FSPV workers who are exposed to the risks during installation and maintenance. This was based on the purpose of collecting inputs since they are important considerations for contextually relevant design interventions. OSH risk perception was considered as a way of understanding the degree of risk involved in various human-machine and environment interfaces so that prioritization of risks can be carried out and divided into immediate,

medium term and long-term mitigation measures. Chapter 4 covers the studies seeking and summarizing responses from safety managers and FSPV workers.

Since no such studies have been carried out in the past in the FSPV sector on risk perception, a questionnaire (on a five-point Likert scale) was developed. In addition, another questionnaire was also designed to understand the socio-demographic profiles of FSPV workers. This is a first-of-its-kind effort to capture both risk perception and socio-demographic data/information in this emerging sector.

Safety Managers

Safety managers (n=30) from ten organizations from India, perceived unstable floating platform, slips/trips, falling into water, working alone and skill gaps/training as risks in the very high and high categories. Some of the major concerns expressed by the safety managers and intervention opportunities include:

- Paucity of engineering controls which may be improved through more robustness of the floating platform (weight bearing capacity, durability, material quality etc., additional structures for safety of workers/engineers and ensuring fail-safe design).
- Poor conditions of work and hygiene factors can be addressed through occupational health interventions and workplace/work redesign.
- Lack of Standard Operating Procedures which needs to be developed and introduced across all projects. SOPs enable structured work and acts as a risk management tool.
- Need for understanding level of water surrounding the FSPV project (bathymetry), intensity/flow of waves and weather conditions so as to design technical specifications for FSPV project, safe working hours and provision of safety resources.

Safety manager suggestions include the introduction of safety policies, training, consideration of long-term entropy of FSPV components (effects of corrosion etc.), reducing manual material handling (MMH), screening of workers with fear of water and night work avoidance. Design interventions opined include design/redesign of PPE, safety signage, design of job aids/tools, design of rest shelters and redesign of work organization practices.

The findings of the study been published in conference proceedings as follows:

Sen, A., Karmakar, S. (2022). OSH Risk Perception of Safety Managers and Scope for Ergonomics Design Interventions in Floating Solar Photovoltaic Projects. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) Ergonomics for Design and Innovation. HWWE 2021. Lecture Notes in Networks and Systems, vol 391. Springer, Cham. https://doi.org/10.1007/978-3-030-94277-9_74

Floating solar PV workers

Fifty-three FSPV workers from two sites in India responded to visual risk perception and socio-demographic questionnaires. The mean age (combined from both sites) was 26.69 years indicating a relatively younger workforce engaged in the surveyed projects. The workers were a combination of local and migrant workers and had an average work experience of 1.37 years with almost no worker who received OSH training. Most of the workers belonged to the unskilled and semiskilled

categories. Lack of training in such projects have been identified in previous studies (Brooks & Urmee, 2014, Lucas, 2018, Pavlova, 2019). A major area of concern at both the sites were the presence of hot weather and heat stress as an outcome. Some risk factors include direct sun exposure, limited wind speeds, unacclimatized workers, high exertion, dehydration, old age, uncomfortable clothing (such as PPE) and preexisting medical conditions. Physiological effects of heat stress include heat rash, fainting due to heat (syncope), cramps, dizziness, fatigue, loss of fluids due to excessive sweating, injuries to the muscle tissues and heat stroke. The linkage of heat stress with occupational injuries has been found by a study (Varghese et al., 2018). It is clear that the hot outdoor environment where workers are exposed to the direct exposure of the sun for an 8-hour shift is a critical risk factor which requires immediate attention to prevent both short- and long-term health implications. This part of the research helped in identifying OSH risks in the high and very-high categories thus prioritizing the focus areas.

Other risk factors in the top five perceived OSH risks include falling into water, electrocution, solar radiation, and slips/trips on the floating platform. Since most of the work is performed on a floating platform over a water body, workers are prone to risks of falling into water particularly during the installation phase where all structures including safety measures are not in place. However, workers were found to be wearing life jackets at both the sites.

Objective 4: *To explore cross-cultural aspects of solar photovoltaics workers from an OSH and socio-demographic dimension.*

Cross-cultural studies

Important insights were obtained from the outcome of a collaborative cross-cultural study carried out amongst the solar PV workers (n=135) of India and Saudi Arabia. The cross-cultural variations will serve as inputs for relevant and acceptable country and population specific designs. Important findings include significant difference between the risk perception of two countries in relation to various risk factors such as cold stress, fire, electric stress, hazardous materials, unstable working platform, falling objects, adverse weather conditions, training gaps, psychosocial factors, noise, power tool use, lone working, and work-related stress. This implies that design functionalities and forms will differ according to the local socio-cultural needs of the country/location for which it is designed. The risk factor of heat stress was positively correlated to age, height and weight of the workers engaged in Saudi Arabia and India. Anthropometric dimensions, weight of clothing, tools and equipment and restricting older workers in outdoor work can be some of the considerations in industrial design and design of work. Another cause of concern is falling objects which was positively correlated to weight, height, and age. Contextual PPE design and use for protection of head, eyes and other body parts should be ensured by the stakeholders. Solar radiation and electrocution were found to be negatively correlated with age and income. Future research may explore the reasons for this relationship and the mediating factors thereof. This study adds new knowledge since it is a maiden effort to explore the socio-demographic and cross-cultural aspects which are significant inputs for contextual design interventions. No previous studies have

attempted to investigate these aspects. This part of the research also explores the dimension of cultural ergonomics (Kaplan,1995) in the solar photovoltaic industry.

The findings of the cross-cultural study been published in a journal as follows:

Sen, A., Khamaj, A., Moosa, M., & Karmakar, S. (2022). Cross-Cultural Study on OSH Risk Perception of Solar PV Workers of Saudi Arabia and India: Risk Mitigation through PtD. *Energies*. <https://www.mdpi.com/1996-1073/15/24/9614>. [SCIE & Scopus indexed; Q1 Journal]

Objective 5: *To develop ergonomic design solutions/concepts to protect against the risks for which solutions do not exist using the product design life cycle.*

Objective 6: *To measure the effectiveness of the design interventions from the perspective of risk mitigation ability, ergonomics, usability, and productivity.*

Design approaches and concepts

Amongst several design methods, three different methods were used to generate concepts. The design methods used were Codesign (Sanders & Stappers, 2008), hierarchy of controls (NIOSH) and bow-tie analysis (Meland et al., 2019). The co-design methodology involving the FSPV workers and solar PV engineers resulted in some interesting sketches from which design concepts were further developed. The idea behind this participative approach was to obtain insights from the workers about possible risk mitigation measures since they were close to the risk factors and may have experienced unsafe situations. Important insights came out of this approach whereby participants produced design ideas such as redesign of the fixing system of the solar panel with the pontoon, design of handrails (floating fence) along the fringes of the FSPV installation, anti-glare eye shield, redesign of work rest cycle, anti-slip footwear, clothing to protect against the hot sun, board/platform for carrying out safe maintenance activities and inspection mirror for inspecting the undersides of solar panels without adopting awkward postures. The design concepts are likely to address many of the emerging OSH risks identified through the preliminary exploratory and OSH risk perception studies. Comprehensive design opportunities were obtained for OSH risks high on the risk perception scale (Figure 6.6) through hierarchy of controls matrix. The design solutions ranged from PPE to elimination. The strategy for use of design intervention type will depend upon size and type of project, microclimate, safety budget, type of risk and its priority, time required for implementation and other associated factors. Many interventions are already in use in other industries and occupations but have to be adopted in consideration of the contextual requirements in FSPV projects. For example, design requirements for walkways must consider provision of enough space and weight bearing capacity for workers to navigate to and fro during not only installation and maintenance but also during evacuation in instances of exigencies. The hierarchy of controls can be a quick and effective method for deriving design concepts. The third method i.e., bow-tie analysis was carried out for two top events of “falls into water” and “electrocution”. These two risk events are also amongst the top perceived OSH risks in the very high and high categories. Several preventive and mitigation barriers from a design perspective will

aid in addressing several unwanted occupational situations in FSPV projects before they occur from a preventive design approach.

This part of the research fulfills the objective of developing ergonomic design solutions/concepts to protect against the risks for which solutions do not exist using the product design life cycle.

Although multiple design concepts were developed (Chapter 6), not all can be developed as a prototype and tested within the scope of this research. Therefore, since glare and solar radiation were found to be severe risk factors, an anti-glare and anti UV eye protector is proposed. Falling in the realm of product design, the eye protector called “glare safe” is a novel intervention for protection against outdoor glare and solar radiation affecting the eyes. Presently, safety helmets are standalone PPE that have been designed to protect the head from falling objects. The proposed design retrofits a visor with the helmet aiding both head and eye protection. The adjustable visor allows easy adjustability (moving the visor sideways) to cater to the diverse behavioral and physiological needs of the FSPV workers/users such as drinking water (for hydration in hot environments), wiping sweat, need for adequate ventilation (in a hot environment) and less risks of PPE falling into the surrounding aquatic environment. The rationale for not using sunglasses includes many of its disadvantages while using it with a helmet (helmet strap), discomfort and challenges of storage.

In the process of developing the eye protector, the idea of combining the visor with the safety helmet was conceived. While combining visors with helmets used by bikers is not new, use with safety helmets is a newer approach for dual protection. The design concept of GlareSafe (**Appendix L**) reduces discomfort glare significantly offering significant eye protection (from UV radiation), thus helping in avoiding minor and major occupational eye diseases. GlareSafe also improves job satisfaction and increases productivity. GlareSafe offers good usability as reflected by the SUS score. Stakeholders associated with FSPV workplaces may adopt GlareSafe to improve workplace safety and health for protection against the harmful effects of UV radiation and glare.

Another concern is the avoidance of PPE by workers and users at work in spite of country specific statutory regulations and article 16 of the Occupational Safety and Health Convention, 1981 (No. 155) of the International Labour Organization. Considering these aspects and to promote greater use of PPE, a framework for compliance through design (CtD) is proposed (Figure 6.21). The CtD approach is aimed at designing interventions for better compliance and hence better protection against unsafe situations. This first-of-its-kind approach can be validated for its effectiveness through further extensive case studies in industrial work environments across various sectors.

Several other design concepts have been proposed in this research. In response to addressing the risk of fall prevention, a floating fence design (Figure 6.35) is proposed. The design also has provision for rest areas for workers (which also acts as a fall barrier) and space for tool storage. Falls into water can have serious consequences in terms of both direct and indirect cost and may even result in fatalities. Hypothermia is a possible health effect of falls into water (Bridger, 2018). Rescue and recovery should be important considerations for mitigation if the event i.e., falls into water does take place. Other post event measures such as provision of personal flotation devices, allowing only those workers who know swimming and fall alarm systems should be ensured. The

floating fence will involve additional cost. However, from a cost benefit perspective, adding a floating fence, would far outpace the additional investment. Working on water also entails challenges such as tool loss (accidental dropping of tools into water) which adds to the cost of the project. As mentioned earlier, an added feature of the proposed design is the provision for tool slots which will address the work-related needs. Provision of tool lanyards (one end fixed with the body of the worker) will also prevent them from falling into water. The same approach can be adopted for personal protective equipment, the storage of which in an aquatic workplace is a challenge. Workers have to spend long hours in an outdoor environment on a FSPV project away from land. Adequate space for resting during the work rest cycle is essential. The proposed design provides a backrest for the workers which will allow a resting area and hence higher productivity. Suitable anthropometric and other design considerations must be incorporated for greater usability of the backrest. Durability of the handrail material must also be a significant consideration because of its exposure to outdoor environments in order to prevent entropy and failure in the long term since these projects typically have a lifespan of twenty-five years (Dai et al.,2020).

Workers and supervisors use the walkway floaters during installation, maintenance, and evacuation. These floating structures (also known as pontoons) are interfaces for walking and even running during emergency situations. The redesigned floater (Figure 6.40) will enable sufficient coefficient of friction (Figure 6.38) during the gait cycle which is an important precondition for preventing occupational slips and falls at the same level. The proposed design incorporates tread patterns on the walking surface to reduce slipperiness of the floating platform. Risers on both sides of the floaters have been included to deter users from straying to the sides. Although most slips are non-fatal, the redesigned floaters should be supplemented with a floating fence for greater dynamic stability to prevent falls into water. Slips are not only a function of the walking surface but also depends on the other aspects of a work system and worker status. Factors such as vision of the workers, urgency, footwear tread pattern, illumination, worker age, physical status, alcohol, fatigue, prior experience, and pathological conditions influence occurrence of slips (Gauchard et al., 2001, Chang et al., 2016) and therefore such factors must be considered for a comprehensive risk mitigation approach. In addition, training in safe walking on a floating platform to improve balance and stability (like a gymnast on a balance beam) would act as a preventive measure. Incorporation of such aspects in the pre-work training programmes can go a long way in prevention of deleterious effects.

Carrying out maintenance work in floating solar projects involves working on a constantly moving floating platform, handling loads (solar panels, floaters etc.), navigating gaps, reaching confined spaces and frequent squatting/kneeling. Non-neutral arm and hand postures and work in uncomfortable positions can lead to a host of work-related musculoskeletal disorders (WMSDs) such as neuritis, low back pain, impingement syndrome, bursitis, and repetitive strain injuries (Bridger, 2018). The design of the maintenance board (Figures 6.31 & 6.32) is aimed at mitigating awkward postures, enabling better reach to confined spaces and prevents falls into water. The maintenance board is portable and can be placed between floaters during installation and maintenance. The space for tool storage addresses the problem of tool loss in FSPV projects. Knee rest and handholds allow flexibility and better postural stability in constrained postures. The

maintenance board can also be used as a “bridge” to navigate gaps between walkways by placing the board on parallel floaters.

Amongst the surveyed FSPV projects as a part of the present research, it was observed that the gap between solar panels and the floater surface was meagre. This makes inspection of the components located at the undersides of the panels very challenging from a postural and field of vision perspective. Removal of the solar panels is practically impossible and will significantly increase maintenance time. The novel design of the maintenance mirror (Figure 6.44) will assist the maintenance personnel to inspect remotely located components (by rotating the mirror) to detect wear and tear of equipment without removal of parts or project components. The most important benefit of the intervention is the neutralization of awkward postures and availability of detailed visual field at various angles using the inspection mirror (Figure 6.44). This low-cost intervention is expected to reduce maintenance time and result in lower shutdown time for the FSPV installation. It will also help to avoid work-related occupational disorders such as low back pain, bursitis, and sprains.

Two important aspects may be considered during implementation of the concepts. Firstly, capacity building towards proper use of the design interventions by the users should be ensured. Secondly, efforts should be directed towards manufacturing industrial designs using sustainable materials.

7.3 Testing of hypothesis

Hypothesis 1: Context-specific design interventions addressing the prioritized risk factors would have the potential benefits towards improved safety and occupational health of floating solar PV workers engaged in installation and maintenance.

The literature review (Chapter 2) has revealed the existence of several emerging OSH risk factors in solar photovoltaic projects and those specific to the installation and maintenance of floating solar projects along with their deleterious health effects (Table 2.2). Risk perception data of these OSH factors have been collected from various stakeholders associated with floating solar projects (chapter 4). The risk factors have been prioritized in terms of severity (Tables 4.1, 4.7 and 4.9). The prioritized risk factors requiring immediate attention include falling into water, heat stress, electrocution, solar radiation, discomfort glare, slips/trips on the floating platform, electric flash/fire, and ergonomics risks. In this present research, a comprehensive list of design interventions (chapter 6) has been developed using various tools and techniques (Figures 6.4, 6.5, 6.6, 6.8 & 6.9) to mitigate the identified risks.

The problem of discomfort glare (Figure 6.10) was found to be severe and needs to be addressed as a priority. An anti-glare and anti-UVR eye protector was designed and developed (Figure 6.17). The eye protector was tested through several validation methods namely, a visual performance task, subjective evaluation of glare and perceived usability. All the field studies were preceded by formulation of hypotheses statements (Section 6.9.1). For the visually demanding task, both the time taken to complete the visual task and satisfaction score were found to be significantly higher (The results were significant at $p \leq 0.05$) as compared to the use of safety helmet without eye protector (Table 6.3). The introduction of the eye protector resulted in the improvement of performance of the visual task in the outdoor environment under the sun. The subjective perception

of discomfort glare showed a significant difference on the positive side where subjects who found the glare in the “disturbing” category reduced from 49% (without eye protector) to 4% (with eye protector). In addition, the response to glare in the “satisfactory” category without the eye protector was 12 %, which increased to 55% with the eye protector (Table 6.4). Post usage of the eye protector, the average SUS score came to 84.2 (n=50) which is on the higher side (Figure 6.27).

Apart from the eye protector, several other design concepts aimed at addressing different combinations of contextual risks have been developed within the scope of this research which include the following:

1. Maintenance board for preventing falls and reducing awkward postures.
2. Handrails (floating fence) with resting area and tool storage slots.
3. Redesign of walkway floater surface for preventing slips, trips, and falls.
4. Maintenance mirror for inspecting undersides of solar panels and associated equipment.

The designs were validated through a questionnaire survey (n=73) based on parameters such as ability to mitigate the OSH risks, addresses ergonomics issues, manufacturability, cost benefits and improvement in productivity. Paired two-tailed t test (at significance level 0.05) showed that all design concepts were found to be significantly beneficial as compared to the existing working conditions (Table 6.9). **These findings result in the acceptance of Hypothesis 1 of this research.** Table 7.1 represents the benefits of the design concepts in safety and occupational health of the FSPV workers and other users.

Table 7.1. Design concepts and their benefits from the perspective of safety and occupational health

Design concept	Component	Safety	Occupational Health
Anti-glare and UVR eye protector integrated with safety helmet	Eye protector visor	Protects from UV solar radiation and discomfort glare.	Prevents eye pterygium, cataracts, macular degeneration, ocular melanoma, disability glare and photoconjunctivitis.
	Movable (sideways) eye protector visor	Promotes use of PPE (head and eye safety) in a hot and humid work environment. The integrated design prevents PPE loss (visor) into water resultantly ensuring eye safety.	Prevents dehydration and physiological outcomes of heat stress by addressing contextual needs such as wiping of sweat, hydration (without removing the helmet) and air circulation.
Maintenance board	Portable working board	Enables workers to reach remotely located components/working areas and prevents non-neutral postures.	Prevents falls into water, crevices/gaps (in the floating platform), and work-related musculoskeletal disorders.
Guardrail (floating fence)	Handrail	Prevents slips/trips/falls	Aids in postural balance and prevents occupational injuries

	Backrest	Prevents awkward postures and ensures fall prevention (into surrounding water body) while sitting during rest periods/breaks.	Rest shelter aids in work rest cycle in a hot and humid work environment. Prevents heat illnesses.
Redesign of walkway floaters	Redesigned floater surface	Prevents falls/slips at the same level and in water	Prevents fall related injuries and drowning
Maintenance mirror	Movable inspection mirror	Prevents awkward postures and vision difficulties during maintenance	Prevents work-related musculoskeletal disorders and vision impairment

Hypothesis 2: Cross-cultural factors and sociodemographic traits significantly influence the perception of occupational risks by workers engaged in solar photovoltaic projects.

The findings in Chapter 5 indicate the differential risk perception of solar photovoltaics workers towards similar OSH risks across two countries. Independent two tail t-test revealed that there are significant differences (at $p \leq 0.05$) between how respondents from two countries perceived OSH risks such as cold stress, fire/electric flash, hazardous materials, working platform stability, falling objects, inclement weather, skill gaps, psychosocial factors, noise, power tool use, occupational stress, lone working, and risk from animals (Table 5.3). This indicates that for groups of workers across the two locations (India and Saudi Arabia), the risk perception towards the same risk is different. From the perspective of an occupational practitioner, these findings allow implementation of interventions that are country and population specific. This is also to say that universal designs may not be applicable for all OSH risk factors. On the contrary, universal designs may be adopted for those factors where there is no significant difference i.e., heat stress, solar radiation, electrocution, ergonomics risks and work organization (Table 5.3) across the studied countries.

An analysis of the Pearson's correlation coefficient scores between sociodemographic factors and OSH risk factors reveals several interesting relationships. Age, height, and weight have a positive relationship with heat stress, falling objects and use of power tools for workers engaged in both countries (Table 5.4). Work experience has a negative relationship with heat stress for workers engaged in India while it has a positive relationship for workers in Saudi Arabia. Age and work experience is positively related to ergonomics risks in both locations. This means that propensity of ergonomics risks increases with increase in age and work experience. Weight, income, and work experience are positively related to psychosocial factors in both countries thereby meaning that with increase in weight, income and work experience, psychosocial factors such as loneliness, social disruption, social status, etc., may increase. There are also several kinds of relationships for the studied risk factors (Table 5.4). These relationships provide insights for not only the design of safety tools/PPE but also for designing training modules, occupational health programmes, team formation, compensation, and job design in solar photovoltaics projects. **These findings result in the acceptance of Hypothesis 2 of this research.**

7.4 Novelties of the Study

The insights from this research add new knowledge to the safety aspects associated with the FSPV sector as follows:

1. Maiden effort for the identification and measurement of occupational, safety and health issues in the floating solar photovoltaics sector involving workers and safety managers.
2. First of its kind effort to collect the socio-demographic data of FSPV workers engaged in India.
3. Measurement of risk perception and socio-demographic factors across two countries (India & Saudi Arabia) resulting in cross-cultural insights. The findings will help attract attention towards the mediation and effect of cross-cultural factors on design interventions. Attracting attention towards the severe risk of discomfort glare in floating solar PV projects.
4. This research work makes an effort towards the use of Codesign, PtD approach (bow-tie analysis) and hierarchy of controls for developing design concepts in the context of the FSPV sector. The research contains both a participative as well as a researcher led perspective. A proposed framework for Compliance through Design (CtD) is also introduced.
5. First of its kind effort towards the development of design concepts for OSH related to emerging risks in the FSPV sector.

7.5 Contributions of the study

1. *Contribution to the body of OSH knowledge in the solar photovoltaic industry*

Comprehensive literature review (Chapter 2) has established that little or no research has been undertaken to explore, measure and mitigate the emerging OSH risks in the FSPV sector. Almost all research efforts in the FSPV industry are directed towards technical and efficiency improvements. From a design perspective, efforts are directed towards FSPV system design and innovation thereof. There is only one study (Bhang et al., 2018) related to FSPV projects that is concerned with protection against electrocution. Within the broader solar PV industry, although several OSH risks have been identified (refer to Chapter 2), but only one study (Ho et al., 2020) concerned with roof-top solar projects has developed a PtD protocol that is aimed at risk mitigation. In this background, this present research concentrates on the OSH issues FSPV sector and brings forth the areas of concern, prioritization of risks and mitigation measures from an ergonomics design perspective. This research also identifies different human-machine interfaces and comprehensive design opportunities (Table 2.4). The socio-demographic profiles of the FSPV workers have also been surveyed for the first time in this present research. In addition, the cross-cultural perspectives provide an added dimension to the existing knowledge of the solar PV industry (chapter 5). The findings will serve as important resources for the stakeholders in a fast-growing FSPV sector and add new knowledge to the OSH dimension of the solar photovoltaic industry.

2. *Contribution to design research methodologies and implementation framework*

In the process of exploring the upcoming floating solar projects in India through field studies, a review of literature was conducted to find existing questionnaires to measure the OSH risks in the context of the solar PV industry with reference to FSPV projects. Since no questionnaires/methods were found in the context of FSPV projects, a questionnaire (**Appendix-C**) was developed and used in this research. The visual constructs allow easier collection of data from the perspective of the FSPV workers (who may not be able to read and understand questions). This simple tool is a maiden intervention in understanding and prioritizing the problems being faced by the workers. Another contribution is the development of the Co-design questionnaire (**Appendix-H**) following the generative toolkit approach (Sanders & Stappers, 2008) to obtain design ideas from stakeholders who are also future users. The use of a new method of validation by using a visual task assessment method (tumbling “E” chart) for understanding the effects of design intervention for eye protection proposes a new direction in design research. This study also proposes a framework and strategy for implementation (Figure 2.3) that can be used by the stakeholders. Parameter (p) diagrams for robust designs for the design concepts are also proposed.

3. *Contribution to design approach and paradigm*

During this present research work, the problem of PPE avoidance came up as a major dimension. Non-use or avoidance of PPE has been identified by several previous studies. Many studies are directed towards the use of technology for monitoring of PPE. However, this research proposes a new design paradigm where recombination/reorganization/rethinking can result in newer designs for better compliance. The design and development of the eye protector involves the retrofitting of a visor to a safety helmet. This design approach ensures dual use of both helmet and eye protector offering eye protection and head protection. This aids in compliance requirements as mandated by safety laws and regulations. A framework for Compliance through Design (CtD) is also proposed (Figure 6.21).

4. *Contribution to workers' health & safety*

The central research motivation of the present research was the generation of design concepts (which presently do not exist) that will serve to protect the FSPV workers against the various OSH risk factors. The comprehensive design concepts developed through the present study are likely to prevent near misses, injuries, accidents and even fatalities. Many of the design interventions are low cost and very effective. For example, the eye protector can protect against glare which can cause severe and deleterious effects on the eyes and even permanent loss of vision. In fact, the eye protector can be used for all kinds of outdoor work where there are possibilities of glare.

7.6 Limitations

1. Very few FSPV projects were under construction in India at the time of undertaking this research. Therefore, a purposive sampling approach was adopted since field study sites were limited to only some geographical locations considering only Indian subjects. The responses of the FSPV workers, therefore, may not be representative of a larger set of workers.
2. FSPV projects are new kinds of installations in its first stage of development both in India and globally. This research covers risk identification and mitigation covering this initial phase. Over the long term (a FSPV project has a lifetime of about 25 years), project components go through “entropy” or deterioration of equipment and interfaces. Such changes may lead to newer or additional OSH issues. Accordingly, some proposed designs may not hold over the long in terms of effectiveness.
3. Although all efforts were made to generate Codesign concepts in a comprehensive manner, they are only limited to the knowledge and/or experience of the FSPV workers and engineers to a particular FSPV project design. With more evolution in FSPV project designs across the world, the design concepts may differ. For example, sun protective clothing may not be required in FSPV projects located at cold microclimates. The number of participants in the Codesign process was small.
4. Although psychosocial and work organization risk factors were identified as some of the OSH risk factors, they were not measured because of the limited scope of this research.

7.7 Future Work

1. Deployment of design concepts and the measuring the ability of the design interventions to mitigate the OSH risks through longitudinal studies.
2. Studies on the barriers that may be faced by the users in the adoption of the proposed design interventions.
3. Socio-demographic and cross-cultural aspects in FSPV projects and its relationship with design factors over several geographical locations.
4. Effectiveness studies of the proposed framework of Compliance through Design (CtD) and validation across various industries.

7.8 Conclusion

This research is a maiden attempt to explore the OSH dimensions of FSPV projects with a core objective of risk mitigation adopting a design approach. This thesis work adds new knowledge in the facets of OSH risk identification, measurement, prioritization, and mitigation. This is the first attempt to utilize “designerly” ways of arriving at design solutions in the FSPV sector. Several novel design solutions at different intervention levels are an outcome of this thesis which may be used by stakeholders in the solar photovoltaic industry. Such interventions at an early phase of the FSPV projects is expected to significantly assist in the efforts towards safety and sustainability. This approach will assist in avoiding both direct and indirect costs of deleterious occupational events. It is felt that taking a design concept from the lab to an occupational setting must be one

of the objectives of research. This research work makes a humble effort by developing an eye protector for the solar photovoltaic industry which can in fact be used for all kinds of outdoor work under the sun.

The cross-cultural and socio-demographic perspective elicited in this present research throws light on the importance of considering local and demographic factors in the design process. Although broad design ideas maybe considered for universal use across several countries, but location specific changes in design considering contextual factors must be ensured.

The development of an OSH risk perception questionnaire, Codesign questionnaire (participatory approach in risk mitigation) and novel method of design concept validation is perhaps a new dimension. All these methods/tools will help replicate the studies in other locations and contexts. Similar studies may also be conducted in other types of solar photovoltaic projects. A framework for design implementation suggested in this thesis will be beneficial to practitioners.

This thesis also proposes the concept of Compliance through Design (CtD) which is an effort to address the problem of PPE avoidance using tenets of design thinking. Adopting a CtD approach can be significantly beneficial to ensuring statutory compliance in various industries where PPE is the only line of protection against OSH risks.

The diverse facets of this present research will certainly be beneficial to safety managers, FSPV project developers, workers, policy makers, industrial designers, ergonomists, and other related stakeholders.

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List of Publications

Journal

- Sen, A., Khamaj, A., Moosa, M., & Karmakar, S. (2022). Cross-Cultural Study on OSH Risk Perception of Solar PV Workers of Saudi Arabia and India: Risk Mitigation through PtD. *Energies*. <https://www.mdpi.com/1996-1073/15/24/9614>. [SCIE & Scopus indexed; Q1 Journal]
- Sen, A., Mohankar, A. S., Khamaj, A., & Karmakar, S. (2021). Emerging OSH Issues in Installation and Maintenance of Floating Solar Photovoltaic Projects and Their Link with Sustainable Development Goals. *Risk Management and Healthcare Policy, Volume 14*(May), 1939–1957. <https://doi.org/10.2147/RMHP.S304732> [SCIE & Scopus indexed; Q2 Journal]

Conference proceedings

- Sen, A., & Karmakar, S. (2023). OSH Risk Perception of Floating Solar PV Workers and Identifying Scope for Design Interventions: A Codesign Approach. In: Chakrabarti, A., Singh, V. (eds) *Design in the Era of Industry 4.0, Volume 1*. International Conference on Research into Design 2023. Smart Innovation, Systems and Technologies, vol 343, pp. 117–126). Springer, Singapore. https://doi.org/10.1007/978-981-99-0293-4_10
- Sen, A., & Karmakar, S. (2022). OSH Risk Perception of Safety Managers and Scope for Ergonomics Design Interventions in Floating Solar Photovoltaic Projects. In: Chakrabarti, D., Karmakar, S., Salve, U.R. (eds) *Ergonomics for Design and Innovation. HWWE 2021. Lecture Notes in Networks and Systems*, vol 391. Springer, Cham. https://doi.org/10.1007/978-3-030-94277-9_74
- Sen, A., & Karmakar, S. (2021). Exploring the OSH Scenario in Floating Solar PV Projects in India and Opportunities for Ergonomics Design Interventions. In: A. Chakrabarti et al. (eds.), *Design for Tomorrow—Volume 1, Smart Innovation, Systems and Technologies. International Conference on Research into Design, IIT Bombay, India, 7-10 January 2021*, (Vol 221, pp. 245-255). Springer, Singapore. https://doi.org/10.1007/978-981-16-0041-8_21

Occupational Safety & Health scenario of workers engaged in the installation, operation & maintenance of Floating Solar PV projects

1. This questionnaire is designed to collect views of the officials/engineers/managers or supervisors engaged in the installation, operation & maintenance of Floating Solar PV projects.
2. It aims to understand the risks of the workers engaged in the installation and maintenance of Floating Solar PV projects from the perspective of Occupational Health & Safety.
3. The data/information will be used for academic/research purposes to develop relevant user-centric ergonomics design solutions for workers engaged in the Solar PV industry.
4. Please do not mention any name(s) of persons in this questionnaire.

Research initiative by the Centre For Ergonomics, Department of Design, Indian Institute of Technology, Guwahati, Assam, India

Contact details | Abhijit Sen | Email: sen18@iitg.ac.in M: +91 9038271367

1. Your designation

2. Organization/company (optional)

3. Floating Solar PV project size, location, and country (any executed/ongoing project)

4. Please indicate the type of water body on which the project was installed or being installed.

Mark only one oval.

- Lake
- Reservoir of a Hydroelectric Dam
- Reservoir of a Thermal Power Plant/Gas Station
- Mine Quarry
- Pond
- Lagoon
- Water Treatment Plant
- Other: _____

5. Project completion time (in days/weeks/months/years)

6. The average number of workers engaged

7. Status of the workers

Mark only one oval.

- Permanent
- Temporary (Casual/Contractual)
- Leased
- Mix of permanent & temporary
- Other: _____

8. Skill level of the workers

Mark only one oval.

- Highly Skilled
- Skilled
- Semi Skilled
- Unskilled
- Other: _____

9. Average daily working hours and time (e.g 10 a.m to 5 p.m)

Training, safety aspects, work organization & psychosocial risks

10. Is safety training provided to the workers?

Mark only one oval.

- Yes
- No

11. If Yes, what is the mode of safety training?

Mark only one oval.

- Hands On demonstration
- Instructional material/handouts/posters
- Videos
- Audio messages
- Lectures/briefings
- A combination of the above
- Other: _____

12. What is the language used in training sessions/handouts and who conducts them?

13. Is safety training mandatory or voluntary?

Mark only one oval.

- Mandatory
- Voluntary

14. Is there sufficient cooperation and communication between different stakeholders such as project owner, site engineer and the workers in order to ensure workplace safety?

Mark only one oval.

Yes

No

15. Is worker feedback taken to understand the occupational risks?

Mark only one oval.

Yes

No

16. Is workplace risk assessment carried out before the start or at any stage of the project?

Mark only one oval.

Yes

No

17. Are there measures in place to avoid a high workload and tight deadlines?

Mark only one oval.

Yes

No

18. Have the specific needs and risks of the different worker groups (migrant /contract workers, young and older workers, female and male workers, etc.) been assessed?

Mark only one oval.

- Yes
 No

19. Are methods of working safely effectively communicated in local languages to various kinds of workers (e.g. migrant workers)?

Mark only one oval.

- Yes
 No
 Other: _____

20. Is Shift Work involved during installation and maintenance?

Mark only one oval.

- Yes
 No

21. If Shift Work is involved, what is the shift pattern and duration? (including night shifts if any)

22. Are occupational health check-ups conducted at any stage of the solar PV project?

Mark only one oval.

Yes

No

23. If Yes, what are the reported occupational health problems that workers suffer from?

Working on water, slips, and trips, falls, etc

24. Can work on water bodies/floating structures be avoided?

Mark only one oval.

Yes

No

25. When work near water is necessary, are there work platforms and scaffolding available if needed?

Mark only one oval.

Yes

No

Other: _____

26. Are the walkways/floats been inspected to ensure that they are dry and free from slipping and tripping hazards from water, moss, snow, ice, equipment lying around, etc.?

Mark only one oval.

Yes

No

27. Are the holes/cavities in the Floating Solar PV system safeguarded?

Mark only one oval.

Yes

No

28. Have guard rails/barriers been provided to prevent workers from falling into water?

Mark only one oval.

Yes

No

29. Have safety nets been provided to protect the workers?

Mark only one oval.

Yes

No

30. What kind of hand tools are used for installation?

Mark only one oval.

- Customized hand tools specific to Floating Solar PV projects
- Tools used in other Solar PV installations
- General tools available in the market
- Other: _____

31. Are the tools insulated?

Mark only one oval.

- Yes
- No
- Other: _____

32. Which of the following is used for the cleaning and maintenance of solar panels?

Mark only one oval.

- Manual cleaning with brushes/mops
- Automated systems
- Other: _____

33. What type of cleaning process is used?

Mark only one oval.

- Dry cleaning
- Wet cleaning
- A combination of both
- Other: _____

34. Do the workers wear life jackets when working on Floating Solar PV projects

Mark only one oval.

- Yes
- No

35. Are lifebuoys/life preservers available in sufficient numbers at the project site?

Mark only one oval.

- Yes
- No
- Other: _____

36. Are divers deployed for anchoring and mooring?

Mark only one oval.

- Yes
- No
- Other: _____

37. Did any injury, near miss or accident take place during the installation or maintenance of the project?

Mark only one oval.

- Yes
- No
- Not aware

38. If Yes, please describe the incident in brief.

39. Was there an incident when a worker/workers fell into the water body? If yes what may be the likely reason?

40. Please mention any error committed by the workers during the project that was harmful to them or led to an accident? What do you think maybe the cause of the error?

Use of Personal Protective Equipment (PPE)

41. Which of the following Personal Protective Equipment (PPE) are provided to the workers?

Check all that apply.

- Safety Helmets
- Safety Shoes (with rubber soles)
- Safety Gloves (insulating)
- Masks
- Safety Belt/Harness
- Safety Glasses
- Ear muffs
- Other: _____

42. Any other form of PPE that is provided to the workers

43. Are Fire Extinguishers (Class E) present in the project site?

Mark only one oval.

Yes

No

44. Are first-aid arrangements made available at the project site?

Mark only one oval.

Yes

No

45. Are safety signs & signages displayed at the project site?

Mark only one oval.

Yes

No

46. Is an Emergency Plan in place during the execution of projects?

Mark only one oval.

Yes

No

Other: _____

Electricity-related risks

47. Are only qualified persons allowed to work on electrical equipment?

Mark only one oval.

Yes

No

48. Is a safe distance kept for workers, tools, and materials from high voltage power lines during maintenance/repair activities?

Mark only one oval.

Yes

No

49. Is the grounding of the system ensured at all times?

Mark only one oval.

Yes

No

Other: _____

50. Is the work area at the power inverter area dry?

Mark only one oval.

Yes

No

51. Are workers aware that low voltages can cause surprise shocks and thereby falls?

Mark only one oval.

Yes

No

52. Are workers made aware that even a small quantity of sunlight can produce a voltage potential in the PV system and shock or arc-flash hazards?

Mark only one oval.

Yes

No

53. Are workers provided with suitable Personal Protective Equipment (PPE) when risk reduction measures at source are not sufficient?

Mark only one oval.

Yes

No

54. Are workers accompanied always by at least one co-worker when working on electrical systems, thereby eliminating lone working?

Mark only one oval.

Yes

No

55. Are workers aware of electric risks from damaged solar panels e.g. during cleaning activities?

Mark only one oval.

Yes

No

Hazards that may lead to Musculoskeletal Disorders (MSDs)



56. Is the workplace layout so designed that manual handling operations, such as lifting and carrying are avoided or minimized?

Mark only one oval.

Yes

No

57. Are mechanical aids provided where lifting or carrying of tools, equipment, and material from the land to floating structures and vice-versa, are required?

Mark only one oval.

Yes

No

58. In case a crane is used, are workers operating the crane properly trained?

Mark only one oval.

Yes

No

59. Are measures in place to avoid or reduce the need for workers to perform repetitive movements or to work in awkward postures?

Mark only one oval.

Yes

No

60. Are measures in place to avoid or reduce the need for workers to work frequently in prolonged kneeling or squatting positions?

Mark only one oval.

Yes

No

61. Have workers been trained in safe manual material handling techniques?

Mark only one oval.

Yes

No

62. Are mechanized vibrating hand tools used?

Mark only one oval.

Yes

No

Other: _____

63. Is there any other tool(s) which when used by the worker can lead to Musculoskeletal Disorders?

Specific sources of OSH risks

As a project manager/engineer-in -charge/supervisor please identify the most important specific types of risks faced by the workers



Institute of Technology

64. Which of the following are the specific sources of risk from Solar PV Panels

Check all that apply.

- Cuts and bruises due to sharp edges
- Difficult to carry due to heavy weight
- Lack of proper grips for carrying the panels
- Chemical risks
- Electrical risks
- Difficulties in cleaning
- Difficulties in replacing panels
- Other: _____

65. Which of the following are the specific sources of risk from Floating structures/pontoons?

Check all that apply.

- Falls, slips and risks of falling into water
- Risks from scaffolding (height/stability)
- Instability of the Floating Structure
- Gaps/Holes in the structure
- Other: _____

66. Which of the following are the specific sources of risks from tools?

Check all that apply.

- Weight
- Shape and usability
- Difficulty in carrying them
- Risk of tools falling into water
- Difficulty in reaching points of use
- Other: _____

67. Which of the following are the specific sources of risk from cables/inverters/batteries?

Check all that apply.

- Electrical shocks
- Trips & falls
- Fire
- Carrying cables/wires
- Other: _____

68. Please mention the OSH hazards for workers engaged in civil work associated with solar PV projects

69. Which of the following work environmental conditions are potential hazards?

Check all that apply.

- Rain
- Snow/Cold weather
- Hailstorms/Hurricanes
- Heat
- Noise
- Humidity
- Other: _____

70. Please mention/describe any other specific source of risk.

Suggestions to address the risks from an ergonomics design perspective

If you think that there are significant OSH risks faced by the workers then which of the following can be adopted to address them. The discipline of Ergonomics/Human Factors attempts to "Fit the Job to the Man" by providing design solutions.



71. What among the following can be redesigned to reduce OSH risks

Mark only one oval per row.

	Parameter/System component
Solar PV Panel	<input type="radio"/>
Floating structures (pontoons etc.)	<input type="radio"/>
Scaffolds/Walkways	<input type="radio"/>
Electrical equipment/acessorie s	<input type="radio"/>
Personal Protective Equipment (PPE)	<input type="radio"/>
Frames and supporting structures	<input type="radio"/>
Mooring system	<input type="radio"/>
Cleaning equipment	<input type="radio"/>
Tools/screws/clamps	<input type="radio"/>
Work methods	<input type="radio"/>
Safety Policy	<input type="radio"/>
Workplace Environment	<input type="radio"/>
Workstation/Layout	<input type="radio"/>
Illumination	<input type="radio"/>
Work Organization	<input type="radio"/>

72. Any other suggestion/opinion to address the OSH risks

73. Do you think the risks of workers engaged in Floating Solar PV projects are different from those engaged in other Solar PV projects such as land mounted, rooftop, etc.

Mark only one oval.

Yes

No

Other: _____

74. If Yes, what are the additional/unique risks in your view?

75. What additional safety measures do you think should be taken for Floating solar PV projects?

76. Do you think there should be a set of design standards for solar PV projects for ensuring the OSH of the workers for a safe and sustainable solar PV industry?

Mark only one oval.

Yes

No

77. Do you think there should be an OSH Checklist for better risk management and mitigation for Floating Solar PV projects?

Mark only one oval.

Yes

No

Other: _____

78. Any other suggestions, comments or inputs

Our research team is thankful to you for patiently filling up the questionnaire and contributing to the advancement of science.

This content is neither created nor endorsed by Google.

Google Forms

Floating solar PV projects - Questionnaire on risk perception of safety managers/engineers

Hello Safety Professionals/Managers/Engineers:

Floating Solar Photovoltaic (FSPV) projects are being installed in large numbers on water bodies globally. A large number of workers are being engaged in the installation and maintenance of these projects. The workers are exposed to several emerging Occupational Safety & Health (OSH) risks due to work on both land and water. Understanding the type and degree of each risk is critical for protecting the workers through interventions to prevent injuries, accidents occupational diseases.

This is a risk perception questionnaire for obtaining the views of safety professionals/managers/engineers for understanding and addressing the occupational risks. Your survey responses will be strictly confidential.

Thank you very much for your time and support.

* Required



A photograph of floating solar PV workers engaged in installation



1. Designation/Job Role

2. Country

3. Organization

4. Years of experience

5. Do you have working experience in Floating Solar PV projects?

Mark only one oval.

Yes

No

6. Which of the following types of OSH risks do you think is faced by FSPV workers?

Check all that apply.

Heat Stress

Cold Stress

Solar Radiation

Electrocutation

Fire/Arc Flash

Ergonomic risks such as awkward postures, heavy lifting, repetitive movements, sharp edges, etc.

Hazardous Chemicals/Materials

Aquatic animals/fauna

Slips and trips on the floating platform

Unstable floating platform

Working alone

Falling into water/drowning

Falling objects

Lightning, storms, flora, hail etc.

Lack of training/skill gaps

Psychosocial factors (income, socioeconomic background etc.)

Work organization factors such as working hours, supervision, shift work, etc.

Noise

Use of Power Tools

Occupational Stress

7. Please rate the degree of risk (on a five point risk perception scale) for the following types of OSH risks faced by FSPV workers based on severity, vulnerability, and frequency of exposure. *

Mark only one oval per row.

	Very High Risk	High Risk	Medium Risk	Low Risk	Very Low Risk
Heat Stress	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Cold Stress	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Solar Radiation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Electrocution	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fire/Arc flash	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Ergonomic risks such as awkward postures, heavy lifting, repetitive movements, sharp edges, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Hazardous Chemicals/Materials	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Aquatic animals/fauna	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Slips and trips on the floating platform	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Unstable Floating platform	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Falling into water/drowning	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Falling objects	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lightning, storms, flora, hail etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lack of training/skill gaps	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Psychosocial factors (income, socioeconomic background etc.)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Work organization factors such as working hours, supervision, shift work, etc.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Noise	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Use of Power tools	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Occupational Stress	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Working alone	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

8. Please mention the Top 3 OSH risks that need to be addressed immediately.

9. Which of the following do you think is the best way(s) to mitigate OSH risks in FSPV projects? (you can select multiple options)

Check all that apply.

- Safety training/behavioral change
- Design of Personal Protective Equipment (PPE)
- Design and display of safety signages
- Redesign of workplace
- Design of job aids
- Redesign of work rest cycle/work organization
- Lowering of loads/object weights
- Rest shelters
- Improvement in Work Environment
- Automation
- Planned maintenance keeping in mind weather conditions
- Occupational Safety & Health Standards
- Better Safety Climate/OSH culture
- Better supervision. oversight and risk management
- Other: _____

10. According to you which are the other aspects/areas of concern in FSPV projects for OSH of the workers?

11. Any other views/suggestions for OSH risk mitigation

Floating solar photovoltaic worker OSH risk perception questionnaire

Name of the worker

Heat Stress



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Cold Stress



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Solar Radiation



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Electrocution



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Fire/Electric Arc Flash



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Ergonomic risks such as awkward postures, heavy lifting, repetitive movements, sharp edges, etc.



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Hazardous Chemicals/Materials



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Aquatic animals/fauna



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Slips and trips on the floating platform



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Unstable Floating platform



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Falling into water/drowning



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Falling objects



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Lightning, storms, flora, hail etc.



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Lack of training/skill gaps



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Psychosocial factors (income, socioeconomic background etc.)



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Work organization factors (wages, working hours, supervision, shift work, etc.)



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Noise



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Use of Power tools



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Occupational Stress/Fatigue



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk

Working alone



Very High Risk



High Risk



Medium Risk



Low Risk



Very Low Risk



Institute Human Ethics Committee
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
North Guwahati, Guwahati – 781 039

Institute Human Ethics Committee Approval

The chair and the members of Institute Human Ethics Committee of Indian Institute of Technology Guwahati have considered the project titled “**Ergonomic Design Interventions for ensuring OSH of the workers involved in Floating Solar PV installation and maintenance**” in the meeting convened on 26th February 2021 and given its approval for the same.

Prof. Vimal Katiyar
Deputy Chairperson of IHEC &
Dean R&D, IITG

संकायाध्यक्ष, अनुसंधान एवं विकास -
 Dean, Research and Development
 भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
 Indian Institute of Technology Guwahati
 गुवाहाटी-781039
 Guwahati-781039

Appendix-E

CONSENT FORM: For data collection from FSPV Workers

Note: This format was translated in local language for understanding of the participants.

Project/Study Title	Ergonomic Design Interventions for ensuring OSH of the workers involved in Floating Solar PV installation and maintenance
Name of PI of the project/study	Dr. Sougata Karmakar, Professor & Head, Department of Design, IIT Guwahati
Purpose of the study	The aim of the present study is to investigate the specific nature of problems contributing to the difficulties and its resultant occupational hazards being faced by the workers engaged in the FSPV sector and to design context specific solutions from an ergonomics design perspective.
Procedures	You will be interviewed to collect information on the following: 1. Demographic data 2. Work experience 3. Work flow 4. OSH issues during installation & maintenance Photography and videography will be carried out during the study.
Potential Risks and Discomforts	Neither any drug will be administered, nor will any invasive procedure will be followed. The participant will feel no physical or mental discomfort during the completion of the questionnaire.
Confidentiality	We will plan to publish the results of this study, but it will not include any information that would reveal your identity.
Right to Withdraw and Questions	Your participation in this research is completely voluntary. You may choose to withdraw before, during or after the collection of data/information.
Statement of Consent	Your signature indicates that you are between 18 and 50 years of age and you have read this consent form along with the purpose and procedure of the experiment. You also agree to allow photography and videography during this study.
Signature and Date	Name of the participant:
	Signature:
	Date:

Appendix-F

Questionnaire for collecting socio-demographic and safety information

Location & Project Size:

Please tick ✓ the chosen option

S.No	Parameters	Particulars			
1	Name				
2	Age (in yrs.)				
3	Gender	Male	Female	Other	
4	Height (in cms.)				
5	Weight (in kgs)				
6	Skill level	Unskilled	Semi-skilled	Skilled	Highly skilled
7	Background (Local/Migrant)				
8	Monthly income (Rs)				
9	Education level	Elementary	High School	Graduate	Other
10	Work experience (yrs/months)				
11	Work experience in solar sector (months/yrs)				
12	Working hours				
13	Training on installation/maintenance	Yes		No	
14	Mode of training				
15	Training in Occupational Health & Safety	Yes		No	
16	Tools used				
17	Are the tools insulated (Yes/No)				
18	Personal Protective Equipment used	Safety Helmet	Safety Shoes	Insulating gloves	Safety belt
		Safety glasses	Lifebuoys	Life jackets	Other
19	Occupational Health Check-ups	Yes		No	
20	History of Slips/Trips/Falls	Yes (If Yes no of times=)		No	
21	Observations/Remarks				

Heat Stress Check List

This check list is only to be used when conducting a heat stress risk assessment it should not be used for the purposes of a thermal comfort risk assessment.

Risk Assessment Work Sheet

- Please complete one risk assessment worksheet for each employee.
- Read the questions carefully, and provide an answer in the relevant space provided.
- If you require further information, refer to the relevant web pages.

Name of risk assessor:	
Date of assessment:	
Job being assessed	
Location of assessment	
Name of employee being assessed	

Personal status of employee

Employees age		Is the employee male or female	Male / Female
Is the employee acclimatised:	Yes / No	If Yes provide details of acclimation:	
Is the employee experienced in the job?		Yes / No	
Is the employee experienced in working in the heat?		Yes / No	
Has the employee been trained to work in the heat?		Yes / No	

Please provide a brief description of the work being performed:	
How many employees are involved in this task?	

Where was the assessment conducted? (Please provide a description of the workplace. If necessary use the back of the page to provide a diagram of the workplace and the area)

How long (in minutes) does the work typically take?	a) Without a break:
	b) In a typical shift (excluding breaks):
How often will this task take place:	Daily / Infrequently
Is refresher training given to employees?	Yes / No
If YES how often?	

What were the external climatic conditions? (If measurements are not available, provide a brief description).	Air temperature:	
	Radiant temperature:	
	Air velocity:	
	Relative humidity:	
	Description:	

Hazard Identification

Name of risk assessor:	
Date of assessment:	
Job being assessed	
Location of assessment	
Name of employee being assessed	

This observational check list helps identify potential heat stress hazards. If you observe any of the hazards described, tick the box to the right of that description.

If you identify a heat stress hazards not listed, describe the hazard in the "Other" box, and tick the appropriate answer.

Consideration	Description	Tick
Air Temperature	<ul style="list-style-type: none"> Does the air feel warm or hot? 	
Radiant Temperature	<ul style="list-style-type: none"> Is there a radiant heat source present eg the sun, furnaces; ovens; kiln walls, kilns; dryers; hot surfaces & machinery, exothermic chemical reactions, molten metals, etc.) 	
Humidity	<ul style="list-style-type: none"> Is there any equipment that produces steam? 	
	<ul style="list-style-type: none"> Is the workplace affected by external weather conditions? 	
	<ul style="list-style-type: none"> Are the employees wearing PPE that is vapour impermeable? 	
	<ul style="list-style-type: none"> Do your employees complain that the air is humid? 	
Air Movement	<ul style="list-style-type: none"> Is warm or hot air blowing onto your employees 	
Metabolic rate	<ul style="list-style-type: none"> Is the work-rate moderate to intensive? 	
PPE	<ul style="list-style-type: none"> Is PPE being worn to protect against harmful chemicals, asbestos, flames, extreme heat etc? 	
	<ul style="list-style-type: none"> Is respiratory protection being worn? 	
What your employees think	<ul style="list-style-type: none"> Do your employees think that heat stress is a problem? 	
	<ul style="list-style-type: none"> Do your employees complain of feeling warm or hot? 	
Other		

If you have ticked any of the descriptions to any of the above questions there may be a heat stress risk and you should now conduct a more detailed risk assessment using the heat stress observation checklist.

Personal Risk Factor Checklist

Name of risk assessor:	
Date of assessment:	
Job being assessed	
Location of assessment	
Name of employee being assessed	

This is not intended to replace a medical examination and is only to be used as a preliminary observation tool. If in doubt, seek advice from an occupational health physician who has a knowledge of working in the heat.

Has the employee had a pre-exposure medical examination by a qualified occupational health professional?		Yes / No
If YES :	Have they been cleared to work in an environment where they may be at risk from heat stress	Yes / No
If No	Consult a physician	
	When was their last medical screening done?	
	When is their next medical screening due?	
Before this assessment had the employee completed a pre-exposure medical questionnaire?		Yes / No
If YES :	Were any YES answers provided in the pre-exposure medical questionnaire?	Yes / No
	(If YES consult a physician?)	
When was the questionnaire last administered?		
Please provide any other information that may be relevant to this part of the assessment.		

Heat Stress Observation Checklists

- Each of the following check lists addresses one of the one of the six basic parameters.
- Each parameter is described and a risk score is given for each. The higher the score, the higher the risk it may contribute to heat stress.
- You should observe the environment, taking note of the description provided, and tick the box that best fits your workplace. This will provide you with an estimated risk score for that parameter. You may tick more than one box if the environment is changing, or if the employee is moving between environments.
- If you do not see a description that best fits the work situation you are assessing, or are unsure then tick the **“Don’t know”** box at the bottom of that table. This introduces an uncertainty into the assessment and requires that you conduct a more detailed qualitative assessment.

Air Temperature

What is air temperature and what should you look out for?		
<ul style="list-style-type: none"> • Air temperature is described as the temperature of the air surrounding an employee. • Consider the air temperature surrounding the employee and how you would describe it. 		
Subjective description of air temperature	Score	Tick
• Cool	-1	
• Neutral	0	
• Slightly warm	1	
• Warm	2	
• Hot	3	
• Very hot	4	
Don't Know		

Radiant Temperature

What causes radiant temperature and what should you look out for?		
<ul style="list-style-type: none"> • Thermal radiation is the heat that radiates from a heat source and will be present if there are heat sources in an environment. • <u>Examples</u> include: the sun, electric fires; furnaces; ovens; kiln walls; cookers; dryers; hot surfaces & machinery, exothermic chemical reactions, deep mine tunnel walls; molten metals, etc. • Observe the surroundings and identify heat sources. Consider how close your employees are to these heat sources. Do they need to wear protective clothing to prevent burns etc? 		
Subjective description of radiant temperature	Score	Tick
• Objects colder than the surrounding air are near to worker.	-1	
• There are no heat sources in the environment	0	
• A heat source is present but the employees are not in close proximity to it.	1	
• The heat source surface is warm to touch and there is no risk of contact burns.		
• The heat source surface is hot to touch.	2	
• Employees feel hot when they stand near the heat source.		
• The heat source surface is very hot to the touch and may burn the skin.	3	
• Employees cannot work in close proximity to the heat source for more than 10 minutes without wearing PPE.		
• Contact with the heat source will cause burning.	5	
• Employees cannot work in close proximity to the heat source for more than 5 minutes without wearing PPE.		
• Workers are not permitted to work in the environment without PPE to protect them from the radiant heat in that environment.	6	
Don't Know		

Air Velocity

Air velocity explained		
<ul style="list-style-type: none"> Air velocity is the speed of air moving across an employee and may affect the employee if it is not cooler than the environment. To help you, four categories of air velocity are provided. They are Still, Low, Moderate and High <ol style="list-style-type: none"> Still air, is where there is no noticeable flow of air; Low air speed, is when you can just feel air movement on exposed flesh; Moderate air speed, is when you can feel air movement (e.g. a light breeze) on exposed flesh; High air speed, may be similar to the air speed on a windy day, or at or near fans or other machines or equipment that generate air movement. Things to look out for are wind sources; the presence of fans to reduce the temperature (e.g. during specialist maintenance work?); employees feeling hot or warm air blowing on any exposed skin or is the moving air cooler or warmer than the ambient air temperature. 		
Subjective description of air velocity	Score	Tick
<ul style="list-style-type: none"> Cold air at a high speed (e.g. employees standing in front of an air conditioning unit). Cold air at a moderate speed, or Cool air at a high speed. Cold air and low air speed, or Cool air at a moderate air speed Still air in a neutral environment Warm air and low air speed. Still air in a warm environment Still air in a hot environment. Warm air at a moderate air speed, or Still air in a very hot environment, or Hot air and moderate air speed. Very hot air at a high speed 	<p>-3</p> <p>-2</p> <p>-1</p> <p>0</p> <p>1</p> <p>2</p> <p>3</p> <p>4</p> <p>5</p>	
Don't Know		

Humidity

Humidity explained		
<ul style="list-style-type: none"> When water is heated and evaporates into the air this provides the environments humidity. High humidity environments contain a lot of water vapour and this is important as it reduces the ability of sweat to evaporate from the skin which is the main means by which your employees lose heat. When vapour impermeable PPE is worn, sweat cannot evaporate and increases the humidity inside the PPE. If an employee is wearing this sort of PPE (e.g. asbestos, chemical protection suits etc) the humidity within the microclimate of the garment may be high. Humidity is very difficult to estimate. Profuse sweating may be an indication of high humidity, but it may also be an indication of a high physical activity. Things to looks out for are is the environment susceptible to outdoor conditions, especially in summer? Are there any dryers or other machines producing steam? Do workers complain about the humidity? Are they wearing vapour impermeable PPE? 		
Subjective description of air velocity	Score	Tick
<ul style="list-style-type: none"> No humidity. Air is dry, with no drying processes or other mechanisms for increasing the humidity in the workplace. Humidity seems to be somewhere between very humid and very dry. Air is very humid. Examples may be near drying machines, laundry machines, chemical processes where steam is given off. Vapour impermeable PPE is worn 	<p>0</p> <p>2</p> <p>5</p> <p>6</p>	
Don't know		

Clothing

Clothing explained

- Clothing interferes with our ability to lose heat to the environment. Where heat stress is a risk eg where workers may be wearing PPE, even if the environment is not considered warm or hot. It is important to identify whether the clothing the employee is wearing may contribute to the risk of heat stress.
- It is impossible to list or describe all the clothing that may be worn in industry so only general descriptions of clothing are provided.
- Observe the employee and select the clothing type that best represents what is worn in that workplace. Where employers wear or remove clothing depending on the job or task, it may be necessary to conduct a quantitative heat stress risk assessment.
- Additional information may be obtained by contacting the manufacturer or supplier of the PPE for further advice.

Subjective descriptions of clothing	Score	Tick
• Shorts and a T-shirt. No protective or work clothing worn	-1	
• Light work clothing	0	
• Cotton coverall, jacket	2	
• Winter work clothing, double cloth coveralls, water barrier materials.	3	
• Light weight vapour barrier suits	5	
• Fully enclosed suit with hood and gloves.	6	
	Don't know	

What to do with results from Observations check list

Referring back to each of the parameters you have just observed please tick the score which corresponds to the score you gave each parameter.

The black squares indicate that the score is not available for a particular category For example, Metabolic Rate can only achieve scores of -2, 0, +2, +4 and +6

Where you have a score higher than 1 the greater the heat stress risk. As the scores increase (also shown by colour shading from light red to dark red) so the risk of that parameter contributing to heat stress increases. If three or more of your scores are greater than 1, there may be a risk of heat stress.

If you score greater than 5, then in these situations, physiological monitoring may be required. If you are not competent in measuring, analysing and interpreting physiological measurements you should now seek expert advice.

	SCORES										Don't know	
	-3	-2	-1	0	1	2	3	4	5	6		
Air temperature	■	■								■		
Radiant heat	■	■								■		
Air velocity												
Humidity	■	■			■			■				
Clothing	■	■	■									
Metabolic rate	■		■		■		■		■			

Appendix-H

Design intervention for addressing the problem of glare and UV radiation and protection of eyes of the workers engaged in Floating Solar photovoltaic projects

Design Problem

Utility scale floating solar PV projects are being installed in large numbers in India. FSPV workers are required to work outdoors for long hours under the hot Sun. Glare and UV radiation are two significant OSH risk factors affecting the eyes. The glare is caused due to two main sources apart from direct sunlight. The first one being the reflection of the sunlight from the solar photovoltaic panels and the second source that compounds the OSH risk is the reflection from the surface of the water body surrounding the FSPV installation (reflective glare). There can be discomfort in vision while walking or working on the floating platform. Glare can cause severe discomfort in the eyes while doing work involving dexterity such as connecting wires, attaching panels to floaters and detecting the peripheries/boundaries of the project. The problem can lead to falls, human errors, decrease in productivity, problems in readability of signages/labels, use of equipment and both short term and long-term damage to eyesight. Our research team is engaged in designing solution to ameliorate the problems. Accordingly, we invite you to wear the hat of a designer and express your valuable design solutions in the attached sheet through visual representation/sketches.

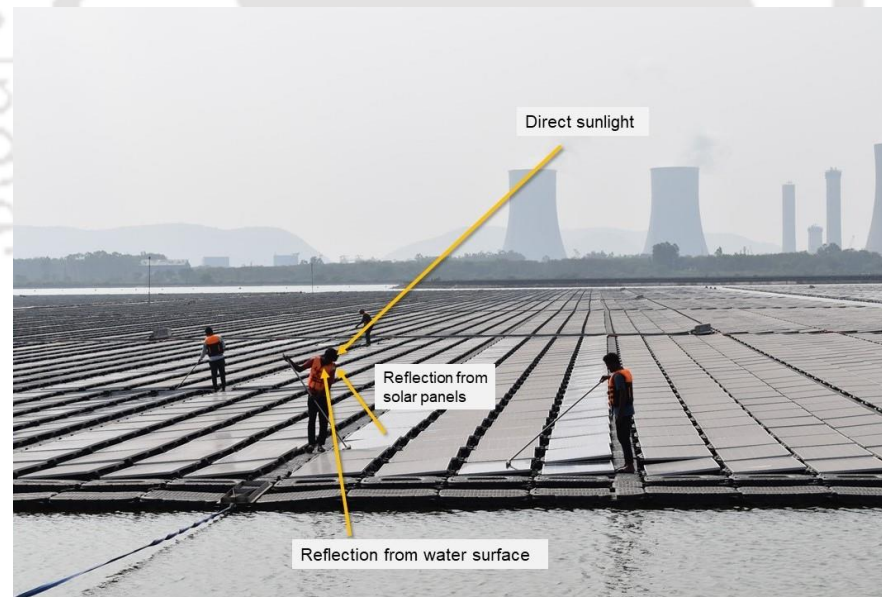


Figure: FSPV workers facing the problem of glare and UV radiation

Your redesign/design solution (s) – you may choose to draw a sketch (preferred) or describe your solution in words. Multiple solutions may be provided.

Age:

Qualification:

Work experience in years:

Do you have any background/experience in industrial design/engineering drawings etc.: Yes/No (if Yes indicate the period: _____ months/yrs.)

Do you have experience in installation & maintenance of any kind of solar PV projects: Yes/No (if Yes indicate the period: _____ months/yrs.)

We thank you for recording your responses | All information will be used for academic purposes only| Contact for queries: sen18@iitg.ac.in |

Eye protector design evaluation

Visual task

1. Experiment date and time

2. Age group in yrs

Mark only one oval.

20 yrs to 30 yrs

31 yrs to 40 yrs

41 yrs to 50 yrs

3. Gender

4. Educational level

Mark only one oval.

Matriculation

Higher Secondary

Graduate/Diploma

Post Graduate

Doctorate

Professional degree

5. Time taken to complete the visual task WITHOUT eye protector

6. Time taken to complete the visual task WITH eye protector

7. Please rate the task WITHOUT the eye protector

Mark only one oval.

- Very Easy
- Easy
- Neutral
- Difficult
- Very Difficult

8. Please rate the task WITH the eye protector

Mark only one oval.

- Very Easy
- Easy
- Neutral
- Difficult
- Very Difficult

Glare assessment (de Boer's scale)

9. Please rate the Glare WITHOUT eye protector

Mark only one oval.

- Unbearable
- Disturbing
- Just acceptable
- Satisfactory
- Unnoticeable

10. Please rate the Glare WITH eye protector

Mark only one oval.

- Unbearable
- Disturbing
- Just acceptable
- Satisfactory
- Unnoticeable

Personal Protective Equipment (PPE) avoidance

11. This design of eye protector will address the problem of PPE avoidance (This is an identified problem where workers often refuse to use PPE due to various reasons)

Mark only one oval.

- Strongly Disagree
- Disagree
- Neutral
- Agree
- Strongly Agree

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Google Forms

System Usability Scale

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	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

GlareSafe

DESCRIPTION

Safety helmet with adjustable eye protector offering protection against discomfort glare, UV rays and protection of head against falling objects. Ergonomic design for protection against risks and addressing contextual needs of users.



TH-3196_186105002



Before



After

Uses: Designed for floating solar photovoltaics projects but can be used for prolonged work in outdoor environments under the Sun.

PPE Materials

Helmet Shell (round brimmed)	HDPE (High Density Polyethylene)
Headband	LDPE (Low Density Polyethylene)
Sweatband	Brushed Nylon with 2mm foam
Channel track	Aluminum
Channel runners	HDPE
Visor	Polycarbonate with polaroid coating

Design evaluation questionnaire for improving occupational safety and health of workers engaged in floating solar photovoltaic projects

Greetings !

We invite your goodself to participate in our survey which pertains to the evaluation of design interventions for the occupational safety and health (OSH) of workers engaged in installation and maintenance of floating solar photovoltaic (FSPV) projects. FSPV projects consist of solar panels fixed on floaters which are installed on water bodies. Research and field studies have established several occupational safety and health issues being faced by the workers. Considering the problems, four design solutions have been developed for risk mitigation/elimination.

We seek your views on the proposed designs as compared to existing designs/method of working based on parameters such as ability to mitigate the risk, ergonomics (compatability between user and interface), manufacturability, cost saving and productivity on a five-point scale. You may agree or strongly agree to the proposed designs if benefits are perceived. You may disagree or strongly disagree if perceived otherwise.

This is a research initiative by the Centre For Ergonomics, Department of Design, Indian Institute of Technology, Guwahati, Assam, India. Your survey responses will be strictly confidential and data from this research will be reported only in the aggregate.

If you have questions at any time about the survey or the procedures, you may contact at +91-9038271367 or by email at sen18@iitg.ac.in.

Thank you very much for your time and support.

*Required

1. Your designation *

2. Your present organization and country (optional)

3. Education *

Mark only one oval.

- Diploma Engineer
- Graduate
- Post Graduate
- Doctorate
- Professional degree

4. Gender *

Mark only one oval.

- Male
- Female
- Prefer not to say

5. Age group in years *

Mark only one oval.

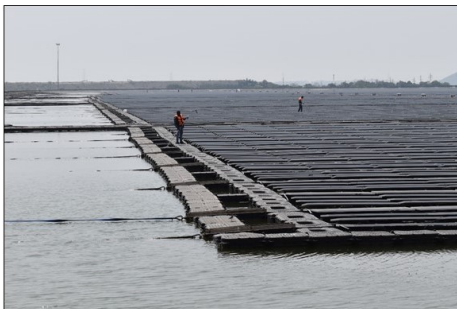
- 20 to 30
- 31 to 40
- 41 to 50
- 51 and above

6. Total years of work experience *

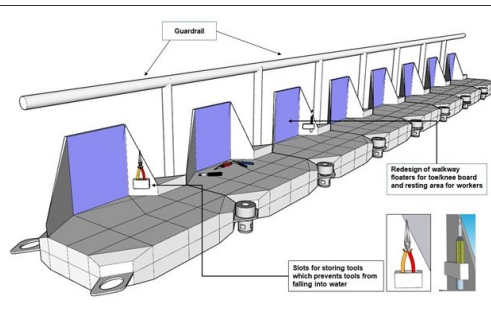
7. Years of experience in the solar photovoltaic industry (optional)

Design of guardrail (floating fence), toe board and resting area for FSPV workers

FSPV projects are installed on water bodies. One of the major occupational safety & health risk is falling into water. To prevent falls, a guardrail design is proposed. Additionally the guardrail provides a backrest for resting and space for storing tools (preventing tool loss). Please express your views on the proposed design as compared to the existing one.



Existing design without guardrail along the periphery



Proposed design with guardrail, tool slots and resting area for workers (backrest)

8. Ability to prevent the risk i.e. prevent falls into water, loss of tools and provide a resting area *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

9. Addresses ergonomics risks/issues *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

10. Easy to manufacture and implement *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

11. Saves direct and indirect cost of incidents/accidents/health effects *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

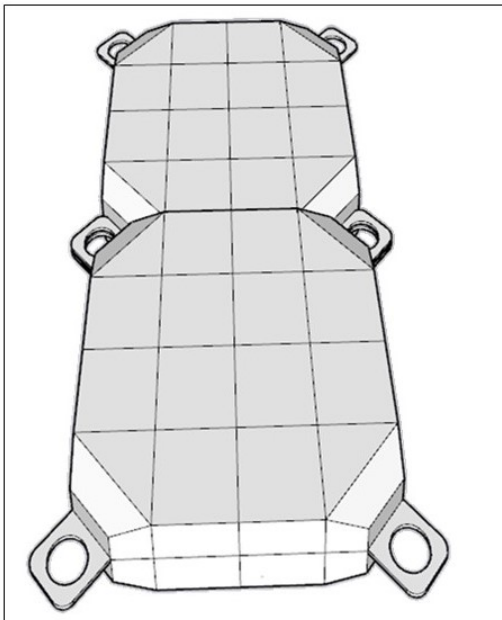
12. Improves productivity *

Mark only one oval per row.

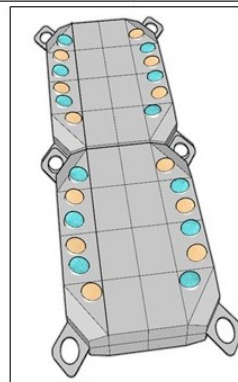
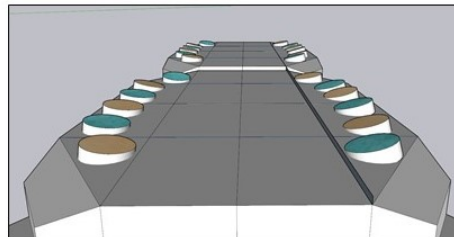
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Redesign of walkway floaters

In the existing design of the walkway floater, the surface is even and does not offer any friction resulting in slips, trips and falls into water. The floater has been redesigned by including risers on the edges so as to prevent users from straying to the edges and thus mitigating the risks.



Existing design of walkway floaters



Proposed design of walkway floaters with elevated risers to promote walking through the central part of the walkway for fall prevention

13. Ability to prevent the risk i.e. prevent falls into water by forcing users to walk along the central area of the floater and not move towards the edges *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

14. Addresses ergonomics risks/issues *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

15. Easy to manufacture and implement *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

16. Saves direct and indirect cost of incidents/accidents/health effects *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

17. Improves productivity *

Mark only one oval per row.

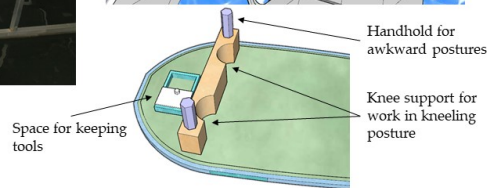
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Design of maintenance board

There are two kinds of floaters used in FSPV projects. The first kind is used for supporting the solar panels and the second one is used for construction of walkways. Maintenance activities is carried out by workers by squatting/sitting/kneeling on the walkway floaters. This method of working involves risks of falling into water and makes many parts/locations below the panels unreachable resulting in awkward postures. The design of a maintenance board is proposed to mitigate the aforesaid risks. Please express your views on the proposed design as compared to the existing working method.



Existing workplace



Proposed design

18. Ability to prevent falls into water and neutralize other risks during maintenance *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing working procedure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

19. Addresses ergonomics risks/issues *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing work procedure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

20. Easy to manufacture and implement *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

21. Saves direct and indirect cost of incidents/accidents/health effects *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

22. Improves productivity *

Mark only one oval per row.

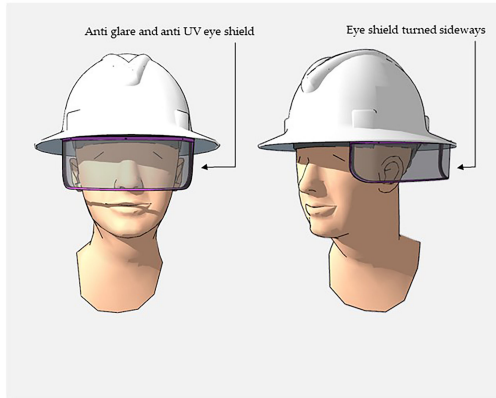
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Design of anti-glare eye shield

FSPV installation and maintenance involves outdoor work. The workers are exposed to solar radiation which can cause significant damage to the eyes. In addition, reflection of sunlight from the surrounding water body and the surface of solar panels causes a glare which affects the eyes and productivity. The design of an anti-glare eye shield is proposed to mitigate the aforesaid risks. Please express your views on the proposed design as compared to the existing one.



Existing working condition



Proposed design intervention

6

23. Ability to protect the eyes from solar radiation and glare *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing working procedure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

24. Addresses ergonomics risks/issues *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

25. Easy to manufacture and implement *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

26. Saves direct and indirect cost of incidents/accidents/health effects *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

27. Improves productivity *

Mark only one oval per row.

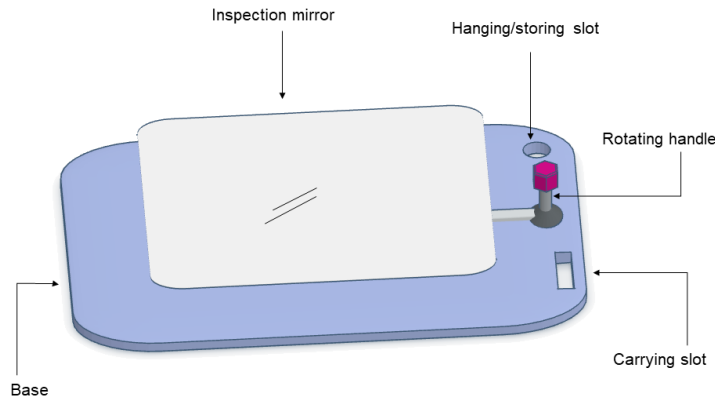
	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

28. Your suggestions, ideas or comments for the proposed or other design interventions for risk mitigation in floating solar PV projects

Thank you for recording your responses.

Design of maintenance mirror

FSPV maintenance involves awkward postures for inspecting the undersides of solar PV panels and wiring system. Removing or taking apart each part in a charged system is practically impossible since it may result in loss of generation and increased downtime. Accordingly, the maintenance mirror is a job aid/tool to help the solar engineers/workers in the inspection process during maintenance. The job aid is designed so as to ensure comfortable postures and easy maintenance of the FSPV system. Moreover, its portable and can be carried easily by the users. Please express your views on the proposed design.



29. Ability to protect the eyes from solar radiation and glare *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing working procedure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

30. Addresses ergonomics risks/issues *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

31. Easy to manufacture and implement *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

32. Saves direct and indirect cost of incidents/accidents/health effects *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

33. Improves productivity *

Mark only one oval per row.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Existing design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Proposed design	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

34. Your suggestions, ideas or comments for the proposed or other design interventions for risk mitigation in floating solar PV projects

Thank you for recording your responses.

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